Defra New Technologies Demonstrator Programme

Demonstration of a double-ended in-vessel composting system

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1. DEFRA NEW TECHNOLOGY DEMONSTRATOR PROGRAMME

The Defra New Technology Demonstrator Programme (NTDP) is a funding stream within the Waste Implementation Programme for projects demonstrating new technologies. The Programme provides assistance in the set up of new waste treatment technology demonstration projects. The Programme is intended to overcome the possible risks of introducing alternative technologies in England through the provision of accurate and impartial technical, environmental and economic information to key decision-makers in local authorities and the waste industry in general.

This report is an overarching document providing a summary of the activities undertaken by Envar, the issues and learning experienced during the project as well as the results obtained in respect of the double-ended in-vessel composting system at St Ives, Cambridgeshire.

The report is designed to assist in the provision of impartial information intended to help overcome the perceived and real risks of implementing new waste technologies in England and to provide accurate and impartial technical, environmental and economic data on project mobilisation, performance and operational parameters. In addition, the report provides an economic assessment of the project and the potential future role that similar facilities could play in diverting BMW from landfill.

The Report has been developed in good faith by Envar, and Defra nor their Advisers shall incur any liability for any action or omission arising out of any reliance being placed on the Report by any Local Authority, organisation or other person. Any Local Authority, organisation or other person in receipt of this Report should take their own legal, financial and other relevant professional advice when considering what action (if any) to take in respect of any waste strategy, initiative, proposal, or other involvement with any waste management option or technology, or before placing any reliance on anything contained therein.

When necessary this report will be utilised by Defra to inform discussion with Local Authorities and others relating to proposed new waste management infrastructure. The report catalogues the key lessons that have been identified from the process to date.

1 EXECUTIVE SUMMARY

The New Technologies Demonstrator Programme (NTDP) is a £30 million programme arranged and funded by Defra from 2003 onwards. The aim of the programme is to provide support to innovative waste treatment technologies to establish them as alternatives to landfill, an important goal given the increasing threat of sanctions under the Landfill Directive. Each technology must prove evidence on the economic, social and environmental viability of commercial scale operations via a series of reports, presentations and advice from Defra-appointed experts.

It is intended that the demonstrators be aimed at key decision makers within Local Authorities, providing them with increasing knowledge of waste treatments and handling to allow them to make the best decisions possible regarding the construction of new treatment systems within their boundaries.

This report covers the project carried out by Envar Ltd entitled “Demonstration of a double-ended in-vessel composting system”.

1.1 Demonstration project and objectives (Section 2)

The overall aim of this project was to design, build and investigate a batch tunnel in-vessel composting technology process. The basic technology chosen, batch tunnels manufactured by the Dutch company Gicom b.v., has been used for many years to produce compost from municipal, commercial and agricultural wastes. The batch tunnel technology has been further developed for this project by incorporating unique heated walls and floors by embedding hot water pipes in the structure of the tunnels at the time of construction. The heated walls and floors were added to determine if this additional feature would shorten the residence time in the tunnels and thereby increase throughput.

The project was set up as a demonstration-scale composting system in which all of the important parameters of composting – operational, health and environmental - could be identified, quantified and optimised. This would provide a standard against which other composting systems could be measured and would provide data to help in the efficient design and operation of other composting systems.

The project system consisted of four computer-controlled composting tunnels and a computer-controlled air scrubber and block of biofilters. This system was used to improve composting procedures for a variety of feedstocks, and to determine and minimise the effect of the composting process upon the environment. The system was designed to process c. 180 tonne batches of waste at a time. This scale was chosen to provide data under meaningful commercial process conditions.

The project, under the terms of the contract agreement, was required to process a minimum of 10,500 tonnes of biodegradable municipal waste (BMW) during a minimum of 8,000 operational hours, processing a minimum of 70 batches of feedstock material.

1.2 Risk Management (Section 3)

At the conclusion of the project an assessment was made of the actual risks encountered during the project, along with their effect on the project, and the steps taken in mitigation.

The main lessons learned from this examination of anticipated and actual risks for similar projects are:

- An experienced and enthusiastic project manager must be in charge of the project at all times and be fully supported by technical and production staff.
- A close association with the technology provider must be established at the beginning of the project and maintained throughout.
- The project must be carried out to the time and cost requirements of a detailed Gantt chart prepared before the start of the project.
- Milestones must be identified and reached for each stage of the project.

1.3 Relevant legislation and authorisation (Section 4)

Planning - A new planning application under the Town and Country Planning Act (1990) was made to Cambridgeshire County Council in February 2006 (application No. H/05003/06/CW). These were the Gicom tunnels to be used in the NTDP project. The application was considered by the Development Control Committee on 15th May 2006. One objection from a local Parish Council on the basis of potential odour problems was submitted. Planning permission was granted at that meeting for the four new tunnels.

Other relevant legislation includes the Environmental Permitting Regulations (2007), Paragraph 7 Exemptions, Paragraph 9 exemptions, the Animal By-Products Regulations, Nitrate Vulnerable Zones Regulations, and the PAS 100 standard and Compost Quality Protocol for composts.

1.4 Plant design (Section 5)

The project was carried out at the Envar Ltd (part of the ADAS Group of Companies) commercial composting site at St Ives Cambridgeshire. The project ultimately used four 180 tonne capacity batch tunnels designed and built by the Dutch company Gicom b.v. These are double-ended and are licensed to compost Category 3 catering waste under the Animal By-Products Regulations (ABPR).

The Gicom batch tunnel composting system was chosen by Envar because of the following attributes:

- Fully enclosed, insulated and independent of the local environment, e.g. changes in ambient temperature.
- Possessing a uniform internal environment for composting to take place, i.e. temperature and oxygen levels being the same in all parts of the composting matrix at the same time. This is accomplished by recirculating air through the composting material by means of fans.

- Having full control over temperature to ensure optimal temperatures for each stage of the composting process. This is accomplished by allowing fresh air to mix with the recirculated air under computer-controlled conditions.
- Able to guarantee that all parts of the composting matrix can be held at the required ABPR pasteurisation temperatures for the required minimum time.
- Able to control oxygen levels to ensure that aerobic conditions are maintained at all times.
- Allowing a tight control over production schedules.
- Allowing detailed data collection, storage and analysis of all the required process parameters, with readings being taken every 15 minutes.
- Having a small foot print for maximum use of available space.
- Able to expand in a modular way in order to respond to increases in feedstock intake.
- Containing and storing any leachate produced.
- Treating process air to remove offensive odours and reduce the level of bioaerosols released to the atmosphere.
- Operating with the minimum amount of labour.
- Fully compliant with ABPR.

1.5 Tendering process for contractors (Section 6)

Envar were required to choose a suitable primary sub-contractor to supply the in-vessel composting technology required to base the research and demonstration programme on. Funding was provided by Envar (via parent company ADAS UK Ltd) to design and build the treatment technology. Funding by Defra was then used to carry out research and a dissemination programme based on the technology and its processes.

The supplier of the in-vessel composting technology chosen for the project was the Dutch company Gicom b.v. This company was selected because of its long track record in designing and building batch tunnel composting systems for the organic waste recycling industry. Gicom were also well known to the project team, and the owners of the St Ives site, as the site already had two Gicom batch tunnel composting systems that were fully compliant with the Animal By-Products Regulations.

In order for Envar to successfully complete the research programme, collaborations also had to be made with key laboratory service providers including:

- NRM
- Eurofins
- Silsoe Odours
- Odournet

- M-Scan

All of the laboratory service providers listed above are key clients to Envar (and parent company ADAS UK Ltd). This meant that the project was able to benefit from set prices within centralised contracts.

In addition, the project was supported by the University of Leeds who provided monitoring assistance and enumeration of bioaerosols sampling agar plates.

1.6 Project waste streams (Section 7)

The project waste streams consisted of varying proportions of mixtures of co-mingled kitchen waste and green waste (from 10% up to 51% kitchen waste by weight), and the organic fines separated from mixed Municipal Solid Waste. Of the 67 runs processing co-mingled kitchen waste and green waste, ten contained <15% kitchen waste and 10 contained >35% kitchen waste. The other runs had intermediate proportions of kitchen waste. A further ten runs containing up to 28% MSW fines mixed with co-mingled kitchen waste and green waste were carried out. Eight of these runs were undertaken to demonstrate that the batch tunnel system could process mixed waste, and the remaining two runs were bio-dried to produce refuse derived fuel.

1.7 Construction process (Section 9)

The tunnels, with an associated enclosed reception area, were constructed by Gicom b.v. for Envar Ltd prior to the start of the project and were integrated into the rest of the composting operation at the St Ives site. The construction phase was managed by an experienced local project management company in close liaison with Gicom and Envar. No significant problems were encountered during the construction phase and the tunnels were completed on time. The project used these commercial scale tunnels to ensure that the results obtained by the project would be of maximum relevance to the UK composting industry. The tunnels were fitted with an air scrubber and biofilter assembly to remove volatile organic compounds and odours from the process air prior to release to atmosphere. Redundant small mushroom composting tunnels were converted into biofilters to remove odours from the tunnel process air during composting.

In addition to the Gicom tunnels, the project modified a detached house on the St Ives site and created a Visitor's Centre for the project. This was used to give presentations during open days, seminars and workshops to illustrate the results obtained by the project.

1.8 Site operations monitoring (Section 10)

The project monitored each stage of the composting process from waste reception, through shredding, batch tunnel composting, windrow composting and screening.

While many of the detailed activities are site-specific, a general account of the important characteristics of each stage is given. Ways in which the processes can be made more efficient are indicated.

1.9 Process monitoring of the tunnel composting of kitchen waste and green waste (Section 11)

The main feedstock type processed by the project was mixtures of kitchen waste and green waste ranging from a minimum of 10% to a maximum of 51% kitchen waste by weight.

A total of 15,774 tonnes of this feedstock was processed in 67 runs through a two-stage batch tunnel composting process compliant with ABPR. The two-stage process involved two pasteurisation periods of 60°C for 48 hours. The tunnels successfully operated for 14,534 hours processing this material. This performance exceeded the requirements of the contract.

For 6 of the runs, the material processed through the batch tunnels was then taken through a windrow composting stage, and screened to produce a compost product. These were called 'intensive' runs. Approximately half of the first stage runs were carried out with the heated floors and walls on, with the other half being operated without heating the walls and floors.

The residence time in the first tunnel composting stage varied from 3.28 to 9.97 days with an average of 4.90 days (st. dev. 1.26). The residence time in the second stage varied from 2.54 to 6.96 days with an average of 4.28 days (st. dev. 1.02). The overall time for both stages varied from 6.69 to 15.22 days (st. dev. 1.67).

The compost temperatures during pasteurisation were measured at 6 different points and showed that all parts of the composting matrix were above 60°C for 48 hours during the required pasteurisation stage as required by ABPR. Minimum air temperatures recorded within the tunnels were also above 60°C during this period.

Oxygen levels were measured throughout the tunnel composting process. Levels were not allowed to drop below 7% in order to ensure aerobic conditions. Total oxygen consumption was also measured for each run. The two stages of a run consumed between 2.0 and 56.7 tonnes of oxygen depending upon composting activity.

Carbon dioxide levels were measured throughout the tunnel composting process. Levels of carbon dioxide in the exhaust gas up to 110,000 ppm (the limiting level of detection) were detected. The total amount of carbon dioxide produced during the two stages varied from 17.5 tonnes to 62.9 tonnes depending upon the activity of the compost.

Small quantities of methane (0 to 69.3 kg per composting run) were detected for a short time during the first stage of tunnel composting. This was interpreted as being produced by some of the feedstock becoming anaerobic when stored prior to arrival at the site. No methane was detected after a few hours of composting in the tunnels.

Ammonia levels were monitored from run 57 onwards. The new ammonia detection system was not set up and operational until this stage of the project. The total amount of ammonia produced in each stage of a run varied from 0.1 to 9.6 kg. In addition to the ammonia data collected by the tunnel computer, two other methods of ammonia detection were utilised.

The rate of water evaporation was determined throughout each run. The amount of water evaporated from each stage of the runs varied from 2.5 to 47.9 tonnes depending upon the activity of the compost. This lost water was partially replaced during the tunnel composting process using spray bars within the tunnels. The decision as to when to add water, and how much water to add, was a decision made by the site Operations Manager on the basis of an inspection of the moisture of the feedstock.

The rate of electricity consumption by the tunnels was continually measured throughout each stage of each run. The cost of running the fans represented most of the electricity consumption. The electricity consumption for the first stage of tunnel composting varied from 1,118 to 4,381 kWh. Consumption in the second stage varied from 562 to 2,552 kWh. The total consumption for each complete run varied from 2,247 to 6,533 kWh. The total electricity cost for both tunnel composting stages was calculated to be £1.36/tonne of feedstock.

This detailed presentation of data indicates clearly the degree of monitoring that is possible using a well designed batch tunnel system. Although a relatively small number of parameters are essential in order to control the composting process i.e. temperature, oxygen levels, time, the additional parameters that can be monitored and quantified e.g. ammonia production, carbon dioxide production, methane detection, add valuable information as to how the composting process takes place. Other additional information such as electricity utilisation, help cost the process.

1.10 Effect of heated walls and floors (Section 11)

The unique configuration of the batch tunnels used in the project consisted of water pipes being embedded in the walls and floors of the tunnels. These pipes were connected to a boiler that heated water that circulated, under computer control, through the pipes. This enabled approximately half of the runs to be carried out with the walls and floors of the tunnels pre-heated at the start of the first stage of tunnel composting, with the other half of the runs having this heating option turned off. The purpose of this exercise was to determine if the pre-heating of the walls and floors would enable the entire composting matrix to reach the temperatures required by ABPR in a shorter time. If this could be accomplished, the throughput of the tunnels would be increased.

A comparison was therefore made of the residence time of the first stages of runs with the heated walls and floors turned on and off. With co-mingled kitchen waste and green waste as the feedstock 28 runs were carried out with the heating turned on and 38 runs with the heating turned off. The mean residence time for the first stage of the heated runs was 4.71 days (st. dev. 0.80) while that for the unheated runs was 5.02 days (st. dev. 1.5). With the 8 runs containing MSW fines used to produce compost-like material, 4 were run with the heating on and 4 with the heating off. The mean residence time for the first stage of the heated runs was 5.26 days (st. dev. 1.04) while that for the runs with the heating turned off was 7.04 days (st. dev. 1.92). This showed a significant reduction in residence time but with a total of only eight runs generating the data.

The above data was not thought to definitively prove that the use of heated walls and floors, with the associated increased construction costs and operating costs (gas), was a significant step forward in batch tunnel design.

1.11 Monitoring of emissions from the tunnel composting of kitchen waste and green waste (Section 12)

The volume of leachate produced by the tunnel composting process was determined and analysed at intervals throughout the duration of the project for a wide range of chemical and physical parameters including heavy metals and biological oxygen demand (BOD). The levels of BOD varied from 264 to 9,237 mgl^{-1}.

A range of volatile organic compounds (VOCs) were measured in the tunnel process air using the methods of top ten screen, thermal desorption and the infrared sensors within tunnels. The top ten method was found to be not sensitive enough to detect VOCs at some of the composting stages. The thermal desorption method was found to be the most useful. Twenty four different VOCs were detected in an analysis of one run.

Ammonia levels in the tunnel process air on 32 runs were detected using Dräger tubes, a bubbler method developed by ADAS, and, at the latter part of the project, by the ammonia probes installed in the tunnels. The efficiency of the scrubber was determined using these methods. The efficiency of the scrubber was found to vary considerably from 0 to 89% depending upon the method of detection used and the stage at which the sampling was carried out.

The efficiency of the scrubber in reducing odours in the tunnel exhaust air ranged from 18-67%. The efficiency of the biofilter system in further educing odour ranged from 42-96%. The overall efficiency of the scrubber/biofilter system in reducing odours ranged from 33-98%. This variation was in part due to the difficulty in obtaining representative odour readings from the exhaust air.

Bioaerosols in the process air were studied by the University of Leeds and are covered in a separate report.

1.12 Process Monitoring of Tunnel Composting of MSW organic fines (Section 13)

The second feedstock type processed by the project was the organic fines separated from mixed Municipal Solid Waste. This was mixed with co-mingled kitchen waste and green waste up to a level of 28%

A total of 1,976 tonnes of MSW fines were composted in 10 runs through a two-stage batch tunnel composting process compliant with ABPR. The two-stage process involved two pasteurisation periods of 60°C for 48 hours, in order to be compliant with ABPR. The tunnels successfully operated for 2,561 hours processing this material.

For eight of the runs (MSW runs 1-5, 8-10) the feedstock was composted in the tunnels in the same way as with the mixtures of kitchen waste and green waste. This was to demonstrate that this mixed-waste feedstock could be successfully composted in the tunnels to produce a compost-like output (CLO).

In the remaining two runs (MSW runs 6 and 7) using this feedstock, the material was taken through an extended second stage of tunnel composting. The extended times in the second stage were employed to bio-dry the material to produce refuse derived fuel (RDF).

Two of the runs using this feedstock to produce CLO were processed through the batch tunnels and then taken through a windrow composting stage, screened and a compost-like output material produced. These were called ‘intensive’ runs. Half of the first stage runs were carried out with the heated floors and walls on, with the other half being operated without heating the walls and floors.

The residence time for the first stage in the CLO runs varied from 4.60 days to 9.67 days. The residence time for the second stage varied from 3.68 days to 6.75 days. The combined residence time for both stages varied from 8.28 days to 16.42 days.

The residence time for the first stage of the two RDF runs varied from 4.85 days to 5.90 days, while the residence time for the second stage varied from 9.93 to 10.00 days. The total residence time for these two RDF runs varied from 14.78 to 15.90 days.

The compost temperatures during pasteurisation were measured at 6 different points and showed that all parts of the composting matrix were above 60°C for 48 hours during the required pasteurisation stage. Minimum air temperatures were also above 60°C during this period.

Oxygen levels were measured throughout the tunnel composting process. Levels were not allowed to drop below 7% in order to ensure aerobic conditions. Total oxygen consumption was also measured for each run. In the 8 MSW runs producing CLO the two stages of the runs consumed between 6.3 and 18.7 tonnes of oxygen depending upon composting activity. In the two MSW runs producing RDF the total oxygen consumption varied from 10.2 to 23.7 tonnes.

Carbon dioxide levels were measured throughout the tunnel composting process. Levels of carbon dioxide in the exhaust gas up to 110,000 ppm were detected. In the 8 MSW runs producing CLO the total amount of carbon dioxide produced during the two stages varied from 15.1 tonnes to 40.30 tonnes depending upon the activity of the compost. In the 2 MSW runs producing RDF the total carbon dioxide produced varied from 27.8 to 46.00 tonnes.

Small quantities of methane (0.3 to 11.1 kg) were detected for a short time during the first stage of tunnel composting the MSW runs producing CLO. The equivalent figures for MSW runs producing RDF were 14.6 and 19.2 kg. This methane was thought to be introduced by some of the feedstock arriving on site containing anaerobic portions, created during the storage of the feedstock before transport.

Ammonia levels were detected for each run. The total amount of ammonia produced in both stages of MSW runs producing CLO varied from 7.9 to 89.8 kg. In the two runs producing RDF the equivalent figures were 55.8 and 57.5 kg. In addition to the ammonia data collected by the tunnel computer, two other methods of ammonia detection were utilised.

The rate of water evaporation was determined throughout each run. The total amount of water evaporated from both stages of the MSW runs producing CLO varied from 11.4 to 43.2 tonnes depending upon the activity of the compost and management practices relating to water replacement. This lost water was partially replaced during the tunnel composting process using spray bars within the tunnels. In the two MSW runs producing RDF the total water lost varied from 36.3 to 39.1 tonnes.

The rate of electricity consumption by the tunnels was continually measured throughout each stage of each run. The electricity consumption for the first stage of tunnel composting in runs producing CLO varied from 1,874 to 3,809 kWh. Consumption in the second stage varied from 1,709 to 3,629 kWh. The total consumption for each complete run producing CLO varied from 4,031 to 5,809 kWh. In the tow runs producing RDF the electricity consumption in the first stage varied from 1,638 to 2,451 kWh, and the second stage (deliberately lengthened) from 3,937 to 6,066 kWh. The total electricity consumption for both stages in these two runs varied from 6,388 to 7,704 kWh.

The total electricity cost of tunnel composting the 13,798 tonnes of feedstock in all of the runs was £18,784, giving an average cost of £1.36 per tonne of feedstock. The cost implications of this electricity usage are discussed in Sections 9 and 19.

A comparison was made of the residence time of the first stages of runs with the heated walls and floors turned on and off. With MSW fines and co-mingled kitchen waste and green waste as the feedstock used to produce CLO, 4 runs were carried out with the heating turned on and 4 runs with the heating turned off. The mean residence time for the first stage of the heated runs was 5.26 days (st. dev. 1.04) while that for the unheated runs was 7.04 days (st. dev. 1.92). In the two runs used to produce RDF the residence time for the first stage with the heating on was 5.90 days and 4.85 with the heating off.

An analysis of the material produced after the windrow composting of this feedstock in the two intensive runs used to produce CLO confirmed the difficulty in complying with the PAS 100 using organic fines derived from a mixed feedstock. The compost-like output contained too many glass fragments and too high levels of copper, lead and zinc. This result emphasises the importance in using source-separated feedstocks to produce high quality composts. The CLO was used in a land restoration project under a paragraph 9 exemption.

Two composting runs were carried out to produce RDF material from a feedstock consisting of co-mingled kitchen waste and green waste, and MSW fines. The average net calorific value of triplicate samples of RDF material from the first run (MSW run 6) and the second run (MSW run 7) was 11.85 MJ/kg and 12.86 MJ/kg respectively. These values are similar to paper, process sludge and wood, but are only half of the calorific value of steam coal. There are also cost implications for the composting process because of the extended residence time in the tunnels necessary to produce the RDF material and the use of additional electricity.

1.13 Project costs (Section 14)

Although run as a research exercise, the project has been successfully carried out in the middle of a commercial composting environment.

An analysis has been carried out on each step of the composting process both at the generic level and at the level of the project. It is recognised that many of the costs are site-specific. For each stage of the process the equipment used by the project was identified and the rate of diesel consumption for each activity has been provided. The capital costs leasing costs and the basis if the running costs have been identified. The electricity costs for running the batch tunnels, by far the largest processing costs, have also been calculated. This was £1.36 per tonne of feedstock processed, taking it through a two-stage batch tunnel process to comply with ABPR. This cost per tonne is quite acceptable in the context of overall processing costs and the relevant income in the form of a gate fee for the feedstock that can be obtained in the industry for the types of wastes processed by the project. The only other significant costs associated with the tunnel composting stage are the labour and diesel costs associated with the filling and emptying of the tunnels using front end loaders.

A summary of the required analysis of capital costs, processing costs and overheads for a composting facility similar to the one used for the project is given. As this was a research project the costs of analysis, both in terms of labour and laboratory costs was much higher than in a normal commercial environment. Also, some of the additional equipment installed in the tunnels as part of this monitoring process would not normally be employed.

After the end of the project the site obtained an ABPR license that enabled it to comply with the regulations using a single pasteurisation stage rather than the two pasteurisation stages previously required. This effectively halved the electricity costs for tunnel processing, halved the labour and diesel costs associated with filling and emptying the tunnels, and doubled the tunnel throughput without significant capital investment. Future operation of the project tunnels in a normal commercial environment will therefore be significantly more profitable.

The use of a system to remove plastic during the screening of the compost product enabled the cleaned oversize material to be re-shredded and put back through the composting operation. This resulted in only stones and plastic requiring landfilling. Efforts are being made as part of the site's commercial activity to reduce the level of contamination in the incoming feedstock which will result in a reduction of the landfilling costs of these contaminants.

The modular nature of the batch tunnels would enable the planned and cost-effective expansion of a commercial system in a way that would be linked to the income obtained in the form of a gate fee for the contracted receipt of feedstock.

1.14 Dissemination (Section 15)

A Visitor's Centre was opened on the St Ives site on 5th October 2007. This was used to hold 18 open days, presentations and workshops throughout the life of the project, concluding with a Final Seminar to which major individuals involved in the composting industry were invited. A total of 79 different stakeholders attended these events with 239 individual visitors.

The project attended six exhibitions and conferences at which the results of the project were presented either on a stand or by means of a talk. Eleven articles have been written on the project results so far with a number of technical articles in preparation.

Further technical and general publications on the results of the project will be undertaken during the early part of 2010.

1.15 Discussion and conclusions (Section 16)

This section discusses the details and the implications of the project data that have been identified in the results sections of this report.

Topics covered include:

- **The effect of variation in feedstock composition on the composting process.** This section illustrates the ability of the batch tunnel system to effectively process a wide range of mixtures of green waste, kitchen waste and MSW fines.
- The ability of the batch tunnel composting system to process co-mingled kitchen waste and green waste up to at least a 30% inclusion rate for kitchen waste without extending the composting period. This result illustrates the importance in controlling the bulk density and moisture of the material being composted in the batch tunnels.

- The success of the project in reaching all of its required targets in terms of the tonnage of waste processed, the number of composting runs undertaken, and the number of operational hours for the batch tunnel. The tunnels operated with very high degree of reliability throughout a wide range of ambient temperatures and feedstock mixtures.
- **The site-specific nature of many of the costs associated with in-vessel and windrow composting.** The costs associated with feedstock shredding, tunnel composting, windrow composting and screening are examined. Site-specific costs are differentiated from costs directly associated with the tunnel composting.
- **The importance of minimising the levels of contamination of feedstock with plastic and other inert materials.** The improvement of feedstock quality and freedom from contamination is one of the most important requirements of a successful composting industry.
- The ability of the batch tunnels to comply with ABPR not just with a two-pass system but also a single-pass system (achieved with the project tunnels after the end of the project). The ability to comply with the rigorous standards of ABPR with a single pasteurisation stage effectively doubles the throughput of the batch tunnel system.
- **The emissions to the environment of the various liquid and gaseous emissions from the tunnel composting process.** Emissions from the tunnel composting process were found to be very low and well within the limits of the Environmental Permit.
- **The processing costs of tunnel composting.** The main cost associated with running the batch tunnels – electricity to run the aeration fans – has been quantified.
- **The use of the mass balance and energy balance models**. These two models provide useful tools to predict the performance of in-vessel composting systems.

1.16 Project protocols (Section 17)

This section includes the project protocols, methods used to monitor site operations procedures, tunnel composting, windrow composting, emission monitoring, and standard operating procedures (SOPs) used by the project. Legislative and policy drivers for waste recycling

2 DEMONSTRATION PROJECT AND OBJECTIVES

2.1 Background to the Envar New Technologies Demonstrator Project

This section provides a brief background to composting technologies, an introduction to the basis of the project, and follows the development of the project from its initiation to completion.

The need for high quality research work on the composting process itself and the effect of composting on the environment and of the health of operators and others is well recognised.

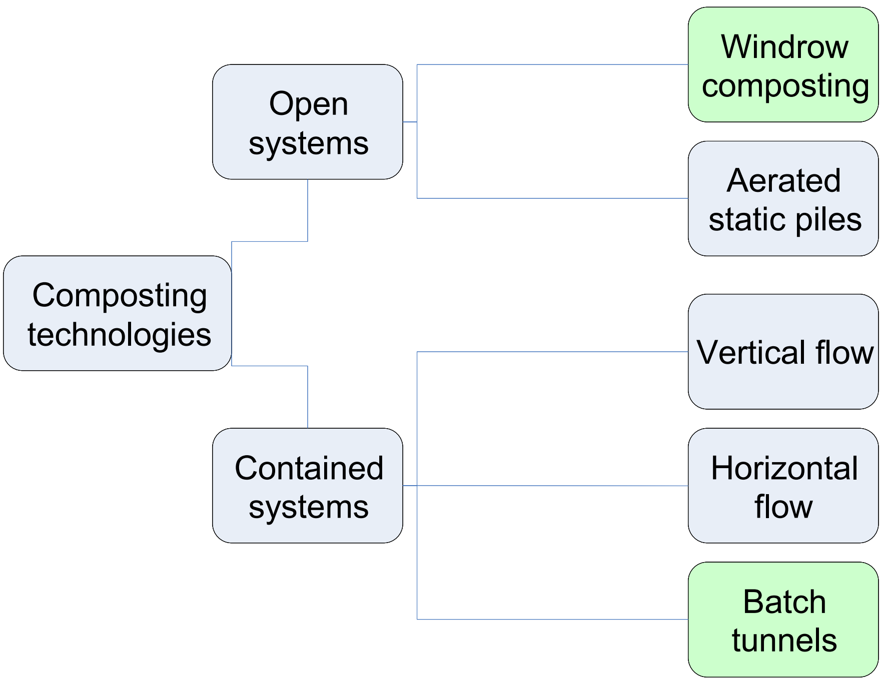
In its report entitled "Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes", [The Defra Report] published by Defra in March 2004[1], the Introduction includes the statement "Areas where there is less work and the science is less certain include releases to soil and water and releases from composting, or other forms of waste management like mechanical biological treatment or anaerobic digestion."

This report has been the main driver for this project.

Composting technologies

There are many different ways of composting organic waste. Methods range from very simple open-air operations to sophisticated in-vessels systems. Figure 1 identifies the main options available.

Figure 1: Methods of composting



[1] http://www.defra.gov.uk/ENVIRONMENT/waste/statistics/documents/health-report.pdf

The two main open-air systems are windrow composting and aerated static pile composting. Windrow composting involves taking shredded feedstock, such as green waste, and forming it into long rows – called windrows- up to 3 m high and 6 m wide with a triangular or trapezoid cross section. The windrows are regularly turned to mix and expose new surfaces to allow micro-organisms in the material to convert the waste into compost. The process takes 8 – 20 weeks.

Figure 2: Windrow composting

In aerated static pile composting a windrow is formed on top of perforated pipes or a perforated floor through which air is blown or sucked. This ensures that the material remains aerobic and offers a degree of temperature control. The windrow is not turned. The process takes 8 – 20 weeks to produce compost.

Figure 3: Aerated static pile composting

Vertical flow systems are continuous enclosed operations with shredded feedstock entering at the top of the equipment, passing downwards while being taken through a composting process, and exiting at the bottom. The residence time can be 10 – 14 days. The exited material is then normally taken through a windrow composting process.

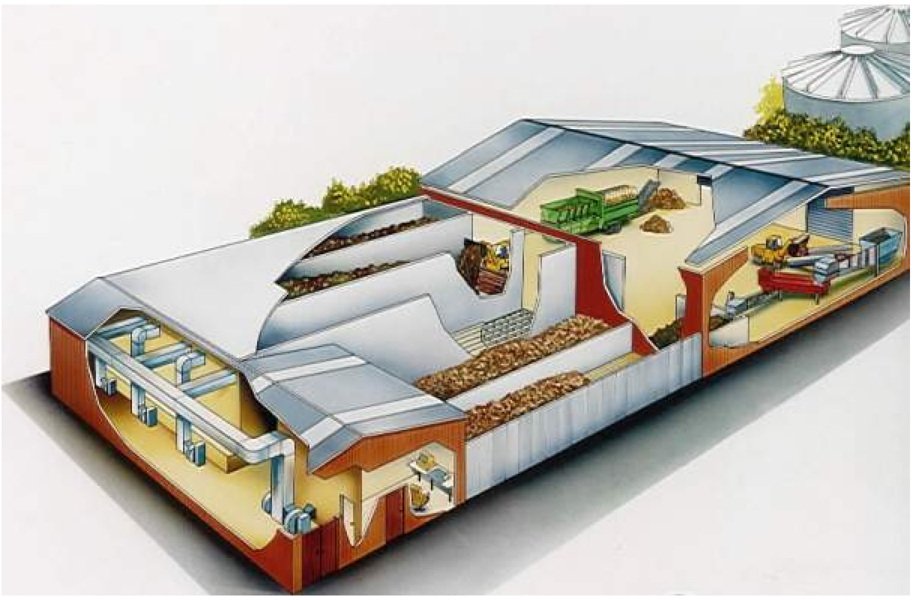
Figure 4: Vertical flow system

In horizontal contained systems, which operate in a continuous way, shredded feedstock enters at one end of the equipment and travels horizontally while being taken through a composting process exiting at the other end. The residence time can be 10 – 14 days. The exited material is then normally taken through a windrow composting process.

Figure 5: Horizontal flow composting

Batch tunnels operate in a different way from the previous two contained technologies. A tunnel is an enclosed concrete rectangular box that can hold 100 – 600 tonnes of shredded feedstock. The floor of the tunnel is perforated and attached to a fan that blows air through the composting material, providing aeration and a high degree of environmental control by monitoring and managing temperature, oxygen levels and moisture.

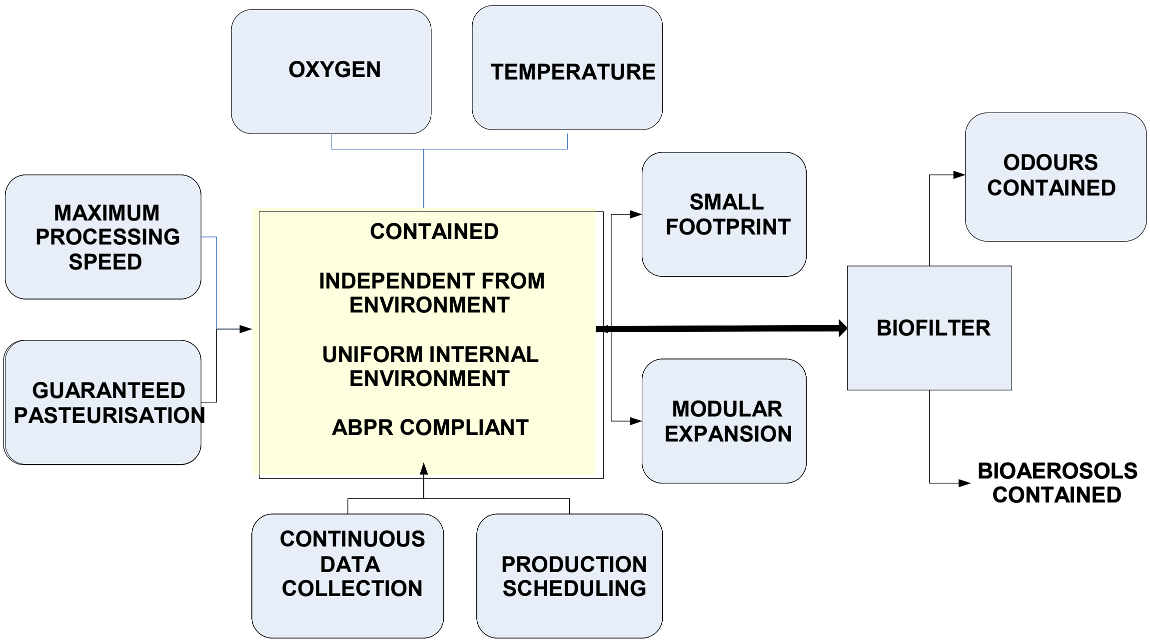
Figure 6: Batch tunnel composting



The requirements of an efficient composting technology

The required characteristics of an "ideal" or optimised contained composting system are summarised Figure 7.

Figure 7: Characteristics of an optimised contained composting system



If composting is carried out within a container, rather than in an open environment, such as with windrow or aerated static pile composting, it should be possible to obtain a number of advantages, including some or all of the following depending upon the exact composting technology chosen:

- the control of the environment of the composting micro-organisms so that they may operate in a controlled way at or near optimum conditions;

- a significant reduction in the time needed to take composting to a particular stage;
- a predictable and cost-effective production schedule;
- a clearly defined and demonstrable pasteurisation stage;
- a compost product with predictable, uniform and quality controlled properties;
- detailed records of the composting process;
- the avoidance of anaerobic conditions with a reduction or elimination of anaerobic odours; and
- a control of odour-carrying, and bioaerosol-carrying, air.

The degree to which these advantages are in practice obtainable from the various composting technologies available will vary greatly from one technology to another.

A number of parameters have to be considered in designing and operating an optimised composting system as was utilised for the Envar NTDP system. The most important of these are considered below.

Containment of feedstock

In order to take advantage of the greater control made possible by a contained system the composting feedstock has to be contained. This may be accomplished in a number of ways, such as the containment:

- of an open process within a building;
- within open-topped concrete bays inside a building;
- within a sealed concrete or steel vessel with continuous input of feedstock and output of compost; and
- of individual batches of feedstock within a sealed concrete or steel vessel.

This last method, containment within a sealed vessel, was selected for the project, along with containment within a building during the pre- and post-composting stages.

Independence from the environment

Open composting systems can be greatly affected by changes in temperature, the occurrence of heavy rain, and by very dry or windy conditions. A contained system seeks to isolate the composting process from changes in the local environment.

The system selected for the project is a fully insulated system that operates efficiently independently of weather conditions.

Increased speed of operation

Windrow and aerated static pile composting take a considerable time, e.g. up to 3 – 4 months. Much of this extended period is caused by the composting micro-organisms operating under less than optimal conditions.

The system selected for the project exercises complete control over the composting environment with all of the material kept at the required composting temperature.

Reduced facility foot print

Open composting systems occupy large areas of land. As this land is often covered with concrete there may be considerable cost and planning permission implications. A contained system seeks to process an equivalent quantity of feedstock in a much smaller area.

The system selected for the project offers a footprint that is less than 40% of the footprint of a windrow system.

Production schedule control

A very important factor in cost control is the effective use of labour and equipment. This is only possible if a cost-effective production schedule can be operated using all resources in the most efficient way. Open composting systems are subject to many variables, such as weather conditions, so that many open composting facilities do not operate to a controlled and predictable schedule.

The system selected for the project operates under strict production schedule control.

Guaranteed aerobic conditions

Odour problems caused by the creation of anaerobic conditions are discussed elsewhere in this report. It is very difficult, if not impossible, to guarantee aerobic conditions throughout all of the material composted by a windrow.

The system selected for the project uses a forced air supply that ensures that oxygen levels cannot drop below a nominated percentage, e.g. 10%, thereby guaranteeing aerobic conditions at all times.

Effective and uniform temperature control

In open systems there is a considerable range of temperatures throughout the composting heap at any one time. The control of these temperatures by the composter is essential in order to carry out a rapid composting process producing a uniform and predictable compost product. The purpose of developing batch tunnels with heated walls and floors was to speed up the composting process by ensuring that even the coolest parts of the composting material was at the required temperature.

The system selected for the project uses a re-circulated air procedure which reduces temperature variation across the entire composting mass to just a few degrees.

Ensured pasteurisation

Many of the organic wastes used in composting contain significant levels of human, animal and plant pathogens, and also viable weed seeds. They may also be subject to the Animal By-Products Regulations.

The computer-controlled system selected for the project brings all of the composting material to the same temperature, then allows that temperature to rise to the level required for pasteurisation, and maintains that temperature for the required period of time before reducing the temperature to that which is required for the composting process. The system can provide the degree of control over the composting process required by the Animal By-Products Regulations.

Efficient leachate control

Open systems that are exposed to the environment can experience odour and containment problems through the release of leachate.

The system to be used by the project produces little leachate, and, as it is fully enclosed, no leachate is produced from rain water. The leachate that is produced can be re-circulated back on to the composting material before the pasteurisation stage.

Efficient odour control

Because the composting process is contained, it should be possible to ensure that any odour-carrying air generated is processed to remove odours before it leaves the composting container.

The system selected for the project guarantees aerobic conditions and therefore does not generate anaerobic odours. All process air is taken through a computer-controlled scrubber and biofilter system to remove odour from the air before it is released to atmosphere.

Appropriate data collection and analysis

As with any other manufacturing process, it is essential that adequate production data is collected. This enables the process to be quality controlled, for example to prove that a particular batch of material has been adequately pasteurised under the Animal By-Products Regulations.

The system selected for the project is computer controlled. All process data, including temperature, oxygen, carbon dioxide, ammonia, humidity and energy consumption are automatically collected and recorded in a form that allows full analysis. Data is collected every 15 minutes.

Cost-effective expansion

Any composting technology employed, especially the more capital-intensive technologies, must be capable of being expanded in a cost-effective way.

The system selected for the project is modular, allowing the expansion of the facility to match the volume of feedstock throughput.

Minimum labour costs

Labour costs form a major proportion of compost processing costs. Any system that reduces the requirement for labour, without compromising safety and quality, is favoured. Many of the contained composting systems available, through the use of automation and computer control, can process large quantities of organic wastes with a very small labour requirement.

The composting system selected for this project involves the minimal movement of the composting material, with a corresponding reduction in labour costs.

2.2 Project aims

The overall aim of this project was to design, build and investigate a batch tunnel in-vessel composting technology process. The basic technology chosen, batch tunnels manufactured by the Dutch company Gicom b.v., has been used for many years to produce compost from municipal, commercial and agricultural wastes. The batch tunnel technology has been further developed for this project by incorporating unique heated walls and floors using hot water pipes embedded in wall and floors during tunnel construction that are connected to a boiler to provide hot water.. The intention of this development was to determine in this form of heating would enable pasteurisation temperatures to be reached in a shorter time in order to increase the throughput of the tunnels.

The project was set up as a demonstration-scale composting system in which all of the important parameters of composting – operational, health and environmental - could be identified, quantified and optimised. This would provide a standard against which other composting systems could be measured and would provide data to help in the efficient design and operation of other composting systems.

The project system consisted of four computer-controlled composting tunnels and a computer controlled air scrubber and block of biofilters. The aim of the project was to improve composting procedures for a variety of Municipal Solid Waste based feedstocks, and to determine and minimise the effect of the composting process upon the environment. The system was designed to process at least 180 tonne batches of waste at a time. This scale was chosen to provide data produced at the same scale as commercial process conditions.

The project tunnels were part of a large composting facility, licensed to process 105,000 tpa of organic wastes. The main feedstock for the site is local authority kerbside collected kitchen waste and green waste. The waste is shredded on arrival and loaded into the tunnel for processing compliant with ABPR. After tunnel composting the pasteurised material is windrow composted for at least 8 weeks, passed through a 10 mm trommel screen, with the screened material being supplied to local farmers as a soil improver and source of plant nutrients. Details of the methodology of windrow construction and turning are given in SOP 3.

The project, under terms of the contract agreement, was required to process a minimum of 10,500 tonnes of biodegradable municipal waste (BMW) during a minimum of 8,000 operational hours, processing a minimum of 70 batches of feedstock material.

The project was intended to develop optimised composting regimes that would:

- produce safe, high quality composts from a variety of MSW-based feedstocks in the shortest possible time
- have minimal effect upon the environment
- have minimal effect upon operator and public safety
- operate with the most efficient use of energy

- determine essential technical data, such as mass and energy balances, the physical, chemical and microbial properties of the composts produced, and all leachate and gaseous emissions

During the feedstock trial research phase of the project staff from the University of Leeds carried out various monitoring sessions for bioaerosols and unique and rigorous temperature monitoring. Envar and the University of Leeds were able to work together closely on the site and share data as agreed with the Technical Advisory Committee. The University of Leeds team were also active in monitoring and evaluating the research carried out by the project for Defra.

Under the terms of the contract Envar were committed to develop an on-site visitor centre that would host stakeholders from local authorities, academia, the Environment Agency for England and Wales and the waste management industry. An initial target of 75 stakeholder visits was detailed within the contract agreement. Envar were able to exceed this figure by early 2008 and hosted a final project seminar during April 2009.

The techniques developed by this project, and the technical data generated, can be utilised by designers and operators of commercial-scale in-vessel composting systems in the UK. The results of this project will therefore have a significant leverage effect upon other composters, and will also help educate, and give confidence to, the general public that composting facilities do not constitute a threat to their local environment.

The projects scope of works (as detailed originally within the full proposal and confirmed later within the contract agreement) is covered in the following sections.

2.3 Project waste streams

The composting tunnels were used to compost a number of organic waste streams derived from Municipal Solid Wastes. These included:

- kerbside collected kitchen waste
- kerbside collected kitchen waste combined with kerbside collected green waste
- organic fines from mixed MSW (Municipal Solid Waste)

The kitchen waste and green waste were processed in a wide variety of ratios. The MSW fines were co-composted with a mixture of green waste and kitchen waste in order to reduce the bulk density and moisture of the material filled into the tunnels.

2.4 BMW diversion

Table 1 indicates the total quantity of BMW that was expected to be diverted by the project at the time of the project proposal.

Table 1: Estimated BMW diversion

Waste Streams	Municipal	Amount	Biodegradable Content	Total NTDP Compliant
Kerbside collected kitchen waste	Yes	1,000	90%	900
Kerbside collected kitchen waste combined with kerbside collected green waste	Yes	3,000	90%	2,700
Organic fines from mixed MSW	Yes	800	60%	480
Green waste	Yes	800	90%	720
Total amount of BMW processed				**4,800**

2.5 Other output materials

With the exception of the organic fines obtained from mixed Municipal Solid Wastes, the feedstocks used in this project were all source-separated, allowing the treatment of material with a low percentage of contraries. This enables the production of compost that is suitable for a number of uses, such as soil improvement. The material resulting from the composting of the organic fraction of mixed Municipal Solid Wastes, obtained after mechanical separation, had a higher level of contraries and would be only suitable for restoration projects. The final material produced from eight of the MSW fines was a compost-like output (CLO), while the material produced by two of the runs was treated as refuse derived fuel (RDF).

2.6 Residues

It was estimated that c. 2,300 tonnes of compost product would be produced during the course of the project.

2.7 Mass balance

Part of the project was to weigh material entering and leaving each of the tunnel stages, and also to weigh the final product and oversize produced. This would provide a guide as to the efficiency of the composting process and the yield of product obtained. A spreadsheet model of the mass balance was to be produced.

2.8 Energy balance

The total containment of the composting process, made possible by the use of the batch composting tunnels, and the ability to accurately measure energy inputs and outputs during composting through continuous monitoring and computer analysis of the data, makes this system ideal in determining and optimising the energy balance.

The use of batch tunnel composting over a number of years has resulted in the development of a system for maximum energy conservation by:

- The efficient insulation of the composting tunnels and the associated aeration ducting.
- The correct sizing of the aeration fans to ensure that excess energy is not used in the provision of the required level of aeration.
- The design of the aeration ducting to minimise energy loss.
- The calculation of the correct physical properties of the composting matrix, e.g. bulk density, moisture, load per m^2 of floor area, depth, to ensure that aeration is efficiently ensured without the use of excessively large fans.

It was one of the purposes of the project to accurately measure and optimise the energy balances of composting processes using a number of different feedstocks and a number of different composting regimes. A spreadsheet model of the energy balance was to be produced.

2.9 Emissions

The composting batch tunnels consist of a completely closed system except for exhaust process air passing through a scrubber and biofilter before release to atmosphere.

The total control over the air supply system that is possible, under computer control, ensured that:

- The composting matrix remained aerobic at all times. The computer can be programmed to not allow oxygen levels in the recirculating air, and hence the composting material, to drop below a predetermined level, e.g. 7%. Therefore, anaerobic conditions, with the associated offensive odours and typical VOCs (Volatile Organic Compounds), would not occur.
- There would be no fugitive, odorous emissions released during the composting process through the use of the computer-controlled air scrubber and biofilters.

Part of the project was to look at accurately measuring the emission of odours, VOCs and bioaerosols from the composting process, an activity made possible by the total containment of the composting process, and to further develop methods of minimising the release of these components into the atmosphere. Details of the methodology of emissions monitoring are given in Section 17.4.

2.10 Engineering strategy & standards

The long track record of the company producing the batch composting tunnels used in the project ensured that the engineering strategy and standards were of the highest order.

The supply contract was according with the ORGALIME S 2000 General Conditions for the Supply of Mechanical, Electrical and Electronic Products (Brussels, August 2000).

During the commissioning stage of the project a protocol was drawn up, to be signed by both parties at successful completion. The technical commissioning of the system carried a one year guarantee.

The guarantees apply to the following items:

- labour, materials and software;
- the aeration system;
- the sprinkler installation in tunnels;
- the measurement and control instruments;
- all built in equipment;
- spare parts.

2.11 Project research principles and protocol

The need for high quality research work on the composting process itself, and the effect of composting on the environment and on the health of operators and others, was well recognised.

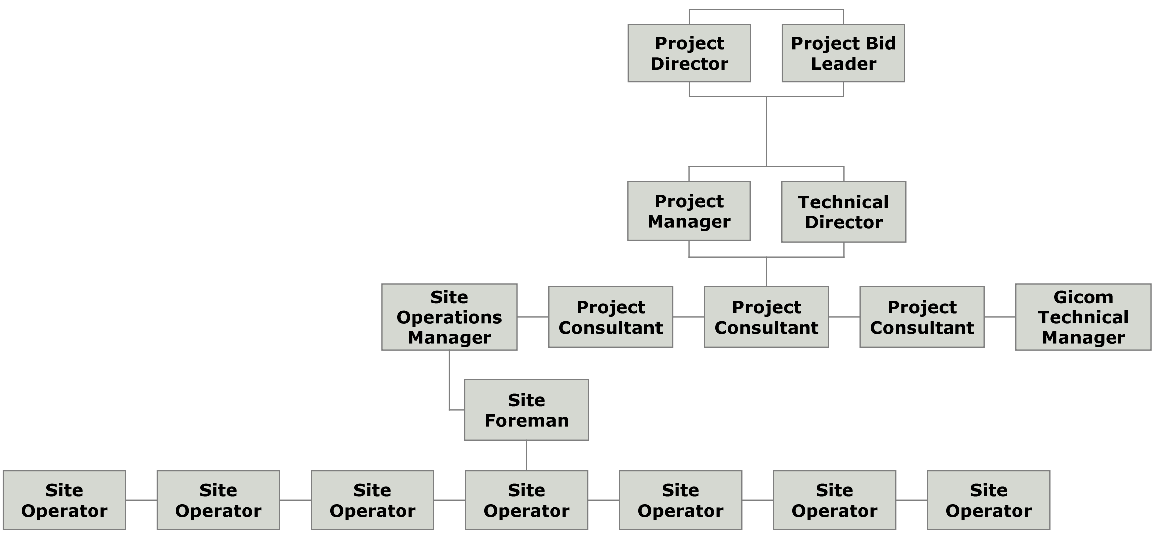
In its recent report entitled "Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes", published by Defra in March 2004, ["The Defra Report"] the Introduction included the statement *"Areas where there is less work and the science is less certain include releases to soil and water and releases from composting, or other forms of waste management like mechanical biological treatment or anaerobic digestion."*

One of the aims of the project was to provide some of this missing information for composting operations. Without this information the development of the composting industry, and hence the ability to recycle the biological component of Municipal Solid Wastes, will be limited and uncertain.

2.12 Project management

The management structure employed by the project was as follows:

Figure 8: NTDP Project management structure



Weekly project meetings were held throughout the course of the project between the Project Manager, the Technical Director, and the Project Consultants. Monthly meetings were held between the above and the Project Director. Regular meetings were held with the Site Operations Manager.

2.13 Development of the project

An initial contract variation was sought by Defra during late 2007 to Incorporate composting tunnel G4 into the project. This was deemed necessary to improve the efficiency of trial runs by allowing non heated wall runs through tunnel G4 while heated runs were processed via tunnel G3. Defra approved this contract variation in February 2008.

During the summer of 2008 a further contract variation was approved by Defra to allow the use of all four tunnels to introduce further improved efficiency during the composting of the chosen feedstocks. The addition of tunnels G5 and G6 (G5 using heated wall and floor technology) meant that the processing time could be greatly improved by enabling all of the systems tunnel capacity to be used to process the specific feedstocks. Approval of this variation ensured that the composting trial phase was completed on time (Spring 2009).

A third contract variation to the project was approved by Defra during the autumn of 2008. This concerned the nature of the feedstocks to be composted. Initially the project listed the feedstocks to be processed as green waste, co-mingled green waste and kitchen waste, kitchen waste, and the organic fraction of Municipal Solid Waste. The proposed modification involved the first three of these wastes. It was proposed instead that the project should process a range of feedstocks varying in the proportion of kitchen waste to green waste between fixed upper and lower limits.

The basis for the contract variation included the following arguments:

- Green waste does not come under the Animal By-Products Regulations and does not need to be composted within a contained system.
- The low gate fee that can be obtained for green waste, as compared to kitchen waste or co-mingled kitchen waste and green waste, would not make it cost-effective for anyone in the industry to use a sophisticated in-vessel system for composting. Therefore, processing this feedstock in the composting tunnels would have no practical benefit for the industry.
- The industry does not compost kitchen waste on its own: it is always mixed with other feedstocks such as green waste. This is necessary because the high density and high moisture levels of the kitchen waste make it impossible for an aeration system, such as that used in the tunnels, to supply oxygen to the material or to control temperatures.
- A range of mixtures of kitchen waste and green waste from 10% kitchen waste to 50% kitchen waste would represent the range of feedstocks collected by Local Authorities across the UK, and that processing this continuum of mixtures would produce data that would be of the greatest relevance to the industry.

3 RISK MANAGEMENT

As with all engineering projects there are a number of significant risks ranging from planning, financial to construction/contractor risks. The potential risks that might have been encountered by this project were identified in the project application, along with an assessment of the likelihood of the risk, the consequences of the risk, and strategies to reduce the risk. These are summarised in Table 2.

At the conclusion of the project an assessment was made of the actual risks encountered during the project, along with their effect on the project, and the steps taken in mitigation. These risks are summarised in Table 3.

The main lessons learned from this examination of anticipated and actual risks for similar projects are:

- An experienced and enthusiastic project manager must be in charge of the project at all times and be fully supported by technical and production staff.
- A close association with the technology provider must be established at the beginning of the project and maintained throughout.
- The project must be carried out to the time and cost requirements of a detailed Gantt chart prepared before the start of the project.
- Milestones must be identified and reached for each stage of the project.

Table 2: Project Risk Assessment before the start of the project

Risk Category	Specific Risk	Likelihood	Consequences Of Failure	Strategies To Reduce Risk Of Failure
Site selection	Problems with planners	Low	Delay of operation	• Planners fully informed of project activities
	Problem with Environment Agency	Low	Delay of operation	• EA fully informed of project activities
	Problems with landlord	Low	Delay of operation	• Landlord fully informed or project activities • Lease contract with landlord
	Problems with local community	Low	Delay of operation	• Public fully informed of project activities though consultation with planners
Technology selection	Non-compliance with regulations (e.g. ABPR)	Low	Cessation of regulated activity	• Regulators (e.g. EA/SVS) fully informed of project activities • Demonstrable track record of applicant and composting technology • Strict management of project activities to ensure compliance • Regular monitoring of environmental parameters

Risk Category	Specific Risk	Likelihood	Consequences Of Failure	Strategies To Reduce Risk Of Failure
	Non-compliance with WML (Waste Management License) (leachate/odour)	Low	Cessation of regulated activity	• EA fully informed of project activities • Strict management of project activities to ensure compliance • Regular monitoring of environmental parameters
	Inability to generate high-quality data	Low	Inability to satisfy quality requirements of project	• Selection of technology company with a demonstrable track record of high quality equipment and operation
	Unacceptable effect upon the local environment (odour/bioaerosols)	Low	Delay of operation	• Strict management of project activities to ensure compliance • Regular monitoring of environmental parameters
Technology supplier	Financially unviable	Low	No project equipment available or equipment not supported	• Selection of technology company with a demonstrable track record of high-quality equipment and operation • Use of ADAS QA vetting process
	Inability to deliver on schedule	Low/moderate	Delay of project	• Selection of technology company with a demonstrable track record of high quality equipment and operation • Use of ADAS QA vetting process

Risk Category	Specific Risk	Likelihood	Consequences Of Failure	Strategies To Reduce Risk Of Failure
	Equipment does not work	Low	Inability to deliver project targets	• Selection of technology company with a demonstrable track record of high quality equipment and operation • Use of ADAS QA vetting process
	Equipment not maintained or repaired	Low	Inability to deliver project targets	• Selection of technology company with a demonstrable track record of high quality equipment and operation • Use of ADAS QA vetting process
Staff	Inability to work at required technical level	Low	Delay until staff replaced or retrained	• Existing site staff very experienced
	Problems with health (bioaerosols)	Low	Possible cessation of project activity or redesign of equipment or process resulting in project delay and increased costs	• Existing staff familiar with personal protection systems and health and safety procedures
Costs	Costs – Processing costs beyond budget	Low/moderate	Cut back of scope of project	• Costs calculated on the basis of existing composting operations on site • Previous extensive experience of project team

Risk Category	Specific Risk	Likelihood	Consequences Of Failure	Strategies To Reduce Risk Of Failure
	Costs – Capital costs beyond budget	Low/moderate	Cut back of scope of project	• Selection of technology company with a demonstrable track record of high-quality equipment and operation • Working to an agreed contract with technology supplier
	Costs – equipment repair or replacement	Low	Cut back of scope of project	• Selection of technology company with a demonstrable track record of high-quality equipment and operation • Working to an agreed contract with technology supplier • Equipment guaranteed for one year • Adequate insurance
	Costs – disposal to landfill (contraries) beyond budget	Low	Cut back of scope of project	• Calculation of quantity of contraries that will require landfilling • Selection of technology company with a demonstrable track record of high-quality equipment and operation • Quality control of feedstock by written agreement with supplier
Match funding	Delay in obtaining	Medium	Delay until replacement found	• Different funding streams being approached

Risk Category	Specific Risk	Likelihood	Consequences Of Failure	Strategies To Reduce Risk Of Failure
Sub-contractors/partners	Sub-contractors financially unviable	Low/moderate	Delay until replacements found	• Use of ADAS QA vetting process
	Inability to deliver on time	Low/moderate	Delay to project	• Use of ADAS QA vetting process
	Inability to deliver required quality of work	Low/moderate	Delay until replacements found	• Use of ADAS QA vetting process • Replacements identified
	Withdrawal from project	Low/moderate	Delay until replacements found	• Use of ADAS QA vetting process • Replacements identified
Insurance	Site insurance	Low	Project cannot operate	• Use of ADAS QA vetting process
	Equipment insurance	Low	Project cannot operate	• Use of ADAS QA vetting process
	Public liability insurance	Low	Project cannot operate	• Use of ADAS QA vetting process
	Professional indemnity insurance	Low	Project cannot operate	• Use of ADAS QA vetting process
Waste stream	Loss of contract	Low/moderate	Delay until replacement contract obtained	• Contract in place with supplier • Replacement identified
	Insufficient quality of feedstock	Low/moderate	Delay until replacement feedstock located	• Contract in place with supplier • Replacement identified
	Insufficient quantity (seasonality)	Low/moderate	Delay until replacement feedstock located	• Contract in place with supplier • Replacement identified
Fire	Fire damage to equipment	Low	Delay until equipment replaced or repaired, or cessation of project if damage extreme	• Fire precautions in place • Site security in place

Risk Category	Specific Risk	Likelihood	Consequences Of Failure	Strategies To Reduce Risk Of Failure
Flood	Water damage to equipment	Low	Delay until equipment replaced or repaired, or cessation of project if damage extreme	• All equipment in sealed units within a building • Site security in place

Table 3: End of project risk assessment

Risk Category	Specific Risk	Problems Encountered During The Project	Steps Taken To Counter The Risk	Result Of Steps Taken
Site selection	Problems with planners	None	Discussions were held with the County planners before the submission of the planning application for the building and operation of the project tunnels. A detailed application was submitted to support the building of the tunnels. This was accepted by the planning committee. .	Planners fully informed of project activities before the start of the project and during the project itself.
			After planning permission had been granted, a liaison committee was set up including County planners, local Parish Councils, District Council, County Council, Environment Agency, and Environmental Health. This met at c. 3 monthly intervals during the course of the project. The committee was informed about site operations, including the operation of the project. Members of the committee were able to ask questions and express any concerns	

Risk Category	Specific Risk	Problems Encountered During The Project	Steps Taken To Counter The Risk	Result Of Steps Taken
	Problem with Environment Agency.	None	The Environment Agency were part of the liaison committee (see above).	EA fully informed of project activities before and during the project.
	Problems with landlord.	None	The landlord was kept fully informed of the intention to apply for planning permission for the project tunnels and provided with full design details.	Landlord fully informed of project activities at all times.
	Problems with local community.	One objection at the planning application stage by a local Parish Council regarding potential odour problems.	A statement was made by David Border at the County planning committee meeting to explain that the use of a scrubber and biofilter system with the project tunnels would reduce the risk of odour problems. A liaison committee including the Parish Council was set up (see above).	Public fully informed of project activities though the attendance of the local Parish and District Councils.

Risk Category	Specific Risk	Problems Encountered During The Project	Steps Taken To Counter The Risk	Result Of Steps Taken
Technology selection	Non-compliance with regulations (e.g. ABPR)	None	Animal Health (State Veterinary Service) and the Environment Agency were brought into discussion before the start of the project. The design and operation of the project tunnels were discussed in detail with the local Animal Health officers to secure their agreement under the 1774/2002 Animal By-Products Regulations (ABPR). The Environment Agency was also fully informed through attendance at the liaison committee meetings (see above) and regular site inspections. Compliance with regard to ABPR and the site Environmental Permit was considered an absolute requirement for the project and great attention was paid to ensuring that the design of the tunnels and their operation were tightly controlled.	Regulators fully informed of project activities at all times.
	Non-compliance with WML (leachate/odour).	None	The project activities complied fully with the conditions of the WML (now Environmental Permit) in terms of leachate and odour.	No problems relating to leachate and odour were associated with the project.
	Inability to generate high-quality data.	None	The Gicom tunnel computer was used to collect and analyse process data. This was backed up by the manual recording of other supporting data.	High-quality and original data was collected throughout the course of the project.
	Unacceptable effect upon the local environment (odour/bioaerosols).	None	The project was carried out using the scrubber and biofilter system to treat the tunnel composting exhaust air before release to atmosphere.	No problems relating to odour or bioaerosols were associated with the project.

Risk Category	Specific Risk	Problems Encountered During The Project	Steps Taken To Counter The Risk	Result Of Steps Taken
Technology supplier	Financially unviable	None	Only companies with a well established reputation, and who were well known to the project managers, were used in the project. Close contact was maintained between the project manager and Gicom and the other suppliers of equipment used in the project.	No problems were encountered with the technology suppliers in terms of financial viability.
	Inability to deliver on schedule.	There was a slight time delay in completing construction of the tunnels. The construction of the heated walls and floors, carried out for the first time, resulted in a delay in the building of the tunnels of a few weeks.	The technology provider was selected on the basis that they had successfully constructed many tunnel composting facilities on schedule and to budget, Close contact was maintained between the project manager and Gicom and the other suppliers of equipment used in the project. Regular meetings were held with Gicom staff building the tunnels and with supporting technical and sales Gicom staff in Holland. A detailed Gantt chart was prepared at the start of the project to ensure that the construction and commissioning of the tunnels was carried out on time and that any potential delays were identified as soon as possible. Milestones were identified for each stage of the project, e.g. planning, permitting, construction and commissioning. These were regularly assessed and compared with the project Gantt chart.	The delay in construction of the tunnels did not damage the overall success of the project. The technology provider now has experience in constructing tunnels with heated walls and floors.

Risk Category	Specific Risk	Problems Encountered During The Project	Steps Taken To Counter The Risk	Result Of Steps Taken
	Equipment does not work.	Problems were encountered with the oxygen probe at one point. Ammonia readings were problematic at the start of the project.	The technology provider was selected because of their excellent reputation in constructing composting tunnels that work well with a wide variety of feedstocks. Oxygen probe was replaced. Ammonia probe was recalibrated.	Although a few readings were lost, enough data was collected to allow significant conclusions to be made regarding these two parameters.
	Equipment not maintained or repaired.	Repair and maintenance work was carried out efficiently and on time.	The technology provider was selected as the company was well known to project staff as having an excellent reputation for technical and maintenance support. Close contact was maintained between the project manager and the Gicom technical support team.	The down time of the equipment was kept to a minimum.
Project management	Insufficient control over costs and the delivery of targets.	None	The selection of high-quality and experienced project managers ensured that adequate control over project activities was maintained at all times. This was one of the most important steps carried out to ensure the successful delivery of the project.	Adequate control of the project activities was maintained.
Staff	Inability to work at required technical level.	The technical staff were more than capable of carrying out the project and interpreting the results. During the project there was a change in site manager.	Technical staff were carefully selected to ensure they had the required experience and knowledge to carry out the project. A new site manager was appointed.	The technical staff successfully carried out the project and interpreted the results. The new site manager successfully carried out the site's responsibilities to the project.

Risk Category	Specific Risk	Problems Encountered During The Project	Steps Taken To Counter The Risk	Result Of Steps Taken
	Problems with health (bioaerosols).	None. No health problems were encountered during the project.	All staff were trained regarding safe working procedures. Standard operating procedures were prepared. Staff were supplied with appropriate personal protection equipment and were properly supervised.	No health problems were encountered during the project.
Costs	Costs – Processing costs beyond budget.	None. The processing part of the project was carried out within budget.	The project manager maintained close control over expenditure throughout the project and reported progress at regular intervals.	The processing part of the project was carried out within budget.
	Costs – Capital costs beyond budget.	None. The tunnels were constructed within budget.	The project manager maintained close control over expenditure throughout the project and reported progress at regular intervals.	The capital cost of building the tunnels was within budget.
	Costs – equipment repair or replacement.	Repairs and modifications to the oxygen and ammonia monitoring system were carried out.	The project manager maintained close control over expenditure throughout the project and reported progress at regular intervals.	The repair and modification costs were within budget.
	Costs – disposal to landfill (contraries) beyond budget.	Disposal of contraries to landfill were at expected levels.	Estimates of likely quantities of materials requiring landfilling, and associated costs, were made during the preparation of the budget for the project.	Disposal costs were at expected levels.
Match funding	Delay in obtaining	None. No match funding was required	Not applicable	Not applicable
Sub-contractors/partners	Sub-contractors financially unviable.	None.	Only companies with a well established reputation, and who were well known to the project managers, were used in the project.	No problems were encountered with the financial viability of any supplying company.

Risk Category	Specific Risk	Problems Encountered During The Project	Steps Taken To Counter The Risk	Result Of Steps Taken
	Inability to deliver on time	None	Only companies with a well established reputation, and who were well known to the project managers, were used in the project. The project manager maintained close control over progress throughout the project	No problems were encountered with sub-contractors ability to deliver on time.
	Inability to deliver required quality of work	None	The project manager maintained close control over progress and quality throughout the project	No problems were encountered with the quality of the sub-contractor's work
	Withdrawal from project	None	The project manager maintained close control over progress and the activities of the sub-contractors throughout the project	No problems were encountered with sub-contractors withdrawing from the project
Insurance	Site insurance.	None	The composting tunnels and the activities carried out by the project were covered by the normal company and site insurance.	The project was adequately insured at all times.
	Equipment insurance.	None	The composting tunnels and associated equipment were covered by the normal company and site insurance.	The equipment used by the project was adequately insured at all times.
	Public liability insurance.	None	The project operated under the normal company public liability insurance.	The project was adequately covered in terms of public liability insurance at all times.

Risk Category	Specific Risk	Problems Encountered During The Project	Steps Taken To Counter The Risk	Result Of Steps Taken
	Professional indemnity insurance.	None	The project operated under the normal company professional indemnity insurance.	The project was adequately covered in terms of professional indemnity insurance at all times.
Waste stream	Loss of contract.	None	Close contact was maintained with the supplying local authorities and commercial company.	Contracts enabling the supply of adequate quantities of the desired feedstocks were maintained throughout the project.
	Insufficient quality of feedstock.	Although there was some variation in the quality of the feedstock the overall quality was within requirements.	All deliveries of feedstock were checked by site operators to ensure they were within the agreed contract specifications.	The quality of feedstock used was within the requirements of the project.
	Insufficient quantity (seasonality).	The quantities of green waste available dropped during the winter months as expected.	Composting runs requiring high proportions of kitchen waste to green waste were carried out during the winter months.	A full range of mixtures of kitchen waste and green waste were processed by recognising, in part, seasonal supply variations.
Fire	Fire damage to equipment.	None	Normal site precautions were taken to prevent the occurrence of fire. Adequate fire fighting equipment was in place. Site staff were trained to react to any fire incident. Site security was in place.	No fire incidents occurred during the project.
Flood	Water damage to equipment.	None	Normal site precautions were in place to prevent any risk of flooding.	No flooding incidents occurred during the project.

4 RELEVANT LEGISLATION AND AUTHORISATION

4.1 Planning

A new planning application under the Town and Country Planning Act (1990) was made to Cambridgeshire County Council in February 2006 (application No. H/05003/06/CW). This application covered the replacement of an existing building (used for storage) with one of the same height and footprint to contain four enclosed composting tunnels. These were the Gicom tunnels to be used in the NTDP project.

A preliminary meeting was held with the Council planners prior to submission in order to take on board any comments or concerns. No significant concerns were raised.

The application was considered by the Development Control Committee on 15th May 2006. One objection was received at the meeting from a local Parish Council on the basis of expected problems with odours produced by the new tunnels. David Border (Head of Composting for ADAS) gave evidence that the new tunnels were to be fitted with a scrubber and biofilter system that would prevent any odour problems. This argument was accepted and planning permission was granted at that meeting for the four new tunnels.

During the planning meeting it was proposed that a Liaison Committee should be set up to enable stakeholders to communicate effectively with the site operators about current and proposed activities that would affect the local environment.

A Liaison Committee was set up and met later in the year. The membership of the committee consisted of the following organisations:

- Local County Councillor.
- Local District Councillors.
- Local Parish Councillors.
- Cambridgeshire County Council waste planning officer.
- District Council Environmental Health Officer.
- Environment Agency site inspector.

The committee now meets 3 or 4 times a year, and has been very successful in enabling the company to provide information on its activities and ambitions, and enabling the local stakeholders to ask questions and make comments.

The time taken to obtain planning permission for a new development within an existing composting facility, and the chances of success, will depend upon a number of factors:

- The role, if any, that the County planners see for the specific composting facility in their Local Waste Plan.
- The role that the County sees for composting as opposed to alternative methods of treatment for organic waste.

- The number and location of other composting or anaerobic digestion facilities in the County.
- The need, or not, for an Environmental Impact Assessment.
- The timing and frequency of the planning committee meetings: typically every month or every two months.
- The professionalism of the planning application and the degree to which the concerns of the planners, e.g. the proximity principle, have been addressed.
- The likely effect upon the local environment and nearby residents and businesses.
- Any increase in the quantity of feedstock to be processed.
- Any change in the nature of the feedstocks.

Because of the above factors, it is difficult to create a timeline for a specific planning application. However, most planning applications will consist of the following steps:

- Preliminary meeting with planners.
- Preparation of full planning application (Outline planning permissions can not be obtained for waste operations).
- Discussion of planning application with planners before submission.
- Revision of planning application.
- Submission of planning application.
- The application will be copied by the Council to a number of consultees, including the Environment Agency, Environmental Health, and Highways.
- After the results of the consultation have been received the application may be determined by the planners without being put in front of the planning committee, or, more likely, and if any objections have been received, it will have to be considered at one of the planning meetings.
- The applicants, and any objectors, are normally allowed to attend, and speak at the planning meeting.
- The applicant is normally informed if the application has been successful within a few days of the meeting at which it is considered.
- If the application is unsuccessful he/she is informed and the reasons given. It may or may not be possible for the applicant to modify the application to answer these objections and then resubmit.

The entire process can vary from four to five months (as with this application) to well over a year if the planning application is in any way contentious or large in scale. It is essential that the thoughts of the planners are obtained before the application is submitted and that the application is as professional and detailed as possible.

Planning permission for the tunnels used in this project was obtained from Cambridgeshire County Council. Details of the time taken for applications within the County are given at http://www.cambridgeshire.gov.uk/environment/planning/applications/how+long+will+it+take+to+get+planning+permission.htm.

The statutory period for applications is normally eight weeks, but for applications which are accompanied by an Environmental Impact Assessment, the statutory period is sixteen weeks. This does not always mean applications are determined within these periods. If the application is considered a departure from the Local Development Plan, it would be sent to the Secretary of State before the issuing of any planning permission.

Currently the target for the County is to determine 45% of County Matter applications (not involving Environmental Impact Assessment) for minerals and waste development within 13 weeks of registration.

The company's experience in making this planning application, and the relative speed by which permission was obtained, result in the following recommendations being made to other composting companies wanting to build a new in-vessel composting facility within an existing composting operation:

- Read the County's Local Waste Plan to determine the position of the existing composting facility within this plan, and to determine the County's policies regarding the development of composting facilities. For example, there is currently a strong move towards the use of anaerobic digestion as a method of processing organic waste.
- Meet with the local planners at a very early stage in order to obtain an initial opinion on the likelihood of success and to identify any potential problems, e.g. any height restrictions, or their attitude, if relevant, to feedstock coming from outside the County.
- Find out the dates of the County Planning Committee meetings and the deadlines for the submission of planning applications.
- Time the preparation of the application to meet the next feasible submission date.

- After the preliminary meeting with the planners, prepare a detailed planning application paying particular attention to odour, noise and bioaerosols. (In this case it was possible to demonstrate that there would be an improvement in odour and bioaerosol emissions because of the use of a scrubber and biofilter system, and no significant increase in noise).
- Although a planning consultant was not used in this particular application it is recommended that a planning consultant with specific experience in obtaining planning permissions for composting sites should be used. All future planning applications made by the company will use a planning consultant.
- Before a planning application is prepared, set up a Liaison Committee including local Parish Councillors, the District and County Councillors for the area, the Environment Agency, the County planners, and Environmental Health. The proposed application can then be discussed and any concerns addressed. (In this case the Liaison Committee was set up after the application had been accepted. The one objection to the development might have been averted if the Liaison Committee had been in place at the time of the application).
- Hold the liaison committee meetings at three or six month intervals even if no application is being progressed at the time. This is a very useful format for keeping local representatives and regulators informed about site activities and proposed developments.

4.2 Environmental Permitting Regulations (2007)

The Environmental Permitting (England and Wales) Regulations 2007 (EP) came into force on the 6th April 2008. The intention is to make existing legislation more efficient by combining ‘Pollution Prevention and Control Regulations (2000)’ and ‘Waste Management Licensing Regulations’. Any permits currently issued under the Waste Management Licensing (WML) Regulations will automatically become Environmental Permits.

The project was carried out under the existing Environmental Permit of the St Ives site. This was first obtained in 2002 (as a Waste Management License), and modified in 2004 and 2006 as the quantity of feedstock processed at the site increased. The current Environmental Permit for the site allows the processing of up to 105,000 tonnes a year of a wide range of organic wastes.

The initial Waste Management License for the site was for the windrow composting of green waste only. Obtaining this license was a fairly simple procedure that raised no objections from consultees as the site had been well-established as a mushroom composting site for nearly forty years.

The license was altered in 2004, and again in 2006, to allow the composting of increasing quantities of co-mingled green waste and kitchen waste, and separately collected kitchen waste. The processing of these wastes required the use of the enclosed batch tunnels. It was also necessary to obtain a license under the Animal By-Products Regulations for the composting of catering waste.

The use of batch tunnels as a composting technology does not raise any particular problems in obtaining an Environmental Permit. In fact, the containment of the composting process, and the potential for the treatment of process air to remove odours, make this technology particularly attractive in terms of minimising the impact of composting on the local environment.

The design of the newer tunnels used by the project included a scrubber and biofilter system to remove odours from the process air. These items were included partly to play a role in the project itself, but also to ensure that planning permission could be obtained easily and that the associated increase in throughput of the site would not result in problems with the Environmental Permit.

This method of contained composting is viewed favourably by the Environment Agency because of the enclosure of the process, the ensuring of aerobic conditions, and the treatment of process air to remove odours.

The commonest potential problem in obtaining, and keeping, and Environmental Permit for a composting facility is the generation of malodours. The batch tunnel system successfully avoids this problem. In some other systems, where the creation and maintenance of fully aerobic conditions cannot be assured, or the process air cannot be treated, malodours can be a considerable problem.

4.3 Animal By-Products Regulations (ABPR)

Following the outbreak of Foot-and-Mouth Disease (FMD) in 2001, the Government introduced a ban on the feeding to animals of catering waste that contains or has been in contact with animal by-products (ABPs). This ban was subsequently reflected by the EU Animal By-Products Regulation and became mandatory in all member states.

The ban includes the use of used cooking oils (UCOs) originating in restaurants, catering facilities and kitchens, including central kitchens and household kitchens.

Animal by-products (ABPs) are animal carcases, parts of carcases or products of animal origin that **are not** intended for human consumption. This includes **catering waste**, used cooking oil, former foodstuffs, butcher and slaughterhouse waste, blood, feathers, wool, hides and skins, fallen stock, pet animals, zoo and circus animals, hunt trophies, manure, ova, embryos and semen. Devolved administrations are responsible for ABP policy in Scotland, Wales and Northern Ireland.

In addition to the other outlets for animal by-products, catering waste may continue to be disposed of to landfill, although it is possible that alternative outlets such as composting treatment will be increasingly used for such material. The Government established the Waste Implementation Programme which aims to increase the diversion of biodegradable **municipal** waste and improve the sustainability of waste management. This should progressively assist in the general move away from landfill and help provide some impetus towards the establishment of more composting plants.

Currently, the St Ives composting site only processes catering waste. This is kerbside collected material collected from domestic premises as either kitchen waste, or co-mingled kitchen waste and green waste (grass, tree trimmings, leaves).

Licences are obtained by application to the local Animal Health (previously known as the State Veterinary Service). The licences are policed by Animal Health and enforced by Trading Standards.

Background to the Regulations

Under the Animal By-Products Order 1999 (SI 1999/646)[2] (as amended by SI 2001/1704)[3] it was an offence to allow livestock, including wild birds, access to catering waste containing meat or products of animal origin, or catering waste which originated from a premises on which meat or products of animal origin were handled. The aim was to prevent the introduction and spread of serious animal diseases such as Foot-and-Mouth Disease that can be in the meat. Although this did not prevent the composting of catering waste containing meat or products of animal origin, the ban on access by wild birds did, in practice, prevent its use on land (whether treated or not). This effectively banned composting as treatment and recovery methods for such catering waste.

Under the EU 1774/2002[4] legislation the treatment standard for composting is 70°C for 1 hour with a maximum particle size of 12 mm. This treatment standard is mandatory for any premises that treat category 3 animal by-products other than catering waste, or category 2 animal by-products that have been pressure rendered. The requirement for 12 mm maximum particle size means a maximum of 12 mm in one plane i.e. a feather may be 300 mm long, but if it is less than 12 mm thick it will fall within the 12 mm range.

Treatment under the EU standard only requires a single stage in a closed reactor to be approved under the Regulation (in contrast to the national standards for catering waste as outlined below).

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[2] http://www.opsi.gov.uk/si/si1999/19990646.htm

[3] http://www.opsi.gov.uk/si/si2001/20011704.htm

[4] http://eur-lex.europa.eu/LexUriServ/site/en/consleg/2002/R/02002R1774-20060401-en.pdf

Under EC 1774/2002, member states are permitted to carry out the treatment in approved composting premises of low-risk animal by-products and catering waste which contains meat or which comes from a premises handling meat. Animal by-products must be treated to a set EU standard, but the Regulation permits member states to introduce their own national standards for premises which are handling only catering waste (and not any other animal by-products).

ABPR risk assessment

A risk assessment was carried out (2002)[5] to look at the risk to animal and public health from a wide range of pathogens. It concluded that composting or anaerobic digestion could be safely done providing suitable safeguards and treatment standards were introduced. The risk assessment was based on a 'credit' system, which rated each stage of the treatment process as worth a certain number of credits, depending on the level of pathogen removal. The risk assessment concluded that a system needed to demonstrate a 50,000-fold reduction in pathogen level to be safe. The system would also have to have multiple barriers (i.e. more than one treatment stage) to reduce the possibility that any material could bypass the system.

The alternative national standards were set following the publication of the risk assessment and a public consultation exercise based on the recommendations made in the risk assessment. The national standards for England are set out in the Animal By-Products Regulations 2005.

Current ABPR processing standards for catering waste

Under the current UK Animal By-Products Regulations (2005)[6] the minimum time/temperature and maximum particle size requirements for composting are as follows:

Table 4: Approved composting methods for catering waste under UK ABPR (2005)

[5] http://www.defra.gov.uk/foodfarm/byproducts/documents/report5.pdf
[6] http://www.opsi.gov.uk/si/si2005/20052347.htm

System	Minimum temp	Minimum time	Max particle size
Composting (closed reactor)	60°C	2 days	40cm
Biogas	57°C	5 hours	5 cm
Composting (closed reactor) or biogas	70°C	1 hour	6 cm
Composting (housed windrow)	60°C	8 days (during which windrow must be turned at least 3 times at no less than 2 day intervals)	40cm

A composting plant treating category 3 catering waste (such as the St Ives site) to one of the UK national standards must either have a two-stage composting system, or must treat only catering waste where measures were taken at source to ensure that meat was not included. In a two-stage composting system, the first composting stage must be done in a closed vessel. The second stage need not be enclosed. In a one-stage system for 'meat-excluded catering waste', the composting must be done in a closed vessel.

Defra normally expect that the two composting stages take place in separate and distinct vessels/areas (i.e. the catering waste is treated in one vessel, then moved to a second vessel or a windrow for the second stage). However, some systems where the material is mixed may be able to achieve both stages in a single vessel. It would need to be demonstrated that the material within such a vessel achieves the two time/ temperature treatment stages separately, and that between completing the first stage and the second stage, the material is mixed (e.g. by an auger or other turning device). Separation between the two stages to prevent cross-contamination is also vital (e.g. in a vertical system, ensuring liquid cannot bypass the first stage by dripping or seeping down into the second stage). A system where the material remains static within the vessel (such as at the St Ives site) could not be considered as able to achieve both stages in the single vessel, as although it may be possible to attain the temperature requirements, the material is not mixed in between. Consequently, any material in a cold spot in the first stage will remain in a cold spot in the second stage, and may not be properly composted. The same applies to systems which operate on a plug flow basis, if they do not have a specific mixing mechanism. Material passing through a plug flow system may achieve the two temperature requirements at separate points, but simple movement through the system does not constitute mixing. In these instances, material would have to be removed from the vessel to a separate second composting stage.

Alternative processing methods under UK ABPR 2005

There is a provision in the UK ABPR 2005 Regulations for alternative methods of treating catering waste. Approvals will normally only be given for plants achieving one of the standards above or the EU standard. However, the implementing Regulations provide that 'the Secretary of State may approve a different system if he/she is satisfied that it achieves the same reduction in pathogens as those methods (including any additional conditions imposed on those methods) in which case the approval must fully describe the whole system'. This provision has been included to allow the approval of systems which achieve the required treatment standards but which may otherwise vary from the requirements of the Regulations i.e. it is intended to allow flexibility for new approaches or innovations that may not be reflected by the current Regulations.

The material processed during the project was tested by Eurofins Laboratory Ltd. (Woodthorne, Wergs Rd., Wolverhampton, WV6 8TQ). As all the material processed by the project was classified as catering waste, only tests for *Salmonella* had to be carried out.

Composting and (EC) 208/2006

On 7th February 2006 the EU issued an amendment to 1774/2002 that has become known as 208/2006[7]. The amendment concerns Annexes VI and VIII of 1774/2002 and permitted methods of processing for composting plants. Although this Regulation was in place in 2006 it was not until September 2008 that Defra issued Guidance on how the Regulation would apply. It was not possible to apply for a license under this Regulation until then. In fact, the guidance on this Regulation is still not complete and there is considerable confusion amongst composters. A level paying field does not yet seem to have been established.

Basic effect of the 208/2006 regulation

Regulation 208/2006 allows for the approval of alternative composting standards for the treatment of animal by-products. Rather than setting out the process requirements (time/temperature/particle size) for treatment of raw material it permits the operator to specify their own treatment parameters, provided that the operator can demonstrate through microbiological testing of the finished product that the system has produced sufficient pathogen reduction (and of course provided the system still complies with all other aspects of 1774/2002).

[7] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:036:0025:0031:EN:PDF

The operator must be able to demonstrate a 5 log reduction of certain marker bacteria. The Regulation also requires that a 3 log reduction of infectivity in thermoresistant viruses is demonstrated 'whenever they are identified as a relevant hazard'. As material from composting plants is likely to end up on land to which animals may have access (following a suitable grazing ban in the case of farmed animals) Defra's current position is that viruses will be assumed to be a relevant hazard and the 3 log reduction of infectivity of thermoresistant viruses must be demonstrated.

Similarly the processing of manure in technical plants is now not restricted under 208/2006 to the single EU treatment standard in 1774/2002, but may also benefit from the same demonstration of a 5 log reduction of certain marker bacteria, and a 3 log reduction of infectivity in thermoresistant viruses.

New Marker Pathogens for Sampling Under 208/2006

Under the existing 1774/2002 rules, the marker organisms which must be used for sampling in composting plants are clearly specified (*Salmonella* and *Enterobacteriaceae*). The tests for these markers are well-established, and previously the protocol has been for samples to be sent to Defra-approved private laboratories who would test for the presence of these markers (official samples taken by Animal Health would be sent to the VLA). The VLA would be responsible for approving the private laboratories. The VLA would also be responsible for the QA (quality analysis) audit of the testing itself.

However, Regulation 208/2006 allows for the introduction of 2 new elements:

- New marker organisms not previously tested for by the VLA and not necessarily with well-established tests available (e.g. *Enterococcaceae*).
- Regulation 208/2006 also permits the operator to nominate other markers that they may wish to use, provided this marker can be used to demonstrate to the satisfaction of the approving officer an equivalent risk reduction to the markers named in the Regulation.

This is a highly flexible approach and the existing testing regime cannot support it. Defra believe that beyond a few key players there will not be a lot of uptake for testing under 208/2006, and laboratories are unlikely to be prepared to support expensive development work on a large number of new and unfamiliar tests, which may then hardly ever be used. Defra say they need to look at new, more flexible and more targeted ways to approach testing.

Regulation (EC) 882/2004

Under Regulation (EC) 882/2004[8] on official controls for the verification of compliance with feed and food law, and animal health and welfare rules, laboratory tests where they are carried out as part of an official control should be carried out in accordance with the provisions of the Regulation. Regulation 882/2004 sets out the various standards (e.g. ISO (International Organisation for Standardisation) standards) that must be met by laboratories wishing to be approved or designated under this legislation. The new composting rules under 208/2006 are an opportunity to introduce a more flexible approach in accordance with the provisions of the Official Food and Feed Controls.

Replacement Of Enterobacteriaceae With Escherichia coli Or *Enterococcaceae* In Routine Sampling In All Composting Plants

As well as introducing alternative standards for composting based on pathogen reduction, Regulation 208/2006 also makes changes to the on-going sampling regime previously set out in Regulation 1774/2002. These changes apply to all approved composting plants handling animal by-products, not just to those approved under Regulation 208/2006.

Under Regulation 1774/2002 the on-going sampling regime for composting plants handling animal by-products was *Salmonella* and *Enterobacteriaceae*. The requirement to test for *Salmonella* remains the same under Regulation 208/2006. However the test for *Enterobacteriaceae* has now been changed to a choice between either *Escherichia coli* or *Enterococcaceae* (but see below).

Composting plants handling only catering waste will not be affected by this change, as they are required on a routine basis only to test for *Salmonella*, and this has not changed.

Transitional measures

Under Regulation 882/2004 (see above), all laboratories carrying out official tests must be accredited to ISO 17025.

However, Regulation 2076/2005 lays down transitional measures for this requirement of Regulation 882/2004. It permits laboratories that were carrying out official tests prior to 1 January 2006 to continue using these tests until 31 December 2009.

From 1 January 2010 all laboratories carrying out official tests must be accredited to the ISO 17025 standard for those tests. This includes all tests required either by Regulation 208/2006 or by Regulation 1774/2002.

[8] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:165:0001:0141:EN:PDF

Defra have also permitted laboratories that previously were testing for *Enterobacteriaceae* under Regulation 1774/2002 a transitional period which enabled them to continue testing for this organism while official guidance on the implementation of Regulation 208/2006 was drawn up. These laboratories should now be moving to testing for *Escherichia coli* or *Enterococcaceae* in accordance with Regulation 208/2006. In line with all laboratories operating under Regulation 882/2004, Defra would expect these laboratories to be testing for *Escherichia coli* or *Enterococcaceae* to the ISO 17025 standard by 1 January 2010.

Effect of changes in ABPR legislation on batch tunnel composting

The batch tunnel system chosen for the project was known to have a high degree of control over the composting environment, in particular the temperature of the composting material. The computer controlled aeration system, using re-circulated air, creates a very uniform environment, with temperatures varying only by a few degrees throughout the composting mass at any one time. The actual temperature at which the composting material is kept is controlled by means of varying the amount of fresh air brought into the system under computer control. This enables the composting material to be taken through a tightly controlled time/temperature regime. The use of six temperature probes, two of which are in the potentially coolest part of the tunnels, ensures that all of the composting material is maintained at pasteurisation temperatures for the required length of time. This system has been proven to be demonstrably robust in meeting the requirements of the 1774/2002 Animal By-Products Regulations.

The recently operated 208/2006 Regulations allows the submission of alternative composting methodologies. The four tunnels used by the project have now been successfully taken through the requirements of these new Regulations to gain approval for what is referred to as 'single pass' tunnel composting. This means that the required reduction in the presence of the test micro-organisms has been achieved after a single pasteurisation stage instead of the two as previously required by the 1774/2002 regulations. This effectively doubles the throughput of the tunnels, with a significant reduction in the cost of processing catering waste feedstock.

The process of obtaining single pass for the Gicom tunnels was a long and detailed procedure. The initial submission to Animal Health for permission to use single pass operation with the Gicom batch tunnels was made on 25th November 2008. The submission consisted of three components:

- A detailed operational procedure for single pass composting in the tunnels,
- A HACCP plan covering every stage of the process from the specification and reception of the feedstock to the pasteurised material leaving the tunnel for the windrow composting stage.

- A set of trial data produced by Defra-accredited and independent laboratories to demonstrate that all of the required tests had been successfully passed.

After discussions with Animal Health a detailed set of tests were agreed, including an ‘oven test’ which involved taking the test indicator micro-organisms through the specified time/temperature regime for pasteurisation, but outside the composting environment.

All the tests were completed successfully and a “temporary approval of composting plant for validation purposes” was issued on 21st April 2009. After successfully carrying out the required tests the site moved to the second stage of Official Validation – Positive Release. At this point the sampling of batches had to continue for a further two months with the material not being released until the test results were known. The license was finally obtained on September 2009.

Other composting technologies can be tested for approval under the 208/2006 regulations. However, to be successful they must demonstrate a high degree of control over the temperatures of the composting environment equivalent to that of the batch tunnels and prove that no material can bypass the pasteurisation temperatures.

4.4 Paragraph 7 Exemption (Waste for the benefit of land)[9]

The compost produced by the project from source-separated kitchen waste and green waste is still considered a waste and comes under waste control regulations. In order for the compost to be used in agriculture it is necessary to obtain a Paragraph 7 exemption from the Environment Agency. In order to obtain an exemption it is necessary to prove that that the compost provides benefit to agriculture or ecological improvement. Benefit to agriculture is defined as ‘the physical, chemical or nutrient enhancement of soil to support crop growth’. Detailed guidance notes on the exemption are available.[10]

Strict conditions are enforced regarding the analysis of the compost itself and the agricultural land on which it is to be used. The exemption allows a maximum of 1,250 tonnes of compost to be stored on agricultural land for a maximum of one year, and it must be stored where it is to be used. The compost can only be applied at a maximum rate of 250 tonnes per hectare. The exemption is chargeable and requires annual renewal.

Paragraph 7 exemptions were successfully obtained for all of the compost produced by the project from source-separated feedstocks, and the compost was used on farms local to the St Ives site.

[9] http://www.environment-agency.gov.uk/static/documents/Business/para_7_legislation_1989063.doc
[10] http://www.environment-agency.gov.uk/static/documents/Business/7guidanceEP2_1.pdf

Although the procedure requires considerable time and data input the process is quite clear. It typically takes several weeks to obtain a paragraph 7 exemption and a considerable amount of analytical and technical data is required. Therefore, there has to be careful planning to ensure that the exemptions are in place at a time when the farmers need the material and the site has it available.

Envar has an excellent relationship with the local Environment Agency that has been built up over many years, and regularly meets with them to discuss site activities and plans.

4.5 Nitrate Vulnerable Zones [EU Nitrate Directive (91/676/EC)][11]

Nitrate Pollution Prevention Regulations 2008 (Statutory Instrument 2008/2349)[12]

Nitrate Vulnerable Zones (NVZs) now cover an estimated 68% of England and smaller parts of Scotland and Wales, as part of the UK implementation of the European Union (EU) Nitrates Directive. This is an environmental measure designed to reduce water pollution by nitrate from agricultural sources. Aspects of the Directive apply to the application of compost, such as that produced by the project, to agricultural land. Even though compost has a much lower readily availability nitrogen content compared with most farm manures, it is still covered by the regulations.

The rules include closed periods for spreading organic manures with a high available nitrogen content and manufactured nitrogen fertilizers. The closed period for spreading organic manures with a high available nitrogen content varies depending on crop (grass or tillage land) and soil type (sandy and shallow soils or other). The closed period for spreading manufactured nitrogen fertilisers varies depending on crop (grass or tillage). A calendar year whole farm loading limit of 170 kg/ha total livestock manure nitrogen applies which must include nitrogen excreted by livestock whilst grazing. Unless the compost is produced from livestock manure it is not included in this limit. However compost is subject to the rolling 12 month field limit of 250 kg/ha total organic manure nitrogen on the area of the field available for spreading. Compost should be incorporated into the soil as soon as practicable, and within 24 hours if the land is sloping and within 50 metres of surface water that could receive run-off from land. A risk map must be produced for land receiving organic manures. Amongst other requirements this must show watercourses, springs, wells and boreholes and associated non-spreading areas.

[11] http://ec.europa.eu/environment/water/water-nitrates/directiv.html
[12] http://www.opsi.gov.uk/si/si2008/pdf/uksi_20082349_en.pdf

The practical effect of these regulations on the project was to limit the application rate of the compost on local farms to not more than c.30 tonnes per hectare. For the industry as a whole, this is an important Regulation as it requires composters to find an appropriately large land bank for their compost. The application is based on total nitrogen content not readily available nitrogen. Therefore the stability of the compost does not affect the amount that can be spread per hectare.

4.6 PAS 100 Standard

This is the nationally accepted standard for composts produced from source-separated feedstocks, and has been produced by the Waste & Resources Action Programme (WRAP) and the (then) Composting Association (now the Association for Organic Recycling (AFOR)).

The standard specifies the requirements for the process of composting, the selection of input materials, the minimum quality of composted materials, and the storage, labelling and traceability of compost products. A composting site and its products can be accredited for PAS 100 if it meets the required standards.

At the time of the project the St Ives site did not have accreditation under PAS 100 and delivered its composts, including compost produced during the course of the project, to local farmers under paragraph 7 exemptions.

The PAS 100 standard can be downloaded from the WRAP website[13]. Additional information on PAS 100 is also available[14]. Obtaining and keeping the PAS 100 has cost implications for a composter. These should be compared with costs associated with the paragraph 7 alternative. However, marketing a compost that is made to a widely accepted standard has definite marketing advantages.

4.7 Compost Quality Protocol[15]

This protocol has been produced by WRAP and the Environment Agency. The protocol seeks to identify and define the point at which waste – including compost - ceases to be a waste, and therefore does not come under the control of waste regulations.

The main criteria for a compost ceasing to be a waste are:

- The compost has to be produced from a defined list of source-separated feedstocks.
- The compost must reach the requirements of an approved standard (normally PAS 100).
- The compost is destined for one of an approved list of applications.

[13] http://www.wrap.org.uk/composting/production/download_pas_100.html
[14] http://www.wrap.org.uk/composting/production/bsi_pas_100.html
[15] http://www.environment-agency.gov.uk/static/documents/Business/WRA01_47_Compost_QP_v1c.qxd.pdf

Taking the extra step to obtain recognition that the compost produced is a product and not a waste gives and important advantage in a very competitive market for agricultural soil improvers where a wide range of competing organic materials are available.

4.8 Paragraph 9 Exemption (Reclamation, restoration or improvement of land)[16]

The compost produced by the project from the organic fraction of municipal solid waste is considered to be a compost-like material, rather than a compost, and under waste control legislation cannot be applied to agricultural land. Currently, the Environment Agency does not allow the use of 'compost' produced from mixed waste, such as the organic fines of municipal solid waste, on agricultural land. It can, however, be used in reclamation or restoration projects if a Paragraph 9 Exemption is first obtained from the Environment Agency.

The application rate of the material is limited to a maximum of 20,000 cubic metres per hectare and a depth of two metres. Material can be stored for a maximum of six months at the place of use.

The process of obtaining a paragraph 9 exemption is basically similar to that for paragraph 7 exemptions, although the data required differs. Helpful information can be found on the Environment Agency website.[17]

The compost-like output produced by the project from the organic fines of municipal solid waste was used at a restoration project being carried out by the company under a Paragraph 9 exemption. As with the paragraph 7 exemptions the process takes several weeks and is aided by a good working relationship with the local Environment Agency officers.

[16] http://www.environment-agency.gov.uk/static/documents/Business/para_9_legislation_1989080.doc
[17] http://www.environment-agency.gov.uk/business/topics/permitting/34783.aspx

5 PLANT DESIGNS AND SOURCING

5.1 Introduction

This section describes the site on which the NTDP project was set up, the design concepts of in-vessel composting facilities, and the reasons behind the choice of the technology provider for the project.

5.2 The Envar composting site at St Ives

The site has been producing compost since 1964. Until 2002 it produced compost for the mushroom industry from cereal straw and chicken manure. In 2002 it obtained a Waste Management Licence to produce agricultural compost from a variety of organic wastes. After changes in legislation, the Waste Management Licence was converted to an Environmental Permit. The site currently has an Environmental Permit to process up to 105,000 tonnes of organic waste a year. The site is also licensed under the Animal By-Products Regulations (ABPR) to process meat-included catering waste Figure 9: Aerial view of the St Ives composting facility shows an aerial view of the St Ives site.

Figure 9: Aerial view of the St Ives composting facility

Feedstock is received over the weighbridge with vehicles then travelling to the main reception and shredding building. After unloading and shredding with a Doppstadt shredder the feedstock is moved to the NTDP Gicom composting tunnel reception area. Here the shredded feedstock is filled into the tunnels for the two-stage ABPR pasteurisation stages. After tunnel composting the material is moved to the windrow composting area where it undergoes at least 8 weeks of windrow composting with the windrows being turned once a week. The composted material is then taken to the product screening and storage Dutch barn where it is taken through a 10mm mesh McCloskey screen. Screened product is stored under the barn until taken off site by local farmers.

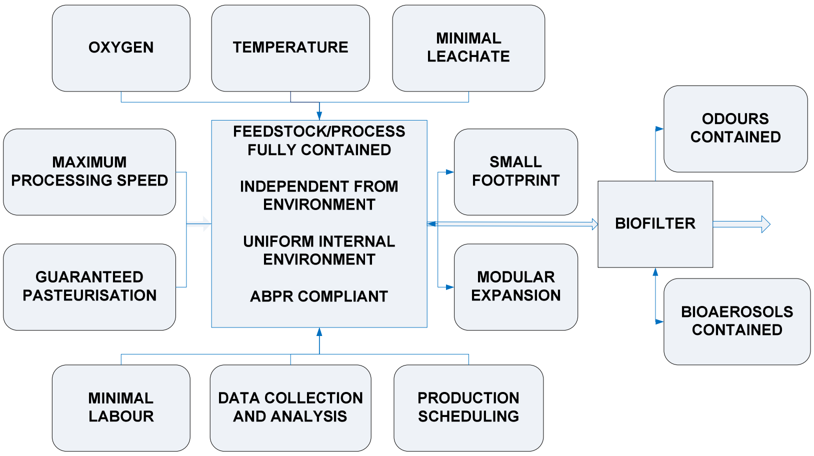
5.3 An optimal in-vessel composting technology

It is generally considered that in-vessel composting technology should have the following characteristics to promote optimal composting:

- Be fully enclosed, insulated and independent of the local environment, e.g. changes in ambient temperature.
- Possess a uniform internal environment for composting to take place, i.e. temperature and oxygen levels being the same in all parts of the composting matrix at the same time.
- Have full control over temperature to ensure optimal temperatures for each stage of the composting process.
- Be able to guarantee that all parts of the composting matrix can be held at the required ABPR pasteurisation temperatures for the required minimum time.
- Control oxygen levels to ensure that aerobic conditions are maintained at all times.
- Allow a tight control over production schedules.
- Allow detailed data collection, storage and analysis of all the required process parameters, with readings being taken at least every 15 minutes.
- Have a small foot print for maximum use of available space and be able to expand in a modular way in order to respond to increases in feedstock intake.
- Contain and process any leachate produced and treat process air to remove offensive odours and reduce the level of bioaerosols released to the atmosphere and be operated with the minimum amount of labour.

These requirements are summarised in Figure 10.

Figure 10: Characteristics of an optimal in-vessel composting technology



The Gicom composting technology selected for the project satisfies these requirements, as will be examined below.

5.4 Gicom batch tunnel composting technology

Gicom b.v. has designed computer controlled batch tunnel composting facilities for the mushroom and waste composting industries since 1984. The technology incorporates measurement and control devices, biotechnical process control, and air handling systems, all designed to work together for optimum efficiency with the software system.

Gicom tunnel technology has a number of different applications, including:

- The composting of biowaste, food waste, sewage sludge, industrial sludges, manure, municipal solid waste and anaerobic digestion residue.
- The biological drying of municipal solid wastes and other waste streams containing organics.
- The production of mushroom composts from poultry litter and straw.

Gicom tunnels are constructed in a modular fashion with different tunnel sizes depending upon the volume of feedstock to be processed. The tunnels can vary from 15m to 50m in length and from 4m to 8.5m wide. Each tunnel, depending upon its size, can process between 60 and 600 tonnes of feedstock. Each facility includes a different number of tunnels depending upon the design requirements for throughput. Facilities have been constructed with between 3 and 50 tunnels. Gicom tunnel facilities can be designed to handle between 4,000 and 400,000 tonnes of feedstock each year.

Gicom was selected as the technology provider for the NTDP project because of their strong track record in constructing batch composting tunnels with excellent environmental control. They were also chosen because of the reliability of two pre-existing Gicom composting tunnels on the St Ives site built in 1994. Gicom adapted the design of the NTDP tunnels to incorporate the unique heated walls and floors that were to be studied by the project.

5.5 The novelty of the Gicom tunnels used in the NTDP project

The use of Gicom tunnels in the UK has been largely restricted to the composting of straw and poultry manure to produce compost for the mushroom industry. There has been limited use of the technology within the UK for the processing of biodegradable municipal waste, despite its proven track record in other countries.

It was the purpose of the NTDP project to build upon this track record and improve upon the technology itself, its method of monitoring and control, and to optimise its use in the composting of biodegradable municipal waste.

The improved technology used in the NTDP project uniquely incorporated heated walls and floors. One purpose of the project has been to look at whether or not the use of heated walls and floors increases the efficiency of the composting process by reducing the time taken to reach the pasteurisation temperatures required by ABPR. Any reduction in the time taken to reach pasteurisation temperatures will result in a decrease in the overall residence time in the tunnels. This, in turn, has a significant effect on the throughput of the facility and hence the unit cost of production and the income that the tunnels can generate. The walls and floors of the tunnels have been constructed containing water pipes connected to a gas boiler. Two of the four tunnels were connected to the heating system, and these were used for c. 50% of the runs. A comparison between the results for the heated and unheated runs provides a good overview of the effectiveness of the heated walls in speeding up the composting process. The tunnels also have additional gas monitoring equipment to help determine the effect of using the tunnels on the local environment.

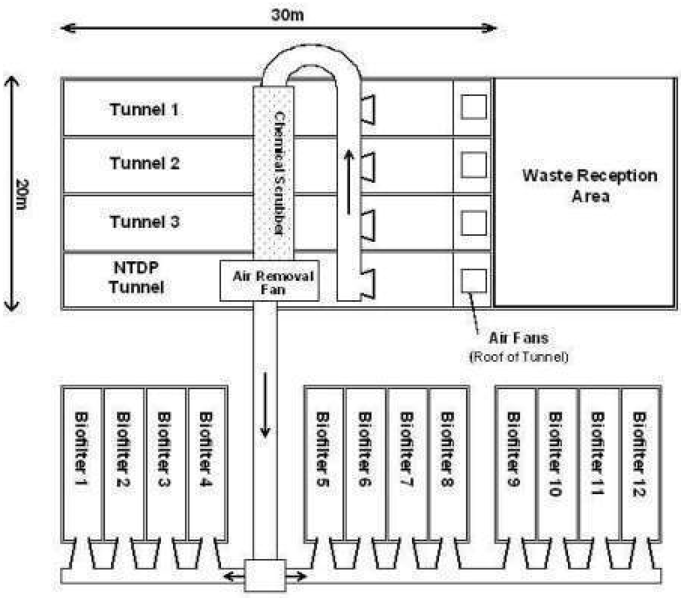
5.6 The Gicom batch tunnel composting facility at St Ives

The Gicom facility at St Ives used by the NTDP project consists of four double-ended tunnels. These are 5m x 5m x 35m. The walls, doors and roof are insulated, and doors are installed at both ends to allow the separate filling and emptying of the tunnels. This has the advantage of keeping processed feedstock separate from unprocessed material, an essential requirement of the ABP Regulations. The tunnels are labelled G3, G4, G5 and G6. The Technical Area above the tunnels holds the tunnel fans, the boiler to provide heated water to the tunnel walls and floors, and the scrubber. The scrubber removes ammonia and other volatile materials from the tunnel exhaust air. After leaving the scrubber, the exhaust air passes through biofilters situated next to the tunnels. The biofilters remove odorous chemicals from the tunnel exhaust air before the air is released to atmosphere. Figure 11 shows a schematic of the facility.

Figure 11: The Gicom composting facility at St Ives used by the NTDP project

Figure 12 is a plan of the facility from above and shows the location of the main components.

Figure 12: Plan of the Gicom composting facility at St Ives



The tunnel labelled 'NTDP tunnel' was the first one used in the project and was designated as the Defra project tunnel. As the project preceded all four of the tunnels were used.

The tunnel reception area receives shredded feedstock from the main site reception area by means of a tractor/trailer system. The feedstock is filled into the two first stage tunnels (G3 (original NTDP tunnel in Figure 12) and G5 (tunnel 2 in Figure 12) using Volvo front-loaders with the outer tunnel doors closed and the inner (reception side) doors open. The inner doors are then closed and the first stage of composting carried out. At the end of the first stage the semi-composted material is taken back out into the cleaned reception area and transferred to the second stage tunnels (G4 (tunnel 3 in Figure 12) and G6 (tunnel 1 in Figure 12) with the outer doors closed and the inner doors open. The inner doors are then closed and the second stage of composting carried out. After the second stage the material is removed by Volvo front-loaders from G4 and G6 with the inner doors shut and the outer doors (leading to the windrow composting concrete pad) open. This technique of using doors at each end of the tunnels at different stages allows the entire process to be compliant with the hygiene requirements of ABPR and prevents the contamination of fully pasteurised compost by untreated or partially pasteurised material.

Figure 13 shows the outside doors of the tunnels through which the completed second stage compost is removed.

Figure 13: Outer door of tunnels

Exhaust air from the tunnels is taken through a scrubber situated in the enclosed Technical Area on top of the tunnels and then fed to a batch of biofilters outside the building.

Figure 14 shows the main exhaust ducting that takes exhaust air from the tunnels to the biofilters.

Figure 14: Ducting linking tunnels to the biofilters

For most of the project only biofilters 2 – 8 were used. This was because it was found that if all twelve biofilters were used the biofilter material tended to dry out and become less efficient. Closing off some of the biofilters increased the amount of water-saturated exhaust air passing through the remaining biofilters. This enabled moisture levels to be maintained at an adequate level.

Figure 15 shows one of the biofilters containing shredded willow as a biofilter matrix. Other material can be used as the biofilter matrix such as other types of shredded wood, peat, compost and wood chips. The twelve biofilters were originally 30 tonne capacity composting tunnels used by the site to prepare mushroom compost. They are 16 m by 3m by 3 m. They were converted by Gicom into biofilters by connecting them to the exhaust ducting of the tunnels and filling them with the shredded willow matrix. This kind of matrix can last for 2 – 3 years as an effective means of odour removal before requiring replacement.

Gicom calculated the maximum volume of tunnel process air that would pass through the scrubber and hence the biofilters. This enabled them to calculate the mass of biofilter material required to adequately treat the air to reduce odours to level acceptable to the site environmental permit.

Although all twelve biofilters were used at the start of the project it was found that a more efficient biological action was accomplished by just using biofilters 2 – 8. With the larger number of biofilters the biofilter matrix tended to dry out.

Figure 15: One of the tunnel biofilters containing shredded willow

The Technical Area above the tunnels contains all of the equipment used to run and monitor the tunnels. Figure 16 shows the four fans that supply air to the tunnels. The box containing the main electronics of the system can also be seen, along with the temperature probes inserted through the roofs of the tunnels into the composting material. Each tunnel has four temperature probes that are positioned at regular intervals along the central length of the tunnel. Once the tunnel has been filled with feedstock the temperature probes are inserted through the roof of the tunnels to a depth of about 0.5m into the composting material. They are removed prior to the tunnel being emptied. Two additional fixed temperature probes measure the temperature of air entering and leaving the tunnels.

Figure 16: Tunnel Technical Area

Figure 17 shows the horse-shoe shaped scrubber, and also the white plastic piping that feeds hot water into the heated walls and floors. The arrangement of these heating pipes is best seen in the section of this report that covers the construction of the tunnels.

Figure 17: Scrubber and heated water pipes

The tunnels, scrubber and biofilter are controlled by a computer situated in a nearby building. Figure 18 shows a screenshot of a schematic of one of the tunnels showing the temperature probes and the fan settings. The procedures for calibrating the temperature probes are given in SOP 13.

Figure 18: Screen shot of schematic of a tunnel

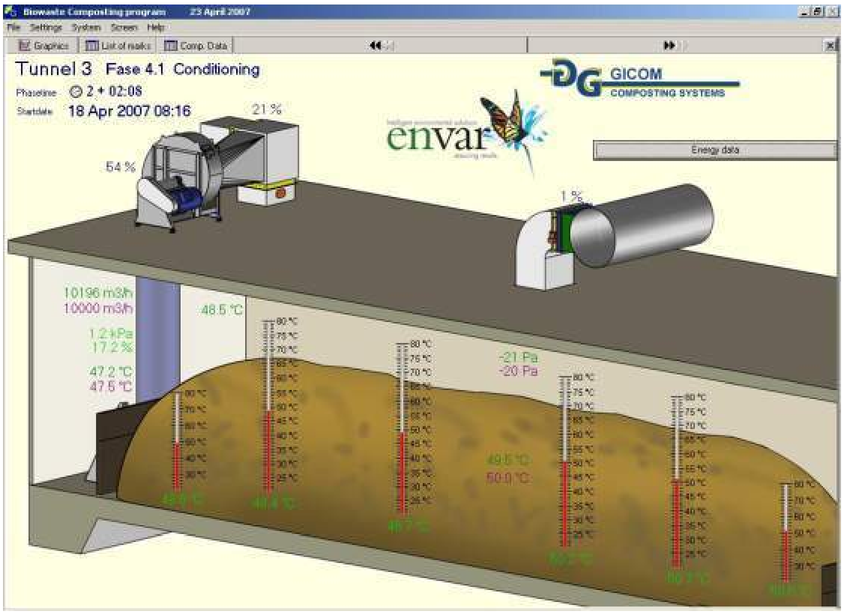
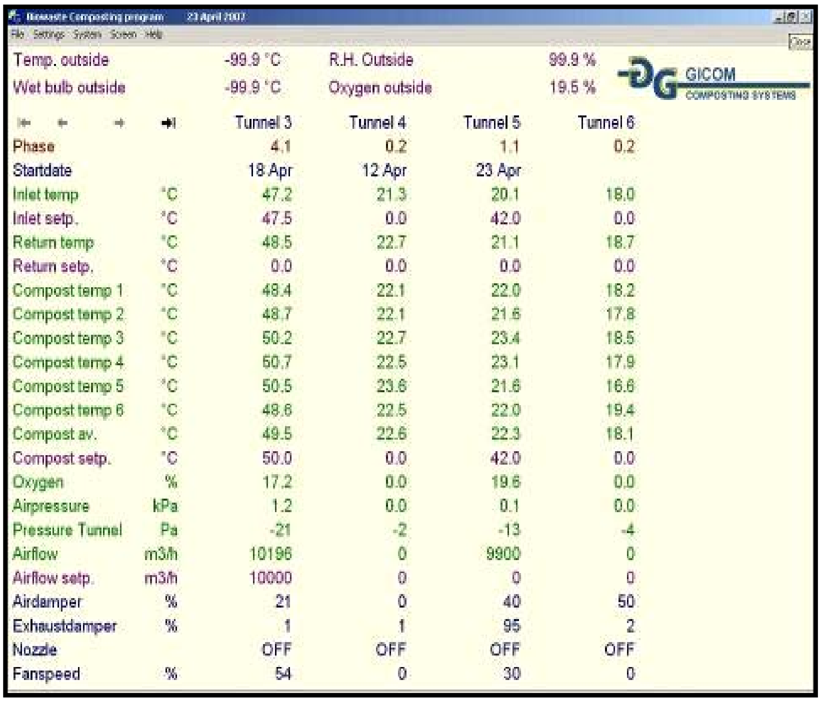


Figure 19 is a screen shot of the main data screen showing temperature and other data for all four tunnels. The set points, determined by the operator, are in purple and current readings are in green and blue.

Figure 19: Screen shot of main data screen for the four tunnels

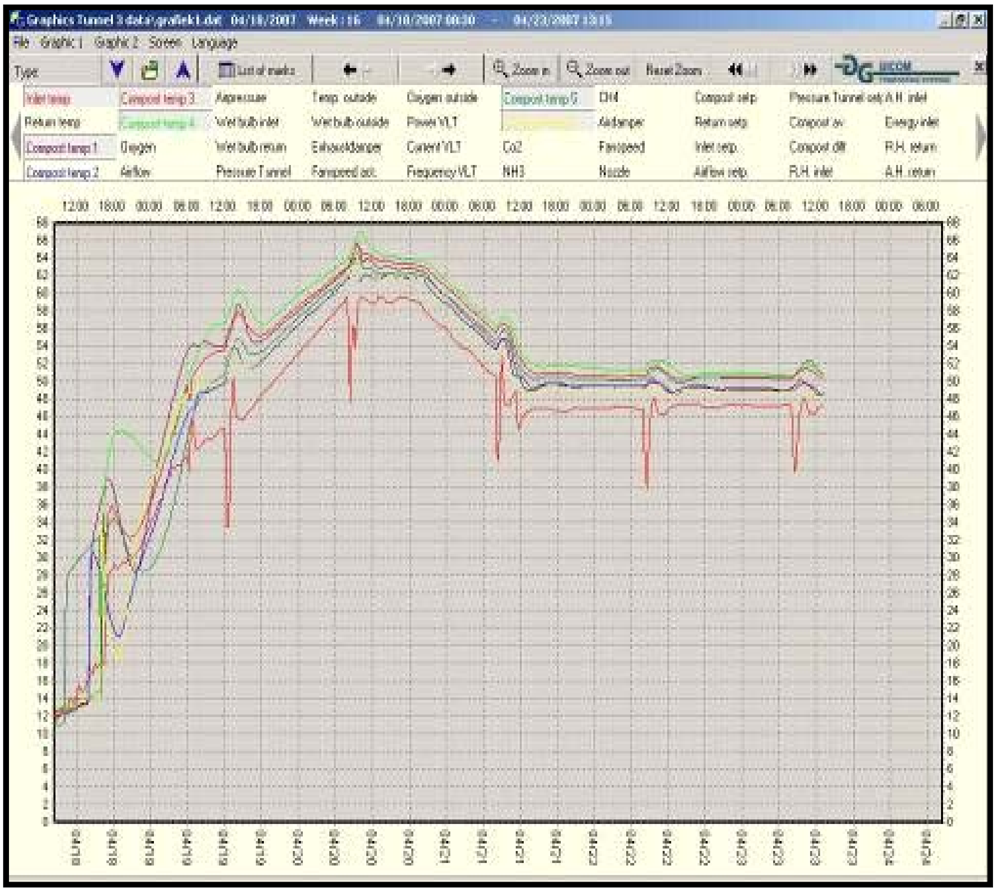


Temp. outside		-99.9 °C	R.H. Outside		99.9 %
Wet bulb outside		-99.9 °C	Oxygen outside		19.5 %

		Tunnel 3	Tunnel 4	Tunnel 5	Tunnel 6
Phase		4.1	0.2	1.1	0.2
Startdate		18 Apr	12 Apr	23 Apr	
Inlet temp	°C	47.2	21.3	20.1	18.0
Inlet setp.	°C	47.5	0.0	42.0	0.0
Return temp	°C	48.5	22.7	21.1	18.7
Return setp.	°C	0.0	0.0	0.0	0.0
Compost temp 1	°C	48.4	22.1	22.0	18.2
Compost temp 2	°C	48.7	22.1	21.6	17.8
Compost temp 3	°C	50.2	22.7	23.4	18.5
Compost temp 4	°C	50.7	22.5	23.1	17.9
Compost temp 5	°C	50.5	23.6	21.6	16.6
Compost temp 6	°C	48.6	22.5	22.0	19.4
Compost av.	°C	49.5	22.6	22.3	18.1
Compost setp.	°C	50.0	0.0	42.0	0.0
Oxygen	%	17.2	0.0	19.6	0.0
Airpressure	kPa	1.2	0.0	0.1	0.0
Pressure Tunnel	Pa	-21	-2	-13	-4
Airflow	m3/h	10196	0	9900	0
Airflow setp.	m3/h	10000	0	0	0
Airdamper	%	21	0	40	50
Exhaustdamper	%	1	1	95	2
Nozzle		OFF	OFF	OFF	OFF
Fanspeed	%	54	0	30	0

Figure 20 is a screen shot of the compost temperature and air temperature profile of one tunnel run. The warming up, pasteurisation and cooling-down stages can be seen.

Figure 20: Temperature profile of a tunnel run



5.7 Compliance with Environmental Permit and ABPR

Because of the total enclosure of the tunnel operation, and the use of a scrubber and biofilter system, the facility complies fully with the site's Environmental Permit in terms of odour, noise, dust and vermin control.

The facility fully complies with ABPR in that:

- It is possible to demonstrate that all of the composting material reaches the required 60° C for 48 hours (even with no wall or floor heating).
- There is complete separation of dirty and clean areas.

These matters are discussed in more detail in other sections of the report.

5.8 Processing after the tunnel composting stages

After the composted material was removed from the tunnels after the second pasteurisation stage it was moved by Volvo front-loaders onto a concrete pad and formed into windrow c. 3m high, 5m wide and c. 80m long. Each windrow held about 1,000 tonnes of material.

The windrows were turned on a weekly basis using a front loader for a period of at least 8 weeks. The composted material was then fed into a McCloskey 621 trommel screen using a 10mm mesh screen. Part of the way through the project, the trommel screen was fitted with a Komptech Hurrikan system to remove plastic and stones from the oversize fraction. This enabled the cleaned oversize fraction to be put back into the composting system for re-processing, without the build up of plastic in the compost, while the plastic and stones are landfilled. This removal of plastic and stones from the oversize prevented the build up of these materials in the system and resulted in a cleaner product.

The <10mm screened product was then collected by local farmers for use as a soil improver, and spread on their land under a Paragraph 7 exemption.

5.9 Performance measurement procedures

The procedures used to measure the performance of the composting process are outlined in Section 17 – Project Protocols.

The main performance parameters measured in the tunnels are shown in Table 5.

Table 5: Major tunnel performance parameters

- Inlet and return air temperatures (°C)
- Compost temperatures at six different points in the tunnel (°C)
- Fan speed (%)
- Oxygen (%)
- Oxygen utilisation (tonnes)
- Carbon dioxide production (ppm)
- Carbon dioxide (tonnes)
- Ammonia production (ppm)
- Ammonia production (kg)
- Methane production (ppm)
- Methane production (kg)
- Evaporation (kg/h)
- Evaporation (tonnes)
- Electricity usage (kWh)
- Water spraying (tonnes)
- Biofilter temperatures (°C)
- Wall temperatures (°C)

6 TENDERING PROCESS FOR CONTRACTORS

Envar were required to choose a suitable primary sub-contractor to supply the in-vessel composting technology required to base the research and demonstration programme on. Funding was provided by Envar (via parent company ADAS UK Ltd) to design and build the treatment technology. Funding by Defra was then used to carry out research and a dissemination programme based on the technology and its processes.

The supplier of the in-vessel composting technology chosen for the project was the Dutch company Gicom b.v. This company was selected because of its long track record in designing and building batch tunnel composting systems for the organic waste recycling industry. Gicom were also well known to the project team, and the owners of the St Ives site, as the site already had two Gicom batch tunnel composting systems that were fully compliant with the Animal By-Products Regulations. After working with these tunnels for many years they were regarded as providing the most robust system for controlling and recording the composting of the range of feedstocks to be processed by the project.

Preliminary discussions with Gicom confirmed their interest in the project and generated ideas on how the batch tunnels could be uniquely improved by the use of heated walls and floors. The details of the design and operation of the heated walls and floors were finalised and determined to offer a unique approach to the composting of municipal solid waste. A contract for the building of four batch tunnels with heated walls and floors was awarded to Gicom.

Envar negotiated key terms with Gicom b.v based on an ORGALIME S2000/SE01 contract (incorporating general conditions for the supply (and erection) of mechanical, electrical and electronic products). The use of the model contract helped to simplify the contract agreement process between Envar and GICOM b.v as the primary sub-contractor. Terms were familiar to both parties and it was relative to deliverables and services being provided (e.g. not only the construction of the technology but the electronic based computer system that accompanies it).

An agreement was made between the two parties on 8th February 2006.

Mobile equipment such as shredders, screens and front loaders used by the project were owned by the site and were not purchased by the project.

GICOM b.v was the primary subcontractor and upon contract agreement were instructed to design and build the in-vessel composting facility, including heated wall and floor technology, a scrubber system and a computer system to ensure the process is fully computer controlled.

GICOM b.v designed and built all of the individual components of the system at their factory in The Netherlands. Components and materials were then shipped to the UK and onward to the Envar composting facility in St Ives, where designated GICOM work teams were in place to complete concrete and foundation infrastructure works, construction and commissioning of the new system. GICOM used their own electronic engineers to develop specific software for the system. Key parameters were built in and set points were made for temperature and airflow management.

In order for Envar to successfully complete the research programme, collaborations had to be made with key laboratory service providers including:

- NRM
- Eurofins
- Silsoe Odours
- Odournet
- M-Scan

All of the laboratory service providers listed above are key clients to Envar (and parent company ADAS UK Ltd). This meant that the project was able to benefit from set prices within centralised contracts.

In addition, the project was supported by the University of Leeds who provided monitoring assistance and enumeration of bioaerosols sampling agar plates.

7 INPUT AND OUTPUT CONTRACTS

7.1 Project Waste Streams

Two main sets of waste streams were used by the project.

Kitchen waste and green waste

Feedstocks were required for the project that accurately reflected the biodegradable wastes currently available for composting within the UK. The majority of this waste comprises kerbside collected, source-segregated kitchen waste and green waste.

Feedstock was supplied to the project by:

- Dacorum Borough Council
- West London Waste
- Essex County Council
- Enfield Borough Council
- Saffron Walden Council
- St Albans District Council
- London Waste

Each Council has its own method of collecting the waste. Some collect green waste and kitchen waste separately, while others collect co-mingled kitchen waste and green waste. Where co-mingled waste is collected, the percentage of kitchen waste present in the mixture will vary according to the detailed collection methods used by the Council.

When the feedstocks arrive on site the site operators will control where they are deposited in the reception area. This enables them to vary the proportion of kitchen waste to green waste to ensure a mixture of feedstocks that will compost well. This ability to vary the proportions of the two main wastes has been utilised by the project to examine the effect of varying the proportion of kitchen waste in material being filled into the tunnels.

Contracts for local authority wastes are obtained after an often lengthy competitive tendering process. Although many factors are considered by the local authority in awarding the contracts, such as technical knowledge, location and track record, the gate fee for the waste is a dominant factor. Competition for local authority contacts is intense as a long term contract can give financial security to a site. Increasingly, contracts are being offered by local authorities for shorter time periods than in the past. This is often in anticipation of increasing competition driving the contract price down in the future.

The preparation of tender documents by composting companies is time consuming and costly. Inputs are required from technical, operational, sales, financial and legal specialists.

Part of the tendering process includes a statement by both parties of the agreed maximum degree of contamination (plastic/glass etc.) in the feedstock that is acceptable, and what happens to, and who pays for, any material that contains more contamination than is allowed. The level of contamination agreed varies from on contract to another by typically varies from 3 – 5%. It is important to clarify whether this is a weight or volume measurement as the same figure will represent differing amounts of contamination according to how the figure is achieved. The costs of contamination include disposal costs for the contaminated material, and associated increased costs in removing any contaminants either from the feedstock by means of a picking line or mechanical sorting, or from the compost product by screening.

MSW (Municipal Solid Waste) fines

This material has passed through a mixed-waste separation process to remove recyclables and valuable materials (e.g. metals, paper, card), leaving a screened dry particulate substrate. This by-product is organic rich and therefore ideal for composting after mixing with other appropriate organic wastes.

Ten runs of the project were carried out using MSW fines from the Shanks Waste Management Ltd facility at Frog Island. The material was obtained on the basis of providing material for the project and not part of a contract. These fines had been previously shredded and screened and were delivered to St Ives on demand. The fines were mixed with kerbside collected green and kitchen waste and composted under the same regime as the mixtures of kitchen waste and green waste.

Eight of the MSW runs were used to produce CLO material. This was subsequently used in a land restoration project.

For two of the MSW runs, once the material had met ABPR (Animal By-Products Regulations) pasteurisation requirements, the Gicom system was used to blow air through the mixture to encourage the evaporation of water and dry the material. The subsequent material was analysed as a potential refuse derived fuel (RDF). The material was subsequently used in a land restoration project.

7.2 Output materials

Compost made from kitchen waste and green waste

The main market for compost derived from kitchen waste and green waste is local agriculture. The compost can be demonstrated, by chemical analysis, to have a value in excess of £10/tonne in terms of nitrogen, phosphorus and potassium at current prices. This value is linked to the current cost of artificial fertilisers and can vary considerably. Although the value of the compost can be demonstrated in this way, it is most unlikely that a farmer would pay this much for the compost. The current market value for such material is £4 - £5/tonne. Costs associated with transport, paragraph 7 exemptions or PAS 100, must also be considered. Increasingly, farmers are looking for quality assurance for the compost they buy and are requiring PAS 100 or an equivalent standard. Composts are normally taken through 10 – 25 mm screens before being sold.

The agricultural requirement for compost is very seasonal, with windows of opportunity for applying the compost being restricted to times between crops. This means that the composter has to allow for the storage of considerable quantities of compost on site until it is required by the farmer. Alternatively, farmers can be requested to store the compost on their land until required.

Composts made from kitchen waste and green wastes compete in the market place with many other organic materials such as biosolids, and other agricultural or industrial organic by-products. This competition will increase with the entry of organic digestates from new anaerobic digestion facilities into the market place. If the compost is made to the PAS 100 standard and the Compost Quality Protocol it can be sold as a product and not disposed of under a paragraph 7 exemption.

The compost produced from mixtures of kitchen waste and green waste was screened to < 10 mm. The product was then supplied to local farmers as a soil improver used on arable land for a nominal charge. The results of a research project carried out by ADAS on the use of compost made from these feedstocks in agriculture are available on the Internet.[18] These results include a detailed analysis of the benefits that can be achieved by the use of such compost in agriculture.

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18 http://www.compostresearch.com/project_areas/soil_quality/index.html?menu_pos=project_areas

MSW (Municipal Solid Waste) fines

The compost-like output (CLO) produced from the MSW fines cannot currently be sold into the agricultural market under Environmental Agency rules. These rules only allow compost from source-separated feedstocks to be applied to agricultural land. CLOs made from mixed waste feedstocks cannot be applied to agricultural land. It can, however, be sold or supplied into restoration projects as long as it matches a stringent set of parameters to ensure that no environmental damage is caused. A research project by ADAS on the use of mixed waste composts in restoration will be completed shortly[19]. This project contains much useful information on the use of such materials in restoration. The Environment Agency has recently agreed to a research project being carried out to look again at potential markers

7.3 Residues

Oversize material (> 10 mm) from the compost made from kitchen waste and green waste was cleaned by passing it through a Hurrikan system towards the end of the project to remove plastic and stones. It was then re-shredded and re-composted. This enabled the re-composting of this material without the build up of plastic in the compost. The plastic and stones were landfilled

Oversize material from the MSW fines composted product was landfilled.

Leachate produced during the composting process was taken through a water treatment plant before being discharged off site into a local watercourse as allowed by the site's License to Discharge. Details of the procedure for analysing leachate are given in SOP 5.

[19] http://www.compostresearch.com/project_areas/soil_formation_trials/index.html?menu_pos=project_areas

8 FINANCIAL CLOSE AND ECONOMIC ASSESSMENT

8.1 Financial Close

Envar was funded by Defra to carry out a programme of research and dissemination based on an in-vessel composting system, designed and built by GICOM b.v, with integrated heated walls and floors. The contract agreement between Envar and Defra was signed on 10th July 2006.

Payments were scheduled monthly throughout the project and paid in full on satisfactory completion of relative project milestones.

Envar (via the parent company ADAS UK Ltd) provided full funding to enable the in-vessel composting system to be built by GICOM b.v. Commissioning of the system was completed in line with the required start dates for the Defra funded research and dissemination programme.

In addition, Envar (via parent company ADAS UK Ltd) provided funding to convert the old site managers house into a visitor centre for the dissemination programme within the project.

8.2 Cost Summary

Table 6 below summarises the total costs for the project by category at financial close. Invoicing and project spending commenced from May 2006 and ended during April 2009. Figure 21 highlights the cost categories as a percentage of total project costs at financial close.

Table 6: Summary of Costs at Project Close

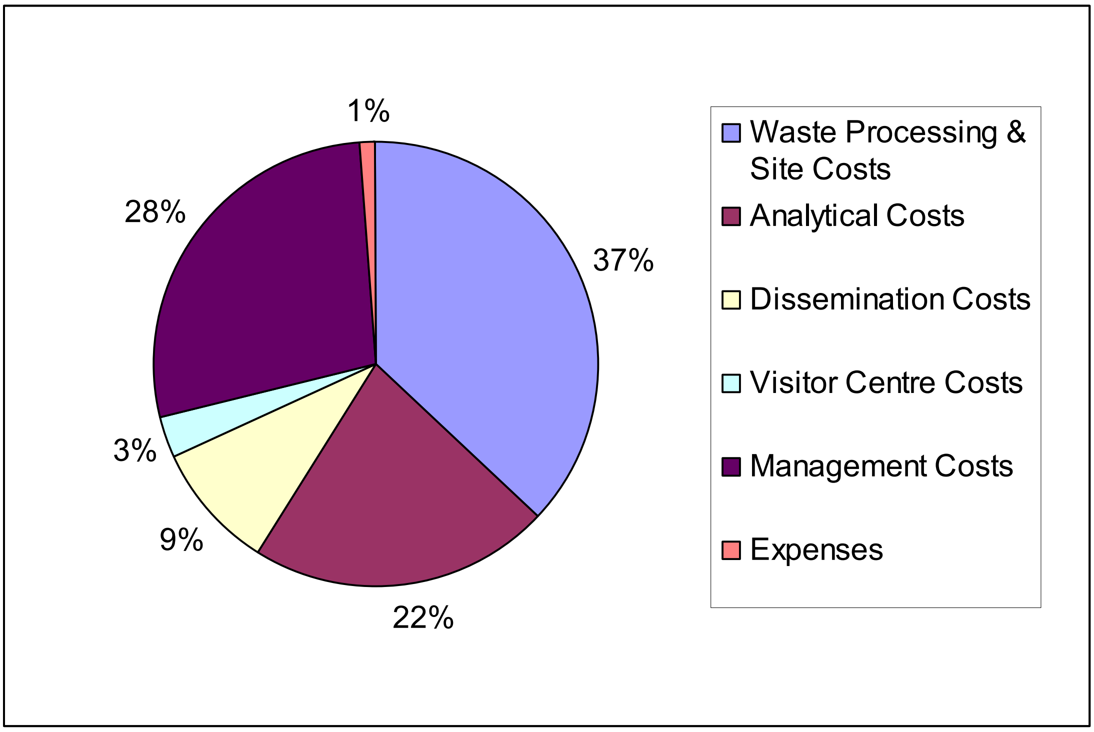
Cost Type	Totals (£)
Waste Processing & Site Costs	
Waste Processing Costs	£249,361.49
Waste Disposal Costs	£18,264.75
Provision of Project Facilities	£120,026.38
Total Processing & Site Costs	**£387,043.37**
Analytical Costs	
Laboratory Services	£68,848.74
Staff Time	£164,051.38
Total Analytical Costs	**£232,900.12**
Dissemination Costs	
External Costs (Exhibitions & Meetings)	£22,985.34
Staff Time	£80,660.06
Total Dissemination Costs	**£103,645.40**
Visitor Centre Costs	
Building/Improvements	£23,027.31

Cost Type	Totals (£)
Professional Charges	£7,150.00
Total Visitor Centre Costs	**£30,177.31**
Management Costs	
Project Management Time	£191,132.34
Technical Management Time	£111,607.55
Total Management Costs	**£302,739.89**
Expenses	
Mileage	£5,871.40
Subsistence	£1,440.28
Travel	£1,142.60
Total Expenses	**£8,454.28**
Total Costs (Excluding VAT)	**£1,065,569.62**

VAT

VAT has been applied at 17.5% for all invoices and costs pre December 2008. VAT after this date has been applied at 15%.

Figure 21: Cost category totals as a percentage of total project costs at financial close.



8.3 Economic assessment of project activities

Costs associated with the project were categorised under a number of key headings to enable a more simplified identification of key areas of project spend.

The following text provides details of the specific cost categories.

Waste Processing & Site Costs

Waste processing and site costs were accumulated predominantly during the research trials where in excess of 77 composting runs were completed. Costs for waste processing covered man time required, associated machinery depreciation, fuels for the technology and machinery and other utilities. Calculations were made to allocate these costs against specific durations of the composting runs associated with the project. Details of the costs are given in Section 14 of this report.

The costs of processing the feedstock can be divided into three stages:

1. Receipt and treatment of feedstock prior to being filled into the composting tunnels.
2. Processing within the tunnels.
3. Windrow composting, maturation and screening com material after the tunnel composting stage.

The costs associated with stage (1) are very site and technology specific and to some degree are independent of the batch tunnel composting technology which is the focus of this project. They depend very much on the efficiency of receiving the feedstock, the degree of mixing or moisture adjustment required, the size and type of shredder used (fast or slow) the distance between the reception/shredding area and the tunnels and the size of equipment such as conveyors or front loaders used to move the feedstock prior to filling the tunnels.

The main elements of the pre-tunnel stage that are related to the tunnels themselves are the particle size, moisture and uniformity of the shredded feedstock. As the feedstock in the tunnels is not moved or mixed during the tunnel stage it is essential that the shredded feedstock is as uniform as possible. If it is not variations in temperature across the tunnels can occur. Such variations, if they were allowed to occur, would affect the confidence with which the pasteurisation stage could be achieved. Similarly, if the particle size was too small, or the moisture too high, the ability to accurately control temperatures and to ensure aerobic conditions are maintained during the tunnel composting process might be compromised.

For this reason, the pre-tunnel composting stage may be slightly different from that using other in-vessel systems by the amount of attention given to the preparation of the feedstock. For example, a slow shredder is preferred to a fast shredder because of the particle size generated, water is added at the shredding stage if required, and the shredded material is thoroughly mixed before filling into the tunnels.

The costs associated with stage (2), i.e. the tunnel composting stage are very technology specific. As shown in Section 14 of this report the main costs are associated with the filling and emptying of the tunnels using front end loaders, and the electricity costs associated with the aeration fans. Details of the methods used to measure electricity usage by the tunnels is given in SOP 6.

The costs associated with stage (3), i.e. the windrow composting, maturation and screening costs are again mainly site specific and independent of the batch tunnel technology. They are a function of the distance from the tunnels to the windrow composting area, the size of the windrows, the frequency of turning, the number of turns, the distance from the windrows to the screening area, the size and number of the screens used, and the mesh size of the screen.

The main effect that the batch tunnel composting stage has on the post-tunnel stage is the degree of control achieved in the particle size and moisture of the material starting the windrow composting stage. This is very reproducible because of the care taken when filling the tunnels and the ability to add water during the tunnel composting stage if necessary.

Waste disposal Costs

A waste disposal budget was put in place to deal with any processed waste material for which a user market could not be found. This consisted mainly of plastics and material produced from the MSW composting runs. Costs for waste disposal were low (£18,264.75) considering the tonnage of waste processed during the project (15,774 tonnes).

Waste processing and site costs were £387,652.65 which accounted for approximately 37% of total project costs.

Analytical Costs

Analytical costs were accumulated during the project research trials. NRM laboratories, Silsoe Odours and Odournet were the key suppliers of analytical services and costs of analysis and reporting of results accounted for £68,848.74 of the cost for this category.

Staff time was required throughout the project research trials to monitor the process and provide emission, waste, compost and leachate samples for analysis.

Analytical costs were £232,900.12 which accounted for approximately 22% of total project costs. Costs are broken down as £164,051.38 for associated staff time and £68,848.74 for laboratory services.

Dissemination Costs

Dissemination costs consisted of staff time and other external costs. The external costs covered preparation and exhibitor fees for various waste industry exhibitions and conferences. Materials and articles were also produced to disseminate the project via websites and key waste industry publications.

The costs for site visits under the NTDP banner were captured under this category. During the project Envar hosted representatives from 79 stakeholder groups which included presentations in the visitor centre.

Dissemination costs were £103,645.40 which accounted for approximately 9% of total project costs.

Visitor Centre

A number of improvements were required to the site building that was allocated for use as the NTDP Visitor Centre at Envar, St Ives. Renovation and architectural services account for the total costs for the visitor centre.

Visitor centre costs were £30,177.31 which accounted for approximately 3% of total project costs.

Management Costs

Staff time was required for technical, dissemination and overall project management. The costs were split between project & dissemination management and technical management. Overall project management, technical management and dissemination management spanned over 3 years from inception in 2006.

Management costs include time and materials associated with the preparation of routine reports, meetings and other communications.

Management costs were £302,739.89 which accounted for approximately 28% of total project costs.

Expenses

Cost of project expenses was captured as mileage costs (at 40p per mile), subsistence costs and other travel. This cost was collated from project related movements for the project over 3 years since 2006.

Expenses were £8,454.28 which accounted for less than 1% of total project costs.

8.4 Effect of composting facility capacity on costs

This project involved the processing of 15,774 tonnes of a variety of feedstocks through the pre-tunnel, batch tunnel, and post-tunnel stages. The project took place in the centre of a site licensed to take 105,000 tonnes a year of feedstocks.

It would be of interest to look at how the costs associated with different stages of the project (as given in Section 14 and Section 8.3) would vary with commercial sites of different processing capacity.

In the batch tunnel system it is the throughput of the tunnels themselves that determines the maximum throughput of the composting facility. The throughput of the tunnels depends upon a number of factors:

- The size of the tunnels
- The number of tunnels
- The number of pasteurisation stages required by ABPR

- The residence time within the tunnels

The type of tunnels used by the project is available in sizes ranging from 100 to 600 tonne capacity. Since it is important to fill a tunnel as quickly as possible, the size of tunnel chosen for a site has to be considered in terms of the expected throughput of the facility. Ideally a tunnel should be filled in a day or less and should be empty between fills for as short a time as possible. For example, in one Gicom facility in Italy 1,000 tonnes a day for feedstocks are processed by tunnels of 600 tonne capacity.

The number of tunnels to be constructed is also, obviously, an important calculation and, again, is a function of the volume of feedstock expected for the facility. As the batch tunnel system is modular, it is possible to add more tunnels as the capacity of the site increases. In this way it is possible to control the capital expenditure of the composting facility to match, to a considerable extent, the volume of feedstock entering the site. The capital expenditure can therefore be linked to the expected contracted income from gate fee and compost sales. This is a very important attribute of a system that can be expanded in a modular way.

The ability to obtain an ABPR license with one rather than two pasteurisation stages, as achieved at the site used by the project, immediately doubles the throughput of the batch tunnels with very little additional capital cost. Of course, this also significantly reduces the labour and diesel costs of filling and emptying the tunnels, and also reduces the electricity costs of the tunnel composting stage.

The residence time in the tunnels is approximately halved if a single pasteurisation stage can be demonstrated to comply with ABPR (see above). In addition, the quality of the aeration system, the controlling software, and the experience and skill of the operators has a significant effect upon the time taken to reach and maintain the time temperature regime required by ABPR. Tight control of the feedstock and the process can reduce the residence time to effective increase throughout of feedstock by at least 10% with all the concomitant benefits in terms of reduced capital expenditure and operational costs.

As a site expands, other parts of the process must also be expanded, or, rather more efficiently, any expansion should be anticipated, in that it is normally cheaper to over-specify for example, the initial size of a reception area, or the concrete pad for windrow maturation, when a site is being set up rather than enlarge a reception building or to add on smaller sections of concrete at a later date.

9 CONSTRUCTION PROCESS

9.1 Construction of the Gicom composting tunnels

The construction stage of the project was managed by an external company – Acorus Ltd. They liaised directly with the specialist company employed to remove the existing building on the footprint for the tunnels which contained some asbestos panelling, and also with Gicom b.v. who carried out the construction of the new tunnels once the existing building had been cleared. Much of the equipment needed for construction, I including scissor lifts and loaders were brought over from Holland by Gicom. This construction process is part of an overall plan for the renovation and improvement of site facilities.

The construction of the tunnels to be used in the project began with the demolition of an existing building on the proposed footprint of the tunnels at the beginning of July 2006 (Figure 22). A specialist company was employed to remove old asbestos cladding sheets from the building. The demolition phase was carried out on time and without incident with the asbestos material being disposed of at a licensed side.

Figure 22: Demolition of existing building – 6th July 2006

All subsequent work on constructing and commissioning the composting tunnels was carried out by Gicom b.v. working closely with the NTDP project team and Acorus Ltd. Acorus managed only the construction phase of the tunnels and were not involved otherwise in the project. Once the debris from the demolition work had been cleared, a reinforced concrete floor was laid on top of the existing concrete pad (Figure 23). A local concrete supplier was used to supply and pour the concrete under the direction of Gicom. The same arrangement was used to construct the concrete walls of the tunnels. Twelve redundant mushroom composting tunnels, situated adjacent to the demolished building, that were converted into biofilters for the project can be seen in the background.

Figure 23: Laying the reinforced concrete pad – 26th July 2006

The aeration pipes for each tunnel were then laid on top of the concrete pad (Figure 24). The blue spigots that transfer air from the pipes into the tunnels can be seen projecting from the tops of the pipes. Both the pipes and the spigots were preformed at Gicom's facility in Holland.

Figure 24: Laying aeration pipes – 1st August 2006

At the same time the leachate tanks for each tunnel were put in place (Figure 25). These tanks were placed to receive leachate from the tunnel composting process.

Figure 25: Installation of leachate tanks – 1st August 2006

The plenum chamber for the air supply system was installed (Figure 26).

Figure 26: Installation of plenum chamber – 10th August 2006

The plastic pipes that would carry hot water to heat the floors were then laid between the aeration pipes (Figure 27). As this was the first time that the heating pipes had been used in constructing the floor the methodology of doing so was new to the company and resulted in this stage of the project taking slightly longer than normal.

Figure 27: Installation of floor heating pipes – 11th August 2006

The aeration pipes and water pipes were then covered with a layer of concrete, leaving the spigot holes exposed (Figure 28). This provided a flat and uniform base for each of the four tunnels being constructed. The aeration spigots were recessed in narrow channels in the concrete to prevent their becoming blocked by front loaders filling or emptying the tunnels during normal composting procedures.

Figure 28: Completed floors of tunnels – 31st August 2006

The supports for the concrete tunnel walls were installed (Figure 29). These paired shutters formed the framework into which concrete ifs poured to construct the tunnel walls.

Figure 29: Installation of tunnel wall supports – 5th September 2006

The plastic pipes used to carry hot water to the tunnel walls were then threaded through the reinforcing wires in the wall (Figure 30). As with the heating pipes in the floor, this was the first time that the company had built heating pipes into the walls and had to develop a methodology for doing so.

Figure 30: Pipes for heating walls in place – 19th September 2006

The concrete walls were poured and the supports removed once the concrete had set (Figure 31).

Figure 31: Concrete tunnel walls in place – 31st October 2006

The roofs for the tunnels were then put in place (Figure 32).

Figure 32: Installation of tunnel roofs – 12th November 2006

The supports for the insulated tunnel doors were installed (Figure 33) using Gicom staff and equipment.

Figure 33: Installation of tunnel doors – 30th January 2007

The roof and cladding of the building enclosing the tunnels were then put in place (Figure 34).

Figure 34: Cladding the tunnel building – 13th February 2007

The scrubber, fans and other equipment were installed in the area under the building roof (Technical Area) Figure 35. This step was undertaken before the roof structure was finally put in place.

Figure 35: Installation of scrubber and other equipment – 22nd February 2007

The central computer control unit was then installed and linked to a computer in a nearby building (Figure 36). This process computer was used to monitor, control and analyse extensive process data.

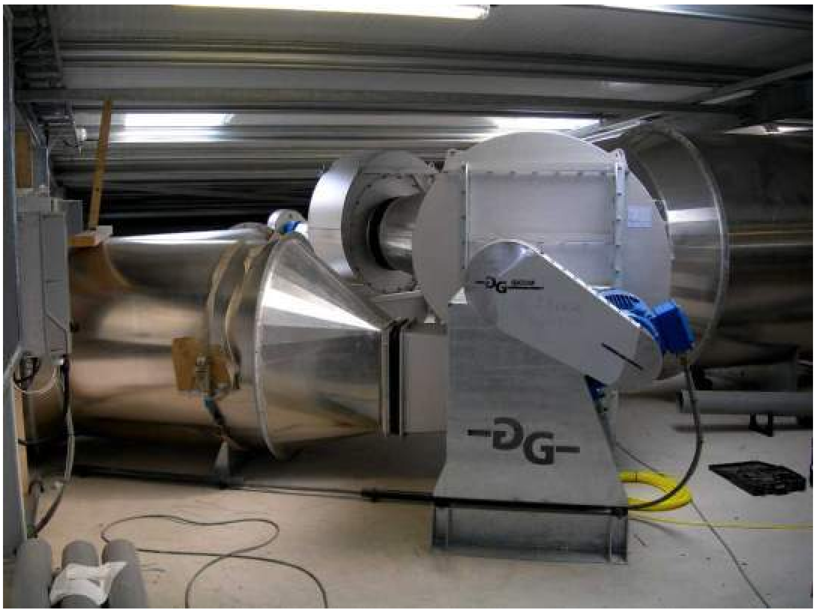
Figure 36: Central computer control unit – 16th March 2007

The removable aeration tubes that transfer air from the fan to the plenum were installed (Figure 37). This structure completed the mechanism by which air is recycled through the composting matrix yet could easily be removed for the filling and emptying of the tunnels.

Figure 37: Aeration transfer tube installed – 26th March 2007

The fans that pull exhaust air through the scrubber were installed (Figure 38).

Figure 38: Installation of scrubber fans – 28th March 2006



The scrubber and fan assembly were then connected to the external biofilters (Figure 39).

Figure 39: Connection of scrubber assembly to external biofilters

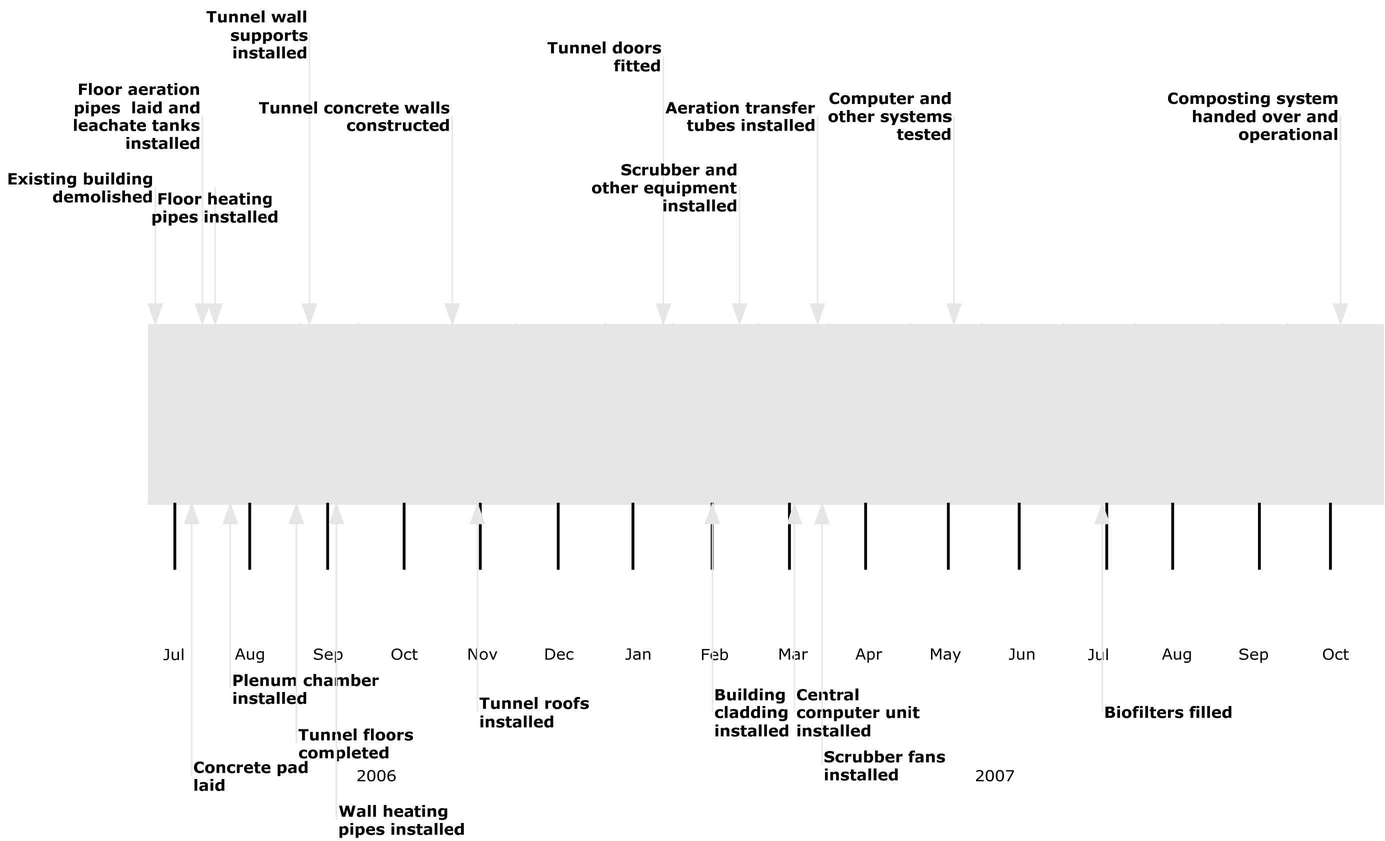
The biofilters were filled with shredded willow and the facility as a whole was declared operational on 17th October 2007 after the computer controlled environmental monitoring system had been thoroughly tested to an approved standard of performance. No significant problems were encountered during the commissioning stage.

The entire building programme was carried out according to a tight schedule agreed between Gicom and Envar. This was accomplished by a very close and regular contact between Gicom, Acorus and Envar. Meeting were held at least weekly to ensure progress was to schedule. The Gicom engineers stayed locally during the working week and normally returned to Holland for the weekends. The considerable experience of the Gicom crew in building and commissioning the tunnels was a great asset in completing the construction stage of the project on time.

The main complication with the construction was the design and construction of the hot water pipe system for the walls and floors of the tunnels as this was the first time that Gicom had made these a feature of their well established construction procedures.

All building works were in full compliance with UK Building Regulations. Acorus met with the building regulators and ensure that the work carried out was up to standard and that the appropriate approvals were obtained. No problems were encountered in this process.

This is a time line showing the various stages of construction of the tunnel composting facility.



9.2 Preparation of the NTDP Visitors Centre

The Visitor Centre was developed on the ground floor of an existing residential building adjacent to the composting site. The work was carried out after a successful planning application to Cambridgeshire County Council. An external view of the Visitors Centre is shown in Figure 40.

Figure 40: NTDP Visitors Centre

The building contains a reception office, two offices for project consultants, a reception room, kitchen, conference room and disabled access toilets. The conference room (

Figure 41) is capable of seating 30 in theatre or 12 in boardroom format, and was fitted with a 56” flat screen television for presentations. Defra-branded information boards have been fixed to the walls. Leaflet stands hold information on the other demonstrators and the Envar facility.

Figure 41: Visitors Centre conference room

The Visitor Centre was officially opened on Friday 5th October 2007 by the MP for North West Cambridgeshire, Mr Shailesh Vara.

10 SITE OPERATIONS MONITORING

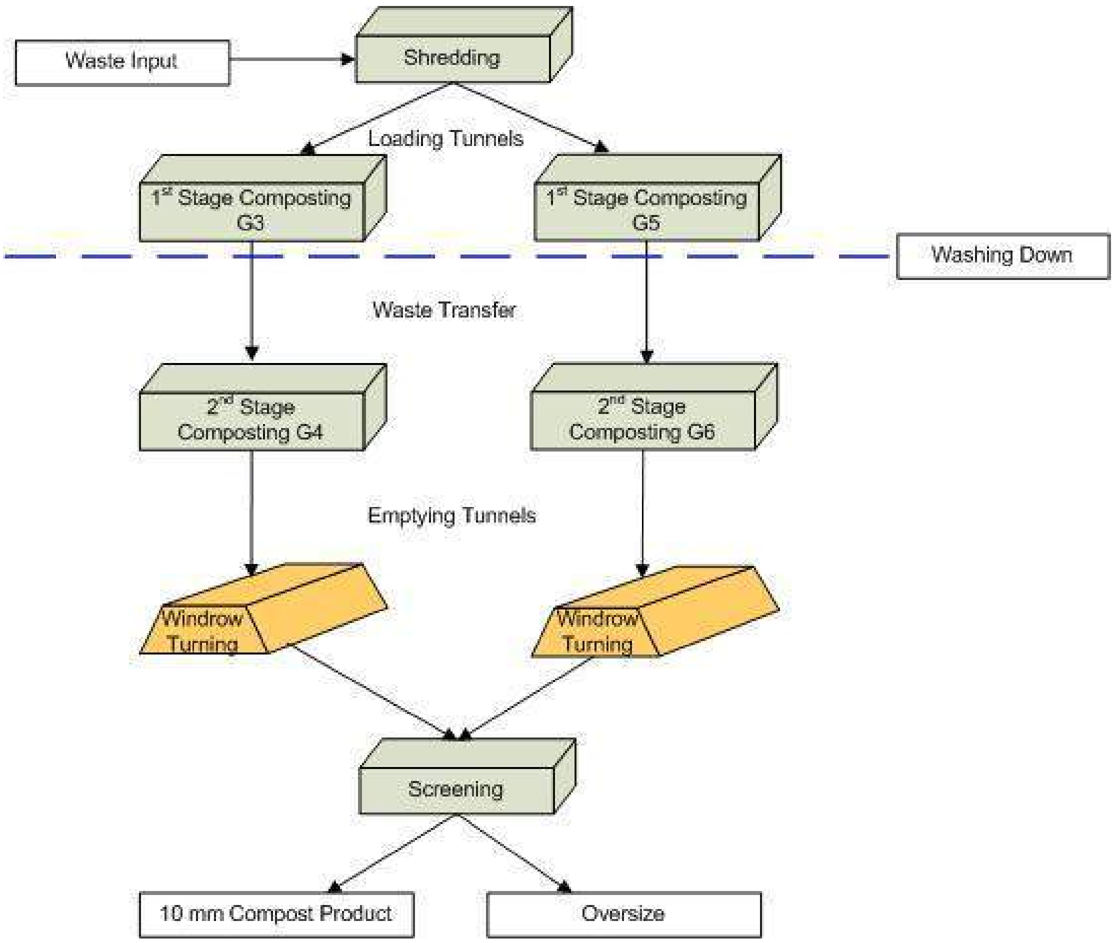
In addition to the monitoring of the performance of the Gicom tunnels through the output of the tunnel computer, the project also monitored a number of other parameters.

The parameters included:

- Waste input;
- Shredding of waste;
- Filling and emptying of the tunnels;
- Washing down;
- Windrow formation and turning ; and
- Windrow screening.

All of these operations, and their sequence, are shown in Figure 42.

Figure 42: NTDP composting process diagram



Waste input

The feedstocks used in the project came from a number of local authorities. These were:

- Essex County Council;
- West London Waste;

- St. Albans District Council;
- Dacorum Borough Council;
- Enfield Council;
- Saffron Walden Town Council;
- London Waste.

The Councils listed above perform separate kerbside collections of kitchen waste (meat included), or collections of co-mingled green and kitchen waste (meat included). The ratio of kitchen waste in material entering the site from individual Councils varied from 10% to 100%. The majority (96%) of waste came from Dacorum Borough Council, St. Albans, Essex and West London Waste. The remaining 4% came from the other Councils.

Sixty runs were carried out using varying proportions of kitchen waste to green waste. A further ten runs were carried out on mixtures of MSW (Municipal Solid Waste) fines (Supplied by Shanks Waste Management Ltd) with co-mingled kitchen waste and green waste.

The waste feedstock was brought onto the St Ives composting site and weighed on the company weighbridge. After weighing, vehicles drove to the main waste reception area to deposit their load. The delivery and unloading of the feedstock complied with Animal By-Products Regulations (ABPR). Vehicle wheels and chassis were washed with a pressure washer before the vehicles left the reception area. The main reception area for the site contained two shredders that processed all incoming material. Some of this was transported to the smaller reception area servicing the project tunnels.

Shredding of waste

ABPR requires reducing the particle size of the catering waste feedstock to <40 cm for a two stage composting process, each with a minimum pasteurisation stage of 60°C for 48 hours.

After weighing, feedstock was fed into a track-mounted Powerscreen 1800 shredder (

Figure 43) by a front end loader. Each tunnel holds between 180 and 220 tonnes of feedstock, depending on the moisture content and density of the shredded material.

The fuel consumption for the shredder was 20 to 48 l/hr, depending on the type of material shredded.

Figure 43: Powerscreen 1800 shredder

Shredded feedstock was loaded onto a tractor and trailer (Figure 44) and transported to the Gicom tunnel waste reception area. It was tipped behind wooden barriers that separate the reception area from the outside of the building.

Figure 44: Tractor and trailer tipping feedstock into the Gicom waste reception area

Filling and emptying of the tunnels

The first stage of the two stage tunnel composting process was carried out in tunnels G3 and G5. The filling of these tunnels was carried out using a Volvo L35B-Pro front end loader (Figure 45). A FEL CASE 621XT front end loader was used to transfer composting material from G3 and G5 to tunnels G4 and G6 for the second stage of tunnel composting. Another front loader (Volvo L70 F) was used to empty G4 and G6 and to transfer the composted material to windrows for the maturation stage.

Figure 45: Front end loaders used to fill the Gicom tunnels

Volvo L35 B

FEL CASE 621XT and Volvo L70 F

Each time the tunnels were loaded or emptied, the material was weighed by the loader operators using weigh cells attached to the loaders. This data covered three operations:

1. Filling of the G3 and G5 tunnels.
2. Transferring composting material from G3 to G4 and from G5 to G6;
3. Emptying the G4 and G6 tunnels.

The above data formed the basis of the mass balance calculations included in this report.

Each time the Gicom tunnels were loaded and unloaded data on the power consumption of the tunnels was recorded. This involved monitoring the electricity consumption of seven pieces of electrical equipment and the consumption of the two boilers providing hot water to heat the walls and floors of tunnels G3 and G4.

The electricity usage reading points were:

1. Main meter (shows total electricity consumption for the Gicom tunnels).
2. Tunnel Fan G3.
3. Tunnel Fan G4.
4. Tunnel Fan G5.
5. Tunnel Fan G6.
6. Scrubber Fan 1.
7. Scrubber Fan 2.
8. Air Compressor.

The electricity usage data formed the basis of the analysis of electricity costs associated with batch tunnel composting included in this report.

The average fuel consumption of the Volvo L35 B for loading G3 and G5 was 4.25 l/hr, 6.34 l/hr for the FEL CASE 621XT to transfer material between tunnels and 6.57 l/hr for the Volvo L70 F to empty G4 and G6.

Washing down

After loading the feedstock into G3 or G5 the floor of the Gicom waste reception area was washed down using an EAGLE 1210H pressure washer. This is a requirement of the ABPR to prevent the contamination of partially processed material transferred from G3 and G5 to G4 and G6, by untreated feedstock.

Windrow formation and turning

After tunnel composting, processed material was unloaded from the tunnels and formed into windrows on a concrete pad for the maturation phase of the composting process. This lasted between 8 and 12 weeks. This length of time was found suitable to produce a final material that was acceptable to the agricultural market after screening. The actual time spent in the windrows, at least 8 weeks, was determined by the required take off of product by customers. Windrows were formed from each of the six intensive kitchen waste and green runs, and from each of the two intensive MSW fines runs. During the period of maturation, windrows were turned on a weekly basis by front end loaders and the time and fuel consumption data for this task were recorded. It took on average 7 litres of diesel to turn a windrow.

Windrow screening

After windrow maturation material was screened using a McCloskey 621 Trommel Screen fitted with a 10 mm sieve (Figure 46). Towards the end of the project a Komptech Hurrikan Windsifter (Figure 47) was purchased by Envar to separate compost product from physical contamination such as plastic and stones. This enabled the separated plastic as stones to be landfilled, while organic oversize material could be re-shredded and returned to the windrow composting process without a build up of plastic contamination.

Figure 46: McCloskey 621 Trommel Screen

Figure 47: Komptech Hurrikan Windsifter

The trommel screen separated the composted material into two fractions with a particle size of <10 mm and >10 mm. The Windsifter then separated different type of materials from the >10 mm fraction. These were:

- Light fraction (containing mainly plastics).
- Heavy fraction (containing stones and metals); and
- Windsifter oversize (containing branches and large pieces of cardboard).

The plastic and stones were landfilled, while the organic oversize material was re-shredded and taken through the windrow composting process again.

Product storage

Screened material (<10 mm) was stored under a Dutch barn until it had been analysed to determine its suitability for use as an agricultural soil improver as required by paragraph 7 exemptions. The material was stored in short windrows up to 5 m in height.

Product removal

The <10 mm product was removed on a regular basis by a number of local farmers who used the material as a soil improver. The material was spread onto agricultural land under of The Waste Management Licensing Regulations (1994) [now The Environmental Permitting (England and Wales) Regulations 2007] paragraph 7 exemptions.

Disposal of oversize and inerts

Non-compostable oversize material, and inerts such as plastics and stones, were removed on a regular basis to a local landfill site. The use of a Windsifter to remove plastic from the oversize enabled the re-shredding and windrow composting of the oversize material. The only material landfilled was plastic and stones, representing just a few percent of the original feedstock.

11 PROCESS MONITORING OF TUNNEL COMPOSTING OF KITCHEN WASTE AND GREEN WASTE

11.1 Introduction

The Gicom tunnels have been designed to facilitate the measurement and control of a wide range of processing parameters. Their design also enables process air to be sampled for a range of gases at a number of points. The raw data generated by the tunnel computer and by additional tests and analyses carried out by project personnel and commercial laboratories is kept on a master spreadsheet. Details of operational monitoring are given in Section 17.2 and 17.3 and in SOP 1.

In order to illustrate typical results using this feedstock, the details of run 57 are provided.

11.2 Process control

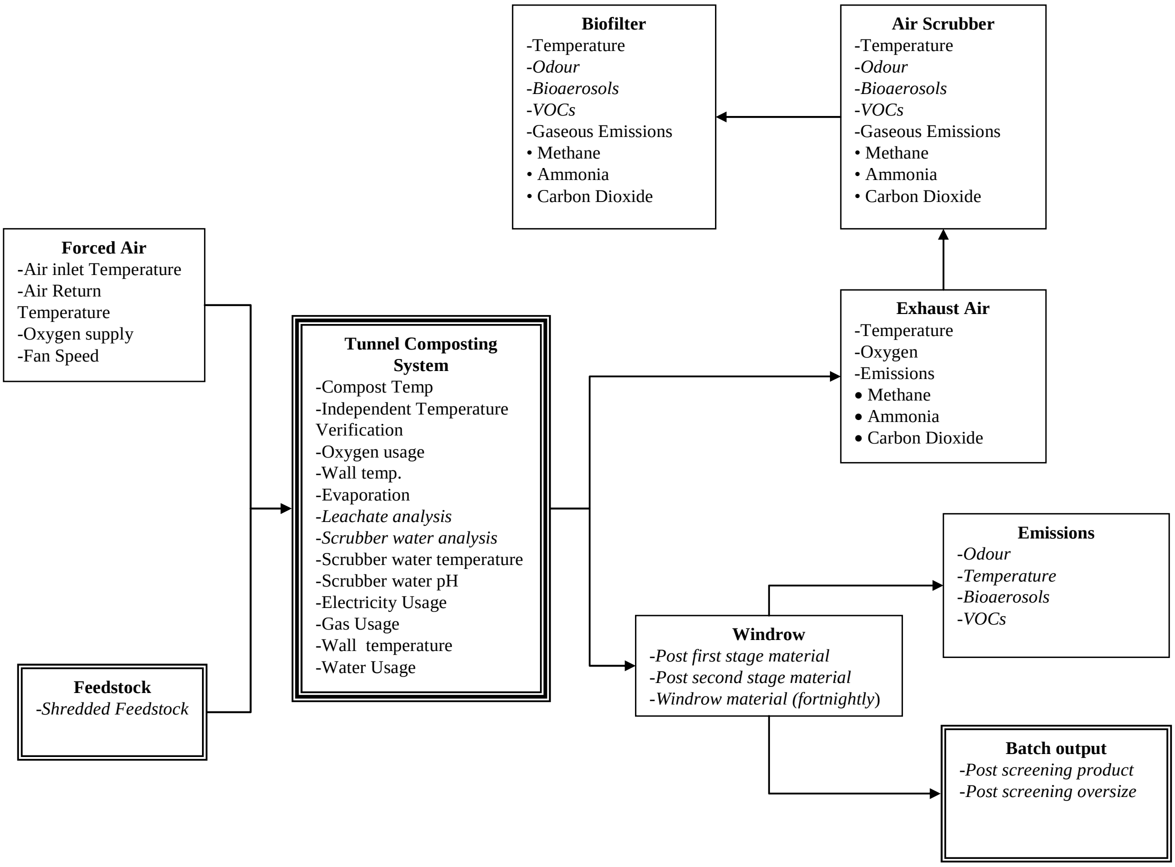
Each composting tunnel was filled with shredded feedstock that is mixed to ensure an appropriate bulk density and C:N ratio for effective composting and as required by the project. The tunnels were filled to a depth of 2.5 - 3.5 metres by a front-end loader, leaving a headspace of 1.0 -1.5m. The ratio of the different, feedstocks, e.g. food waste and green waste was chosen for each run according to the requirements of the project.

In order to establish the detailed operation of the tunnels, a number of parameters were measured by the Gicom tunnel computer. Other parameters were manually sampled to provide independent verification of the data. The Gicom computer data was compiled and subsequently analysed for all the composting runs. This data allowed a determination of the effect of varying proportions of food waste and green waste in the feedstock on the performance of the tunnels.

The raw data collected by the tunnel computers and other manual measurements were collected into an Excel workbook available as an addition to this report.

Figure 48 provides an overview of the composting process and the monitoring which took place during each stage.

Figure 48. Overview of the monitoring taking place on the Gicom Composting System



Once the tunnel is filled and closed, the composting process is controlled by the Gicom computer equipped with custom designed software. The computer system allows dynamic control and pre-programming of a series of processing set points. The computer control system continuously adjusts parameters by comparing the monitored data with the set points.

Figure 49 shows a screen shot from the Gicom tunnel computer. This view shows the location and readings from the six compost temperature probes, the probe measuring the temperature of air entering the tunnel under the perforated floor and leaving the tunnel above the compost, the percentage of fan speed, and the rate of air flow through the tunnel. The start date and time for the run is also shown.

Figure 49: Gicom computer screen shot showing basic parameters being measured

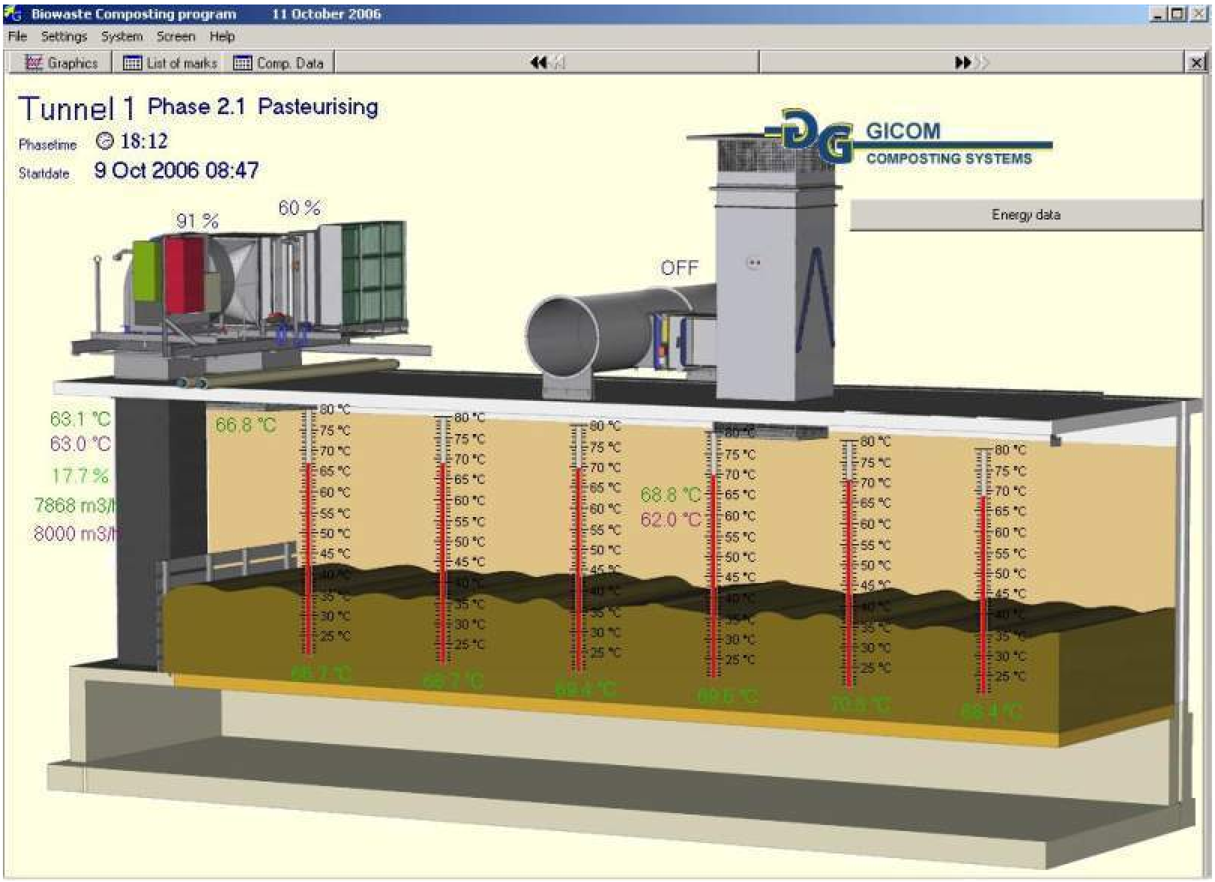


Figure 50 shows the same screen shot with one of the additional data panels open. This panel shows details of the relative humidity, energy consumption, oxygen usage, moisture evaporation, volume of water added during composting, and air flows. Other drop-down panels show additional information.

Figure 50: Gicom computer screenshot showing energy data information panel

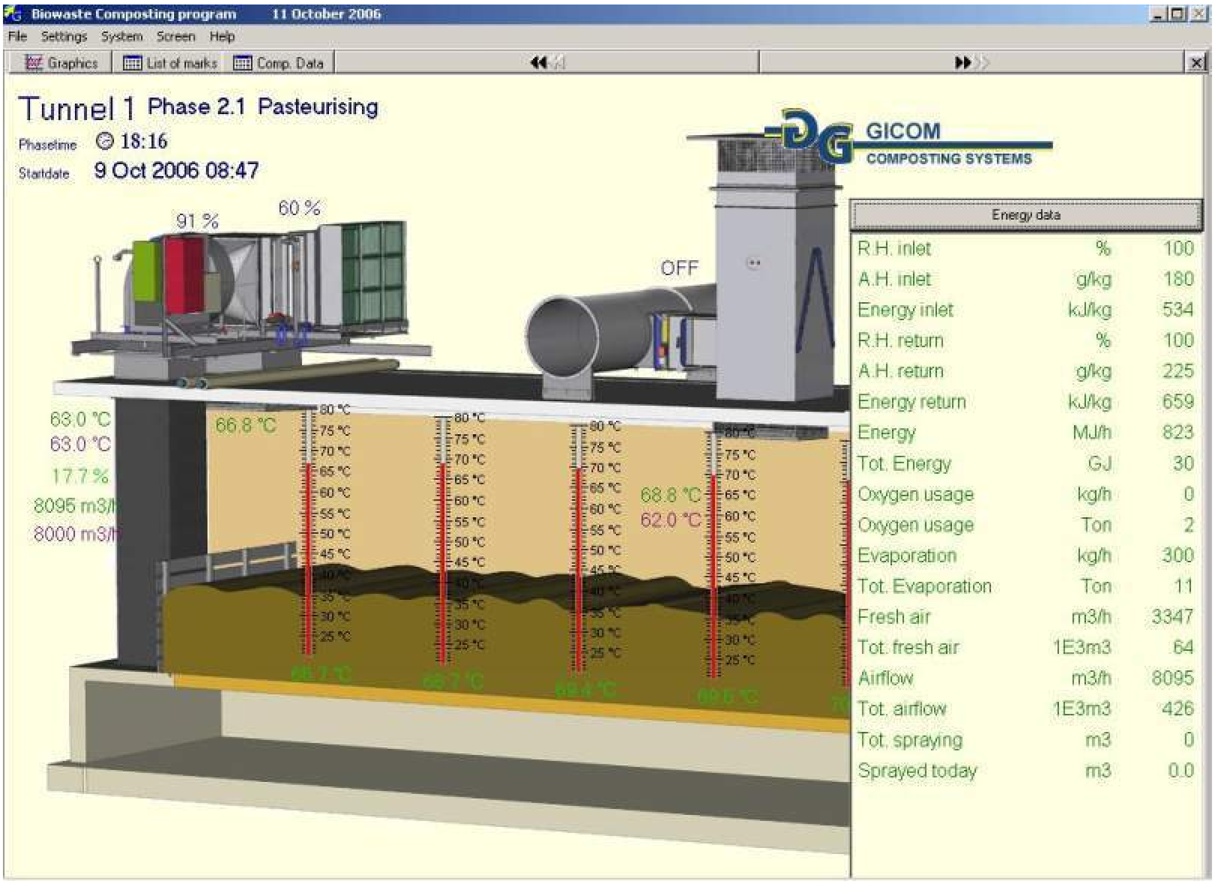
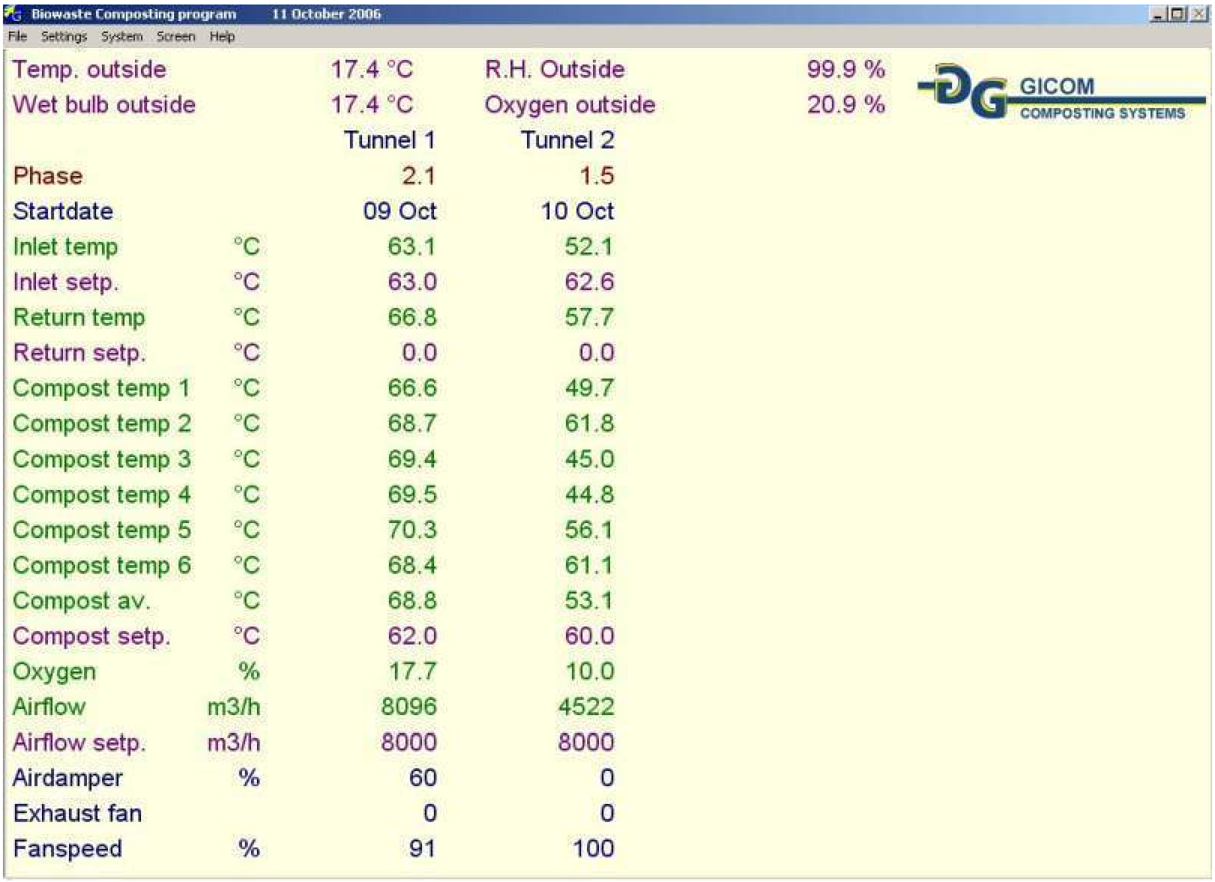


Figure 51 shows another screen shot that provides a snapshot of essential processing data at a particular point in time. This includes compost temperatures, air inlet temperature (coolest), air return temperature (hottest), oxygen levels and rate of air flow.

Figure 51: Gicom computer screen shot showing basic processing data



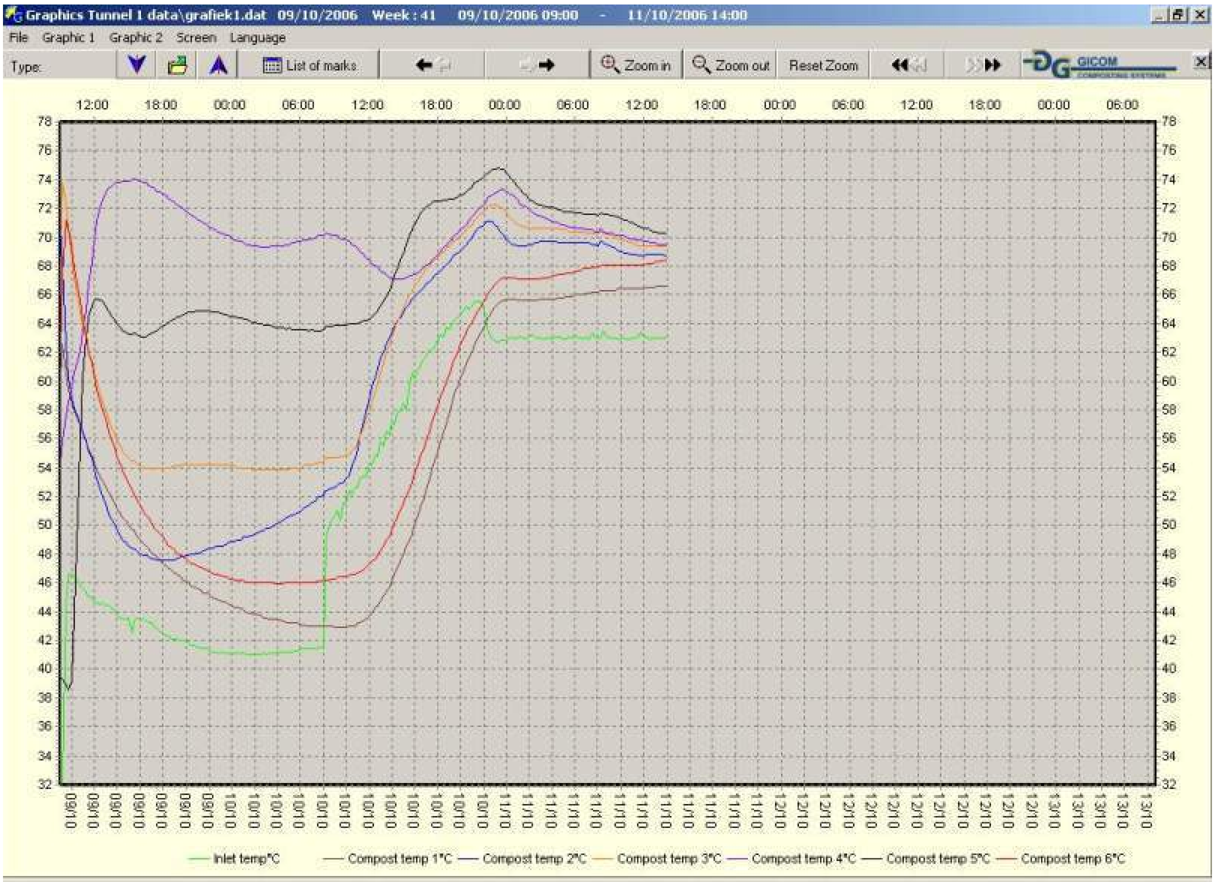
Biowaste Composting program 11 October 2006

File Settings System Screen Help

Temp. outside		17.4 °C	R.H. Outside	99.9 %	GICOM COMPOSTING SYSTEMS
Wet bulb outside		17.4 °C	Oxygen outside	20.9 %	
		Tunnel 1	Tunnel 2		
Phase		2.1	1.5		
Startdate		09 Oct	10 Oct		
Inlet temp	°C	63.1	52.1		
Inlet setp.	°C	63.0	62.6		
Return temp	°C	66.8	57.7		
Return setp.	°C	0.0	0.0		
Compost temp 1	°C	66.6	49.7		
Compost temp 2	°C	68.7	61.8		
Compost temp 3	°C	69.4	45.0		
Compost temp 4	°C	69.5	44.8		
Compost temp 5	°C	70.3	56.1		
Compost temp 6	°C	68.4	61.1		
Compost av.	°C	68.8	53.1		
Compost setp.	°C	62.0	60.0		
Oxygen	%	17.7	10.0		
Airflow	m3/h	8096	4522		
Airflow setp.	m3/h	8000	8000		
Airdamper	%	60	0		
Exhaust fan		0	0		
Fanspeed	%	91	100		

Figure 52 is another type of screenshot that shows the compost temperatures throughout a composting run. This particular screen shot was taken at the time when the pasteurisation stage was commencing. It shows that the wide variation in compost temperatures in different parts of the tunnel immediately after filling rapidly decreases under computer control until all compost temperatures are above the required 60ºC.

Figure 52: Gicom computer screenshot showing compost temperatures



The Gicom computer monitors or calculates over 150 parameters during a tunnel run on a continual basis, with readings taken every 15 minutes. During the duration of the project, the computer recorded over 10 million individual data points. Details of the methodology for recording tunnel data are given in SOP 8.

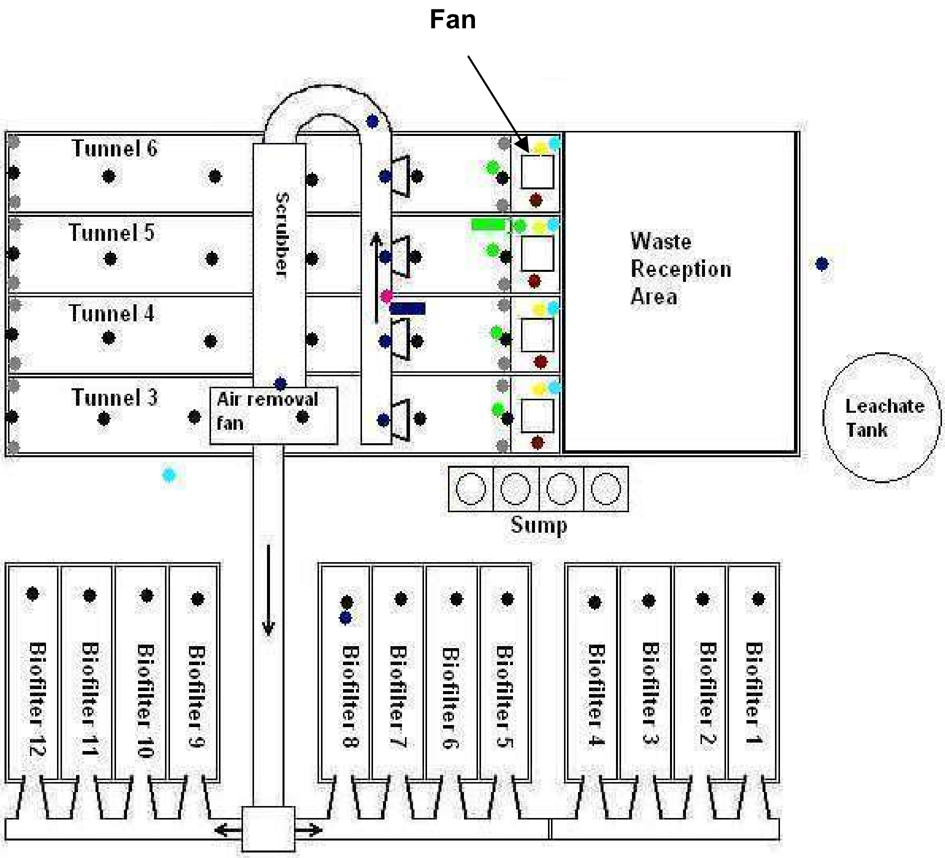
A number of the parameters have greater importance than others when controlling and evaluating the efficiency of the Gicom system. These are listed below.

Table 7: Major performance parameters

- Inlet and return air temperatures (°C)
- Compost temperatures at six different points in the tunnel (°C)
- Fan speed (%)
- Oxygen (%)
- Oxygen utilisation (tonnes)
- Carbon dioxide production (ppm)
- Carbon dioxide (tonnes)
- Ammonia production (ppm)
- Ammonia production (kg)
- Methane production (ppm)
- Methane production (kg)
- Evaporation (kg/h)
- Evaporation (tonnes)
- Electricity usage (kWh)
- Water spraying (tonnes)
- Biofilter temperatures (°C)
- Wall temperatures (°C)

Figure 53 shows the locations within the tunnel composting system where these measurements were taken.

Figure 53: Measurements and sampling in the Gicom tunnel



Key:

- Tiny Tag Loggers (temperature)
- Gicom compost temperature probes
- CO_2, NH_3 and CH_4 probes (central location)
- Sampling points for CO_2, NH_3 and CH_4
- Wet bulb to measure humidity
- Oxygen probe (central location)
- Oxygen sampling point
- Sampling points for CO_2, NH_3 and CH_4 outside
- Inlet temperatures
- Outlet temperatures

Compost temperatures were measured by moveable temperature probes at six different points along each tunnel. Tiny Tag temperature probes were also fitted in each biofilter. Details of the use of data loggers are given in SOP 7.

Fixed temperature probes within the air recirculation ducting of each tunnel fan measured the air inlet (air entering the tunnel) and return air (air recirculated from the headspace after passing through the compost) temperatures. Methane, carbon dioxide and ammonia were sampled from 7 locations within the aeration exhaust system. Every 15 minutes, a sample of exhaust air was pumped to the central sampling location which contained a probe for each of the three gases that measured their concentrations.

The sampling locations were in:

- The exhaust ducting for each tunnel.
- The combined exhaust before the scrubber.
- The combined exhaust after the scrubber.
- Biofilter 8.

Oxygen measurements were taken by sampling the air in the tunnel fan ducting and pumping this to the central probe box for measurement. The humidity of the inlet and return air for each tunnel was measured by wet bulbs fitted on top of the air fan.

Intensive Runs

Within the project, eight 'intensive runs' were carried out. These intensive runs were monitored from the time at which waste entered the site, through the tunnel and windrow composting stages, to the final screening process to produce the compost product.

In addition to the data collected by the Gicom computer system, further manual monitoring was carried out during the intensive runs, including the collection of solid, liquid and gaseous samples. The method used was identical to that used for the monitoring of the co-mingled kitchen waste and green waste.

The material from the windrows was sampled every 2 weeks, specifically to monitor its stability throughout the course of the composting process. The activity of the compost was determined by the weekly monitoring of temperatures within the windrows using a hand-held probe.

Six of these intensive runs were carried out on various mixtures of kitchen and green waste (Runs 2, 7, 15, 22, 31, 45), and two on mixtures of MSW (Municipal Solid Waste) fines with kitchen and green waste (MSW runs 1, 2). These intensive runs were monitored from the time at which waste entered the site, through the tunnel and windrow composting stages, to the final screening process to produce the compost product.

In addition to the data collected by the Gicom computer system, further manual monitoring was carried out during the intensive runs, including the collection of solid, liquid and gaseous samples.

Samples were taken and sent to accredited laboratories for analysis for:

- Inert contaminants.
- Heavy metals.
- Bulk density.
- Nutrients (N, P, K).
- Organic matter.
- Stability.

Samples of the finished compost product were also analysed according to the requirements of the PAS 100 standard. Samples were taken from:

- Shredded feedstock.
- Partially composted material transferred from the first to the second tunnel composting stage.
- Partially composted windrow material.
- Screened compost product.
- Screened compost oversize.

Within the tunnels, the temperature probes linked to the Gicom tunnel computer were verified by the use of TinyTag temperature loggers placed within the composting material in the tunnel corners. Data was downloaded from these TinyTags after each intensive run.

Leachate from the sump collecting water from the G3 tunnel was sampled weekly. Process water (used to spray on feedstock within the first stage of tunnel composting before pasteurisation) was also used in the scrubber. Samples were collected in clean, sealed bottles and sent to an accredited laboratory for analysis of heavy metals, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and nutrients.

The temperature and pH of the sump and process water were also measured on a weekly basis. The procedures for calibrating the pH meter are given in SOP 14.

11.3 Timing of runs

The first run was started on 31st December 2007. The last run was started 6th March 2009. During this period 77 composting runs were completed in the tunnels: 67 runs using mixtures of kitchen waste and green waste, and 10 runs using MSW as feedstock.

11.4 Waste inputs

At the start of the project it was quickly realised that because of the wide variety of collection methods used by local authorities, the collection of kitchen waste and green waste formed a continuum of feedstock. This continuum ranged from almost 100% green waste to 100% kitchen waste in small increments.

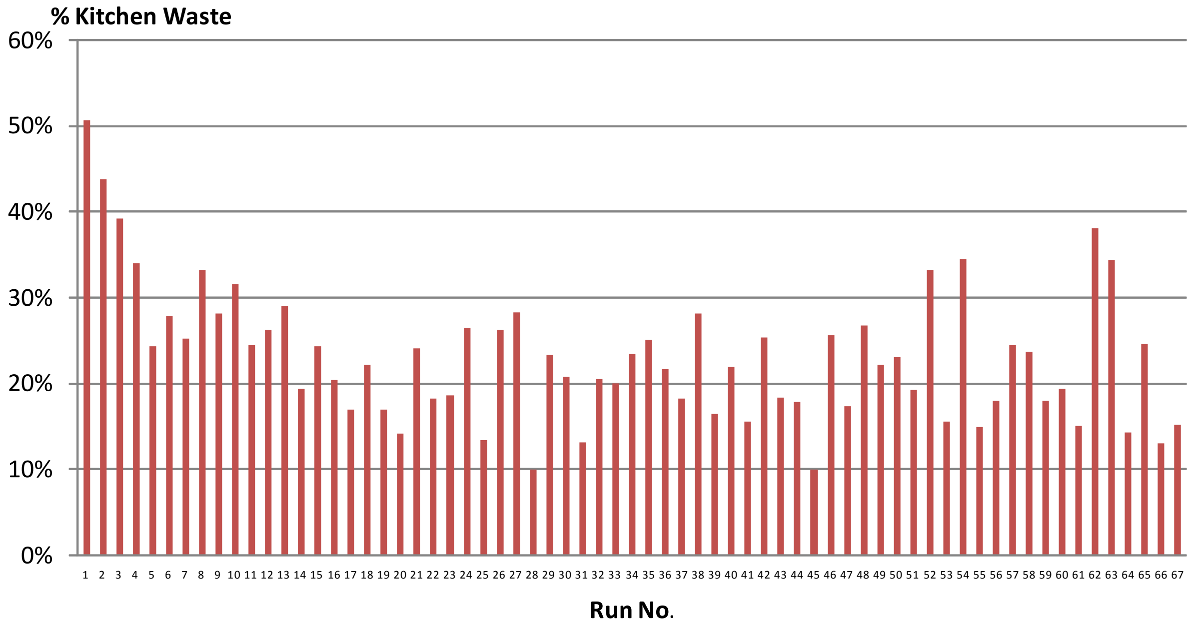
With the agreement of Defra it was determined that the project should process 10 runs with the kitchen waste component representing <15% of the kitchen waste/green waste mixture, 10 runs with the kitchen waste component representing >30% of the mixture, with the remaining runs using controlled proportions of kitchen waste falling between these two extremes. It was agreed that this approach would cover all of the different collection policies used by local authorities and would generate data of maximum interest to the industry.

Each local authority delivering waste into the project provided data on the average proportion of kitchen waste in their collections. This ranged from none at all, i.e. the feedstock consisted only of green waste, through a range of proportions of kitchen waste and green waste, through to 100% kitchen waste.

For each project run, the amount of feedstock contributed by each local authority to a fill was calculated. This was made possible by the routine procedure of weighing each load of feedstock as it arrived and identifying which loads were used to fill each tunnel. A degree of control was possible in the waste reception area that allowed the creation of a range of proportions of kitchen waste and green waste from c.10% to c. 50% to be filled into the project tunnels. There is undoubtedly a margin of error in these calculations as there is a variation in kitchen waste content throughout the year. However, the wide range of proportions of kitchen waste in the feedstock mixtures allows some confidence that the true effect of the kitchen waste on the performance of the feedstock is being estimate.

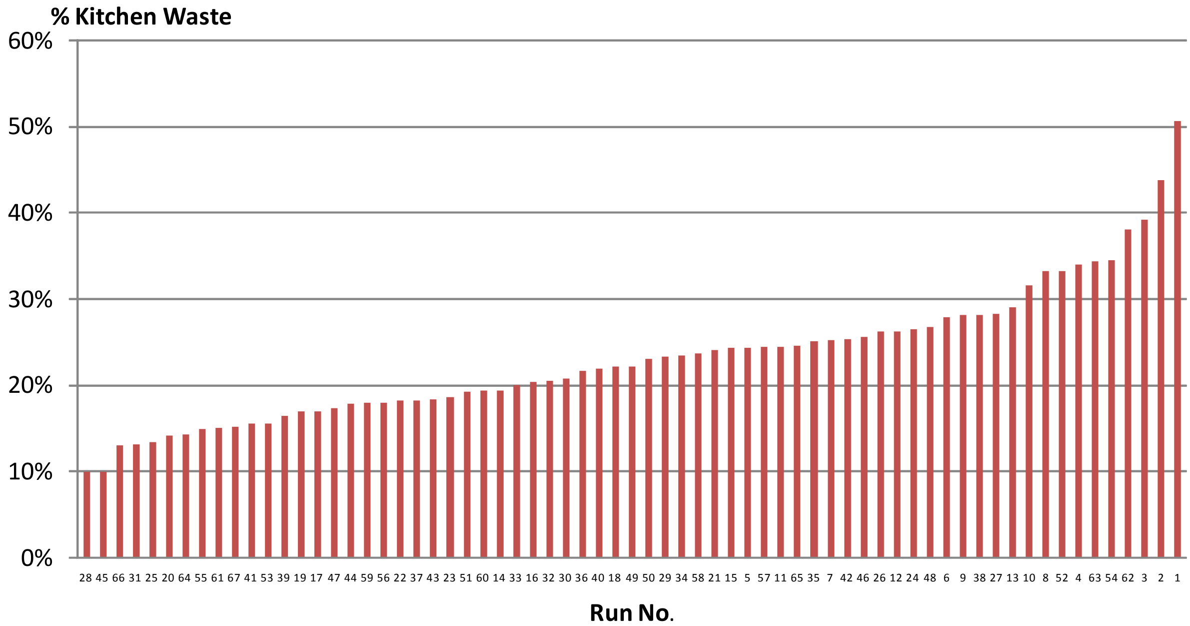
Figure 54 shows the proportion of kitchen waste in each of the 67 runs carried out in date order.

Figure 54: Proportion of kitchen waste to green waste – date order



This data can be rearranged (Figure 55) in order to show the increasing proportions of kitchen waste in the feedstock mixture used throughout the project.

Figure 55: Proportion of kitchen waste to green waste – increasing proportion

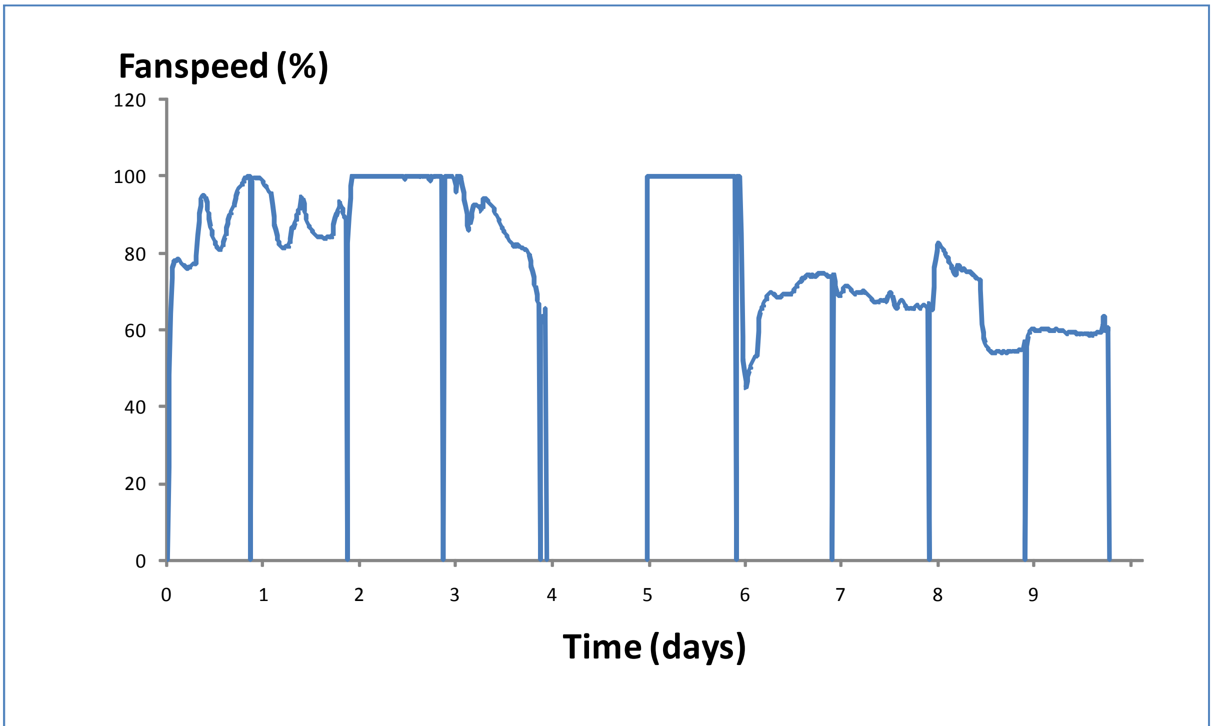


11.5 Residence time in tunnels

The residence time of composting material in the tunnels for the first and second composting stages for each of the 67 runs was calculated. As an example, Figure 56 shows the residence time for the two stages of one particular run (run 57). This run has been selected as it illustrates in detail all of the various types of data collected for each run carried out by the project. The residence time is calculated by determining the time when the tunnel fan is first turned on and the time when it is finally turned off. At 24 hour intervals the tunnel fans are momentarily turned off in order to allow leachate to drain from the aeration pipes in the tunnel floor.

Run 57 was processed without the heated walls and floors being turned on and was not an intensive run. The feedstock contained 25% kitchen waste, and 203.60 tonnes of the feedstock was filled into the tunnel.

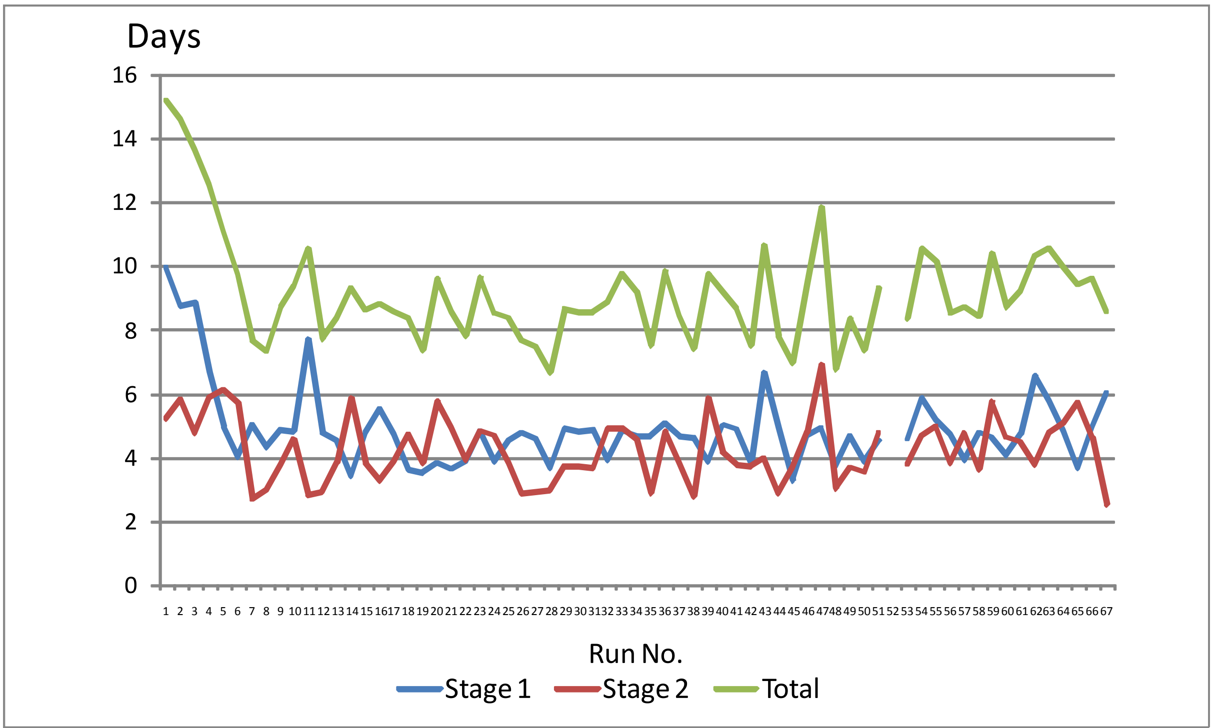
Figure 56: Residence time for Run 57



This Figure shows that the composting material spent 3.94 days in the first stage and 4.78 days in the second stage.

Figure 57 shows the residence times for both stages of all 67 runs.

Figure 57: Residence time for Runs 1 – 67 – date order



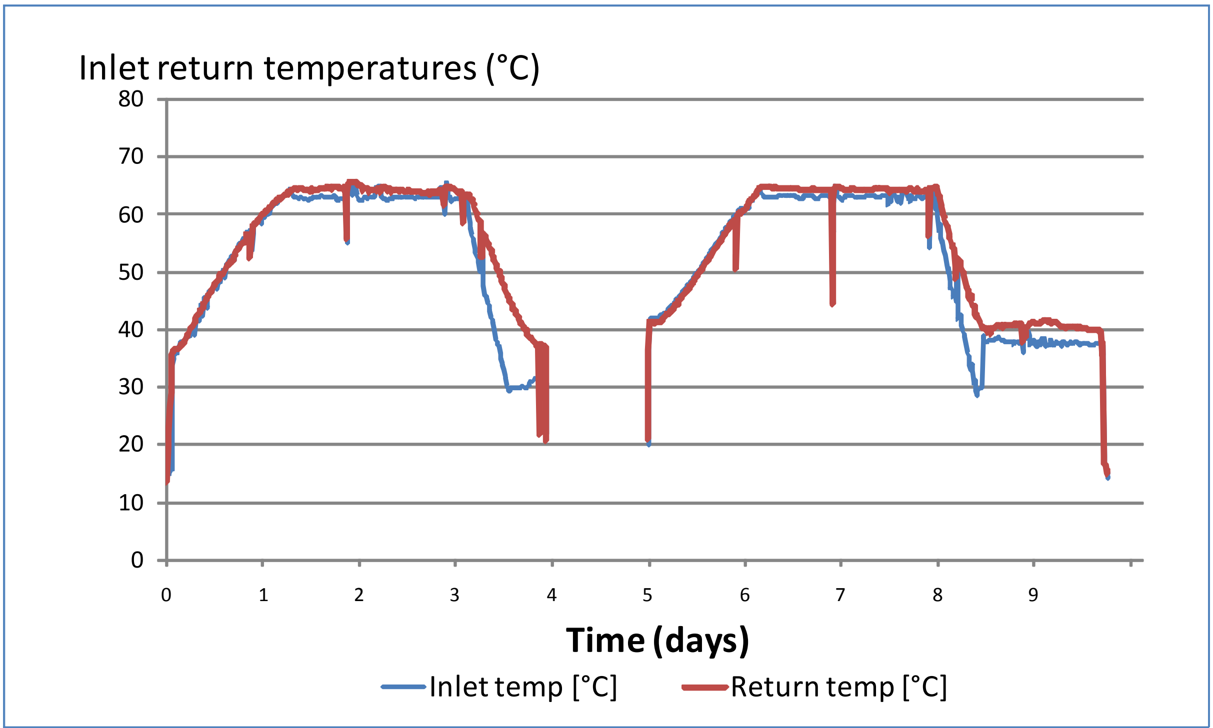
It can be seen that the residence time for the first stage varied from 3.28 days to 9.97 days. The residence time for the second stage varied from 2.54 days to 6.96 days. The combined residence time for both stages varied from 6.69 days to 15.22 days.

11.6 Temperatures - Air inlet and return

The difference in the temperature of air entering the floor of the tunnel (air inlet temperature) and the temperature of the air after it has passed through the compost (air return temperature) is an indication of the range of temperatures throughout the vertical profile of the composting matrix. In order to ensure a uniform composting environment within the tunnel this difference should be as small as possible.

As an example, Figure 58 shows the air inlet and air return temperatures for run 57.

Figure 58: Air inlet and air return temperatures for run 57

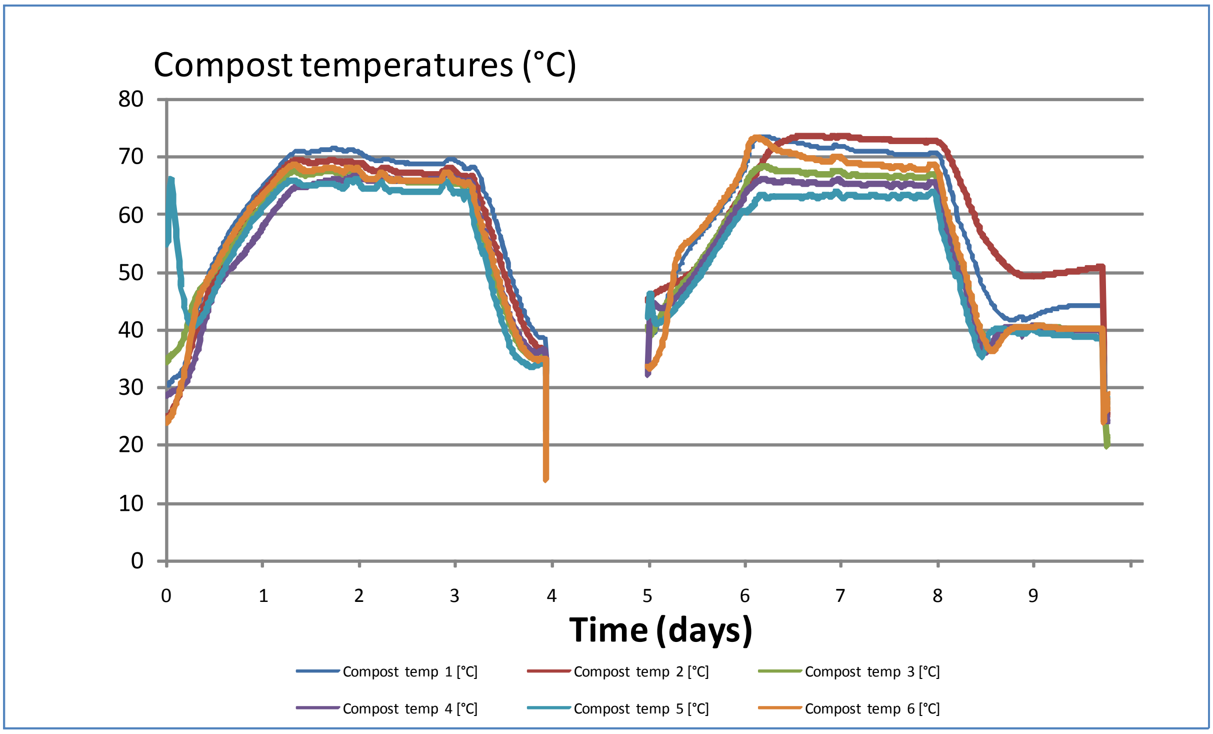


This Figure shows a very close correlation between the air inlet and air return temperatures for both stages of the run, indicating a very uniform composting environment. In both stages the temperatures are above the 60° C required for compost temperatures by the Animal By-Products Regulations (ABPR). The very short drop of the air temperatures every 24 hours is caused by the fans momentarily closing down as leachate is drained from the floor aeration pipes. As will be seen below, these temperature drops are in the air only and not in the compost itself.

11.7 Temperatures – compost

Six temperature probes were inserted into the compost for both stages of each run. In order to ensure as uniform a composting environment as possible, the temperatures recorded by each probe should be as uniform as possible. In order to comply with ABPR all 6 probes have to reach a minimum of 60° C for a minimum of 48 hours. As an example, the compost temperature readings for run 57 are shown in Figure 59.

Figure 59: Compost temperatures for run 57

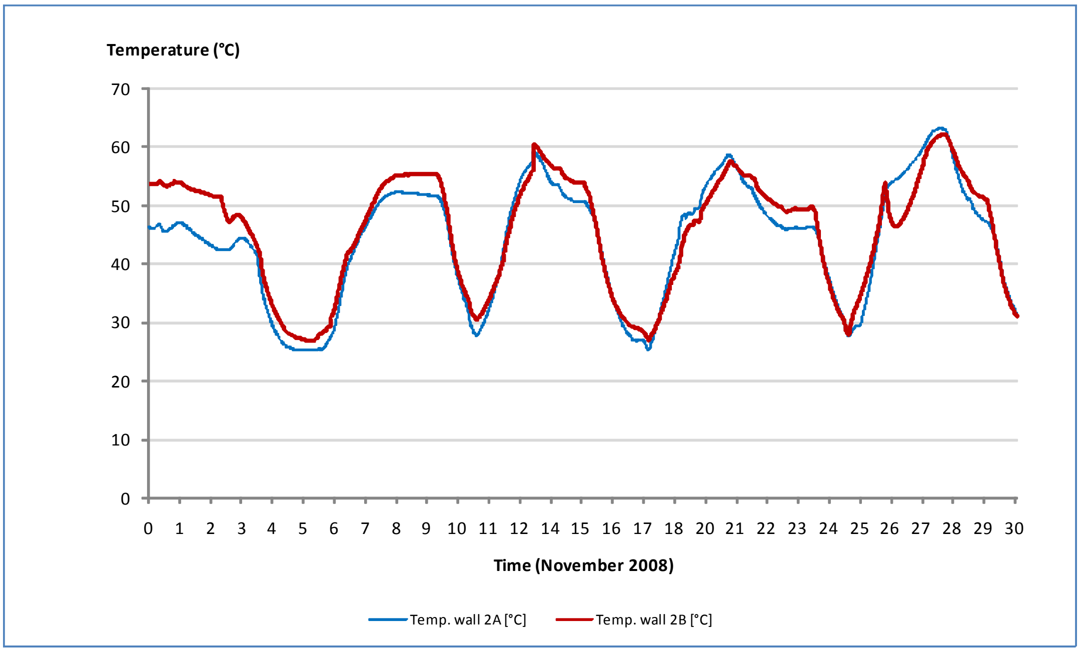


It can be seen that all 6 compost temperature probes exceeded 60° C for at least 48 hours for both stages of the composting process, thereby complying with ABPR.

11.8 Temperatures – Tunnel walls and floors

Temperature probes recorded the temperature of the tunnel walls during each run. This temperature was controlled, to an extent, by the circulating hot water provided by a boiler. As an example, the wall temperatures recorded for tunnel G5 during the month of November 2008 are shown in Figure 60.

Figure 60: Wall temperatures in tunnel G5 – November 2008



This Figure shows the wall temperatures for each of five runs undertaken during the month. Temperatures in excess of 50°C were generated before the pasteurisation section of the first composting stage during each run. The temperature probes are positioned to measure the contribution by the heated water rather than any residual heat left by warm compost after removal from the tunnel.

11.9 Temperatures – biofilter

Exhaust air from the tunnels pass through a scrubber and then a series of biofilters to remove offensive odours. In order to increase the efficiency of the biofiltration process, the temperature of each of the biofilters was monitored and controlled by the tunnel computer.

As an example, Figure 61 shows the temperatures for biofilters 2 – 8 during the month of November 2008.

Figure 61: Temperature of biofilters 2 – 8 during November 2008

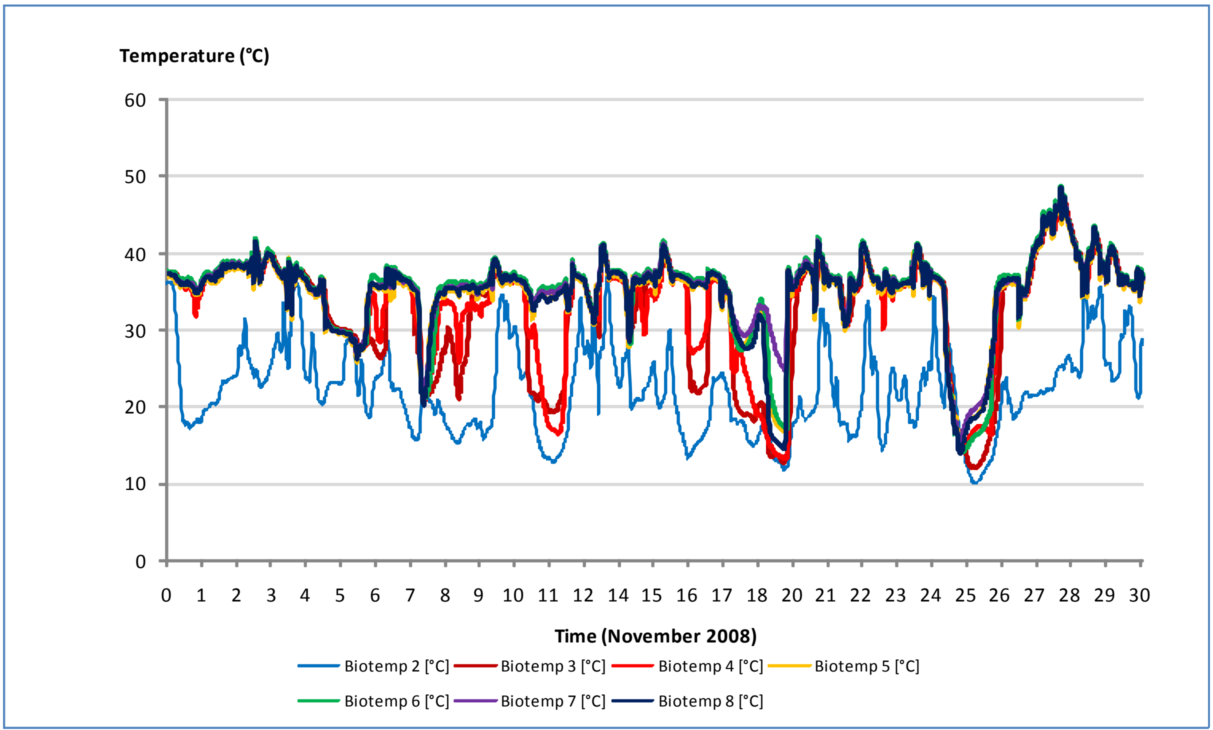


Figure 61 shows that the temperatures of most of the biofilters were maintained within the 28° C to 40° C range for most of the time. Biofilter 2, the biofilter furthest away from the source of the exhaust gas, routinely showed lower temperatures.

Figure 62 shows the average biofilter temperature during November 2008 along with the ambient temperature for the same period.

Figure 62: Average biofilter temperature and ambient temperature – November 2008

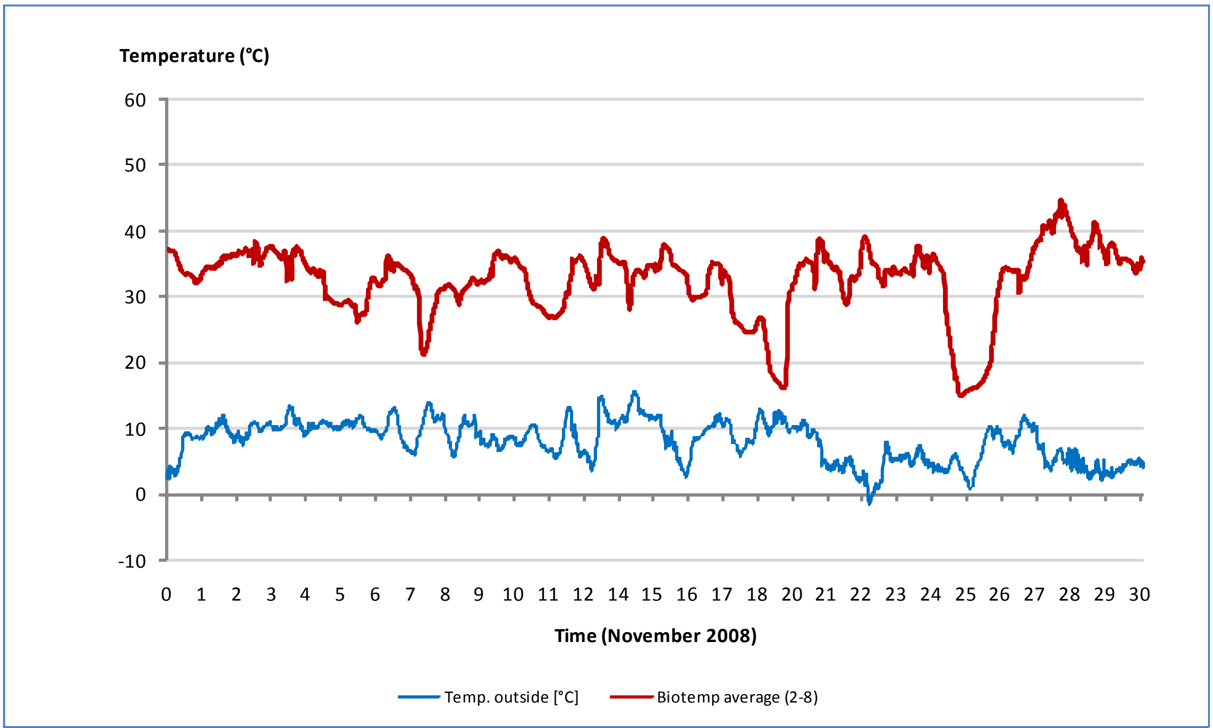
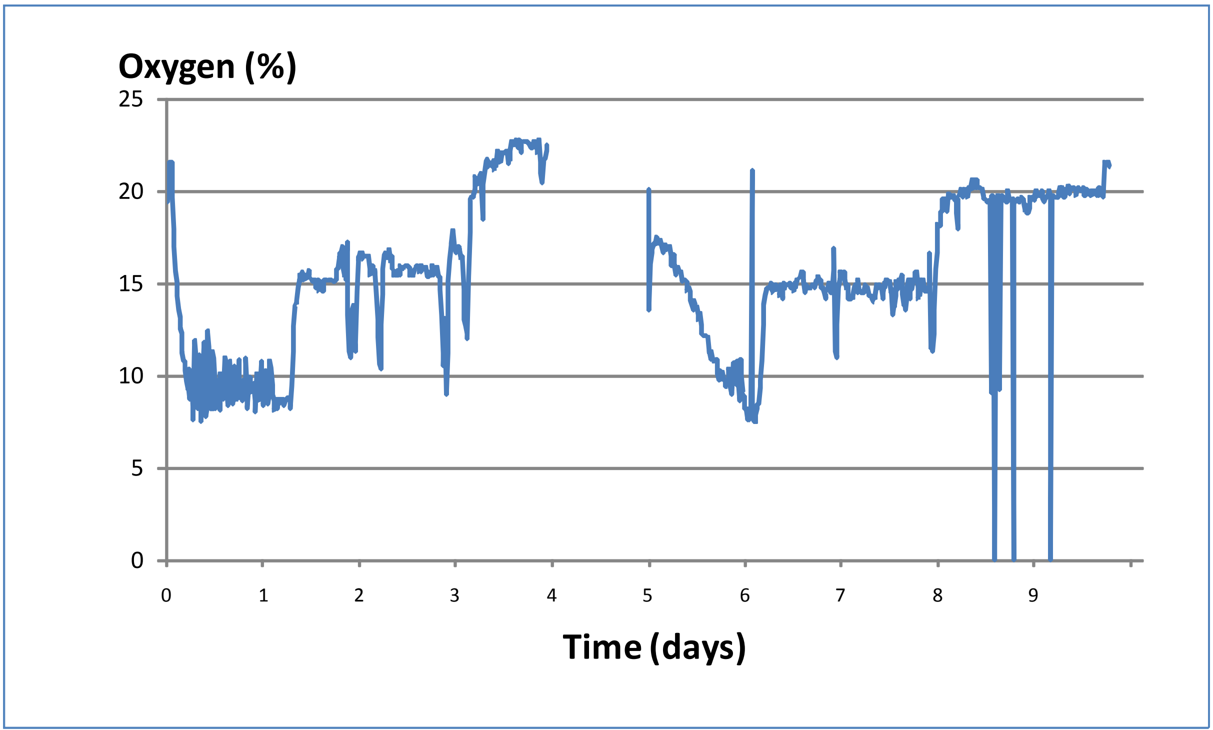


Figure 62 shows that the average biofilter temperature was normally kept within the 28° C to 40° C range. This range was well above the ambient temperature recorded during this time. It is likely the elevated temperature is caused both by the introduction of warm air into the biofilters and microbial activity within the biofilter itself.

11.10 Oxygen consumption

It is vital to maintain aerobic conditions during the composting process. This is to enable composting to proceed efficiently and to avoid the generation of offensive anaerobic odours. A control system within the tunnel computer ensures that a minimum of 7% oxygen is always present in the recirculating air. As an example, Figure 63 shows the percentage oxygen recorded in the recirculating air for run 57.

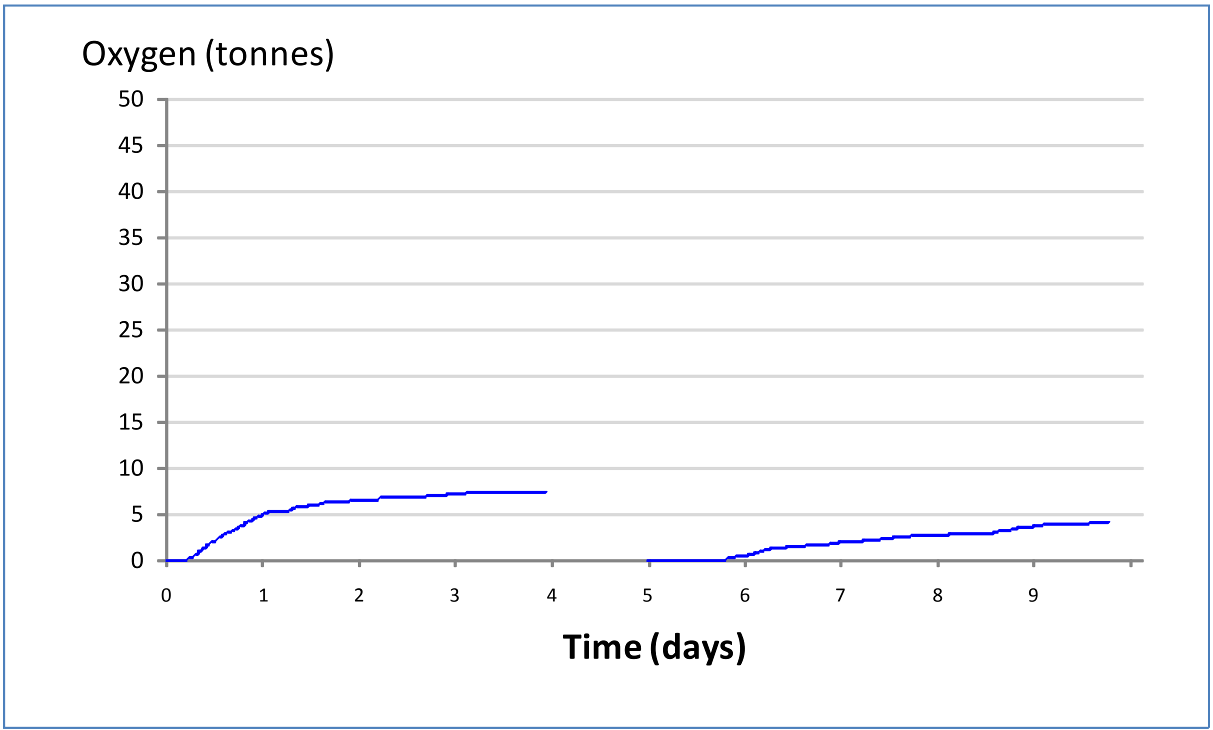
Figure 63: Oxygen levels during run 57



This Figure shows that oxygen levels were maintained above 7% during both stages. The apparent momentary drop in oxygen levels at the end of the second stage is an artefact caused by the momentary shorting of the oxygen probe.

The tunnel computer also records the quantity of oxygen consumed during each run. Figure 64 shows the accumulative amount of oxygen consumed during both stages of run 57.

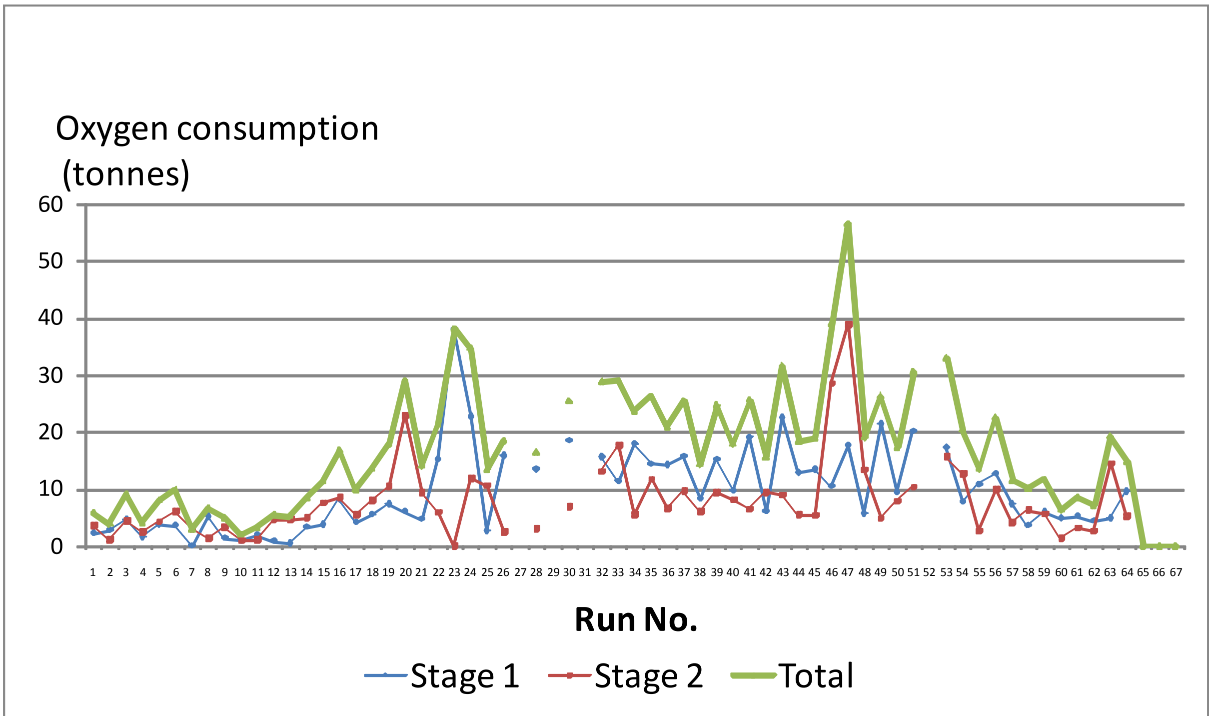
Figure 64: Oxygen consumed during run 57



This Figure shows that during the first stage of this run 7.4 tonnes of oxygen were consumed, and during the second stage 4.1 tonnes were consumed.

Figure 65 shows the amounts of oxygen consumed during both stages of runs 1 – 67.

Figure 65: Oxygen consumed during runs 1 – 67

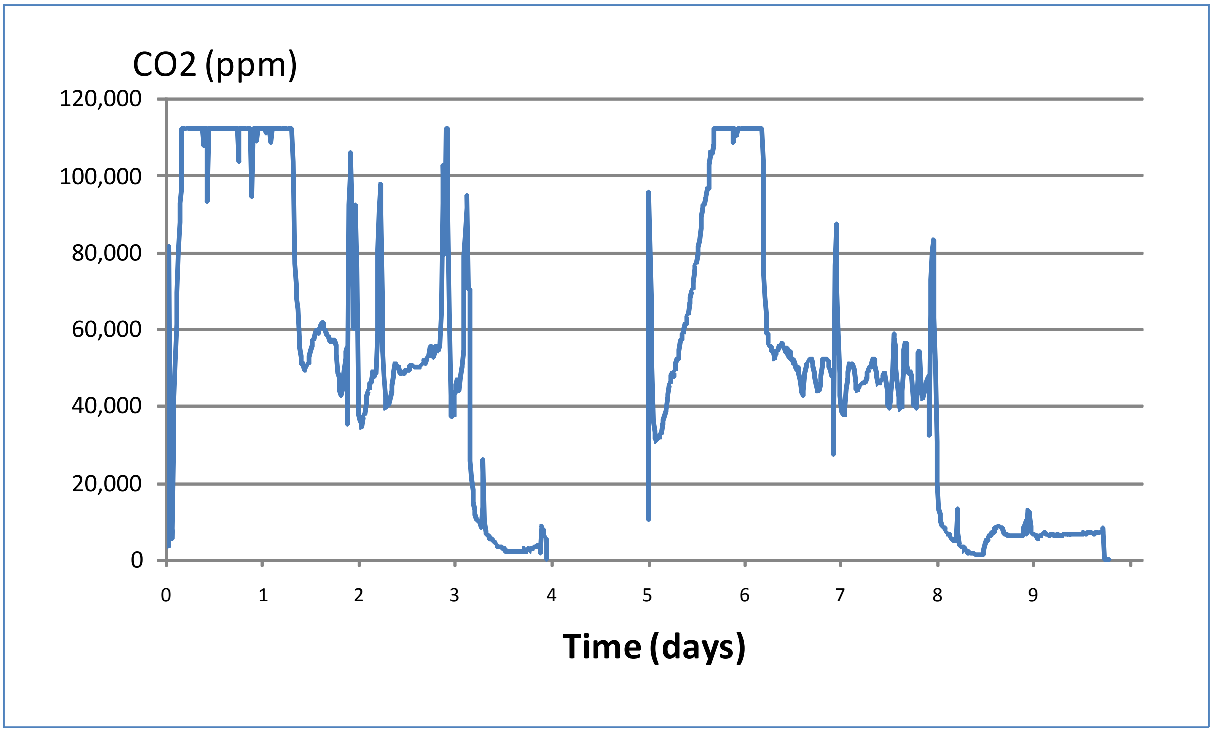


This Figure shows that the oxygen levels consumed during each stage, and between each run, varies considerably. The oxygen consumed during the summer months was considerable higher that during the winter months. The recorded levels of oxygen consumed by both stages varied from 2.0 tonnes to 56.7 tonnes. The gap in data for some runs, including runs 65, 66 and 67, was caused by a temporary problem with the oxygen probe.

11.11 Carbon dioxide

The tunnel computer monitored the carbon dioxide levels in the recirculated air for each run. As an example, the carbon dioxide levels in run 57 are shown in Figure 66.

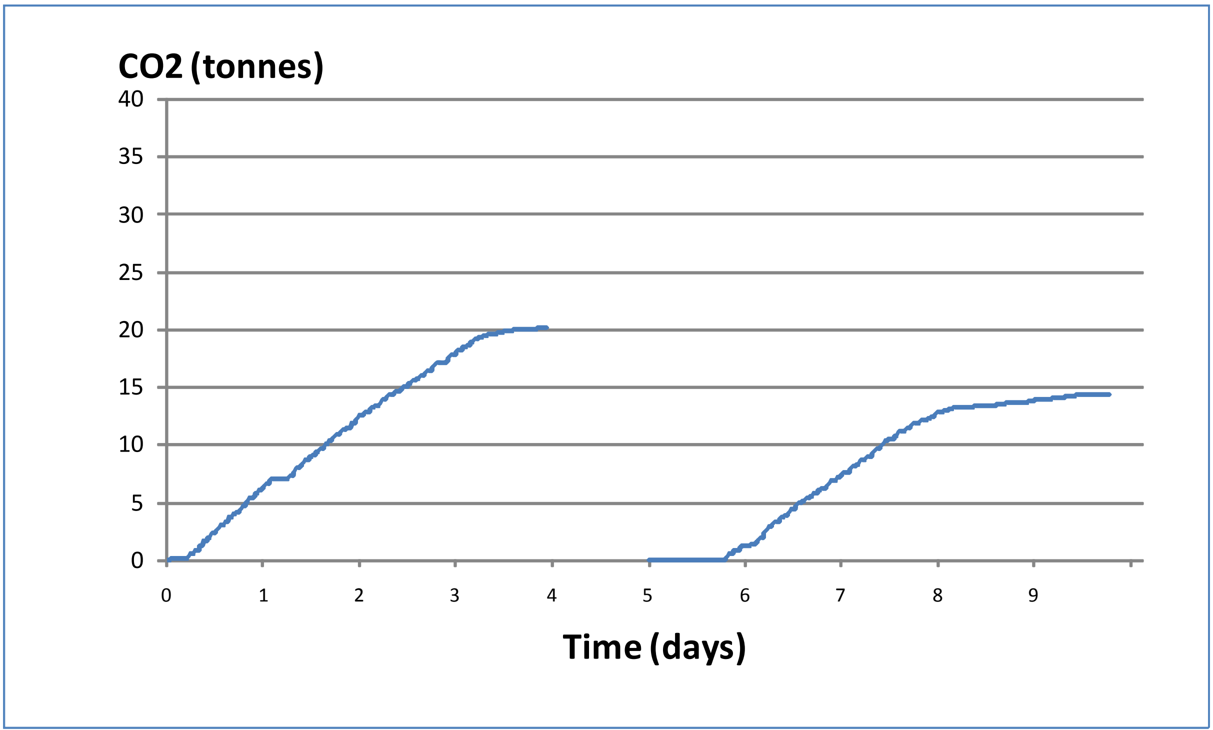
Figure 66: Carbon dioxide levels in run 57



This Figure shows that carbon dioxide levels in excess of 110,000 ppm were generated during the most active sections of both stages. The graphs plateau at the maximum levels of carbon dioxide detection with this system. For each stage, the levels of carbon dioxide dropped off when large quantities of fresh air were introduced during the cooling down sections of the runs.

The tunnel computer also recorded to total quantity of carbon dioxide produced during each run. As an example, Figure 67 shows the total quantity of carbon dioxide produced during run 57.

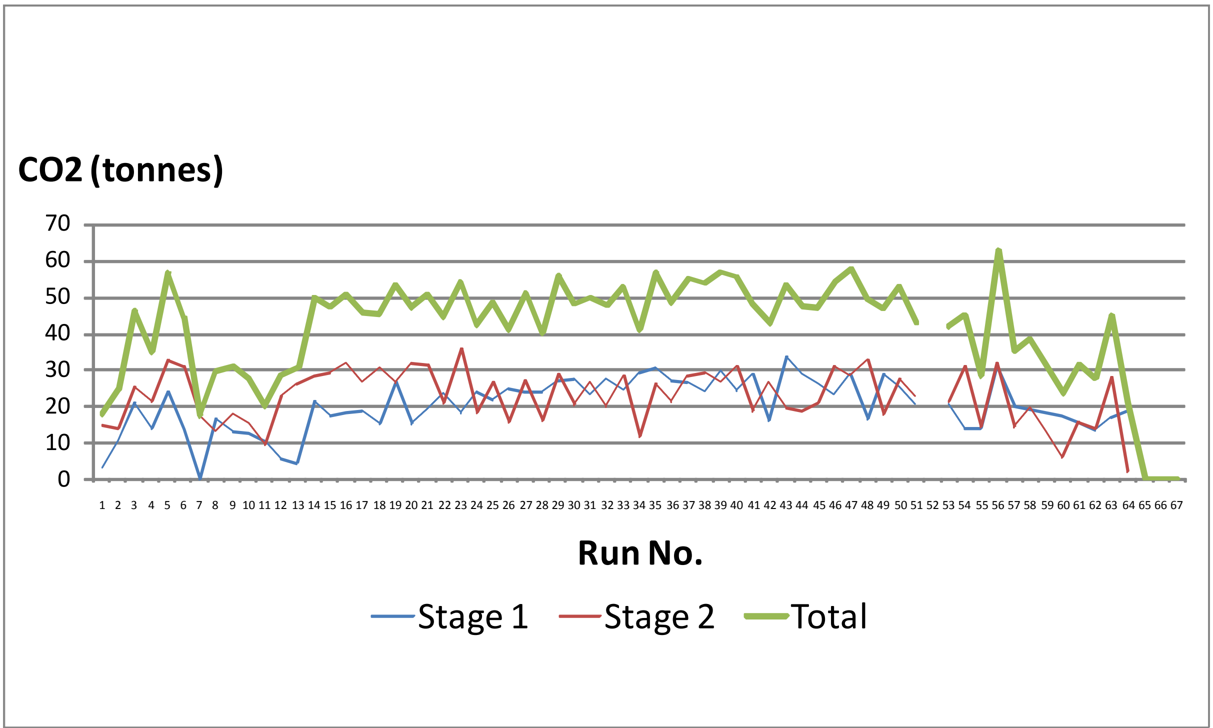
Figure 67: Carbon dioxide produced during run 57



This Figure shows that during the first stage of run 57, 20.3 tonnes of carbon dioxide were produced, and during the second stage 14.5 tonnes were produced.

The amount of carbon dioxide produced for each of the 67 runs is shown in Figure 68.

Figure 68: Carbon dioxide produced during runs 1 – 67

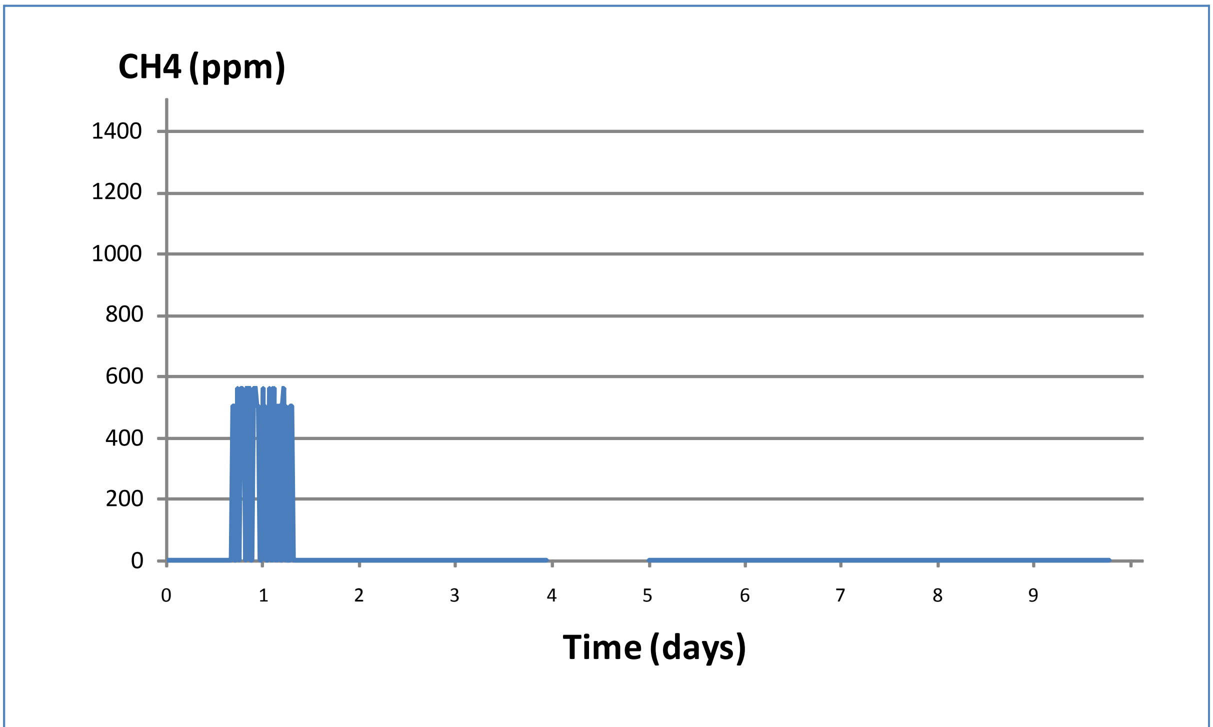


This Figure shows that the total amount of carbon dioxide produced by both stages of each run varied from 17.5 tonnes to 62.9 tonnes. Levels of carbon dioxide produced tended to be higher during the summer months. The carbon dioxide data was not recorded for a few runs.

11.12 Methane

As the composting process is fully aerobic, the presence of methane in the recirculated air was not expected. However, in the early part of the first stage of some runs, small quantities of methane were detected. As an example, the methane levels in run 57 are shown in Figure 69.

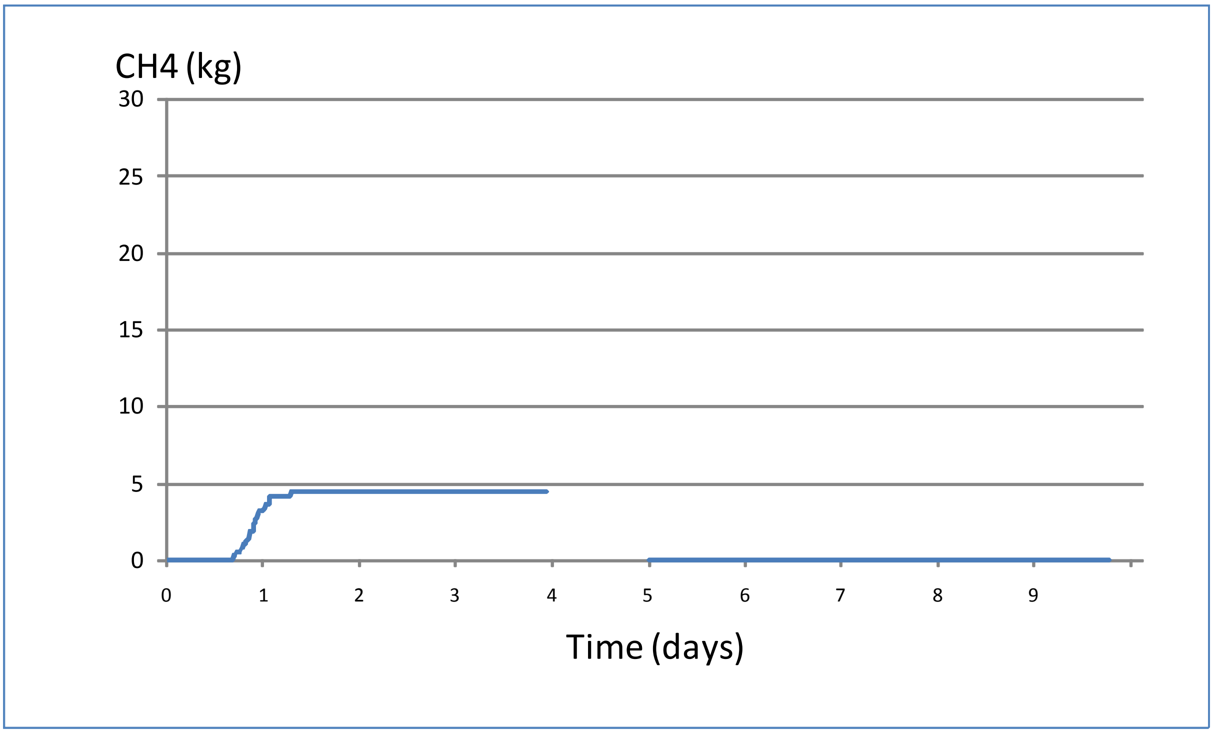
Figure 69: Methane levels detected in run 57



This Figure shows that for a short time levels of methane up to 562 ppm were detected in the recirculating air as the composting material warmed up in the first stage. Methane was never detected later in the first stage and not in the second stage. It was considered that this methane was derived from anaerobic areas within the feedstock filled into the tunnels. Feedstock, especially food waste, left in household collection bins for some time would be expected to become anaerobic and to generate a small amount of methane. Any methane present would be rapidly oxidised as the composting processed commenced.

The tunnel computer also measured the total quantity of methane produced during a run. As an example, Figure 70 shows the amount of methane produced during run 57.

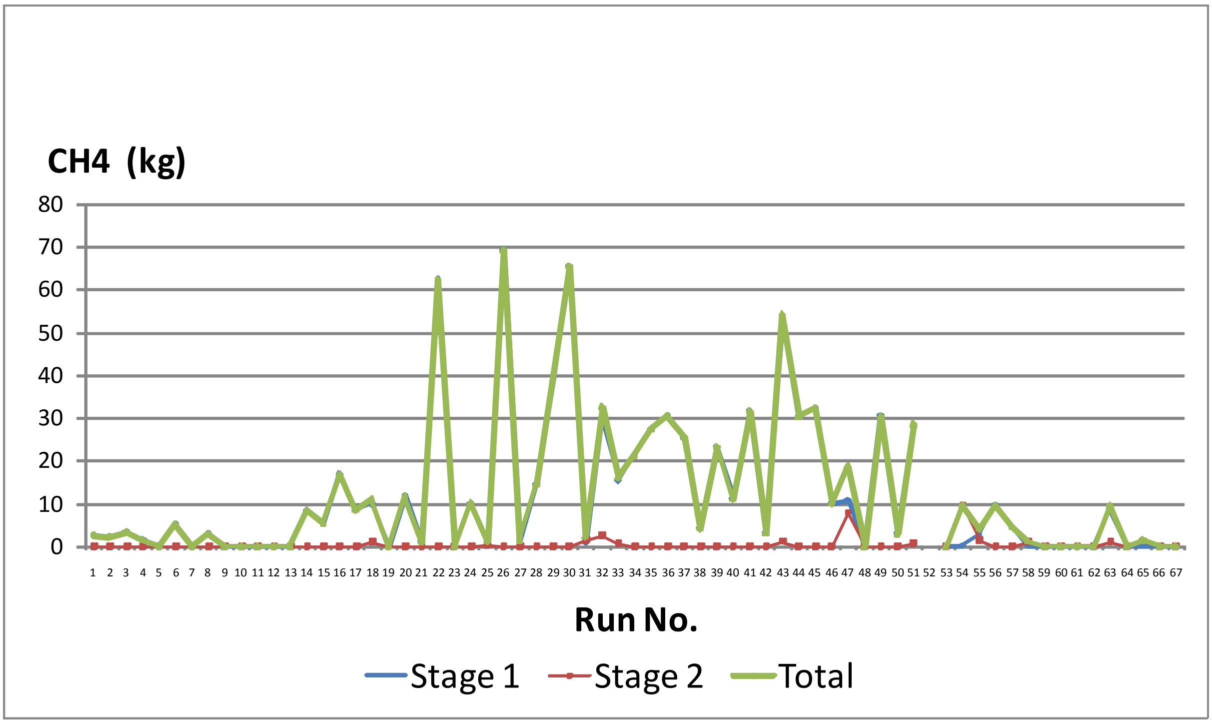
Figure 70: Methane detected during run 57



This Figure shows that during the first stage of run 57, 4.5 kilos of methane were detected.

Figure 71 shows the quantity of methane detected for runs 1 – 67.

Figure 71: Methane detected in runs 1 – 67

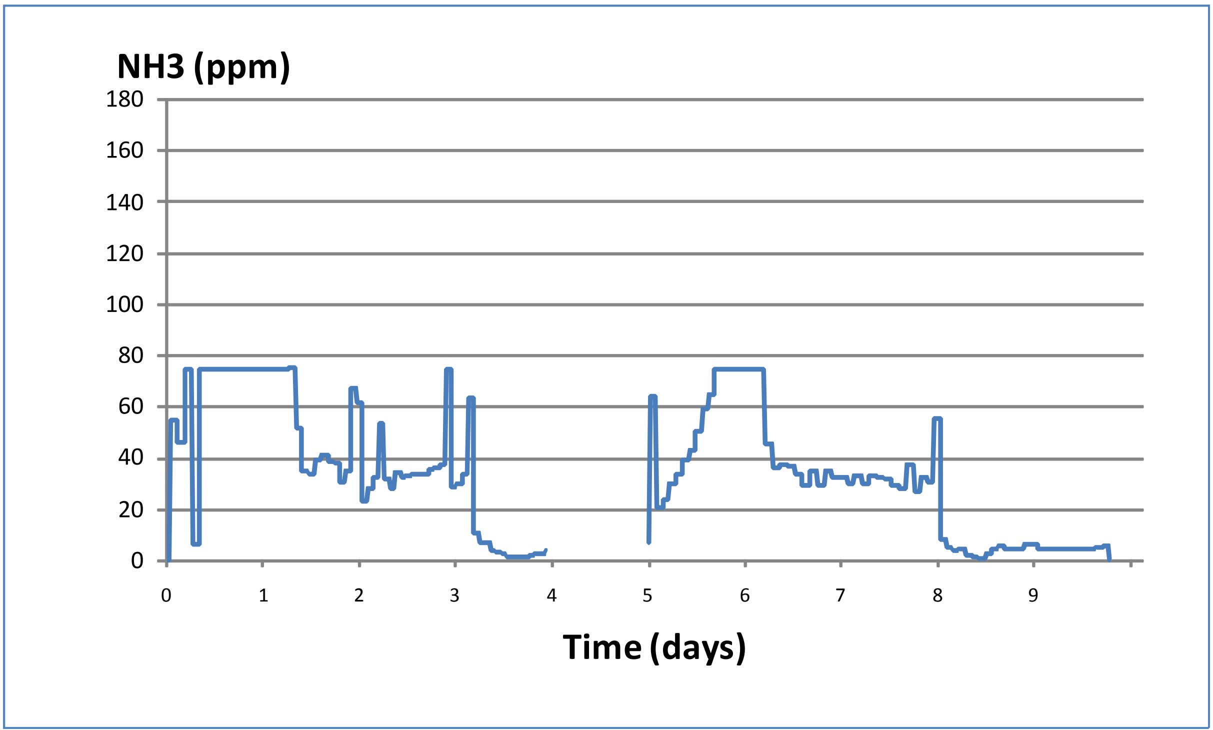


This Figure shows that the quantity of methane detected in the first stage varied from 0 (21 runs) to 69.3 kg. The quantity of methane detected in the second stage varied from 0 (51 runs) to 9.7 kg. Methane was mainly detected during the summer months, probably as a result of higher microbial activity in the feedstock during its collection and storage prior to delivery to the composting site.

11.13 Ammonia

For technical reasons, ammonia was only measured by the tunnel computer from run 53 onwards. Details of the procedure are given in SOP 4. As an example, the ammonia levels detected during run 57 are shown in Figure 72. The plateaus indicate the limit of sensitivities of the detection equipment.

Figure 72: Ammonia levels in run 57

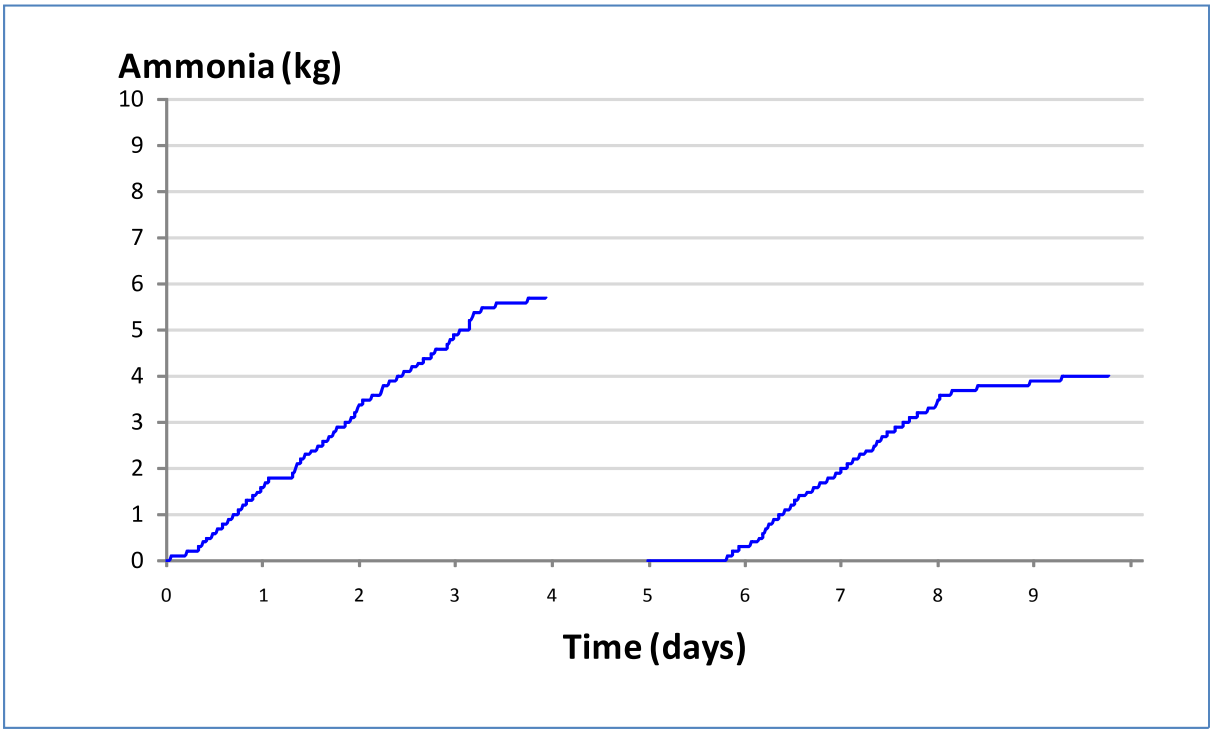


Ammonia was primarily produced during the warming up section of both stages. The chemistry of ammonia production from kitchen waste and green waste can be summarised in the following equation.

$C_{21.6}H_{125}O_{57.7}N + 23.25\ O_2 = 21.6\ CO_2 + 61\ H_2O + 1\ NH_3$

Figure 73 shows the amount of ammonia generated during run 57.

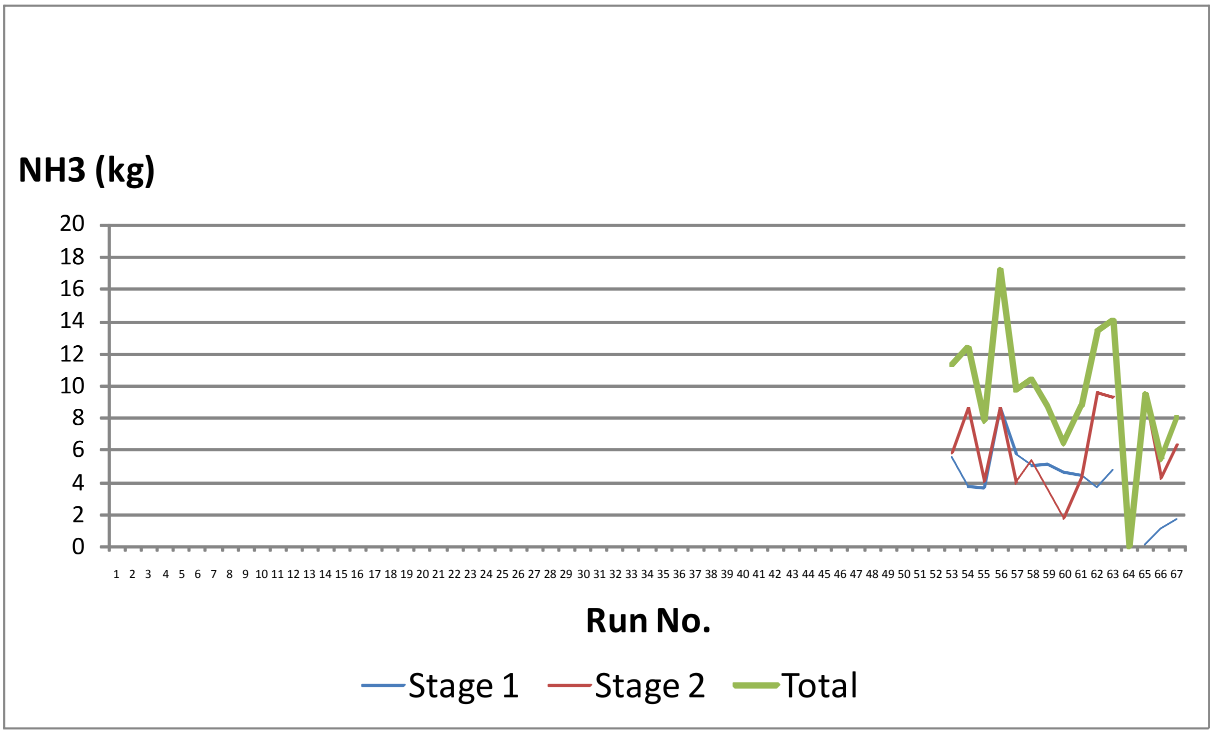
Figure 73: Ammonia produced during run 57



In run 57, 5.7 kilos of ammonia was produced during the first stage and 4.0 kilos in the second stage.

The tunnel computer also recorded the amount of ammonia produced during runs 52 – 67. The results are shown in Figure 74.

Figure 74: Ammonia produced runs 52-67



The amounts of ammonia produced during the first stage varied from 0.1 to 8.6 kg, and the amount produced during the second stage varied from 1.8 to 9.6 kg. The total amount of ammonia produced varied from 0 to 17.2 kg.

11.14 PAS 100 analysis

The compost from the six windrows produced during the intensive runs using this feedstock were analysed and compared with the PAS 100 standard.

Table 8: PAS 100 data for kitchen waste and green waste

		Run 2	Run 7	Run 15	Run 22	Run 31	Run 45	Run 52
Salmonella	**per 25g fresh mass**	Absent	Absent	Absent	Absent	Absent	Absent	Absent
E.coli	**CFU g^{-1} fresh mass**	3500	3067	327	2900	3853	3100	1633
Germination and Growth Test	**reduction as % of germinated plants in peat control**	95.53	98.83	96.67	101.13	104.73	105	101
Germination and Growth Test	**reduction of plant mass above surface as % of germinated plants in peat control**	112.67	142.83	119.70	88.23	69.83	106	153
Germination and growth test	**description of any abnormalities**	No abnormalities	No abnormalities	No abnormalities	No abnormalities	vigour@28 days for rep 3 of test mix	No abnormalities	No abnormalities
Germinating weed seeds or propagules	**mean per litre of compost**	0.00	0.67	1.00	0.00	0.33	0	0

Heavy Metal	Unit	Run 2	Run 7	Run 15	Run 22	Run 31	Run 45	Run 52
Cadmium	**mg kg^{-1} dry matter**	0.36	0.51	0.49	0.51	0.59	0.49	0.50
Chromium	**mg kg^{-1} dry matter**	15.07	18.43	16.43	17.27	16.47	20.97	17.70
Copper	**mg kg^{-1} dry matter**	53.60	67.17	55.60	41.87	60.73	50.50	57.50
Lead	**mg kg^{-1} dry matter**	42.70	98.50	91.57	72.07	83.40	94.27	70.97
Mercury	**mg kg^{-1} dry matter**	0.07	0.06	0.21	0.11	0.21	0.18	0.12
Nickel	**mg kg^{-1} dry matter**	8.88	13.07	55.73	11.53	11.87	12.27	10.53
Zinc	**mg kg^{-1} dry matter**	179.33	229.00	185.33	154.67	193.33	173.33	170.67

Physical Contaminants		Run 2	Run 7	Run 15	Run 22	Run 31	Run 45	Run 52
Total physical contaminants >2mm	**% mass/mass of air-dry sample**	0.09	0.24	0.23	2.29	2.62	2.40	0.18
Stones >4mm	**% mass/mass of air-dry sample**	2.68	6.98	5.31	6.19	1.88	1.22	2.17
Glass >2mm	**% mass/mass of air-dry sample**	0.06	0.00	0.23	0.02	0.02	0.01	0.04
Plastic >2mm	**% mass/mass of air-dry sample**	0.03	0.13	0.00	0.01	0.04	0.01	0.15
other > 2mm	**% mass/mass of air-dry sample**					2.57	0.41	0.00
Comments								

		Run 2	Run 7	Run 15	Run 22	Run 31	Run 45	Run 52
Stability	**mg/g OM/ d**	22.50	8.30	6.23	13.73	13.47	3.17	8.43
C:N		N/D	N/D	10.43	10.03	10.67	10.33	10.77

Table 9: PAS 100 data for MSW runs

		Run 1 MSW	Run 2 MSW
Salmonella	per 25g fresh mass	Absent	Absent
E.coli	CFU g^{-1} fresh mass	<10	<10
Germination and Growth Test	reduction as % of germinated plants in peat control	100	114
Germination and Growth Test	reduction of plant mass above surface as % of germinated plants in peat control	105	105
Germination and growth test	description of any abnormalities	Glass present	Glass present
Germinating weed seeds or propagules	mean per litre of compost	2	0

Heavy Metal	Unit	Run 1 MSW	Run 2 MSW
Cadmium	mg kg^{-1} dry matter	0.88	0.73
Chromium	mg kg^{-1} dry matter	21.23	23.97
Copper	mg kg^{-1} dry matter	239.03	109.33
Lead	mg kg^{-1} dry matter	383.33	397.33
Mercury	mg kg^{-1} dry matter	0.67	0.60
Nickel	mg kg^{-1} dry matter	23.27	30.17
Zinc	mg kg^{-1} dry matter	400.67	383.67

Physical Contaminants		Run 1 MSW	Run 2 MSW
Total physical contaminants >2mm	% mass/mass of air-dry sample	0.88	13.09
Stones >4mm	% mass/mass of air-dry sample	21.23	0.75
Glass >2mm	% mass/mass of air-dry sample	239.03	11.26
Plastic >2mm	% mass/mass of air-dry sample	383.33	0.21
other > 2mm	% mass/mass of air-dry sample	0.67	1.58
Comments			

		Run 1 MSW	Run 2 MSW
Stability	mg/g OM/ d	28.93	14.50
C:N		10.43	10.83

The kitchen waste/green waste samples complied with PAS 100 apart from some post-composting stage contamination with *E. coli* and weed seeds in some of the samples and one sample having a slightly too low stability figure. Procedures for sampling for microbial analysis are given in SOP 15.

The MSW samples, as expected with this type of feedstock, had too high levels of copper, lead and zinc. One sample had a small number of weed seeds present and the stability of one sample was too low.

These results make it clear that post-pasteurisation stage compost must be kept in a way to prevent contamination by bird droppings and wind-blown seeds.

11.15 Biodegradation

Samples of compost were taken from windrows produced during intensive runs to determine the degree of biodegradation. Details of the methodology are given in SOPs 9, 11 and 12. The following figures show the results.

Figure 75: Run 2 – windrow samples

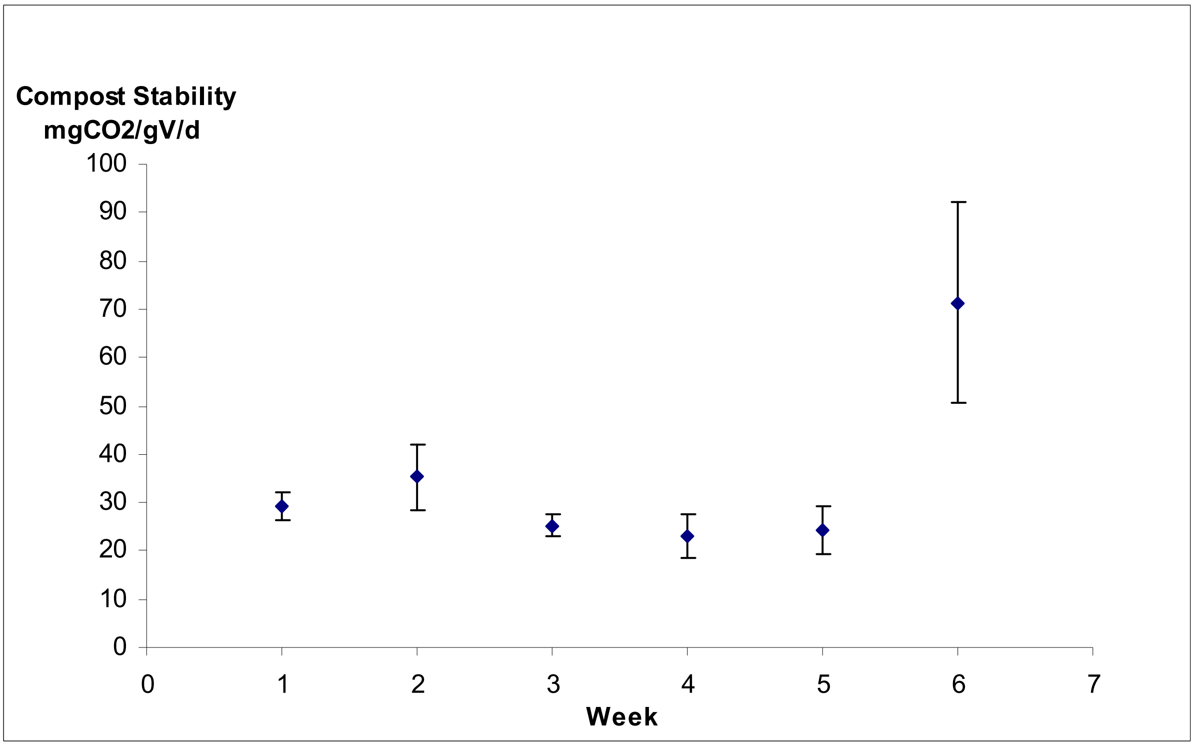


Figure 76: Run 7 – windrow samples

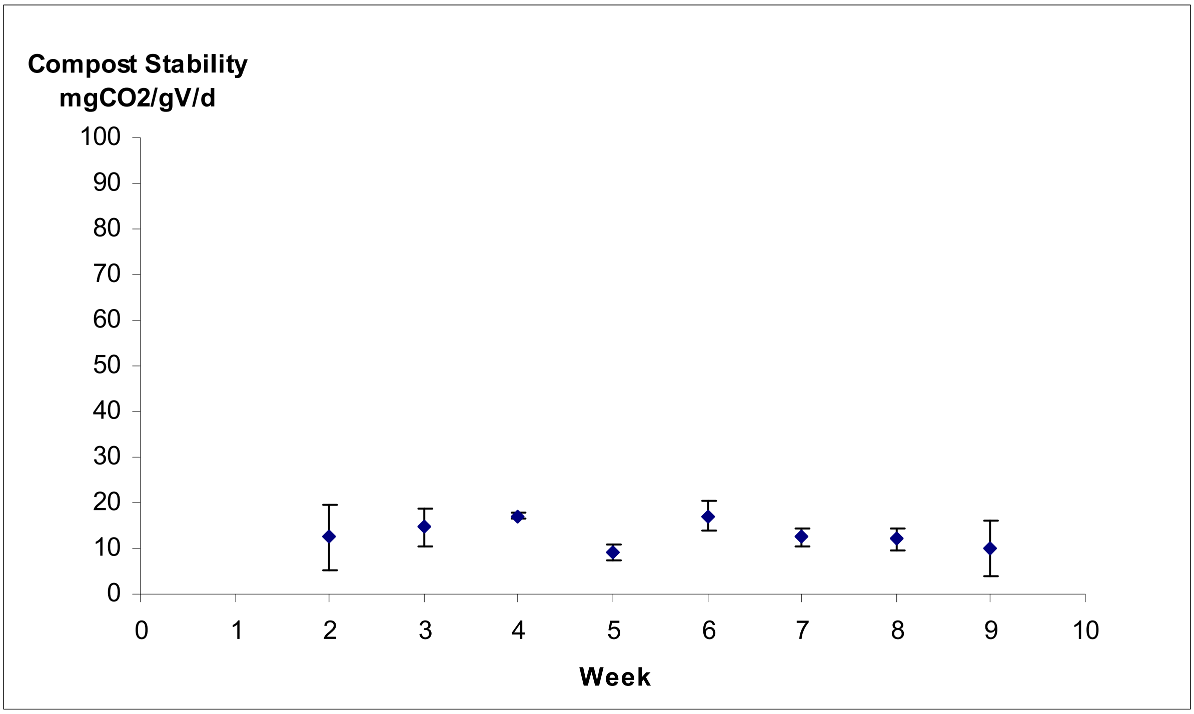


Figure 77: Run 15 – windrow samples

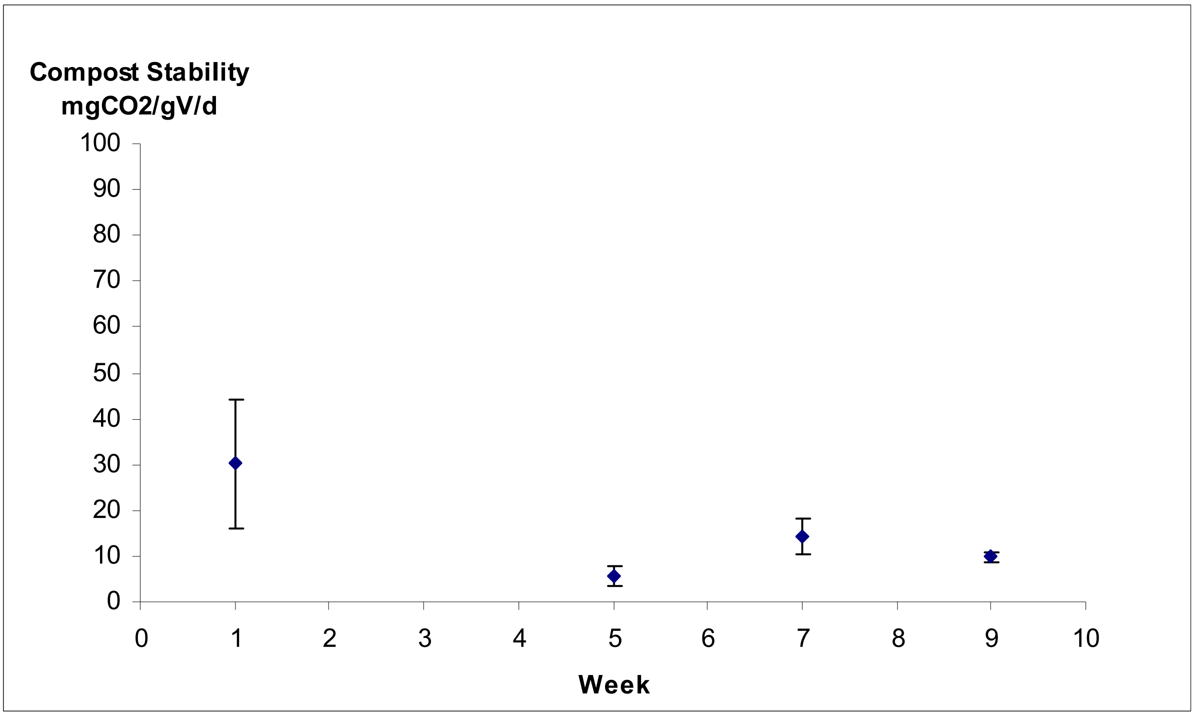


Figure 78: Run 22 windrow samples

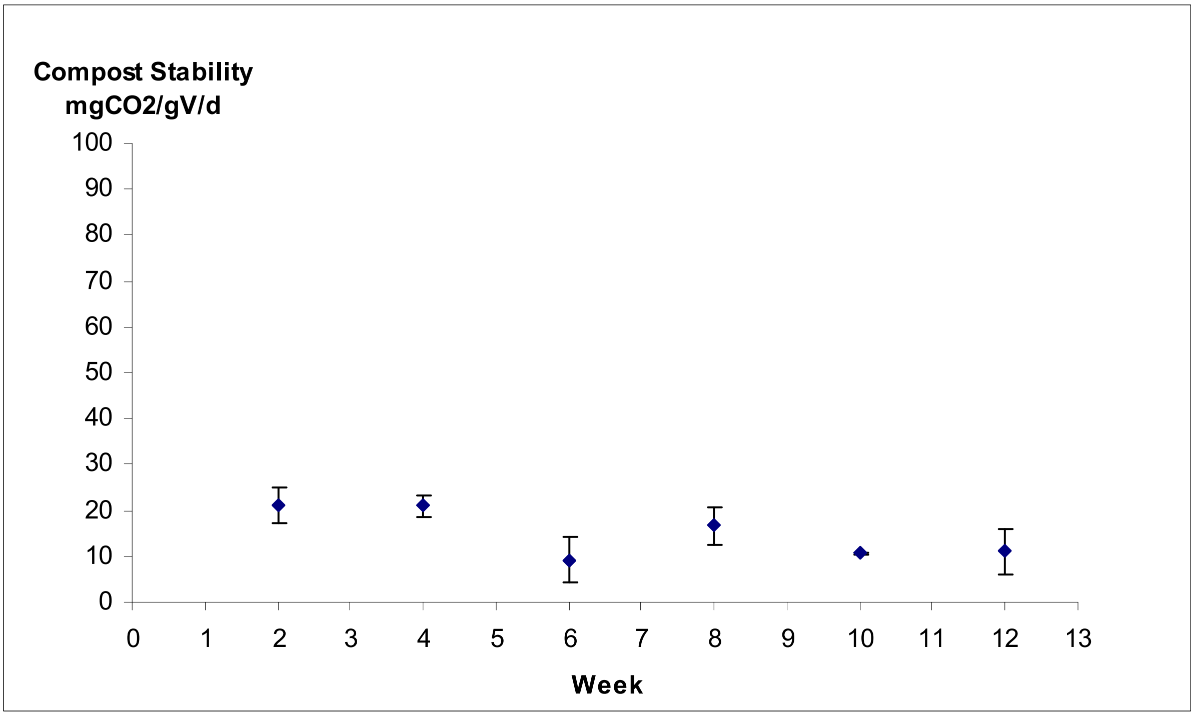
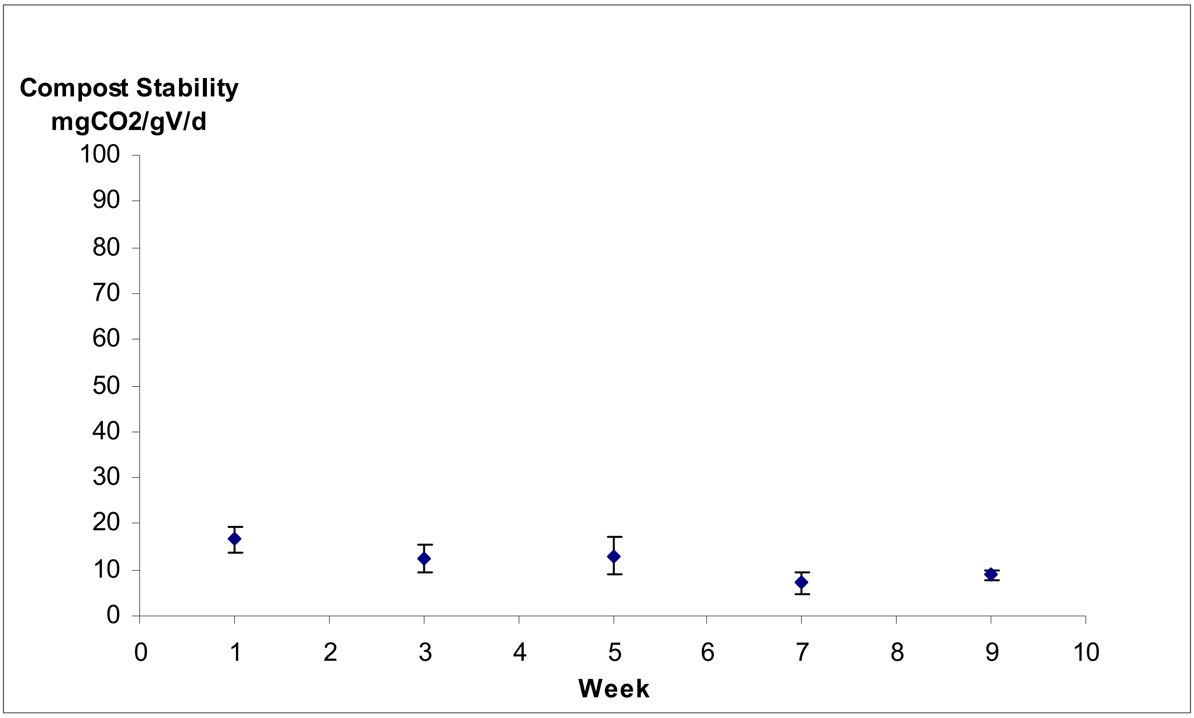


Figure 79: Run 31 windrow samples

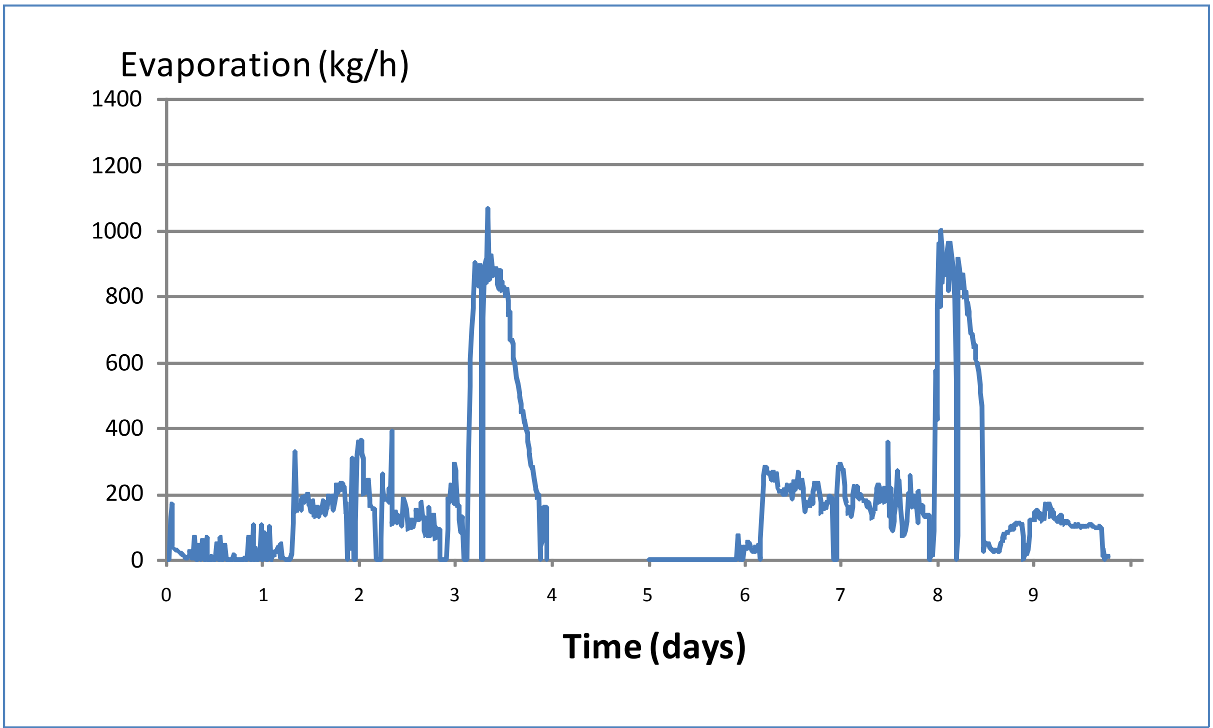


With the exception of one sample from a windrow associated with Run 2 the windrow samples showed levels of mgCO_2/gV/d of <12 after 6 to 12 weeks composting.

11.16 Water Evaporation and spraying

Because of the high temperatures maintained during the composting process, and because of the high volume of air passing through the composting material, a considerable amount of water is lost during the composting process. As an example, Figure 80 shows the rate of water evaporated during both stages of run 57.

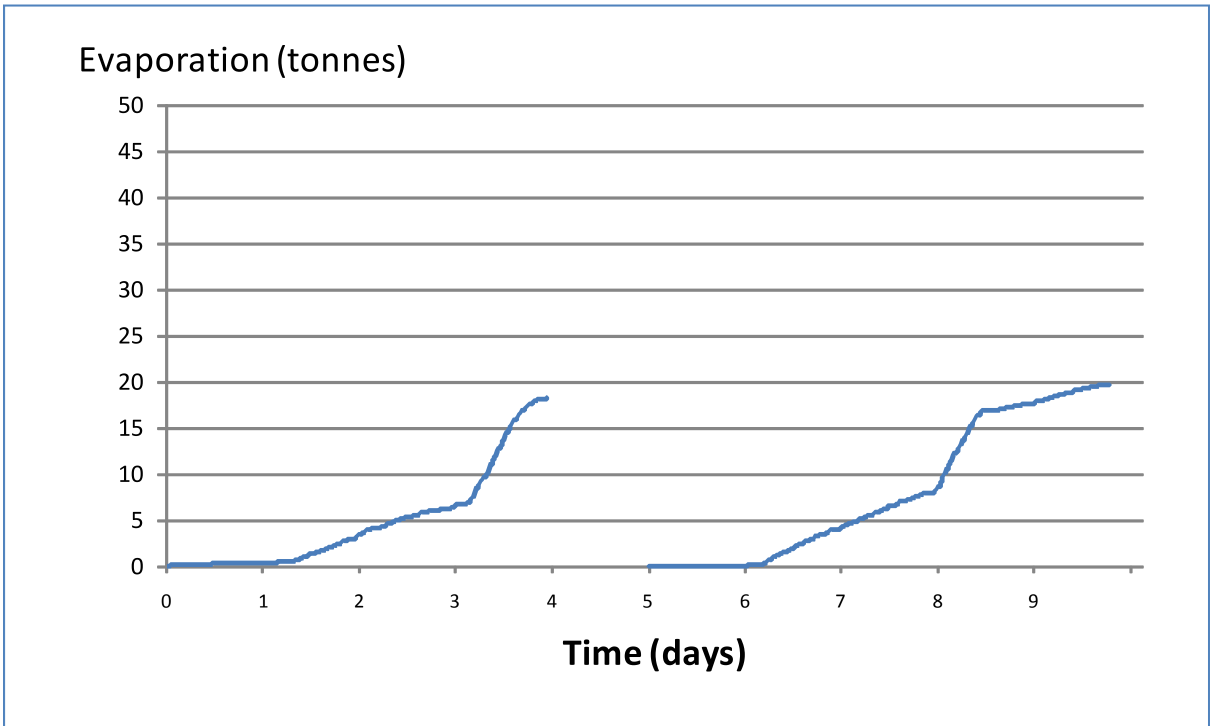
Figure 80: Rate of evaporation during run 57



This Figure shows that the maximum rate of water evaporation for both stages occurs when the volume of fresh air being delivered to the tunnels is greatest during the cool down section.

The quantity of water evaporated is also calculated. The result for run 57 is shown in Figure 81.

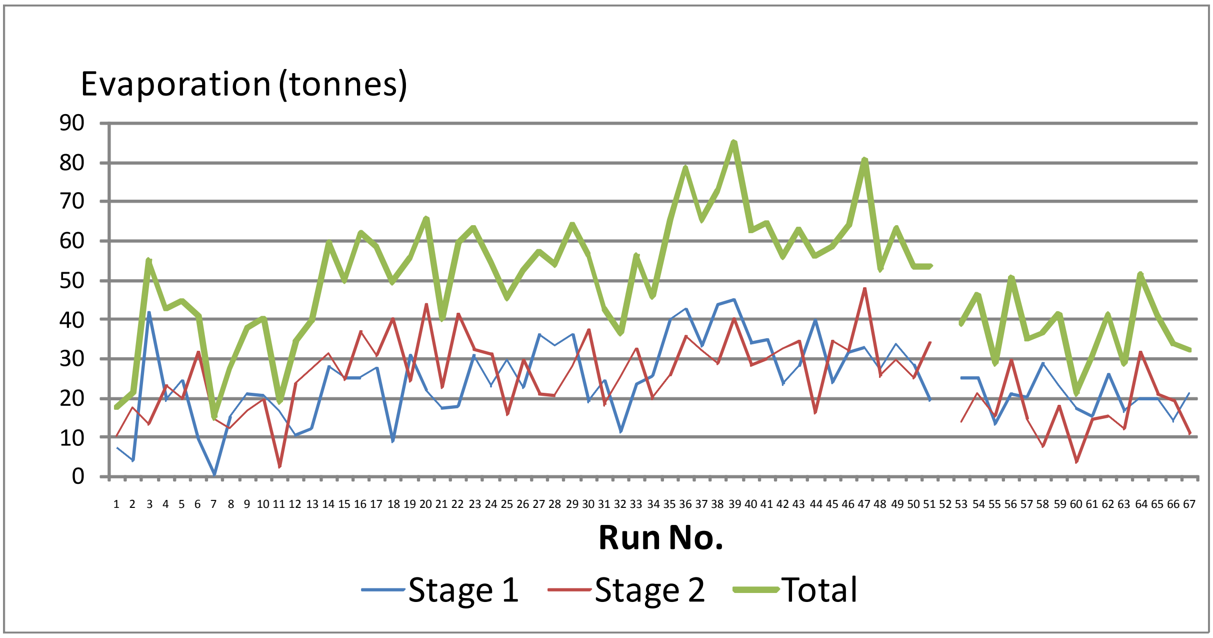
Figure 81: Water evaporated during run 57



This Figure shows that during the first stage of run 57, 18.3 tonnes of water were evaporated, while during the second stage 19.7 tonnes were evaporated.

The tunnel computer also recorded the loss of water by evaporation during runs 1 – 67. The results are shown in Figure 82.

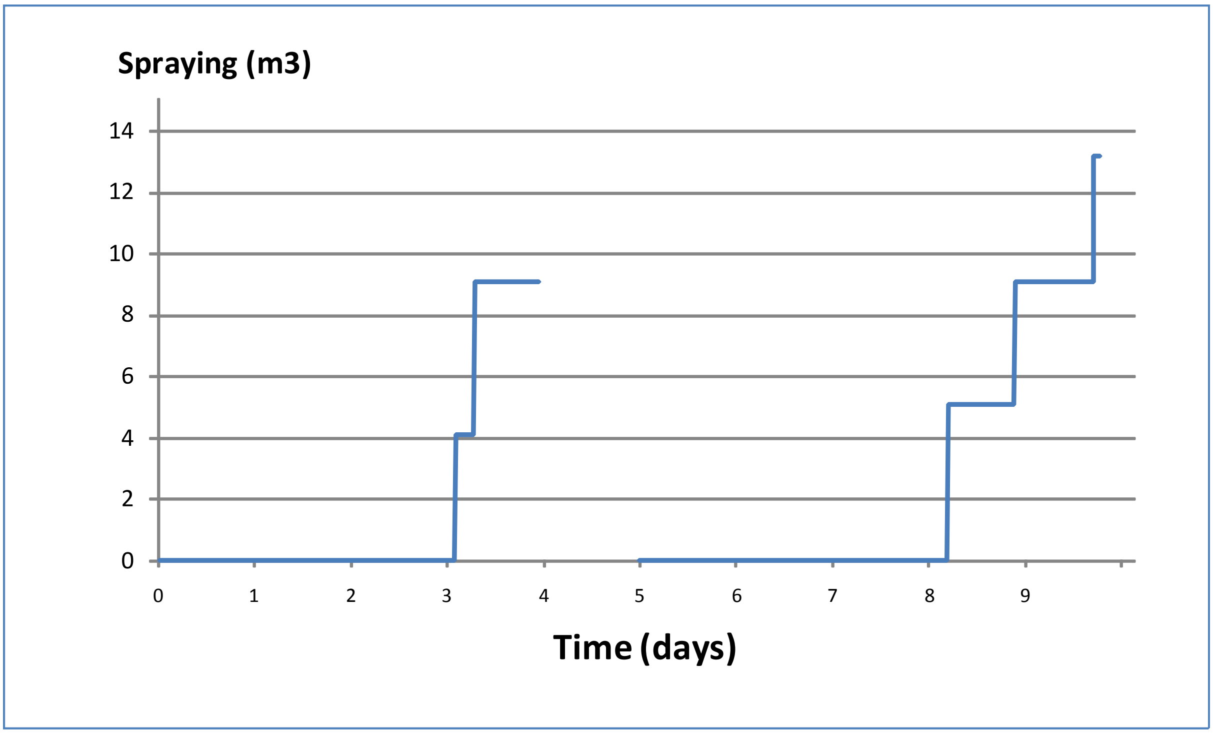
Figure 82: Water loss by evaporation during runs 1 – 67



The amount of water lost by evaporation during first stages of the runs varied from 0.4 to 45 tonnes, while during the second stage the amount lost varied from 2.5 to 47.9 tonnes. The total amount of water lost for the entire run varied from 15.0 to 85.1 tonnes. Most water loss by evaporation took place during the summer months.

In order to compensate for the water losses described above, water was sometimes sprayed on to the composting material through spray bars located on the tunnel roof. For example, the volume of water sprayed during run 57 is shown in Figure 83. The addition of water at this stage is a management decision based on the estimated moisture levels of the feedstock filled into the tunnels.

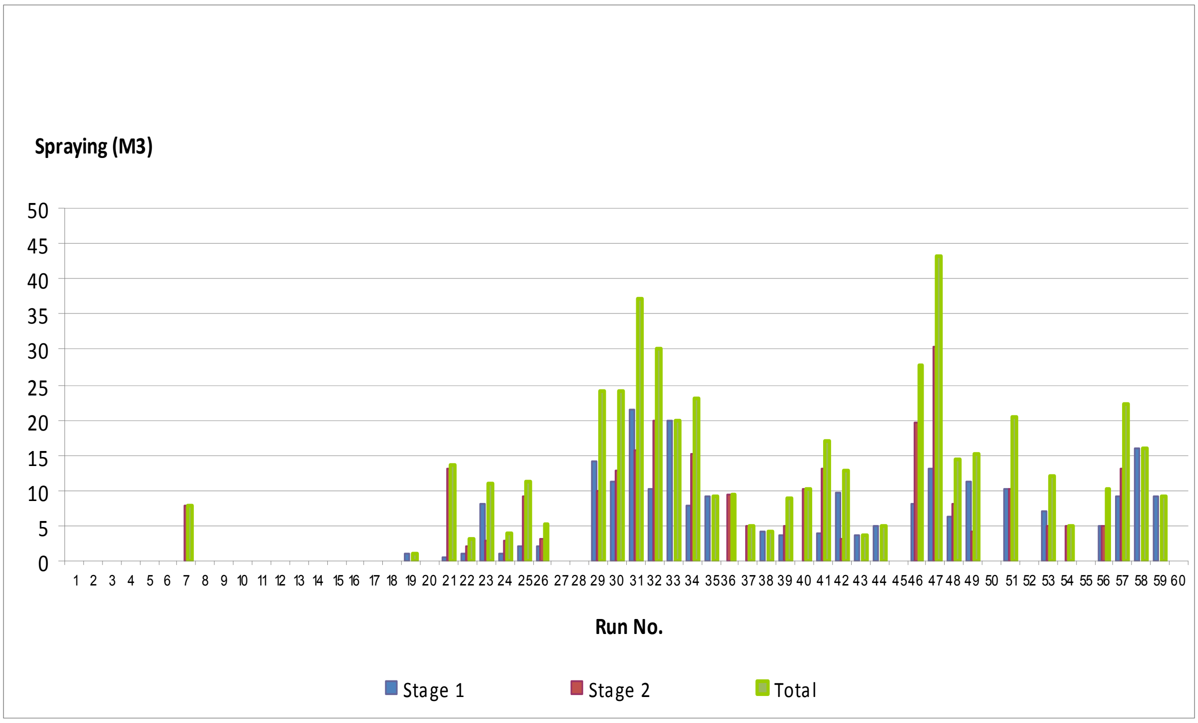
Figure 83: Water added by spraying during run 57



This Figure shows that during the first stage of run 57, 9.1 tonnes of water were added, while during the second stage 13.2 tonnes were added.

The tunnel computer also recorded the amount of water added by spraying for runs 1 -67, as shown in Figure 84.

Figure 84: Water added by spraying during runs 1-67

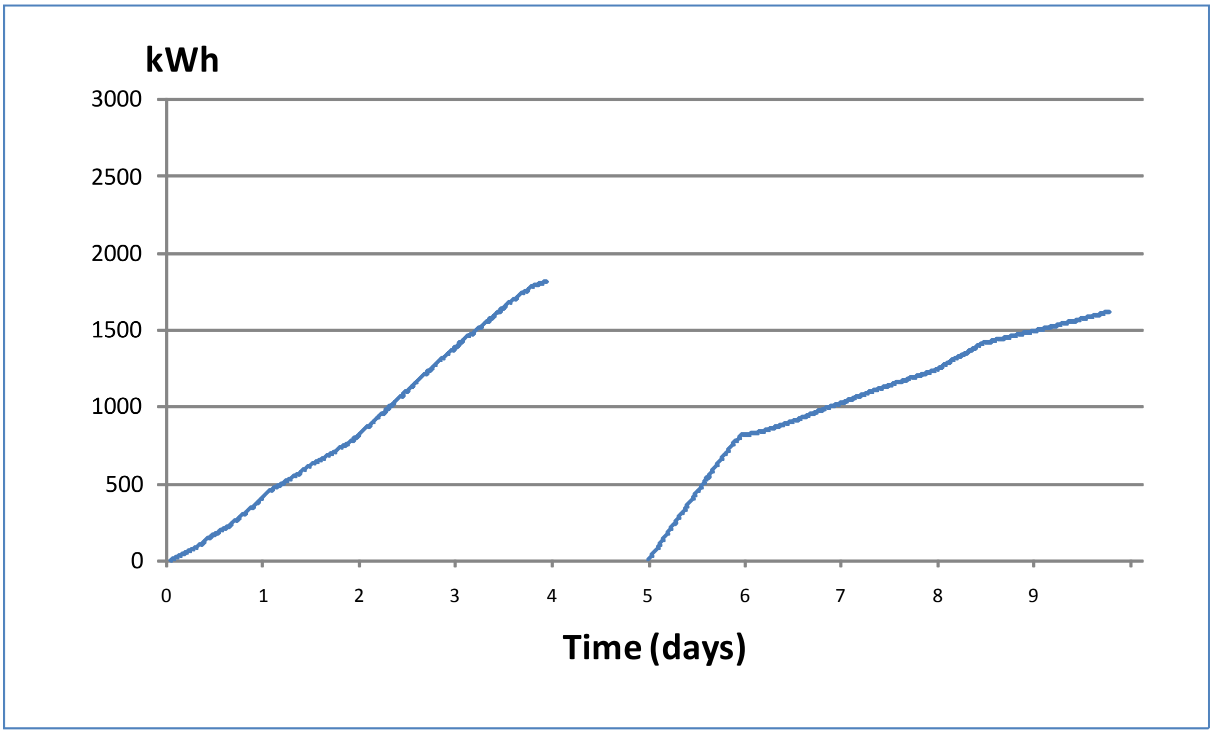


This Figure shows that the amount of water added by spraying during the first stage varied from 0 (32 runs) to 21.4 tonnes. The amount of water added by spraying during the second stage varied from 0 (36 runs) to 30.3 tonnes. The total amount of water added by spraying for the entire run varied from 0 (26 runs) to 43.3 tonnes. The addition of water by spraying was needed primarily during the summer months. Water was not added during most of the early runs as the moisture levels of the feedstock was determined to be such that the addition of further water was not necessary.

11.17 Electricity utilisation

Most of the electricity used to operate the tunnel system is employed in running the large tunnel fans. The tunnel computer measured the usage of electricity by the fans throughout the composting process. As an example, the electricity usage during run 57 is shown in Figure 85

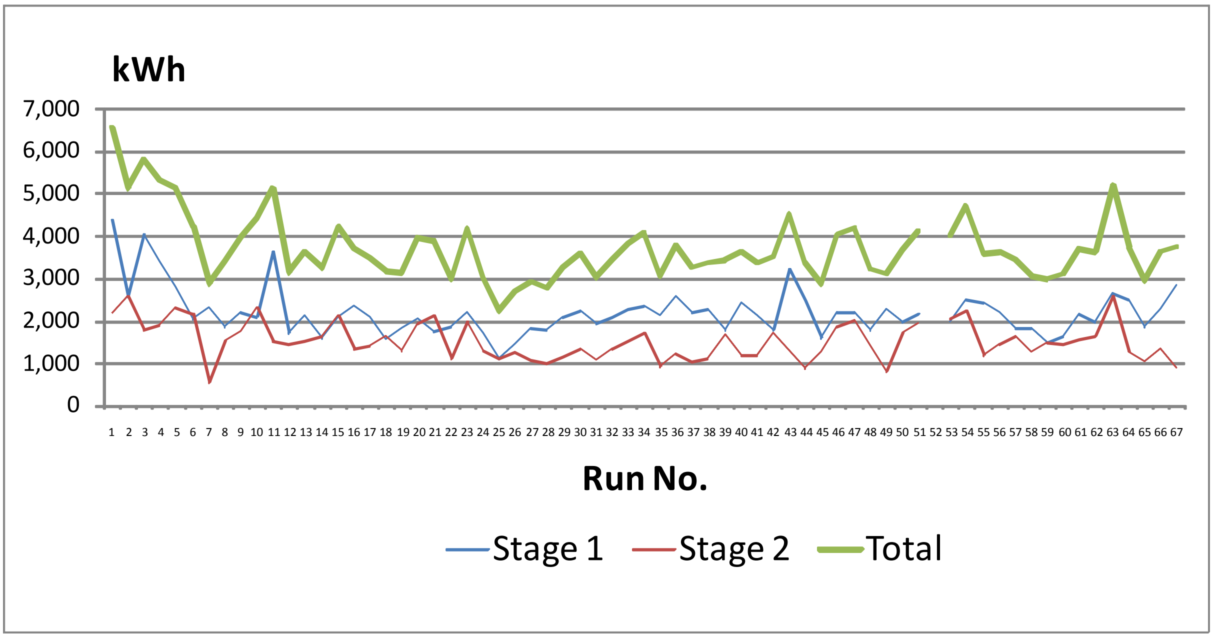
Figure 85: Electricity consumption during run 57



This Figure shows that 1,815 kWh were used in the first stage and 1,620 kWh were used in the second stage.

The tunnel computer also measured electricity consumption for all of the 67 runs, as shown in Figure 86.

Figure 86: Electricity consumption during Run 1-67



This Figure shows that the electricity consumption by the first stage varied from 1,118 kWh to 4,381 kWh. Consumption during the second stage varied from 562 kWh to 2,552 kWh. The total electricity consumption for each run varied from 2,247 kW h to 6,533 kWh. Electricity consumption was highest during the winter months.

11.18 Gas usage for heated walls and floors

The usage of propane gas for the boiler that generates the hot water for the heated walls and floors has been calculated for the length of the project. In total, 3,909.16 cubic metres of gas was utilised, equating to 43,235.33 kWh of energy. This gas was used to heat the walls and floors for the processing of 5,441.49 tonnes of feedstock. This equates to 0.72 m^3 of gas per tonne of feedstock or 7.95 kWh per tonne of feedstock.

11.19 Mass Balance of the tunnel Composting process

In order to calculate the mass balance of the tunnel composting process, the following data was determined:

- The weights of feedstock loaded into the tunnels at each stage during the composting runs were recorded by weigh cells on the front loaders.
- The weights of material transferred from stage 1 to stage 2 of the tunnel composting process were recorded by weigh cells on the front loaders. Details of the calibration of the weigh cells are given in SOP 2.
- The weights of compost removed from the stage 2 tunnels and formed into windrows were recorded by weigh cells on the front loaders.
- The amounts of water sprayed onto the compost in each tunnel stage were recorded by the Gicom tunnel computer.

Table 10 and Table 11 show these weights for runs 1-60 for the composting of combinations of kitchen waste and green waste. This quantitation was carried out at this stage of the project as sufficient data had been collected to allow a meaningful analysis to be undertaken.

Table 10: Weights of feedstock, sprayed water and product in stage 1 for Runs 1 – 60

Run no	Feedstock Tonne	Spray Tonne	End of stage 1 Tonne
1	-	-	-
2	213.62	0.00	163.41
3	215.48	0.00	191.04
4	226.58	0.00	182.62
5	223.95	0.00	172.64
6	245.91	0.00	177.87
7	205.85	0.00	130.30
8	183.96	0.00	163.26
9	219.69	0.00	169.63
10	215.07	0.00	173.69
11	223.70	0.00	135.65
12	186.81	0.00	168.65
13	224.02	0.00	168.70
14	210.14	0.00	187.12
15	225.16	0.00	182.70
16	241.57	0.00	196.40
17	223.92	0.00	191.61
18	245.11	0.00	209.17
19	198.19	1.00	162.22
20	215.95	0.00	180.62
21	192.64	0.60	157.60
22	204.47	1.10	176.26
23	237.11	8.10	169.68
24	214.87	1.00	168.85
25	210.54	2.10	138.08
26	201.31	2.10	171.37
27	223.47	0.00	157.29
28	211.01	0.00	166.79
29	208.88	14.10	174.80
30	233.79	11.30	196.86
31	215.69	21.40	156.59
32	173.81	10.10	143.07
33	202.32	19.90	185.33
34	190.90	7.90	161.00
35	189.16	9.20	152.13
36	200.42	0.00	146.66
37	208.33	0.00	166.58
38	234.50	4.10	191.15
39	232.44	3.70	167.14
40	215.87	0.00	163.46
41	191.01	4.00	164.72
42	209.97	9.70	191.59
43	225.43	3.60	177.51
44	209.74	5.10	162.32
45	225.21	0.00	178.70
46	222.96	8.10	181.36
47	205.52	13.00	182.70
48	222.86	6.20	167.30
49	181.34	11.20	156.64
50	206.17	0.00	171.05
51	225.90	10.10	191.13
52	Repeated run		
53	219.55	7.00	181.78
54	223.50	0.00	175.78
55	195.22	0.00	167.65
56	229.54	5.10	198.09
57	203.60	9.10	179.60
58	211.14	15.90	182.24
59	202.41	9.20	173.69
60	191.14	0.00	154.22

Summary:

Average weight of feedstock into stage 1:	212.9 tonnes
Average weight of water sprayed during stage 1:	4.1 tonnes
Average weight of material out of stage 1:	171.7 tonnes

Table 11: Mass of material moved from stage 1, water sprayed, and compost from stage 2 (Runs 1–60)

Run no	Transfer from stage 1 Tonne	Spray Tonne	Product from stage 2 Tonne	Run no	Transfer from stage 1 Tonne	Spray Tonne	Product from stage 2 Tonne
1	-	-	-	31	156.59	15.80	135.45
2	163.41	0.00	121.34	32	143.07	19.90	125.08
3	191.04	0.00	119.19	33	185.33	0.00	131.55
4	182.62	0.00	140.50	34	161.00	15.20	128.28
5	172.64	0.00	128.79	35	152.13	0.00	107.41
6	177.87	0.00	138.15	36	146.66	9.40	111.76
7	130.30	7.80	110.69	37	166.58	5.10	117.90
8	163.26	0.00	151.26	38	191.15	0.00	144.34
9	169.63	0.00	136.54	39	167.14	5.10	135.49
10	173.69	0.00	137.89	40	163.46	10.20	133.50
11	135.65	0.00	131.24	41	164.72	13.10	130.26
12	168.65	0.00	143.41	42	191.59	3.10	130.32
13	168.70	0.00	135.17	43	177.51	0.00	144.12
14	187.12	0.00	142.75	44	162.32	0.00	114.37
15	182.70	0.00	138.96	45	178.70	0.00	142.99
16	196.40	0.00	159.24	46	181.36	19.60	143.98
17	191.61	0.00	147.59	47	182.70	30.30	150.90
18	209.17	0.00	154.50	48	167.30	8.20	130.95
19	162.22	0.00	126.15	49	156.64	4.10	118.75
20	180.62	0.00	130.04	50	171.05	0.00	128.20
21	157.60	13.10	117.76	51	191.13	10.20	160.27
22	176.26	2.10	143.89	52			
23	169.68	3.00	127.40	53	181.78	5.10	143.86
24	168.85	3.00	122.86	54	175.78	5.10	131.48
25	138.08	9.10	111.28	55	167.65	0.00	124.12
26	171.37	3.10	133.10	56	198.09	5.10	144.56
27	157.29	0.00	126.14	57	179.60	13.20	132.12
28	166.79	0.00	130.04	58	182.24	0.00	143.61
29	174.80	10.00	143.66	59	173.69	0.00	118.76
30	196.86	12.70	161.27	60	154.22	0.00	114.46

Summary:

Average weight of material transferred to stage 2:	171.7 tonnes
Average weight of water sprayed during stage 2:	4.5 tonnes
Average weight of product out of stage 2:	133.3 tonnes

It can be seen that, on average, 212.9 tonnes of feedstock were reduced to 171.7 tonnes after the first stage and were further reduced to 133.3 tonnes after the second stage.

Run 45 will be used as a random example of the calculation of the mass balance that is representative of the composting of kitchen waste and green waste. Run 45 was processed with the heated walls and floors turned off and was an intensive run. The feedstock mixture contained 10% kitchen waste and 178.70 tonnes of feedstock was filled into the tunnel. The calculations were based on the mass balance model of Haug (1993)[20] and on a composting scenario where:

- The inlet and feed temperatures are 20°C.
- The air is at 75% relative humidity.
- There is an estimated degradability of 10% in the first stage and 15% in the second stage.
- The composting process operates at 60°C.
- The process gases are exhausted at 60°C.
- The % total solids at 60°C was assumed to be 40% in stage 1 and 50% in stage 2.
- An estimated 10 tonnes of leachate was collected at each stage of composting.

Feedstock

The feedstock weight is the amount of material that was loaded into the tunnel at the beginning of each stage. The figures for the percentage volatile solids and percentage total solids of the feedstock were obtained from analysis of samples sent to the laboratory.

Biodegradable volatile solids

One hundred percent degradability implies that all the volatile solids present in the feedstock are decomposed within the composting system. However, during the composting process not all the volatile solids in the feedstock are degraded. The fraction that is degraded is referred to as the 'Biodegradable Volatile Solids'. This was determined taking into account the estimated percentage of degradability in each stage, and is calculated by the following equation:

Biodegradable Volatile Solids = Mass of feedstock x % degradability x % volatile solids x % total solids

[20] Haug, R. T. (1993). *The practical handbook of compost engineering: Second ed*. Florida: Lewis Publishers, CRC Press

…Equation 1

For example if,

Mass of feedstock = 100 t

% degradability =30%

% volatile solids = 30%

% total solids = 70%

Then, Biodegradable Volatile Solids = 100 x 0.3 x 0.3 x 0.7 = 6.3 t

Non-biodegradable volatile solids

The amount of non-biodegradable volatile solids refers to the fraction of volatile solids (degradable solids) that is not degraded during the composting process. This is calculated, taking into account the estimated percentage of degradability at each stage, by the following equation:

Non-biodegradable Volatile Solids = Mass of feedstock x (100%- % degradability) x % volatile solids x % total solids

…Equation 2

Ash content

The ash content is the non-volatile inorganic matter in the feedstock. This is calculated by the following equation:

Ash content = (100% - %Volatile Solid) x %Total solid x Mass of feedstock

…Equation 3

For example if

Mass if feedstock = 100 t

% volatile solid =30%

% total solid = 40%

Then, Ash content = (100% -30%) x 40% x 100

= 70% x 40% x100

= 28 t

Water

The moisture content of the feedstock was obtained from the laboratory analysis of samples. The amount of water associated with the feedstock is calculated by the following equation:

Water in feedstock = (100% - %Total solid) x Mass of feedstock

…Equation 4

For example if,

Mass of feedstock = 100 t

% Total Solid = 30%

Then, Water in feedstock = (100% - 30%) x 100

= 70% x 100

= 0.7 x 100

= 70 t

Product

The product refers to the material that was removed from the tunnel after each stage. The product consists of all the solid material that had not been degraded during the composting process, and water that had not been evaporated or removed as leachate.

Non-biodegradable volatile solids

The non-biodegradable volatile solid content in the product is equal to the non-biodegradable volatile solid that was in the feedstock. This involves all the volatile solids that were not degraded during the composting period.

Ash content

Similarly, the ash content in the product is equal to the ash content of the feedstock.

Dry product

The total dry material in the product stream is the sum of the non-biodegradable volatile solid in the product and the ash fraction of product.

Water

The amount of water in the product removed from the composting process was based on the assumed percentage total solids of the product. The amount of water in the product was calculated by the following equation:

$$\text{Water in product} = \frac{\text{Total dry product}}{100\% - \%\text{Total solid}} - \text{Total dry product}$$

…Equation 5

For Example if

Total dry product = 100t

% Total solid = 30%

Then,

Water in product = [100/(100%-30%)] – 100

= [100/70%] – 100

= [100/0.7] – 100

= 42.8 t

Total product out

The total product out is the sum of the dry material out and the water in the product

$$\text{Total product} = \text{Total dry product} + \text{water in product}$$

…Equation 6

Water

Water produced during the composting process

The calculation of the amount of water produced during the composting process was based on the following equation (adapted from Murphy and Power, 2006)

$C_{21.6}H_{125}O_{57.7}N + 23.25O_2 \rightarrow 21.6\ CO_2 + 61H_2O + 1NH_3$

$1322.5 + 23.25(32) \rightarrow 21.6(44) + 61(18) + 17$

…Equation 7

It follows that,

$$\text{Water in the product} = \text{Biodegradable Volatile Solids x } \left[\frac{61 \times 18}{1322.5}\right]$$

…Equation 8

Water vapour

The amount of water evaporated during the composting process is the difference between the amount of water vapour out and amount of water vapour in the system (W.V out – W.V in).

$$\text{Water Vapour Out - Water Vapour In} =$$

$$\text{Water in feedstock} + \text{Water sprayed} + \text{Water produced - Water in Product - Leachate collected}$$

…Equation 9

The relative humidity of the air going in and out of the tunnel was measured by the tunnel computer. For the purpose of this calculation, standard data giving the absolute humidity of air going in was taken as 0.0108g/g of dry air and the absolute humidity of air going out of the tunnel was taken as 0.1187g/g of dry air. This data can also be used to calculate the amount of water evaporated. Therefore,

$$\text{Water Vapour Out - Water Vapour In} = \text{Mass of dry air out (0.1187) - Mass of dry air in (0.0108)}$$

…Equation 10

Air

Air in and out of the process

Dry Gases

The dry gases produced during composting are the difference between the amount of the dry air going out and the dry air going into the system. The stoichiometric amount of dry gases produced during the composting process was calculated using the degradation equation shown in Equation 7. Therefore,

Dry air in – Dry air out = Biodegradable Volatile Solids x

$$\left[\frac{23.25\,(32)}{1322.5} + \frac{21.6\;44)}{1322.5} + \frac{117)}{1322.5}\right]$$

…Equation 11

The mass of dry air in, dry air out, water vapour in and water vapour out of the system can be calculated by solving equations 9, 10 and 11. The mass balance of stage 1 and stage 2 for run 45 are summarised in Diagram 1 a and Diagram 2 a respectively

Diagram 1 a & b) and Diagram 2 a & b), below, show the detailed mass balance of run 45 for stage 1 and stage 2 respectively.

Diagram 1 a: Mass Balance Model of Run 45 Stage 1

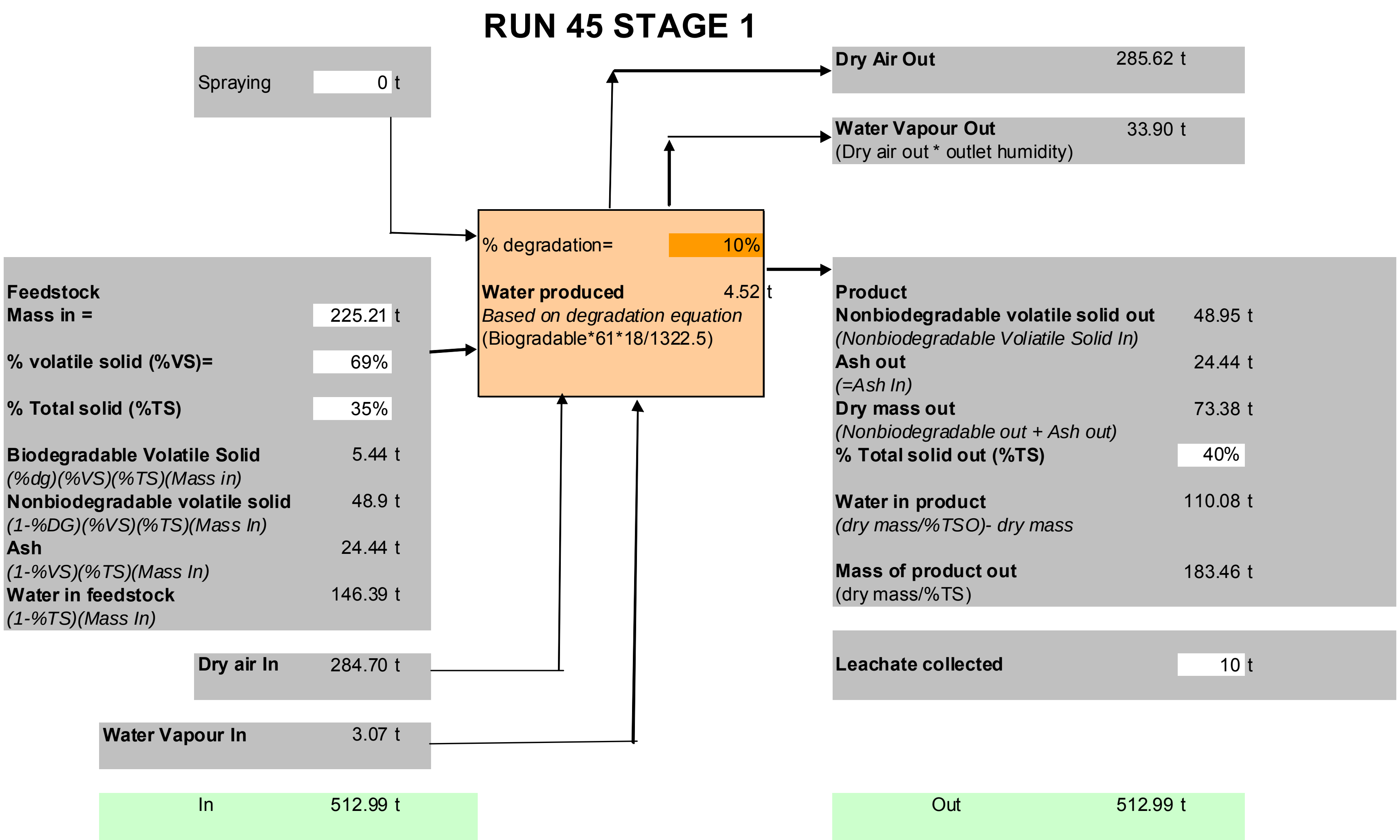


Diagram 1 b: Mass Balance Model of Run 45 Stage 1

Kitchen waste composting

Degradation Equation

$$C_{21.6}H_{125}O_{57.7}N + 23.25O_2 \rightarrow 21.6\ CO_2 + 61H_2O + 1NH_3$$

$$1322.5 \quad + \quad 23.25(32) \quad \rightarrow 21.6(44) + \ 61(18) + 17$$

Assuming constant air flow rate

Water Vapour and Air		
Water Vapour out - Water Vapour In (evaporation)	30.83	t
Water in feedstock+water produced+spray-water in pdt-leachate		
Air Inlet humidity	0.0108	g/g of dry air
(assumption)		
Air outlet humidity	0.1187	g/g of dry air
(assumption)		
D.Air out (0.1147)-D.Air Inl(0.0113)=W.V Out-W.V In		Equation 1
Dry air In-dry air out	-0.92	Equation 2
Based on degradation equation		
Dry air In	284.7	t
{[(W.Vout-W.Vin)+(hum out)(D.A in-D.A out)]/(hum ou-hum in)}		
Dry Air Out	285.62	t
Substitute in equation 2		
Water Vapour In	3.07	t
(Dry air in * inlet humidity)		
Water Vapour Out	33.90	t
(Dry air out * outlet humidity)		

C=	12.0107
H=	1.00794
O=	15.9994
N=	14.0067
C21.6=	259.43112
H125=	125.9925
O57.7=	923.16538
N=	14.0067
Total =	**1322.5957**
23.25O2=	743.9721
21.6CO2=	950.6052
61H2O=	1098.93208
1NH3=	17.03052
H2O=	18.01528

Diagram 2 a: Mass Balance model of Run 45 Stage 2

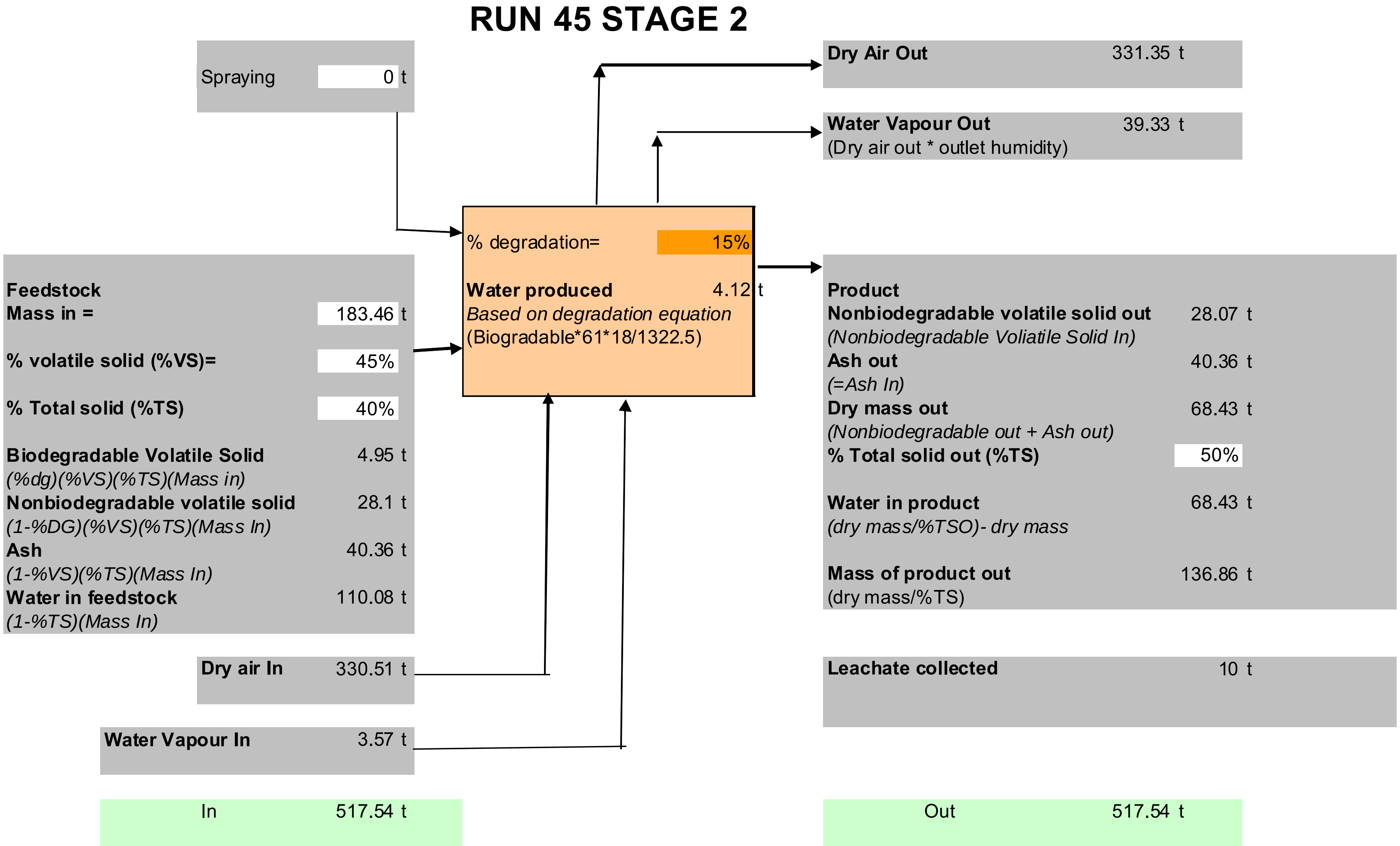


Diagram 2 b: Mass Balance model of Run 45 Stage 2

Kitchen waste composting

Degradation Equation

$$C_{21.6}H_{125}O_{57.7}N + 23.25O_2 \rightarrow 21.6\ CO_2 + 61H_2O + 1NH_3$$

$$1322.5 \quad + \quad 23.25(32) \quad \rightarrow 21.6(44) + \ 61(18) + 17$$

Assuming constant air flow rate

Water Vapour and Air		
Water Vapour out - Water Vapour In (evaporation)	35.76	t
Water in feedstock+water produced+spray-water in pdt-leachate		
Air Inlet humidity	0.0108	g/g of dry air
(assumption)		
Air outlet humidity	0.1187	g/g of dry air
(assumption)		
D.Air out (0.1147)-D.Air Inl(0.0113)=W.V Out-W.V In		Equation 1
Dry air In-dry air out	-0.84	Equation 2
Based on degradation equation		
Dry air In	330.5	t
{[(W.Vout-W.Vin)+(hum out)(D.A in-D.A out)]/(hum ou-hum in)}		
Dry Air Out	331.35	t
Substitute in equation 2		
Water Vapour In	3.57	t
(Dry air in * inlet humidity)		
Water Vapour Out	39.33	t
(Dry air out * outlet humidity)		

C=	12.0107
H=	1.00794
O=	15.9994
N=	14.0067
C21.6=	259.43112
H125=	125.9925
O57.7=	923.16538
N=	14.0067
Total =	**1322.5957**
23.25O2=	743.9721
21.6CO2=	950.6052
61H2O=	1098.93208
1NH3=	17.03052
H2O=	18.01528

In Diagram 1 a, it is calculated that 225.21 tonnes of kitchen/green waste feedstock of 69% volatile solids and 35% total solids would produce 183.46 tonnes of product after the first stage in the tunnel. **Error! Reference source not found.**After the first stage of run 45, 178.70 tonnes was actually measured by the weigh cells. Similarly, in the second stage, the model in Figure 2, calculated a total product weight of 136.86 tonnes while the weigh cells recorded 142.99 tonnes of product after stage 2 in the tunnel.

In the model the calculated evaporation during stage 1 was 30.83 tonnes and during stage 2 was 35.76 tonnes (see Diagram 1 b and Diagram 2 b). For Run 45, the Gicom computer recorded 24 tonnes of evaporation for stage 1 and 34 tonnes for stage 2.

This model can be used a guideline for composting processes of other material. The data of other feedstock can be fed into the model to predict the amount of partly composted material generated at the end of the tunnel composting process prior to windrow composting. However since the scenario is set for a system of starting at ambient condition and composting at 60°C, the moisture content (hence % total solid) of the product need to be assumed. This percentage of total solid in the material is the sensitive part of the program as this determines the dryness of the product out of the tunnel and also plays a major part in calculating the amount of evaporation during the process. During tunnel composting air was blown through the system to cool the material down before removal. At time of removal the percentage of total solid in the material would be lower than it was at 60°C.

11.20 Energy balance

Energy consumption is an important consideration in determining the cost effectiveness of an in-vessel composting system. It is therefore useful to calculate how much energy is used by such a process and to estimate the associated costs.

Heat liberated by the decomposition of organic materials increases the temperature of the solids, water and air in the composting mixture. The released energy also drives the evaporation of water, which is carried from the process in the exhaust gases. Since the compost is at a higher temperature than the surroundings, heat losses will occur from exposed surfaces on the compost, by conduction, convection and radiation. Losses of heat are also mitigated to some extent by the insulating effect of the compost which limits conduction of heat.

For windrows and small composting cells, the heat is dissipated by natural convection and radiation from the surface of the cells. However, for large composting chambers, most of the heat is removed by means of water evaporation into the air flow that should be maintained through the chamber (Themelis, 2005)[21]. In the Gicom composting tunnels, the tunnel wall limits the heat loss due to conduction. Themelis and Kim (2002)[22] found that only 24% of the heat generated by the composting reaction was loss by means of natural convection and radiation from the surface of the bed and walls of a large composting chamber. Therefore, most of the energy generated by the composting process is lost through the evaporation of water and exhaust air. Bach et al. (1987)[23] found that heat loss in commercial scale reactors was predominantly through evaporative heat losses between 75%-86%. Harper et al. (1992)[24] also found that in an enclosed, insulated, environmentally controlled compost reactor (10 tonnes capacity) latent heat losses (due to evaporation) were the dominant method of heat removal and it never dropped below 70% of the total heat loss.

The temperature at any point during composting depends on how much heat is being produced by microorganisms, balanced by how much heat is being lost. The Gicom computer continuously records the air flow rate through the tunnel, the temperature of inlet air, the temperature of return air, the humidity of inlet air and the humidity of return air. These data can be used to determine the amount of energy generated by the composting process within the tunnel. The following energy balance calculation was based on the study of Haug (1993)[25] and Mohabuth (2000)[26].

The amount of energy generated by the compost is the difference between the amount of energy leaving the system and the amount of energy entering the system as indicated by the following equation:

Energy generated = Energy Out – Energy In

[21] Themelis, N.J. (2005). Control of Heat Generation During Composting. *Biocycle*. Pg 28

[22] Themelis, N.J. and Kim Y.H. (2002) Material and energy balances in a large-scale aerobic bioconversion cell. *Waste Management & Research, 20*(3), 234-242

[23] Bach, P. D., Nakasaki, K., Shoda, M., & Kubota, H. (1987). Thermal Balance in composting operations. *Journal Of Fermentation Technology, 65*(2), 199-209

[24] Harper, E., Miller, F.C., Macauley,J., (1992) Physical management and interpretation of an environmentally controlled composting ecosystem. Australian Journal of Experimental Agriculture, 32: 657-667

[25] Haug, R. T. (1993). *The practical handbook of compost engineering: Second ed*. Florida: Lewis Publishers, CRC Press

[26] Mohabuth, N. (2000). Development of a small-scale composting system using energy balance. B.Eng Dessertation, University of Mauritius, Reduit, Mauritius.

…Equation 12

Energy entering the system (Energy in inlet air)

The energy entering a composting system through forced airflow is the product of the mass flow rate of dry air and the enthalpy of the air per unit mass. Therefore,

Energy in Inlet air, $E_{in} = H\, m_{ia}$

Where,

H= enthalpy of inlet air per unit mass, KJ/kg

m_{ia}=mass flow rate of inlet air, Kg/h

The energy in the inlet air is the sum of the energy of the dry inlet air and that of the water it contains at that particular temperature. Therefore, the total energy in the inlet air can be represented by the following equation:

Energy in inlet air = Energy in dry inlet air + Energy of water vapour in inlet air

…Equation 13

$E_{in} = m_{da} (h_{da} + \omega_a h_w) = m_{da} C_{pa} T_a + m_{da} \omega_a C_{pw} T_a$

…Equation 14

Where,

m_{da} = Mass flow rate of dry air, kg/h

h_{da} = Enthalpy of dry air at temperature T_a, kJ/kg of dry air

ω_a = specific humidity of air entering the composting pile, kg water/ kg dry air

h_w = Enthalpy of water vapour, kJ/kg

C_{pa} = Specific heat capacity of air at constant pressure, kJ/kg°C

C_{pw} = Specific heat capacity of water at constant pressure, kJ/kg°C

T_a = Temperature of inlet air, °C

Energy leaving the system (Energy in Air out)

Heat energy leaves the composting system by a convective heat transfer mechanism. The convective heat transfer can occur in two different ways, vaporisation and dry air convection. Vaporisation is the evaporation of water from the composting substrate into the ventilative air flow, whereas dry convection is the change of sensible heat of the dry ventilative air due to temperature differences. The energy leaving the system is represented by the following equation:

Total Energy in air out = Energy due to evaporation + Energy in air out

…Equation 15

$E_{out} = E_{evap} + E_{airout}$

…Equation 16

Where,

E_{evap} =Energy associated with evaporation, kJ/h

E_{airout} = Energy associated with exhaust gases, kJ/h

Energy associated with vaporisation, Eevap

Evaporation causes a mass flux of water from the composting material into the air flow through the system. The air flow has two constituent parts, the dry air and the water vapour it contains. The Gicom computer calculates the amount of evaporation based on the humidity of inlet and return air. Therefore, the rate of energy leaving the system is as follows:

$E_{evap} = m_{evap}\, h_s$

…Equation 17

Where,

m_{evap} = mass flow rate of water evaporated, kg/h

h_s =latent heat of vaporisation, kJ/kg

Energy in Exhaust gases

The temperature difference between the compost mass and the dry air causes a proportional transfer of sensible heat from the composting mass to the air flow. The rate at which the convection heat transfer mechanisms occur will vary depending on the system configuration and on the stage the composting process has reached. The enthalpy of the exhaust gases is the sum of the enthalpy of dry exhaust gases and the enthalpy of the water vapour in the exhaust air. The situation is represented by the following equation:

Energy in air out = Energy in dry air + energy in water vapour of exhaust air

…Equation 18

$E_{airout} = m_{dg}\, C_{pa}T_e + m_{dg}\omega_e C_{pw} T_e$

…Equation 19

Where,

m_{dg} = mass flow rate of dry gas out, kJ/h

ω_e = specific humidity of air leaving the composting pile, kg water/ kg dry air

C_{pa} = Specific heat capacity of air at constant pressure, kJ/kg°C

C_{pw} = Specific heat capacity of water at constant pressure, kJ/kg°C

T_e = Temperature of exhaust gases, °C

Using the data recorded by the Gicom computer, the above equations were used to determine the rate of energy entering, leaving and generated throughout the first and second stage of run 45. The results are illustrated in Figure 87 below. It can be seen that at the beginning of each stage there was no significant difference between the energy in the inlet air and the exhaust air. After the first day in the tunnel the temperature started to rise which widened the gap between the energy in the inlet and the outlet air. This is due to increase in the heat (energy) produced by the compost after the first day in the tunnel.

The regular short term drop in the air inlet and outlet during both stages corresponds to the time when the fan is switched off for leachate removal. As can be seen in Figure 87, the energy produced by the compost was not affected by this interruption. When the composting process was at its peak, the compost produced c.1,000 MJ/h at stage 1 and c. 1,500 MJ/h at stage 2.

At the end of each composting stage the fan blew air through the composting material to bring down its temperature. A fall in the energy generated by the compost can be seen at the end of each stage, due to the material being cooled down by the fan. However, the air leaving the tunnel (air out) tended to have a higher energy as hot air was being exhausted from the tunnel to cool down the material.

Figure 87: Rate of energy entering/leaving the tunnel, and energy generated at stage 1/ stage 2 (Run 45)

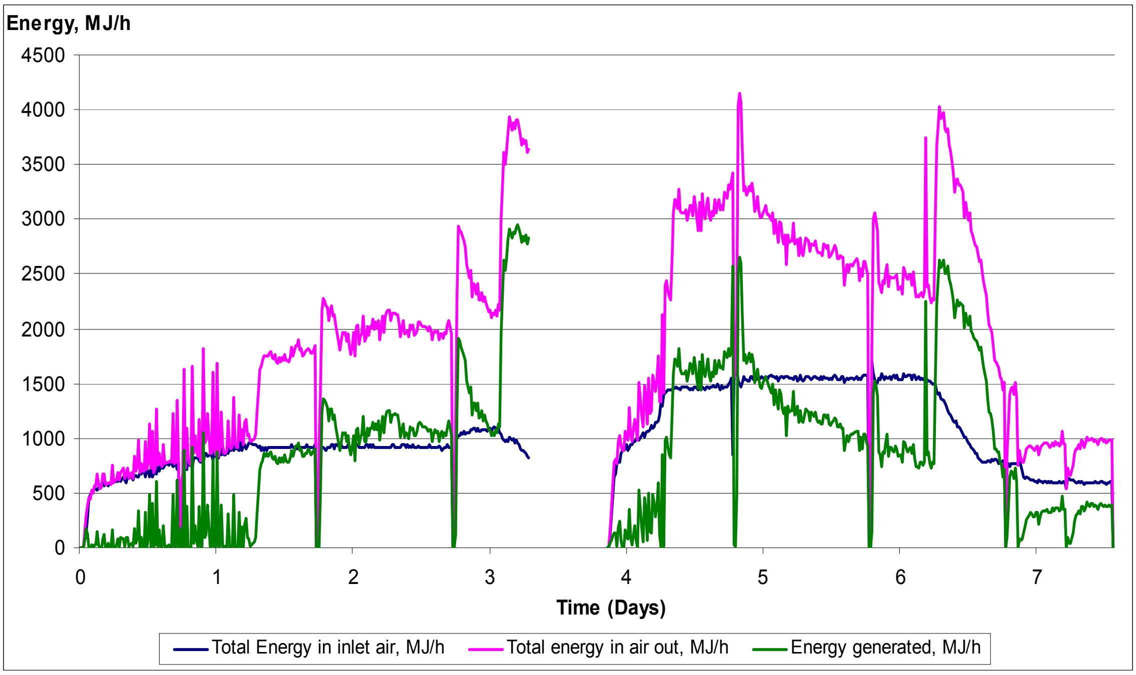
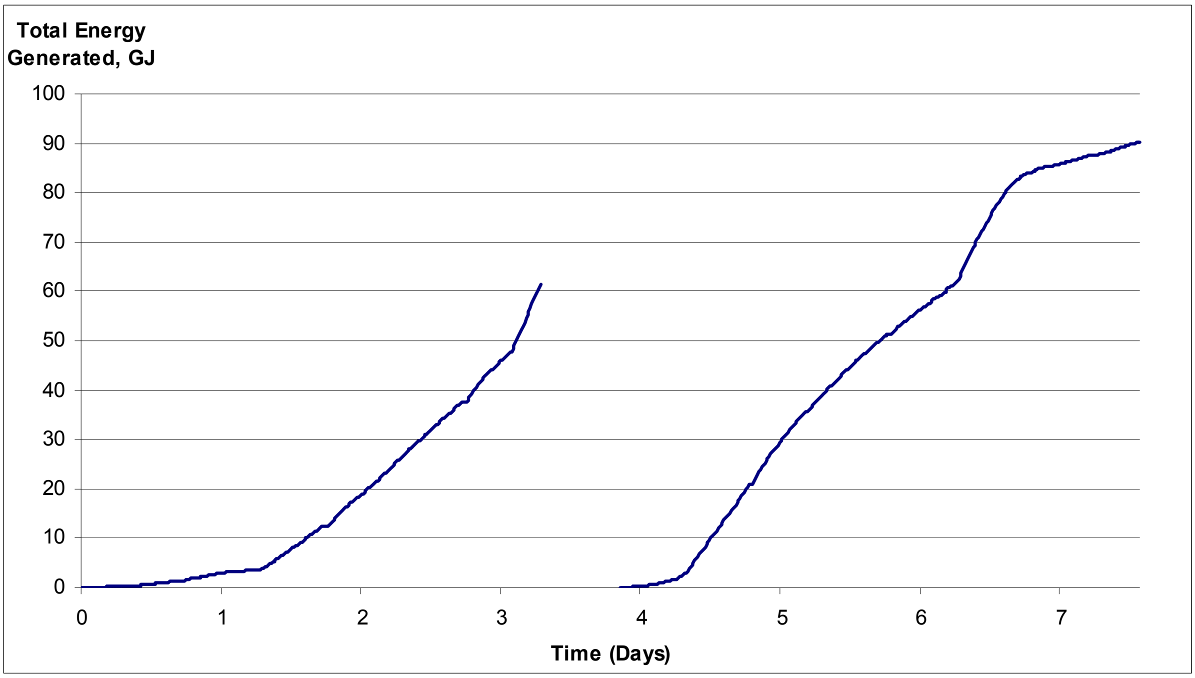


Figure 87 shows the total energy generated by the compost at stage 1 and 2 of Run 45. It can seen that c. 60 GJ and c. 90 GJ of energy were generated by the composting material in stage 1 and 2 respectively. This equates to an energy generation of 300 MJ per tonne of feedstock at stage 1 and 450 MJ per tonne of feedstock at stage 2.

Figure 88: Total energy generated by the compost in the tunnel during the first and second stage of Run 45



The total energy generated by the compost in the tunnel is a function of the rate of evaporation. It can be seen in Figure 89 that the total evaporation follows the same trend as the energy generated chart in Figure 88.

Figure 89: Total evaporation of stage 1 and stage 2 for Run 45

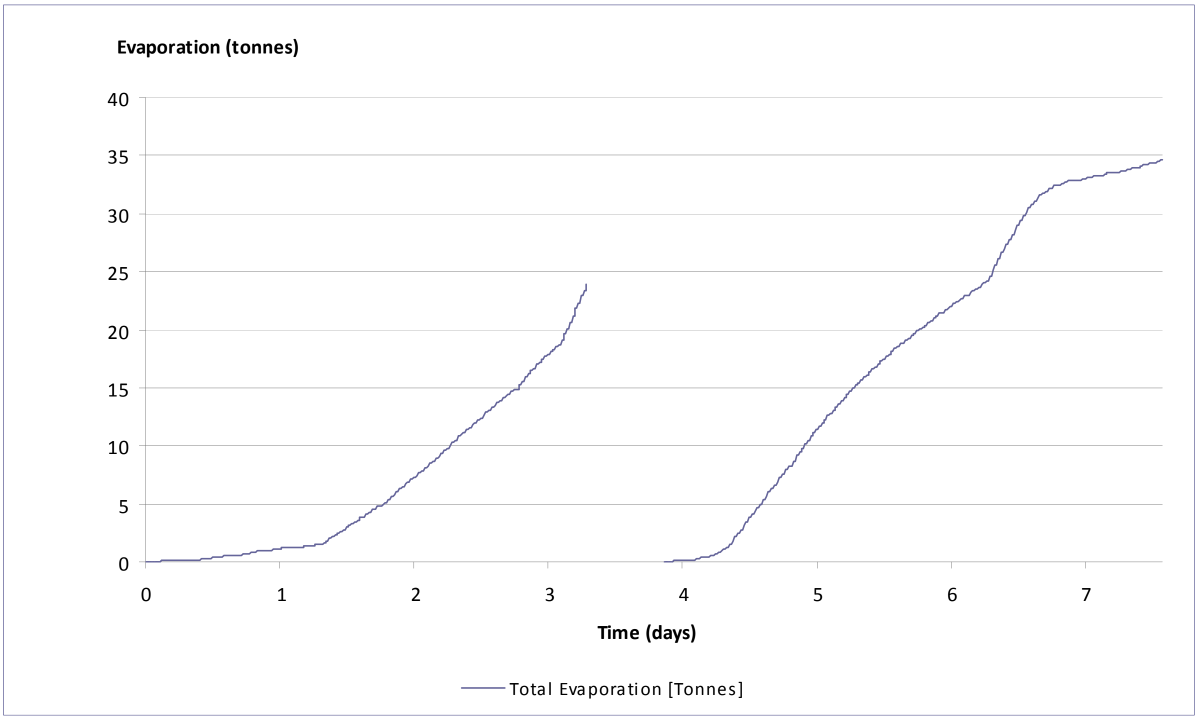
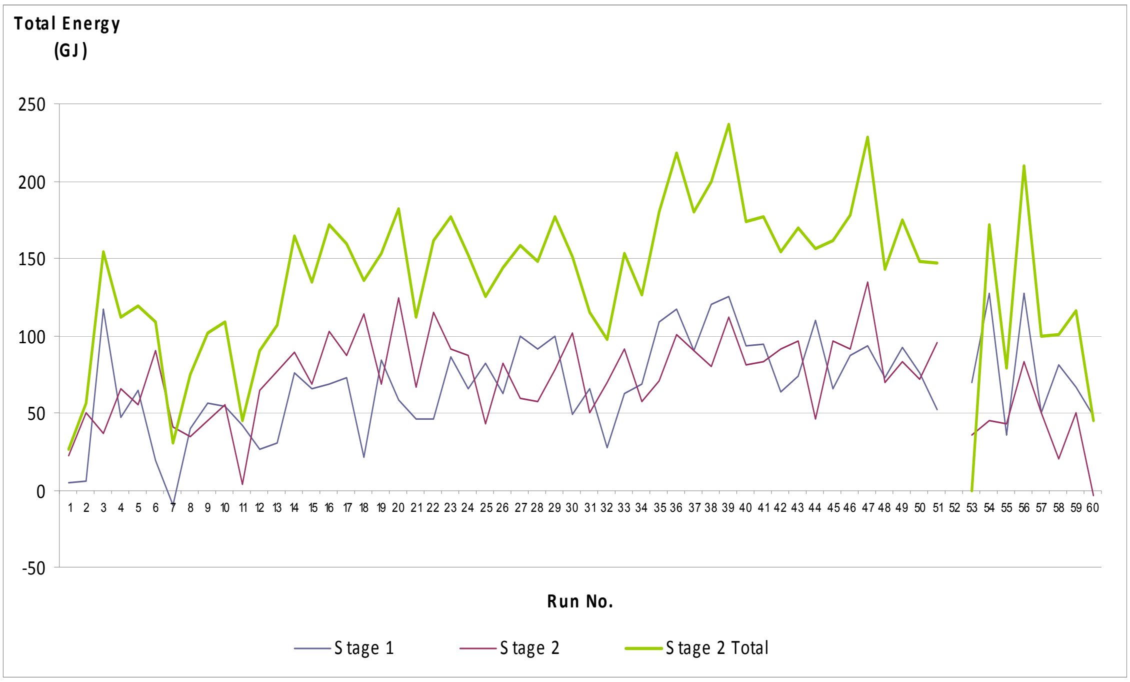


Figure 90 summarises the energy generated by the compost at stage 1, stage 2 and the total energy generated for runs 1 – 60. It can be seen the total energy generated during the sixty runs varied from 30 – 220 GJ.

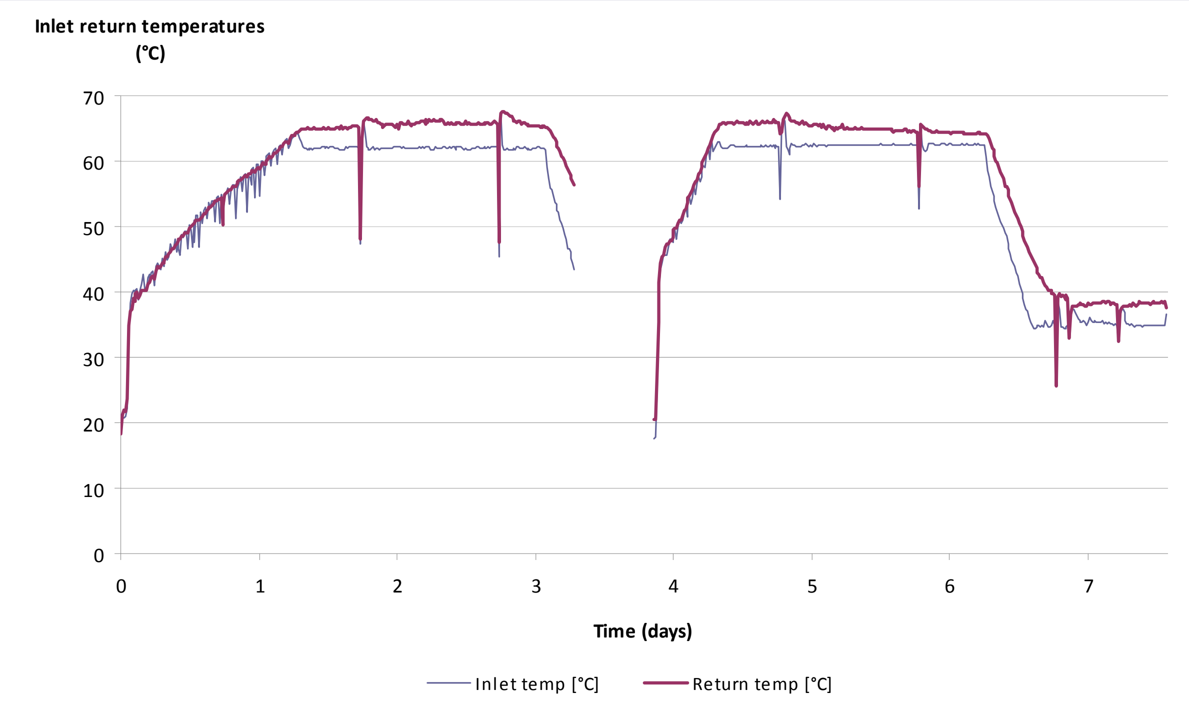
Figure 90: Total energy generated by the compost at stage 1, stage 2 and total overall for Runs 1 - 60



It can be seen in this Figure that for during Run 7, the energy generated was below zero. It was found that negative values of energy generated were observed at the beginning of some of the runs. This was because at the beginning of the run the temperature of return air tends to be higher than the temperature of outlet air. Such an example is shown in Figure 91 where the inlet temperature was higher than the return temperature for a long time. This tends to happen in the winter time when the material is relatively cold and take some times to warm up. This is an important consideration in recognising the effect that cold substrate being filled into the tunnels can have.

At this stage not much evaporation would be expected. At the initial stage the material would be absorbing heat rather than generating heat, which would explain the negative values of energy generated in some cases.

Figure 91: Temperature of inlet and return air at stage 1 and stage 2 for Run 45



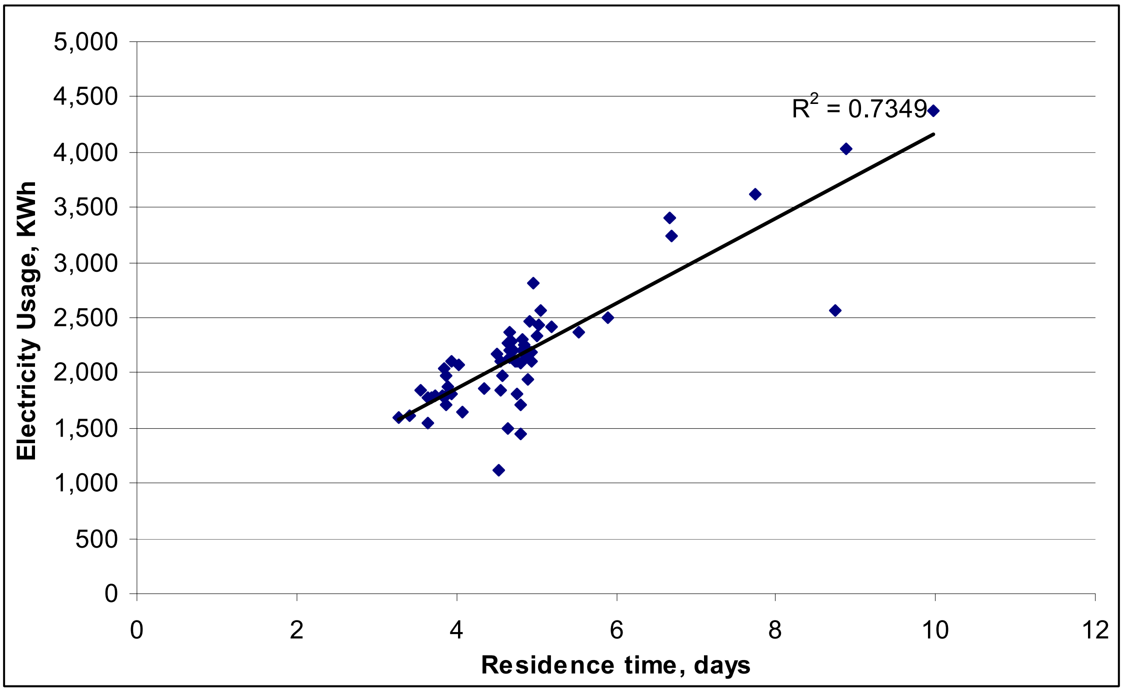
11.21 Factors affecting residence time in the composting tunnels

The previous sections discussed the results obtained from the 60 runs carried out with a mixture of green waste and kitchen waste. The runs were carried out with different proportions of kitchen waste and the various parameters were recorded by the tunnel computer. This section will discuss how some parameters may be affecting each other.

Based on the results obtained for the first 60 runs, an analysis was carried out to assess how any parameter may affect the residence time of the material in the tunnel. The residence time in the composting tunnel is an important factor to consider as it has a major effect on the throughput of the tunnel system, and also the energy (electricity) utilisation and hence cost of the operating the tunnel.

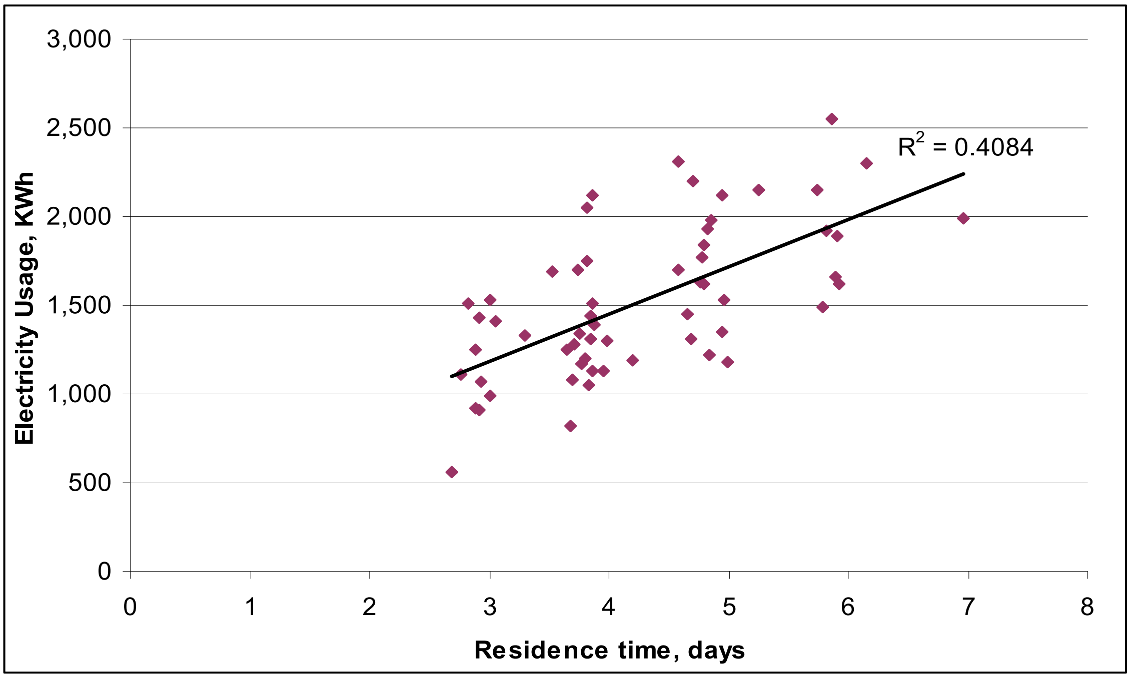
It can be seen in Figure 92 that during stage 1, the electricity usage is directly proportional to the residence time of the material in the tunnel.

Figure 92: Electricity usage versus residence time of material in the tunnel during stage 1



Similar observations can be made for stage 2 in Figure 93.

Figure 93: Electricity usage versus residence time of material in the tunnel during stage 2



The analysis in the following section was carried using the Genstat® statistical software. Regression analysis was carried out to identify whether the residence time of the material in tunnel was affected by:

- The time taken for the material in the tunnel to reach 60°C,
- The percentage kitchen waste in the feedstock,

- The mass of feedstock filled into the tunnel.

The following analysis looks at stage 1 and stage 2 separately.

Stage 1

- **Effect of time taken for material in the tunnel to reach 60°C**

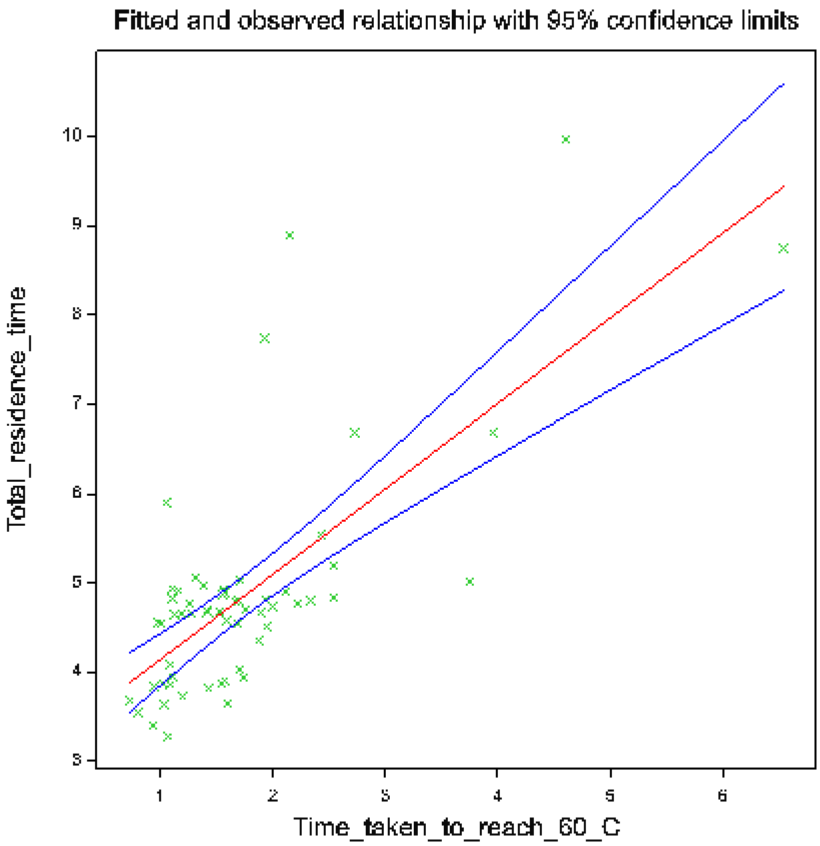
The time taken for feedstock to reach pasteurisation temperatures is an important factor in determining the overall residence time of feedstock in the tunnels. This in turn affects the throughput of the tunnels and hence has a considerable effect upon the economics of the process. Figure 94 shows the variation of the residence time in the tunnel during the first stage of composting with the time for the material in the tunnel to reach 60°C. The software fitted a best fit line with 95% confidence limits.

The analysis shows that in the first stage,

Total residence time = 3.183 + 0.956 (Time taken to reach 60°C)

This relationship accounted for 51.3% variance. The best line was largely influenced by runs 1, 2,7 and 43, which had the longest time taken to reach 60°C.

Figure 94: Variation of the residence time in the tunnels: time (days) to reach 60°C - stage 1

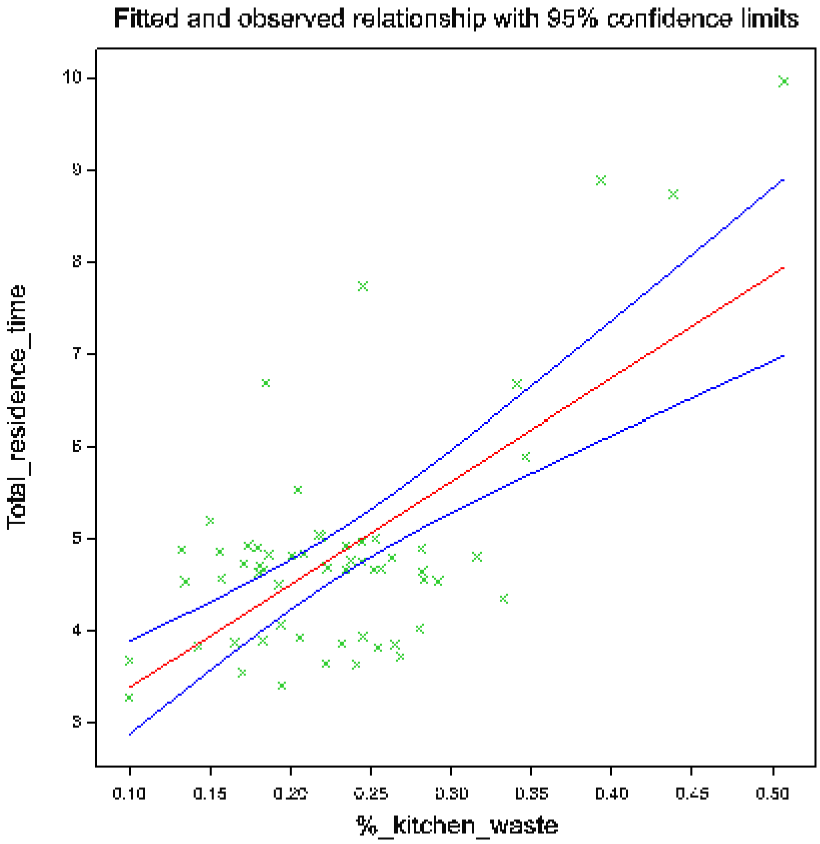


- **Effect of the percentage of kitchen waste in the feedstock**

Figure 95 shows the variation of the residence time with the percentage of kitchen waste in the feedstock for the first stage. There seemed to be a reasonable relationship between the residence time of material in the tunnel and the percentage of kitchen waste in the feedstock. The best fit line accounted for 41.7% variance and yields the following equation:

Residence Time = 2.268 + 11.2 (% Kitchen waste)

Figure 95: Variation of residence time in the tunnel with percentage of kitchen waste in the tunnel



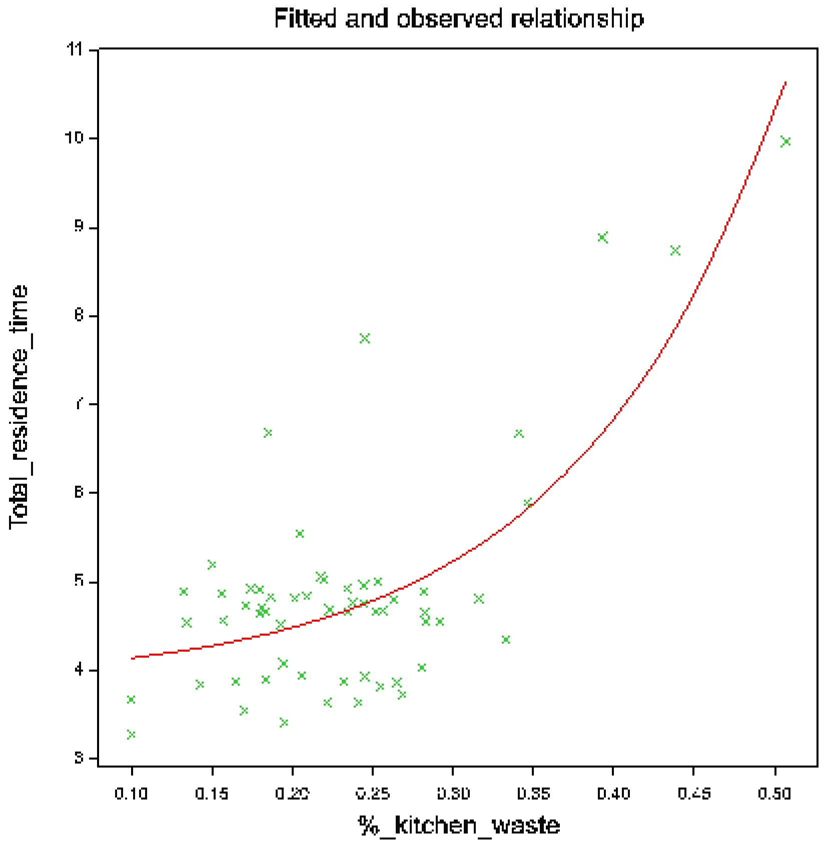
This relationship seemed to be greatly influenced by runs 1, 2 and 3 which had the highest percentage of kitchen waste. However, in Figure 95 it can be seen that there did not seem to be a great effect on the residence time in the tunnel when the percentage of kitchen waste in the feedstock was less than c. 30%. A much longer residence time was observed for feedstock with a percentage kitchen waste greater than c. 30%. As the nature of kitchen waste can vary from one collection round to another the figure of 30% should be considered an approximate guide only.

Therefore, for a better understanding of this situation, an exponential curve was fitted as shown in Figure 96. The percentage variance accounted for was increased from 41.7% to 56.5%.

The equation of the fitted curve is,

Residence time $=3.840+0.140 \times 2131^{\text{kitchen waste}}$

Figure 96: Relationship between residence time and percentage kitchen waste in feedstock



This Figure makes it clear that the effect of the increasing percentage of kitchen waste in the feedstock only becomes evident above the level of 30%, when the residence time increases considerably.

- **Effect of mass of feedstock filled into the tunnels**

Regression analysis using Genstat® did not show any reasonable relationship between residence time and mass of feedstock loaded into the tunnel during either stage no matter what the ratio of kitchen waste to green waste used. Therefore, as long as the proportion of kitchen waste within the feedstock mixture does not exceed c. 30% the tunnels can successfully process the full range of tonnages processed.

- **Effect of time taken to reach 60°C and the percentage kitchen waste on residence time in the tunnel**

From the above results it was found that during the first stage both the time taken to reach 60°C in the tunnel and the percentage kitchen waste in the feedstock can affect the residence time of the material in the tunnels. Therefore, a regression analysis including both parameters (time taken to reach 60°C and percentage kitchen waste in the feedstock) was carried out.

It was found that together the two parameters explained 60.7% of variation. The best fitted equation was,

Residence Time= 2.169 + 0.69 (Time to 60°C) + 6.4 (%Kitchen waste)

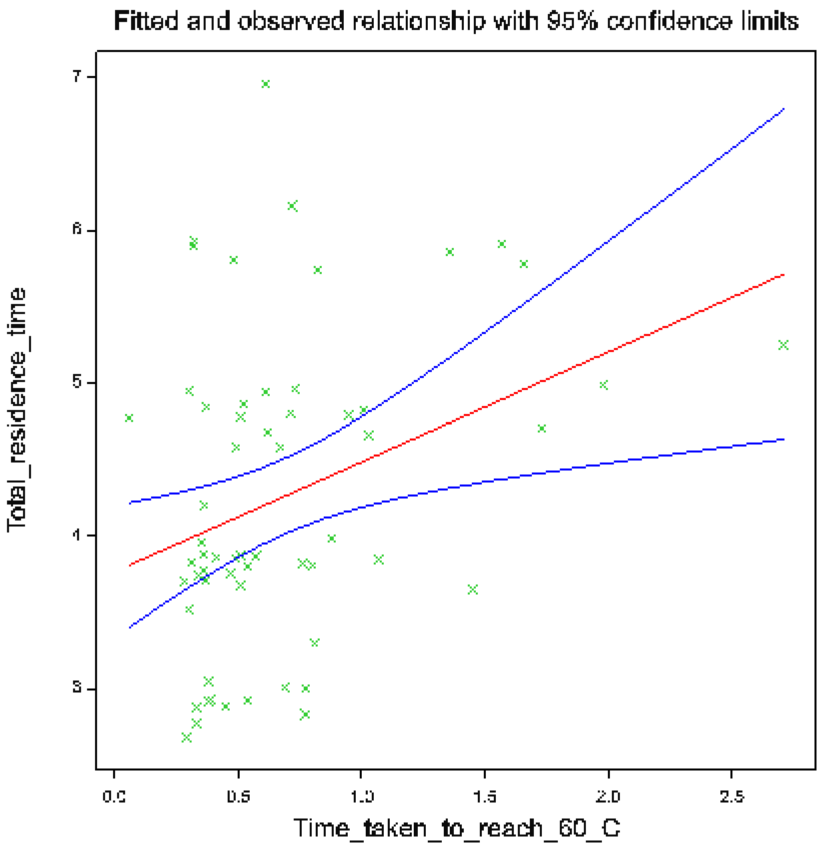
This shows that the two parameters had a considerable combined influence on the residence time during stage 1.

Stage 2

- **Effect of time taken for material in the tunnel to reach 60°C**

The relationship between residence time and the time taken to reach 60°C is much weaker in stage 2 than in stage 1. The best fit line in Figure 97 accounted for only 9.9% of variance. Due to such a low percentage of variance, there did not seem to be a reasonable relationship between the two parameters.

Figure 97: Effect of time taken to reach 60°C on the residence time in stage 2



- **Effect of the percentage of kitchen waste in the feedstock**

The regression analysis did not show any reasonable relationship between the residence time and the percentage of kitchen waste at stage 2. The first stage of tunnel composting is much more sensitive to the proportion of kitchen waste in the feedstock mix as the kitchen waste is wetter and denser during first stage that during the second stage.

- **Effect of mass of material filled into the tunnels**

As in stage 1, the regression analysis showed that the mass of material loaded in stage 2 did not show any reasonable relationship with the residence of the material in the tunnel. As with the proportion of kitchen waste in the feedstock mix, the first stage of tunnel composting is more sensitive to the mass of material filled than the second stage because the bulk density and moisture of the feedstocks are higher in the first stage than in the second stage.

12 EMISSIONS MONITORING FROM TUNNEL COMPOSTING

The Defra Report identified gaps in the information available on the nature and quantity of emissions from composting facilities. The specific gaps included emissions to air, and to controlled waters/ground water.

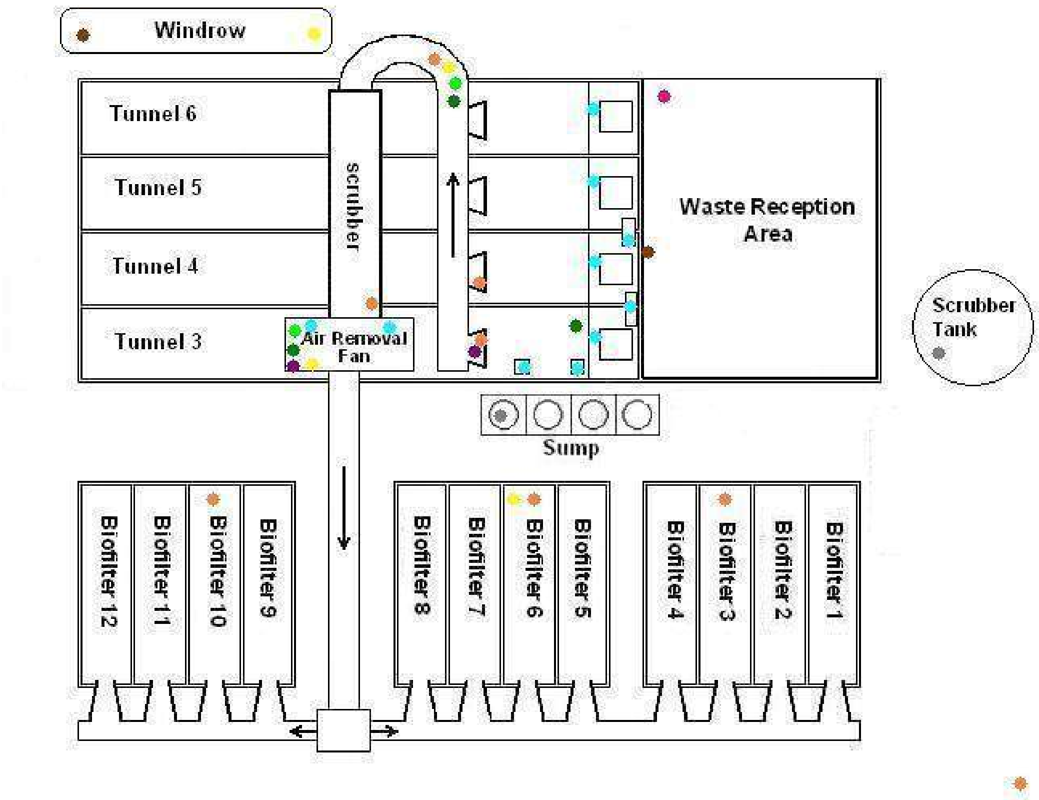
A comprehensive study of gaseous, liquid and solid emissions from the Gicom tunnels was carried out during the course of the project to assess any environmental impact.

The following emissions and abatement monitoring took place between 31st December 2007 and 31st March 2009:

- Leachate and process water sampling; (Protocol Section 17)(SOP 5)
- Volatile organic compound (VOCs) sampling; (Protocol Section 17.4)
- Ammonia sampling (using three different methods); (Protocol Section 17.4) (SOP 4)
- Odour sampling; (Protocol Section 17.4) (SOP 10)
- Bioaerosols sampling. (Protocol Section 17.4)

Figure 98 shows the sampling locations for monitoring and sampling (additional to Gicom computer monitoring) carried out for the project.

Figure 98: Schematic drawing of the Gicom tunnels with sampling locations



The following samples and readings were taken (colour coded):

- Ammonia samples (bubblers).
- Ammonia samples (Dräger tubes).

- Odour samples.
- VOC samples.
- Power consumption readings.
- Leachate samples.
- Bioaerosols samples.
- Biodegradation samples.
- Feedstock samples.

12.1 Leachate analysis and volumes

During the course of the project the pH and temperature of the leachate from the composting tunnels were monitored on a weekly basis. Triplicate samples were taken from the process water tank, which collected leachate from all four tunnels, on each sampling occasion. The samples were tested using a Eutech EcoScan pH/mV/°C meter. Measurements were carried out between 11/01/2008 and 13/02/2009.

The data showed that the pH of the leachate varied between 6.05 and 8.55. The temperature of the leachate varied from 6.7°C to 26.2°C and reflected seasonal variations of the ambient air.

The volumes of the leachate produced in the tunnels were continuously recorded by the Gicom computer. Tunnels G3-G6 produced c. 314 m^3 of leachate between from all 77 project tunnel runs.

Triplicate samples of the leachate produced during each intensive run processing kitchen waste/green waste were collected from the sump and sent to accredited laboratories for detailed analysis (see Table 12). Triplicate samples of the leachate produced during runs processing a combination of MSW (Municipal Solid Waste) fines and kitchen waste/green waste were also collected from the sumps sent for analysis. Results of this analysis are shown in Table 13.

Table 12: Analysis of leachate from Gicom tunnels for co-mingled kitchen and green waste runs

Date	Biological Oxygen Demand	Chemical Oxygen Demand	Total solids	Ammonium Nitrogen	pH	Calcium	Magnesium	Sodium	Chloride	Sulphate	Cadmium	Chromium	Lead	Mercury	Nickel	Zinc	Nitrate Nitrogen
	mg l^{-1}	mg l^{-1}	%	mg l^{-1}		mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	µg l^{-1}	µg l^{-1}	µg l^{-1}	µg l^{-1}	µg l^{-1}	µg l^{-1}	mg l^{-1}
08/02/08	460.67 (±14.01)	99.00 (±14.42)	0.21 (±0.01)	861.67 (±16.86)	6.40 (±0.01)	217.33 (±4.04)	17.03 (±0.32)	43.90 (±2.13)	100.00 (±1.00)	13.30 (±0.92)	0.14 (±0.08)	53.80 (±7.75)	18.07 (±3.32)	0.56 (±0.86)	80.0 (±24.59)	1753.67 (±72.06)	0.0
25/02/08	3725.33 (±58.59)	1671.00 (±5.57)	0.94 (±0.04	1159.00 (±42.33)	6.80 (±0.11)	1052.00 (±159.34)	111.67 (±10.26)	233.00 (±18.33)	437.00 (±17.06)	10.20 (±9.48)	1.95 (±0.33)	91.37 (±15.53)	73.60 (±6.72)	11.82 (±10.80)	144.00 (±22.54)	3243.00 (±364.52)	0.0
28/05/08	4663.33 (±153.08)	2558.67 (±85.66)	1.26 (±0.12)	1165.33 (±47.34)	7.89 (±0.01)	337.67 (±4.04)	82.17 (±1.11)	152.00 (±3.46)	431.67 (±6.51)	0	0.09 (±0.16)	30.43 (±19.17)	63.23 (±11.47)	0.02 (±0.03)	297.00 (±13.53)	1019.67 (±242.84)	0.0
10/07/08	264.00 (33.42±)	1146.33 (±4.04)	0.23 (±0.03)	230.00 (±10.00)	7.26 (±0.03)	92.80 (±3.16)	13.33 (±0.40)	34.37 (±2.99)	79.43 (±5.79)	0.07 (±0.12)	0	55.40 (±30.51)	26.10 (±1.00)	3.56 (±0.77)	111.70 (±13.74)	604.00 (±30.20)	0.0
13/08/08	9236.67 (±926.07)	22093.33 (±666.13)	1.43 (±0.03)	714.67 (±24.91)	5.61 (±0.08)	705.00 (±7.21)	86.43 (±1.10)	128.00 (±6.56)	425.00 (±6.08)	94.77 (±1.91)	0	0.16 (±0.02)	0.13 (±0.01)	0	0.20 (±0.00)	12.27 (±1.22)	0.0
07/10/08	1536.0 (±193.7)	2393.3 (±126.2)	0.25 (±0.02)	264.3 (±25.5)	8.25 (±0.03)	83.9 (±2.9)	18.8 (±1.0)	46.7 (±7.0)	159.3 (±2.3)	0.5 (±0.9)	1.04 (±0.64)	86.90 (±9.85)	37.93 (±5.73)	3.12 (±0.36)	71.2 (±12.3)	660.3 (±100.6)	0.0
10/11/08	504.0 (±91.9)	637.0 (±27.1)	0.10 (±0.01)	97.1 (±2.0)	7.43 (±0.01)	65.6 (±5.6)	7.6 (±0.3)	23.3 (±0.9)	74.4 (±6.9)	5.6 (±0.6)	0.74 (±0.73)	0.09 (±0.01)	26.03 (±7.10)	2.81 (±1.04)	44.8 (±9.3)	571.0 (±65.1)	0.0

Table 13: Analysis of leachate samples taken from the Gicom tunnels for the MSW runs

Date	Biological Oxygen Demand	Chemical Oxygen Demand	Total solids	Ammonium Nitrogen	pH	Calcium	Magnesium	Sodium	Chloride	Sulphate	Cadmium	Chromium	Lead	Mercury	Nickel	Zinc	Nitrate Nitrogen
	mg l^{-1}	mg l^{-1}	%	mg l^{-1}		mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	µg l^{-1}	µg l^{-1}	µg l^{-1}	µg l^{-1}	µg l^{-1}	µg l^{-1}	mg l^{-1}
16/12/08	194.7 (±52.7)	1094.7 (±13.3)	874.0 (±164.4)	119.3 (±4.0)	7.2 (±0.0)	55.9 (±14.1)	8.8 (±0.6)	20.6 (±1.1)	26.0 (±0.3)	1.5 (±1.1)	0.0	1.1 (±0.6)	0.0	0.0	0.4 (±0.2)	0.7 (±0.7)	0.0
06/01/09	207.0 (±65.0)	1732.0 (±101.2)	0.1 (±0.0)	132.0 (±0.0)	7.6 (±0.0)	190.0 (±4.4)	25.1 (±0.7)	94.1 (±9.2)	150.3 (±1.2)	0.0	0.0	0.2 (±0.1)	0.0	0.0	0.0	0.6 (±0.0)	0.0

The biological oxygen demand (BOD) of the leachate varied between 264.00 and 9,236.67 mgl-1(ppm) for co-mingled kitchen waste and green waste runs, and between 194.70 and 207.00 mgl-1 (ppm) for MSW runs.

This high BOD indicates the presence of organic waste in the leachate and the necessity for treatment of the leachate before release from the site. The leachate produced on site is passed through a 6 mm sieve and treated in a biological water treatment facility before release. The process is regulated by a Discharge Licence obtained from the Environment Agency.

Cadmium levels in analysed samples varied from 0 to 1.95 µgl-1 for the co-mingled kitchen waste and green waste runs.

Cadmium levels in the leachate from MSW runs were below detection in both triplicate samples.

Although no mercury was detected in the leachate samples from MSW runs, four out of seven results from the co-mingled kitchen waste and green waste showed mercury concentration above 2 µgl $^{-1}$.

Triplicate samples of the process water were collected after each intensive run and tested for ammonium nitrate (Table 14).

Table 14: Ammonium Nitrate concentration in process water

Run	Process Water Ammonium Nitrate Concentration mg l^{-1} (mg/kg)
2	706.33 (±40.38)
5	161.67 (±6.51)
15	483.67 (±148.50)
22	155.33 (±5.77)
31	84.03 (±22.30)
45	256.67 (±5.51)
52	87.17 (±2.27)
MSW (1)	142.62 (±98.78)
MSW (2)	162.15 (±86.42)

As can be seen in the Table 14, ammonium nitrate concentrations in the process water varied between 84.03 mg l^{-1} and 706.33 mg l^{-1}. Samples taken during the processing of MSW material are identified. The analysis of the process and leachate water did not reveal any components that were unexpected or at elevated levels.

All process water and leachate leaving the project tunnels was treated by the site water treatment plant and was discharged to a local water course. The standard of water released was within the standard limits set by the Environment Agency under the terms of the License to Discharge agreed with the site operator.

12.2 Volatile organic compounds

VOCs are a large group of anthropogenic (derived from human activities) or biogenic organic compounds with relatively high vapour pressures. VOCs can be potential air pollutants, due to their malodorous and hazardous properties (although normally only hazardous at much higher concentrations than those experienced downwind of composting installations). In addition, VOCs can contribute to global warming, stratospheric ozone depletion and tropospheric ozone formation.

VOC sampling is not routinely measured in most composting facilities. There have been many studies carried out on VOC emissions from landfills, but little data is available for the composting process. This gap was identified in the Defra Report. In particular, the Defra Report indicated a lack of knowledge of volatile organic compounds as a whole as well as specific chemicals including 1,1-dichloroethane, chloroethane, chlorothene, chlorobenzene, tetrachloroethene, and benzene.

In order to apply most appropriate sampling method to emissions from the Gicom tunnels, a comprehensive assessment of available equipment was undertaken.

The following technologies were examined during the intensive runs carried out by the project :

2. Infrared sensors and probes;
3. Photo Ionisation Detectors (PID);
4. Photo-acoustic analysers;
5. Gas chromatography-mass spectrometry (GC-MS):
   - Top ten screen;
   - Thermal desorption (TD).

One of the major restrictions in choosing a VOC sampling method was the high temperature (up to 70°C) and high moisture levels of the exhaust air from the tunnels, as most of the above listed equipment cannot operate efficiently under such extreme conditions.

After initial trials with the first three methods it was determined that the GC-MS method would be the most appropriate method. This technology involved taking triplicate samples from the exhaust ducting of the Gicom tunnels in 1 litre tedlar bags (top ten screen method) or Polyethylene terephthalate (PET) bags normally used to collect odour samples for olfactometry analysis (TD method). An odour sampling kit (sampling barrel and vacuum pump) was used to collect samples during warming up, pasteurisation and cooling down stages from the ducting of G3 tunnel and from the ducting after the scrubber.

Top ten analysis

This sampling method included collection of triplicate samples from each of following locations:

- G3 tunnel ducting during warming up stage.
- G3 tunnel ducting during pasteurisation stage.
- G3 tunnel ducting during cool down stage; and
- After the scrubber.

Initial sampling and analysis using top ten screen method showed the following VOCs emissions during the warming up stage of one intensive run composting co-mingled kitchen waste and green waste in the G3 tunnel:

Table 15: VOCs emissions detected by top ten screen method

Volatile Organic Compound	Concentration (ppm)
2- butanone	89
Branched benzene circa C10	21
Ethanol	21
Acetone	11
Unidentified cyclic alkene circa C10	16
Unidentified terpene	31

In one of the samples taken during pasteurisation stage, branched benzene (13 ppm) and terpene (15 ppm) were detected.

The limit of detection of the top ten screen method (10 ppm) was found to be too low to detect VOCs in the exhaust gases from the tunnels during the pasteurisation and cooling down stages and after the scrubber. As it was believed that VOCs will be produced during these stages, these “none detected” results suggested that the sensitivity of the top ten screen method was not sufficient.

Thermal desorption

The second VOCs sampling method used in the project included sending four exhaust air samples from two runs at the following locations to accredited laboratories:

- G3 tunnel ducting during warming up stage.
- G3 tunnel ducting during pasteurisation stage.
- G3 tunnel ducting during cool down stage; and
- After the scrubber.

Four samples were collected during an intensive run of the composting of co-mingled kitchen waste and green waste and another four during an intensive MSW run, and sent to accredited laboratories for TD GC-MS analysis.

PET bags with exhaust air collected from the Gicom tunnels were sent by courier to accredited laboratories where 1 litre of gas from each of the bags was drawn through pre-conditioned Tenax TA tubes using air pump. The sub-samples collected on Tenax TA tubes were analysed using standard TD GC-MS method. The limits of quantification for this method are in parts per billion.

The results of samples collected during the composting of co-mingled kitchen waste and green waste run are listed in Table 16 and for the MSW run in Table 17.

Table 16: Volatile organic compounds in processing of co-mingled kitchen waste and green waste feedstock

Retention time (minutes)	Assignment	Approximate Concentration (ngl^{-1})			
		G3 Tunnel Warming up	G3 Tunnel pasteurisation	G3 Tunnel cool down	After the scrubber
3.20	Trimethylamine	nd	nd	170	170
4.93	Dimethyl sulphide	550	170	nd	16
5.90	1-Propanol	15 000	nd	nd	4.3
7.02	2-Butanone (MEK)	620 000	23 000	3.1	56
7.11	2-Butanol	66 000	260	0.40	3.1
7.55	Ethyl acetate	13 000	nd	nd	nd
7.91	2-Methyl- 1-propanol	6 400	nd	nd	1.8
8.79	3-Methylbutanal	930	130	nd	10
8.96	1-Butanol	1 700	nd	nd	nd
9.07	2-Methylbutanal	610	60	nd	4.1
9.99	3-Pentanone	1 900	890	7.9	12
10.70	Methyl butanoate	370	nd	nd	nd
11.00	3-Methyl-1-butanol	8 600	nd	nd	nd
11.12	2-Methyl-1-butanol	3 700	nd	nd	nd
11.58	Dimethyl disulphide	100	120	6.8	8.1
12.81	Ethyl butanoate	920	nd	3.7	nd
15.19	2-Heptanone	940	360	2.6	5.1
16.62	α-Pinene	29 000	27 000	330	420
17.51	Sabiene ?	13 000	6800	56	71
17.62	β-Myrcene	12 000	7 400	110	140
18.76	Limonene	390 000	250 000	5600	6400
19.80	2-Nonanone	350	480	nd	nd
20.25	Fenchone	380	690	6.9	7.3
21.57	Camphor	1 000	4 400	160	160

The levels of most of the detected VOCs were highest at the warming up stage of tunnel composting and are likely to originate from the fresh feedstock. One VOC (trimethylamine) was present at its highest level at the cooling down stage, although this level was itself very low. A few VOCs (dimethyl disulphide, 2-nonanone, fenchone and camphor) has highest levels during the pasteurisation stage. With the exception of trimethylamine, levels of all the detected VOCs were greatly lower after the scrubber. The only VOC that showed high values after the scrubber was limonene, and this was at only 1.6% of the high level found during the warming up stage.

Table 17: Concentrations of volatile organic compounds during processing of MSW feedstock

Retention time (minutes)	Assignment	Approximate Concentration (ngl^{-1})			
		G3 Tunnel Warming up	G3 Tunnel pasteurisation	G3 Tunnel cool down	After the scrubber
2.48	Acetaldehyde	1 100	nd	430	24
3.24	Trimethylamine	nd	nd	55	10
3.48	Ethanol	170 000	nd	360	300
5.12	Dimethyl sulphide	nd	37	140	150
6.70	2-Methyl propanal	460	110	160	82
6.93	2,3-Butanedione	3 100	60	130	42
7.17	2-Butanone	68 400	320	950	1 600
7.26	2-Butanol	22 500	nd	nd	210
7.70	Ethyl acetate	170 000	nd	nd	290
8.05	2-Methyl 1-propanol	11 000	nd	48	37
8.92	3-Methylbutanal	590	180	290	140
9.21	2-Methylbutanal	1 100	83	150	89
10.49	Propanoic acid ethyl ester	5 900	nd	nd	nd
11.12	3-Methyl butanol	19 000	31	110	58
11.23	2-Methyl butanol	4 100	nd	nd	8.1
12.00	Pentanol	430	nd	nd	nd
13.48	3-Methyl butanoic acid	75	nd	nd	nd
15.28	2-Heptanone	5 000	41	230	140
16.71	α-Pinene	25 100	4 000	8 800	2 400
17.58	β-Myrcene	7 700	2 600	780	660
17.75	2-Pentylfuran	600	nd	1 600	260
18.85	d-Limonene	250 000	29 000	84 000	30 000
19.86	2-Nonanone	2 500	43	410	72
21.63	Camphor or isomer	1 000	430	3 300	220
22.00	Borneol or isomer	740	47	nd	nd
24.12	Bornyl acetate	1 300	nd	240	nd

The levels of most of the detected VOCs were highest at the warming up stage of tunnel composting and are likely to originate from the fresh feedstock. With the exception of trimethylamine, levels of all the detected VOCs were greatly lower after the scrubber. Three VOCs (trimethylamine, 2-pentylfuran and camphor) had the highest levels at the cooling down stage, although all levels were low. The only VOC that showed high values after the scrubber was dimethylsulphide, and this was at a very low level.

12.3 Ammonia

Ammonia is an easily dispersible gas and air pollutant of malodorous and potentially toxic nature. It is produced during the composting process and often represents the main nitrogen-containing gas present in composting exhaust air.

In order to remove ammonia from the exhaust air and reduce odour emissions from the Gicom tunnels, a wet scrubber was installed within the exhaust ducting and its performance was monitored during the course of the project.

Ammonia emissions from the Gicom composting tunnels were recorded from 21st October 2008 and involved utilisation of three sampling techniques:

1. Gas detection tubes (Dräger 2/a with measuring range between 2 and 30 ppm and 5/a with measuring range between 5 and 700 ppm).
2. Bubbler method (method developed by ADAS Boxworth).
3. Infrared probe (installed in the ducting of the Gicom tunnels and monitored by the tunnel computer).

Gas Detection Tubes

Ammonia emission readings using Dräger tubes were taken on a weekly basis and involved measuring emissions from the exhaust air in the ducting before and after the scrubber.

Two sampling points were chosen:

- The ducting before the scrubber;
- The ducting after the scrubber.

Ammonia emissions were monitored from 23rd May 2008 to 11th February 2009 and collected data are listed in Table 18 below. Samples taken during the processing of MSW material are identified.

Table 18: Ammonia emissions- Dräger method

Date	Sampling Number	Pre-Scrubber (ppm)	Post-Scrubber (ppm)	Scrubber Efficiency (%)
23/05/2008	1	100.0	40.0	60
03/07/2008	2	63.0	32.0	49
05/07/2008	3	5.0	10.0	-100
15/07/2008	4	204.0	204.0	0
30/07/2008	5	25.0	35.0	-40
06/08/2008	6	150.0	150.0	0
13/08/2008	7	153.0	153.0	0
20/08/2008	8	150.0	150.0	0
27/08/2008	9	14.9	9.9	33
03/09/2008	10	101.0	101.0	0
10/09/2008	11	140.0	150.0	-7
17/09/2008	12	69.3	39.6	43
24/10/2008	13	202.0	101.0	50
01/10/2008	14	153.0	51.0	67
08/10/2008	15	50.0	20.0	60
15/10/2008	16	5.0	30.0	-500¤
22/10/2008	17	80.0	40.0	50
29/10/2008	18	40.4	10.1	75
05/11/2008	19	39.6	19.8	50
12/11/2008	20	10.0	5.0	50
19/11/2008	21	5.0	2.5	50
26/11/2008	22	0.0	0.0	0
03/12/2008	23	5.0	5.0	0
10/12/2008	24	5.0	2.5	50
17/12/2008	25	10.0	2.5	75
24/12/2008	26	20.0	8.0	60
31/12/2008	27	8.0	4.0	50
07/01/2009	28	0.0	0.0	0.0
14/01/2009	29 (MSW)	5.0	2.5	50
21/01/2009	30 (MSW)	10.0	10.0	0
28/01/2009	31 (MSW)	30.0	15.0	50
04/02/2009	32 (MSW)	20.0	13.0	35
11/02/2009	33 (MSW)	2.0	1.0	50

¤ A very high negative value

Using the Dräger method, 4 of the 33 sampling runs showed negative efficiencies for the scrubber. The positive efficiencies ranged from 0 to 75%.

Bubbler method

This method was based on bubbling sampled air through 250 ml glass conical flasks filled with 80 ml of 0.02 M orthophosphoric acid, for one hour. After the hour, flasks were replaced with new ones for another hour of sampling. The sampled flasks were sent to accredited laboratories for the analysis.

Three sampling points were chosen:

- The ducting before the scrubber.
- The ducting after the scrubber.
- Within the enclosed area above the Gicom tunnels (to collect data on background levels of ammonia).

Ammonia emissions were monitored from 13th March 2008 to 11th February 2009 and the data is shown in Table 19. Samples taken during the processing of MSW material are identified.

Table 19: Ammonia emissions – Bubbler method

Date	Sampling Number	Pre-Scrubber (ppm)	Post-Scrubber (ppm)	Scrubber Efficiency (%)
14/03/2008	1	47.76	28.47	40
03/04/2008	2	49.43	13.64	72
23/05/2008	3	137.04	50.35	63
03/07/2008	4	68.30	46.14	32
05/07/2008	5	6.50	4.54	30
15/07/2008	6	178.57	157.43	12
22/07/2008	7	73.64	63.15	14
30/07/2008	8	22.31	43.08	-93
06/08/2008	9	147.97	122.56	17
13/08/2008	10	19.16	27.98	-46
20/08/2008	11	49.48	35.69	28
27/08/2008	12	10.30	12.51	-22
03/09/2008	13	109.77	128.52	-17
10/09/2009	14	252.98	248.03	2
17/09/2008	15	71.40	47.81	33
24/09/2008	16	1652.22	993.13	40
01/10/2008	17	1327.15	1105.32	17
08/10/2008	18	92.19	22.43	76
15/10/2008	19	30.32	41.18	-36
22/10/2008	20	36.53	23.45	36
29/10/2008	21	40.27	15.74	61
05/11/2008	22	41.13	17.39	58
12/11/2008	23	16.72	8.23	51
19/11/2009	24	8.78	3.64	58
26/11/2008	25	2.71	0.42	85
03/12/2008	26	5.55	1.47	73
10/12/2008	27	6.42	2.58	60
17/12/2008	28	40.07	4.25	89
24/12/2008	29	27.95	17.93	36
31/12/2008	30	9.76	3.69	62
07/01/2009	31	3.26	0.59	82
14/01/2009	32 (MSW)	8.84	1.21	86
21/01/2009	33 (MSW)	7.54	2.71	64

Using the bubbler method, 5 of the 33 sampling runs showed negative efficiency for the scrubber. The positive efficiencies ranged from 2 to 89%.

Infrared probe

Ammonia emissions in the exhaust air from the tunnels were also recorded on a continual basis (every 15 min) by the Gicom tunnel computer. An infrared probe was installed in the enclosed area above the tunnels and ammonia concentrations were measured in parts per million (ppm) at eight different sampling points.

- One in each exhaust ducting of the G3-G6 tunnels.
- The ducting before the scrubber.
- The ducting after the scrubber.
- Biofilter number 8; and
- The enclosed area above the tunnels (to collect data on background levels of ammonia).

Ammonia emissions were monitored by the infrared probe installed in the Gicom tunnels after 21st October 2008. The ammonia results obtained by this method are examined in more detail in the Process Monitoring sections of this report and are also provided in Table 20. Samples taken during the processing of MSW material are identified.

Table 20: Ammonia emissions –Gicom probe

Date	Sampling Number	Pre-Scrubber (ppm)	Post-Scrubber (ppm)	Scrubber Efficiency (%)
22/10/2008	1	3.7	16.4	-343
29/10/2008	2	18.2	7.5	59
05/11/2008	3	7.5	6.7	11
12/11/2008	4	47.6	12.3	74
19/11/2009	5	23.8	21.6	9
26/11/2008	6	12.3	41.6	-238
03/12/2008	7	16.4	9.3	43
10/12/2008	8	13.4	10.4	22
17/12/2008	9	24.9	13.8	45
24/12/2008	10	29.0	10.4	64
31/12/2008	11	5.2	2.3	56
07/01/2009	12	6.7	6.3	6
14/01/2009	13 (MSW)	18.2	19.0	-4
21/01/2009	14 (MSW)	19.9	12.5	37
28/01/2009	15 (MSW)	52.6	32.5	38
04/02/2009	16 (MSW)	239.9	113.1	53
11/02/2009	17 (MSW)	0.6	4.28	-613

Using the Gicom infrared probe method, 4 of the 17 runs showed a negative efficiency for the scrubber. The positive efficiencies range from 6 – 74%.

The three methods for detecting ammonia operate on different principles (Section 17.4) and therefore offer varying results. Overall the levels of ammonia detected in the pre-scrubber were very low compared to levels found in the composting of many other feedstocks such as animal manures, e.g. during the manufacture of compost for growing the commercial mushroom, *Agaricus bisporus*, which uses wheat straw and poultry manure as feedstocks.

The efficiency of the scrubber in removing ammonia varied considerably. While this was in part due to the inherent difficulty in sampling at different parts of the system, with the tunnel composting at different stages, it is also likely that this was also due to the water within the scrubber becoming saturated with ammonia, thereby reducing its efficiency in removing ammonia from the process air.

12.4 Odour

According to the Pollution Prevention and Control (England and Wales) Regulations (the "PPC Regulations") odours are considered as pollution which is defined as emissions as a result of human activity which may be harmful to human health or the quality of the environment, cause offence to any human senses, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment.

Sampling locations for odour sampling are marked in yellow in Figure 95. Details of procedure are given in SOP 10.

Triplicate odour samples were taken from 4 sampling locations:

- The ducting before the scrubber.
- The ducting after the scrubber.
- Biofilter number 6.

Sampling was carried out using a custom-made odour kit comprising:

- Sample barrel.
- PET sample bags.
- PTFE sample tubes with stainless steel fittings.
- Vacuum pump with plastic tube to connect to the barrel;

Triplicate samples were collected from all four sampling points. Samples were sent to a UKAS accredited laboratory (either Silsoe Odours or Odournet) for analysis of odour concentration using the dynamic olfactometry method to BS EN13725. The results are shown in Table 21 and are the geometric means of the triplicate samples. Samples taken during the processing of MSW material are identified.

Table 21: Odour sampling results

Date	Run	Pre-Scrubber ($ou_E m^{-3}$)	Post-Scrubber ($ou_E m^{-3}$)	Post-Biofilter ($ou_E m^{-3}$)	Scrubber Efficiency (%)	Biofilter Efficiency (%)	Overall efficiency (%)
01/03/2008	7	15,519	12,666	3,494	18	72	77
07/04/2008	9	27,806	14,812	4,804	47	68	83
10/07/2008	22	51,526	41,837	11,137	19	73	78
20/08/2008	33	160,374	66,100	2,605	59	96	98
01-02/10/2008	45	67,123	22,018	12,732	67	42	81
20/10/2008	48	7,090	3,212	7,763	55	-142	-9
29/10/2008	50	61,593 (MSW)	22,103	6,630	64	70	89
18/12/2008	MSW 2	20,138 (MSW)	28,971	6,148	-44	79	69
19/01/2009	MSW 6	3,460 (MSW)	4,704	2,313	-36	51	33

The scrubber efficiency varied from 18 – 67%, with two negative efficiency values. The biofilter efficiency varied from 42 – 96% efficiency with one negative efficiency result. The combined efficiency of both scrubber and biofilter varied from 33 to 98% with one negative efficiency result.

In all cases, even with the total negative efficiency result, odour levels in the area around the biofilters were barely detectable, and certainly the odour levels at this point would not lead to any detectable increased odour levels at the site boundary. No odour complaints were made relating to any project activity during the course of the project.

Odour levels were also determined on top of windrow for some of the runs. The results of these analyse are given in the following Table.

Table 22: Odour levels above windrows

Date	Associated run	Ou_Em^{-3}
10/3/2008	7	556
07/04/2008	9	278
10/07/2008	22	1,202
20/08/208	33	175
01/10/2008	45	974
20/10/2008	48	342
29/10/2008	50	1,643
14/01/2009	MSW 1	4,912
14/01/2009	MSW 2	2,250

The odour levels above the windrows made from MSW feedstock were much higher that those above the windrows made from kitchen waste and green waste. However, the windrow figures were much lower that the pre-scrubber figures in the tunnels, and, with the exception of MSW 1, were lower than the post-biofilter levels from the tunnel composting stage. Such levels would be very unlikely noticeable increase the level of detectable odours at the site boundary. No odour complaints associated with project activities were made during the course of the project.

12.5 Bioaerosols

Bioaerosols are usually described as micro-organisms or fragments of living cells suspended in air. They include: bacteria, fungi (yeasts and moulds), actinomycetes, protozoa, spores, pollen, dust mites, fragments of plant material and human and animal debris (skin cells, hair, etc). Most common bioaerosols for composting facilities are micro-organisms and fragments of plant materials.

Bioaerosol sampling for this project was carried out by the University of Leeds and included monitoring emissions of *Aspergillus fumigatus* and mesophilic bacteria at the following sampling locations:

- Exhaust ducting of G3 tunnel.
- Exhaust ducting of G4 tunnel.
- Exhaust ducting before the scrubber.
- Exhaust ducting after the scrubber; and
- Exhaust air from two biofilters (6, 10 and later 3, when block of 9-12 biofilters was blocked off to improve airflow).

Anderson 6-stage Cascade Impact Samplers were used for the collection of samples. The methodology used was based upon Standardised Protocol for the Sampling and Enumeration of Airborne Micro-organisms at Composting Facilities developed by The Composting Association in 1999. Separate sampling sessions were carried out for co-mingled kitchen waste and green waste and MSW runs.

Results of the bioaerosols sampling collected during processing of co-mingled kitchen waste and green waste feedstock and MSW feedstock are provided in a separate report by the University of Leeds.

12.6 Noise

During March 2008 a noise survey was carried out by an independent noise consultant at the site boundaries (north, south, east and west) during daylight hours when the normal site activities were being carried out, and at night time when the project tunnels were the only significant activity taking place on site. This survey indicated that at all times the dominant source of noise was not from the composting facility but from traffic on the two roads that border two of the sides of the site. The project tunnels, and associated vehicle movements, were not seen as an identifiable source of noise at the site boundary.

The site has never received a complaint about noise.

12.7 Dust

Work on the levels of atmospheric particulates and bioaerosols has been carried out by The University of Leeds and is published in a separate report.

12.8 Water quality/flow

All water discharged from the site through the water treatment plant satisfied the standards of the License to Discharge.

12.9 Air quality

This is covered by Section 17.4 of this report and the report to be published by The University of Leeds.

12.10 Climate

Results from the measurement of carbon dioxide and methane produced by the project tunnels are given in Section 11 of this report.

12.11 Building damage

No significant damage was encountered to the project tunnels or associated equipment during the course of the project.

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13 PROCESS MONITORING OF TUNNEL COMPOSTING OF MSW

13.1 Introduction

In addition to the composting of mixtures of kitchen waste and green waste, the project also carried out ten runs (MSW runs 1 to 10) using mixtures of the organic fraction of MSW (Municipal Solid Waste) mixed with co-mingled kitchen waste and green waste.

In recent years in the UK, and elsewhere in Europe, the emphasis has been on the composting of source-separated household organic wastes. The logic behind this has been that only by using such relatively clean material can compost of sufficient quality be generated for use in agriculture and horticulture. This approach has been very successful in generating very large quantities of excellent quality compost that is received with a degree of confidence by the agricultural or horticultural user. The increasing use of the PAS 100 standard has greatly assisted this development.

However, there is a continuing interest in making ‘compost-like’ material (CLO) for possible use in low quality applications such as brown field site restoration. For this reason, 8 of the runs in this project were dedicated to producing CLO from a combination of MSW fines and source-separated kitchen and green waste.

Several in-vessel composting systems, including batch tunnels, have been used to dry ‘black bag’ or other mixed waste feedstocks in order to produce refuse-derived fuels (RDF). This approach is often part of a system that recovers dry recyclable materials such as glass, cardboard and plastic from the waste leaving dry organic matter that can be used as a fuel in a waste to energy plant. For this reason, two of the MSW runs were dedicated to producing RDF from a feedstock of MSW fines and source-separated kitchen and green waste to determine the calorific value of the resultant material.

13.2 Feedstock mixtures

The ratios of MSW, kitchen waste and green waste in each of the ten runs are shown in Table 23. The runs were carried out between 11th December 2008 and 12th February 2009.

Table 23: Feedstock mixtures for MSW runs

	Fill Date	Tunnel	Total wt.	% kitchen waste	% MSW fines	% green waste
1	11-Dec	G3	194.72	17%	24%	58%
2	15-Dec	G5	221.80	16%	22%	62%
3	18-Dec	G3	195.56	16%	27%	57%
4	06-Jan	G5	182.76	27%	28%	46%
5	07-Jan	G3	185.10	18%	28%	54%
6	14-Jan	G5	183.56	23%	26%	51%
7	15-Jan	G3	203.88	20%	26%	54%
8	23-Jan	G5	240.12	19%	21%	60%
9	25-Jan	G3	206.20	20%	24%	56%
10	12-Feb	G5	162.28	32%	28%	40%

An upper limit of 28% (by weight) of MSW fines was set on the grounds that a higher percentage would increase the bulk density of the feedstock mixture to an extent where efficient air movement within the composting tunnels would be compromised. This is especially the case if there is also a high level of kitchen waste present. This decision was based upon experience in composting MSW fines by one of the project team outside this project.

Each composting tunnel was filled with shredded feedstock that was mixed to ensure an appropriate bulk density and C:N ratio for effective composting, and filled to a depth of 2.5 - 3.5 metres by a front-end loader, leaving a headspace of 1.0 -1.5m. The bulk density of the feedstock was determined by operator inspection rather than measurement. The operators have considerable experience in judging the maximum depth to which any feedstock can be filled. All of the different proportions of kitchen waste and green waste had C:N ratios within the range that allows effective composting.

13.3 Process control

As with the composting of co-mingled kitchen waste and green waste, in order to establish the efficiency of the tunnels, a number of parameters were measured by the Gicom tunnel computer. Other parameters were manually sampled to provide independent verification of the data. The Gicom computer data was compiled and subsequently analysed for all the composting runs. This data allowed a determination of the effect of varying the proportions of food waste and green waste in the feedstock on the performance of the tunnels.

The raw data collected by the tunnel computers and other manual measurements were collected into an Excel workbook available as an addition to this report. Once the tunnel was filled and closed, the composting process was controlled by the Gicom computer equipped with custom designed software. The computer system allows dynamic control and pre-programming of a series of processing set points. The computer control system continuously adjusts parameters by comparing the monitored data with the set points.

The MSW runs can be divided into two sections: eight runs were use to produce compost-like output and two runs were used to produce refuse derived fuel.

13.4 Process control for MSW runs producing CLO

The method of processing the MSW mixtures in the tunnels to produce CLO was essentially identical to that used for the processing of co-mingled kitchen waste and green waste. The method of sampling the emissions from these MSW composting runs was also identical to that used for the composting of co-mingled kitchen waste and green waste.

Intensive Runs

Two of the eight MSW composting runs were 'intensive' (MSW runs 1 and 2). These intensive runs were monitored from the time at which waste entered the site, through the tunnel and windrow composting stages, to the final screening process to produce the compost product.

In addition to the data collected by the Gicom computer system, further manual monitoring was carried out during the intensive runs, including the collection of solid, liquid and gaseous samples. The method used was identical to that used for the monitoring of the co-mingled kitchen waste and green waste.

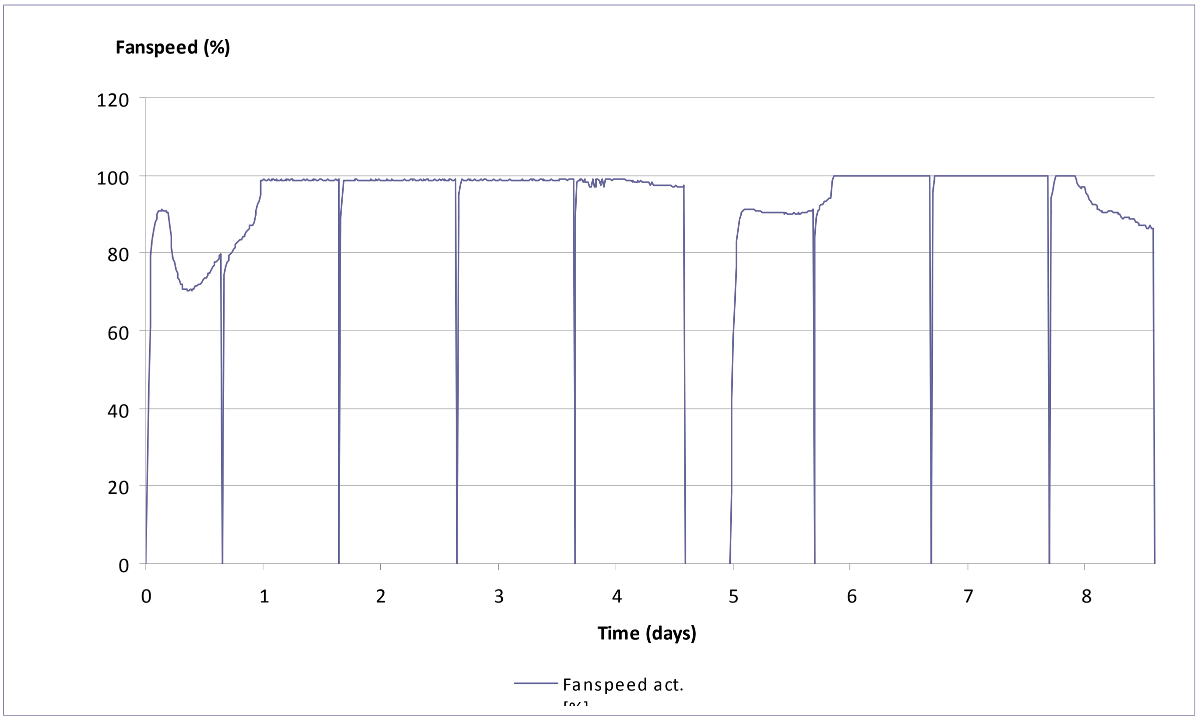
The material from the windrows was sampled every 2 weeks, specifically to monitor its stability throughout the course of the composting process. The activity of the compost was determined by the weekly monitoring of temperatures within the windrows using a hand-held probe.

The data from MSW run 1 is used to illustrate the behaviour of this type of feedstock. This consisted of an estimated 17% kitchen waste, 24% MSW fines and 58% green waste and had the heated walls and floors turned on.

13.5 Residence time in tunnels for MSW runs producing CLO

The residence time of composting material in the tunnels for the first and second composting stages for each of the eight MSW runs was calculated. As an example, Figure 99 shows the residence time for the two stages of one particular run (MSW run 1). This run illustrates in detail the data collected for each run carried out by the project. The residence time is calculated by determining the time when the tunnel fan is first turned on and the time when it is finally turned off. At 24 hour intervals the tunnel fans are momentarily turned off in order to allow leachate to drain from the aeration pipes in the tunnel floor.

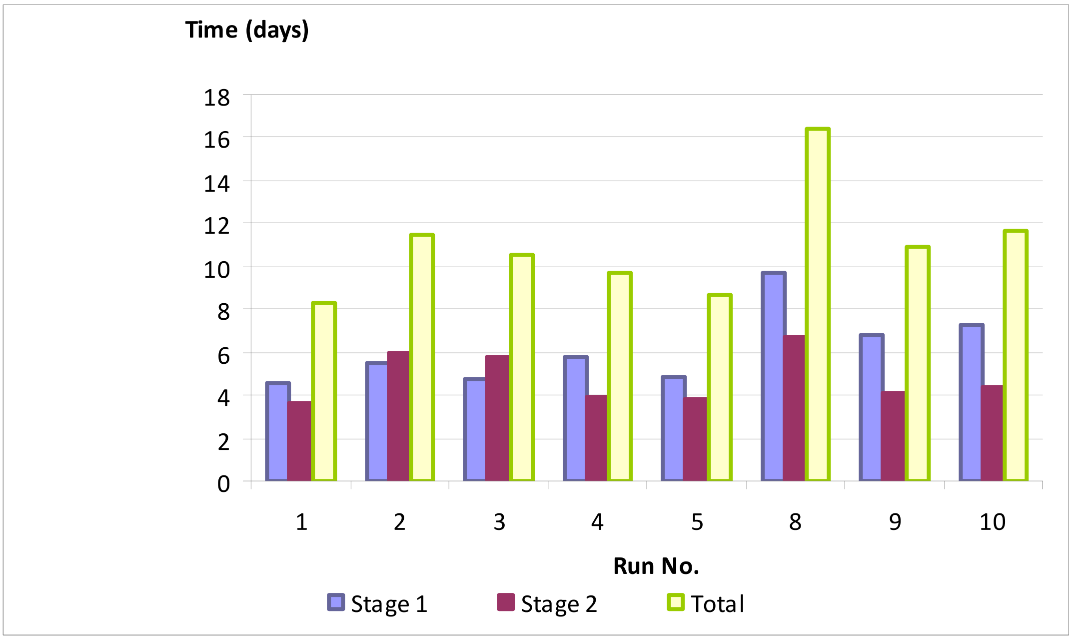
Figure 99: Residence time for MSW run 1 producing CLO



This Figure shows that the composting material spent 4.59 days in the first stage and 3.61 days in the second stage.

Figure 100 shows the residence times for both stages of all eight runs.

Figure 100: Residence time for MSW runs producing CLO



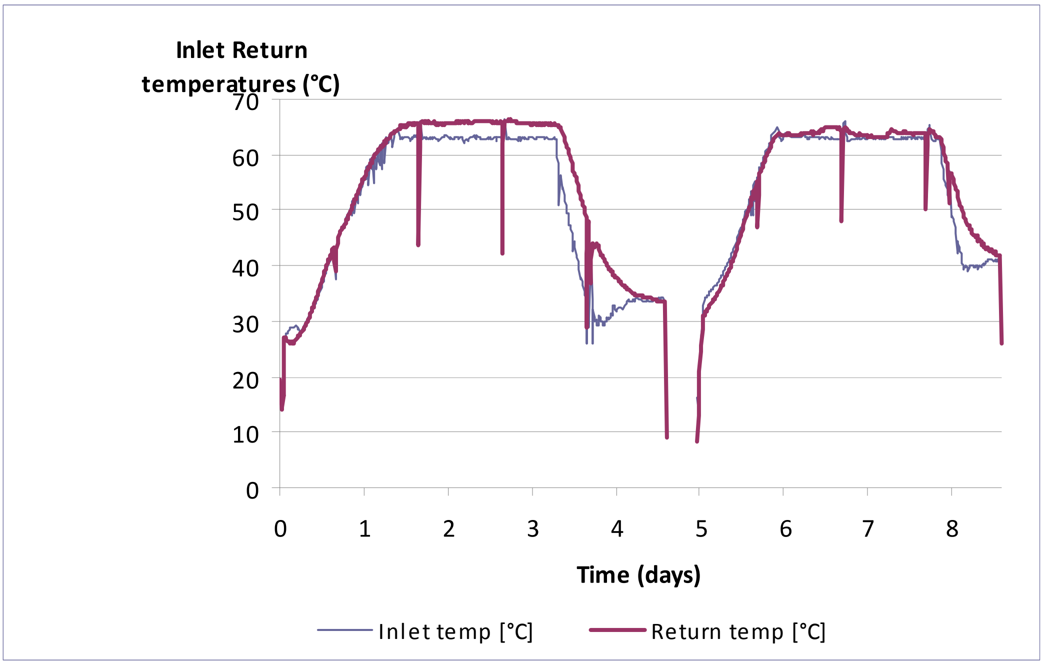
The residence time for the first stage varied from 4.60 days to 9.67 days. The residence time for the second stage varied from 3.68 days to 6.75 days. The combined residence time for both stages varied from 8.28 days to 16.42 days. MSW run 8 had a very long first stage as it was slower than normal in reaching pasteurisation temperatures.

13.6 Temperatures - Air inlet and return for MSW runs producing CLO

The difference in the temperature of air entering the floor of the tunnel (air inlet temperature) and the temperature of the air after it has passed through the compost (air return temperature) is an indication of the range of temperatures throughout the vertical profile of the composting matrix. In order to ensure a uniform composting environment within the tunnel this difference should be as small as possible.

As an example, Figure 101 shows the air inlet and air return temperatures for MSW run 1.

Figure 101: Air inlet and return temperatures for MSW run 1

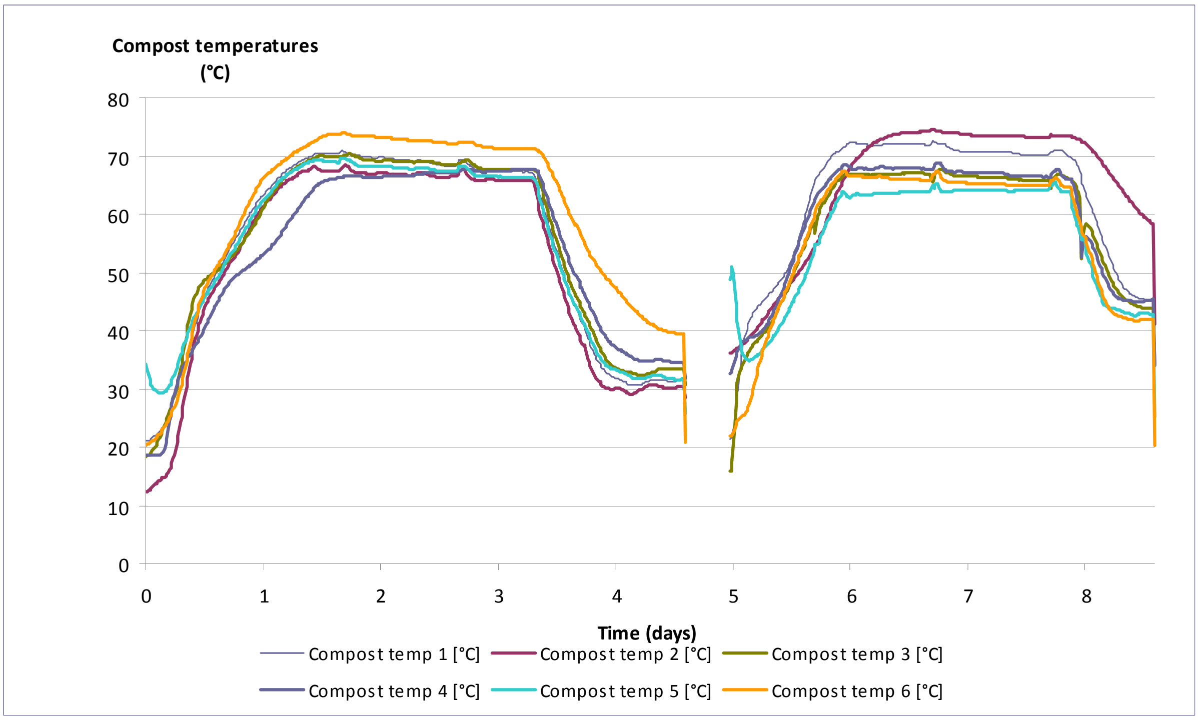


This Figure shows a very close correlation between the air inlet and air return temperatures for both stages of the run, indicating a very uniform composting environment. In both stages the temperatures are above the 60° C required for compost temperatures by the Animal By-Products Regulations (ABPR). The very short drop of the air temperatures every 24 hours is caused by the fans momentarily closing down as leachate is drained from the floor aeration pipes. As will be seen below, these temperature drops are in the air only and not in the compost itself.

13.7 Compost temperatures for MSW runs producing CLO

Six temperature probes were inserted into the compost for both stages of each run. In order to ensure as uniform a composting environment as possible, the temperatures recorded by each probe should be as uniform as possible. In order to comply with ABPR all 6 probes have to reach a minimum of 60° C for a minimum of 48 hours. As an example, the compost temperature readings for MSW run 6 are shown in Figure 102.

Figure 102: Compost temperature for MSW run 1

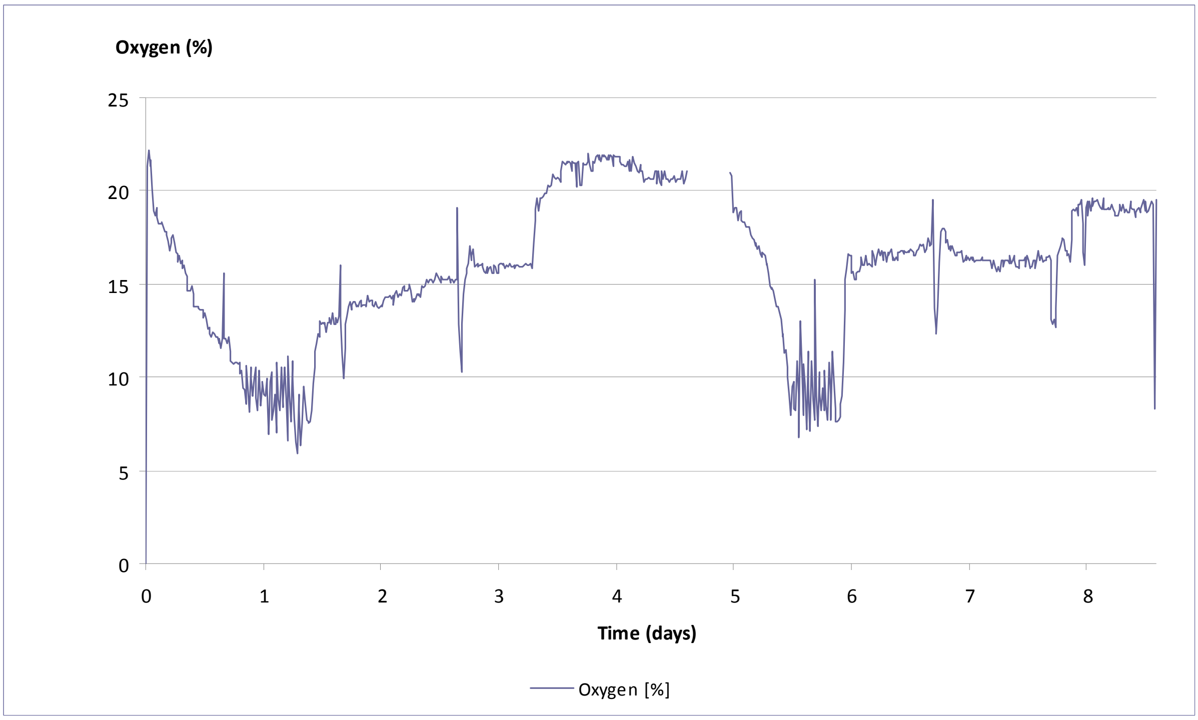


It can be seen that all 6 compost temperature probes exceeded 60° C for at least 48 hours for both stages of the composting process, thereby complying with ABPR. There were no particular problems associated with obtaining the required temperatures using this feedstock.

13.8 Oxygen consumption for MSW runs producing CLO

Figure 103 shows the percentage oxygen recorded in the recirculating air for MSW run 1.

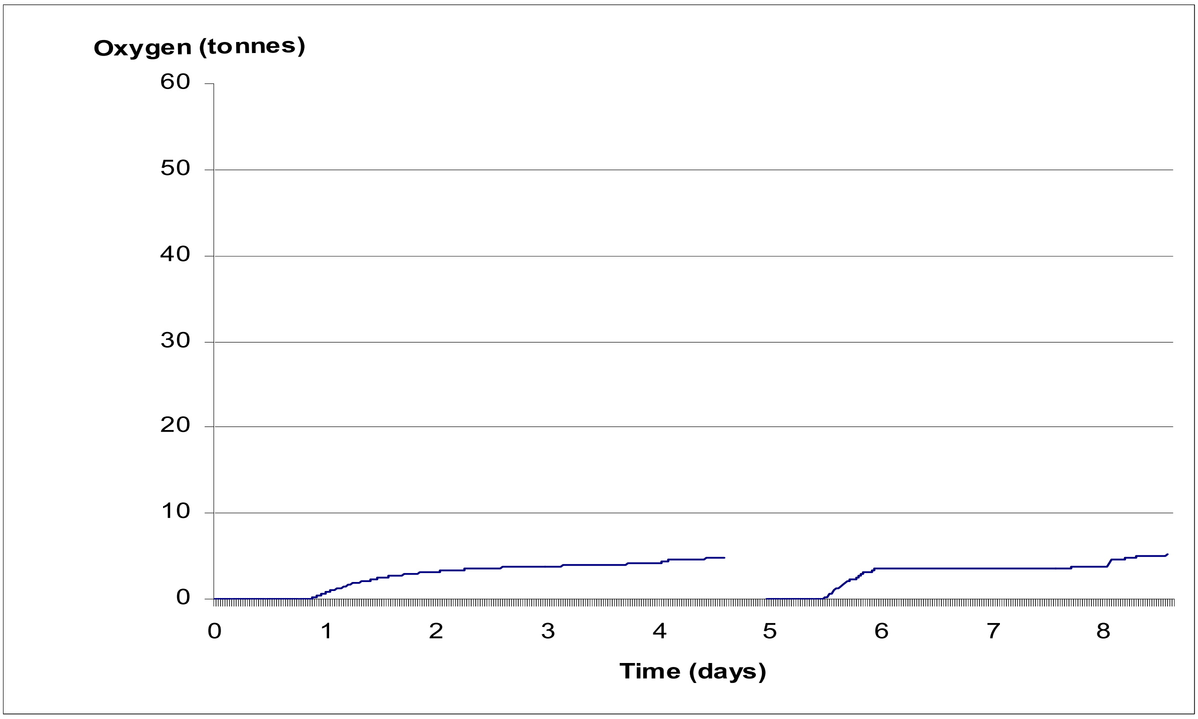
Figure 103: Oxygen levels during MSW run 1



This Figure shows that oxygen levels were maintained above 7% during both stages. The apparent momentary drop in oxygen levels at the end of the second stage is an artefact caused by the momentary shorting of the oxygen probe.

The tunnel computer also records the quantity of oxygen consumed during each run. Figure 104 shows the accumulative amount of oxygen consumed during both stages of MSW run 1.

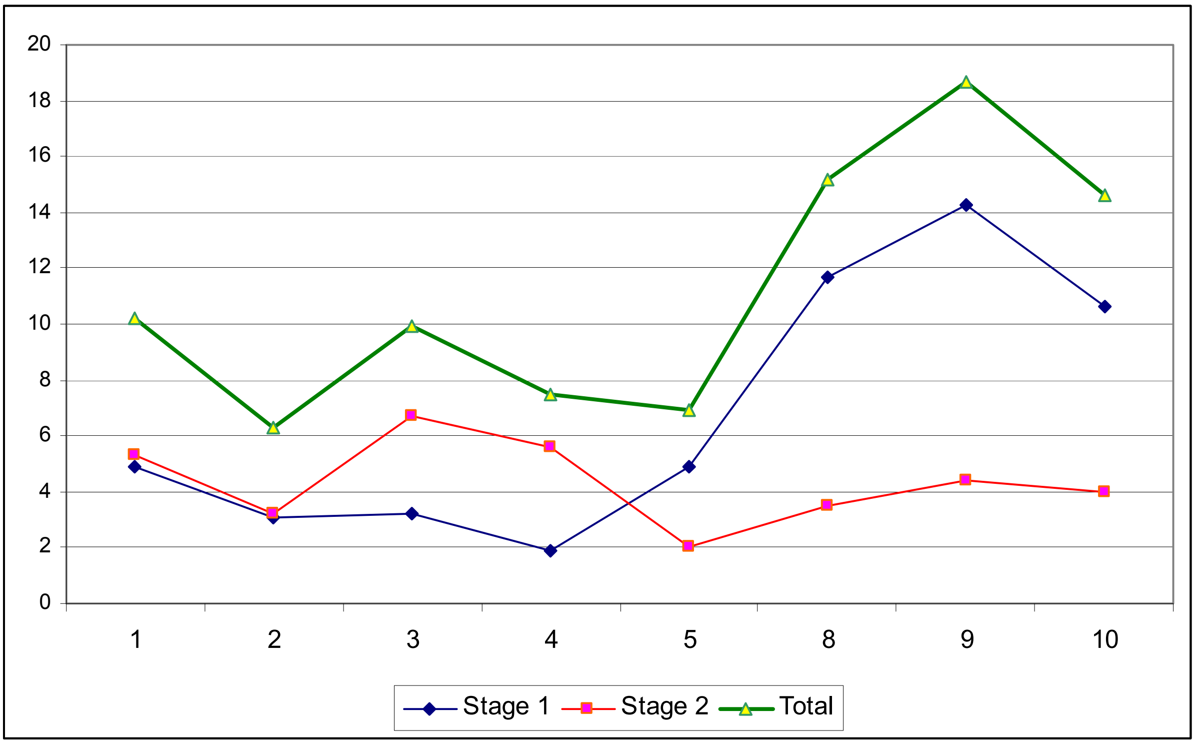
Figure 104: Oxygen consumed during MSW run 1 producing CLO



This Figure shows that during the first stage of this run 4.9 tonnes of oxygen were consumed, and during the second stage 5.3 tonnes were consumed.

Figure 105 shows the amounts of oxygen consumed during both stages of all 8 MSW runs producing CLO.

Figure 105: Oxygen consumed during MSW runs producing CLO

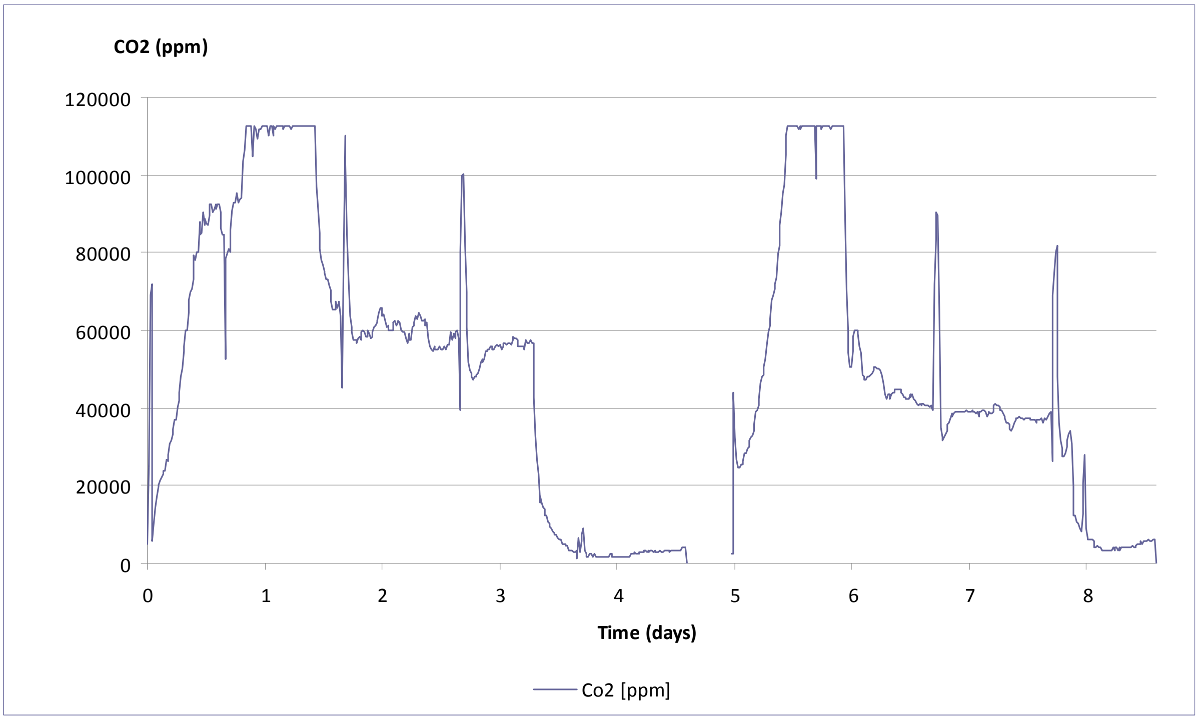


This Figure shows that the oxygen levels consumed during each stage, and between each run, varies considerably. The recorded levels of oxygen consumed by both stages varied from 6.3 tonnes to 18.7 tonnes. This considerable variation in oxygen consumption from run to run was encountered throughout the project.

13.9 Carbon dioxide produced by MSW runs producing CLO

The tunnel computer monitored the carbon dioxide levels in the recirculated air for each run. As an example, the carbon dioxide levels in MSW run 1 are shown in Figure 106.

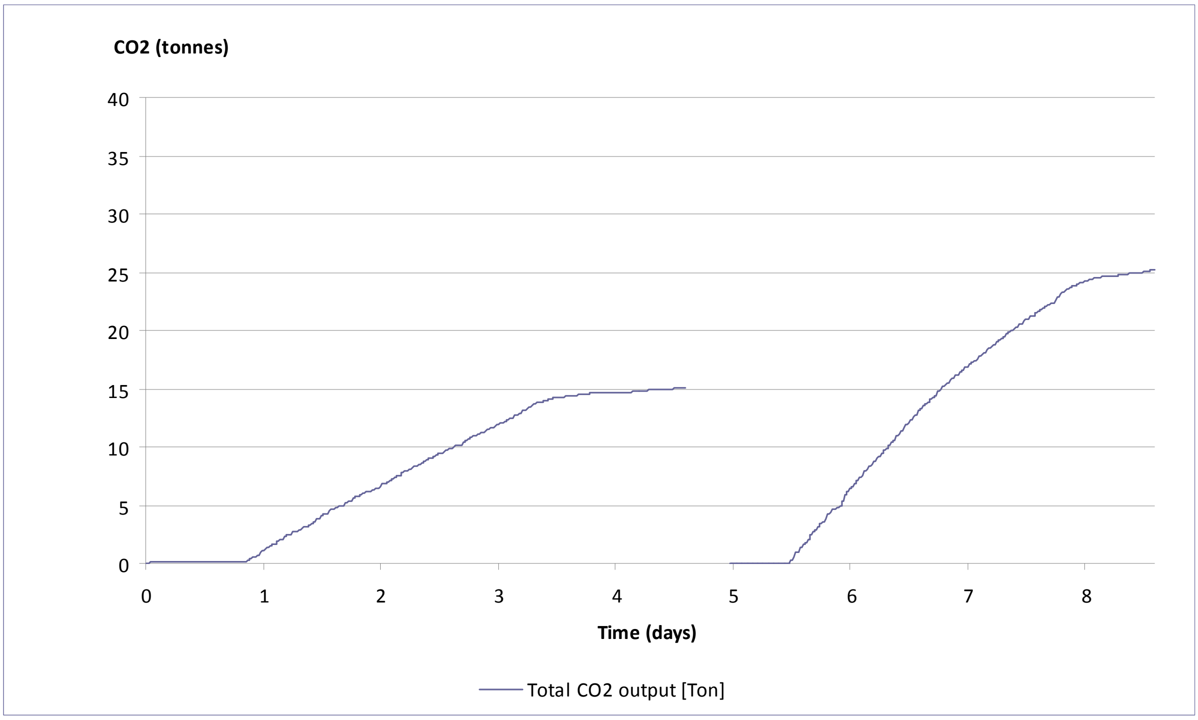
Figure 106: Carbon dioxide levels in MSW run 1 producing CLO



This Figure shows that carbon dioxide levels in excess of 110,000 ppm were generated during the most active sections of both stages. The graphs plateau at the maximum levels of carbon dioxide detection with this system. For each stage, the levels of carbon dioxide dropped off when large quantities of fresh air were introduced during the cooling down sections of the runs.

The tunnel computer also recorded to total quantity of carbon dioxide produced during each run. As an example, Figure 107 shows the total quantity of carbon dioxide produced during MSW run 1.

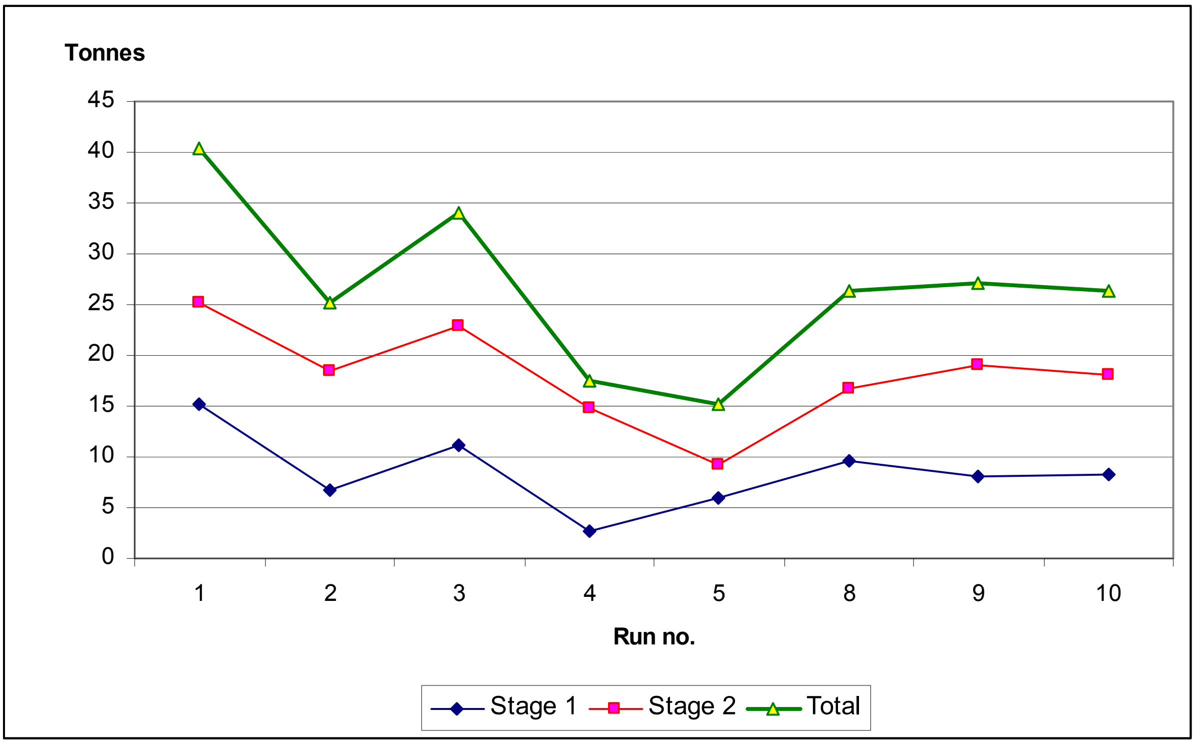
Figure 107: Carbon dioxide produced during MSW run 1 producing CLO



This Figure shows that during the first stage of MSW run 1 15.1 tonnes of carbon dioxide were produced, and during the second stage 25.2 tonnes were produced.

The amount of carbon dioxide produced for each of the 8 MSW runs producing CLO is shown in Figure 108.

Figure 108: Carbon dioxide produced during MSW runs producing CLO

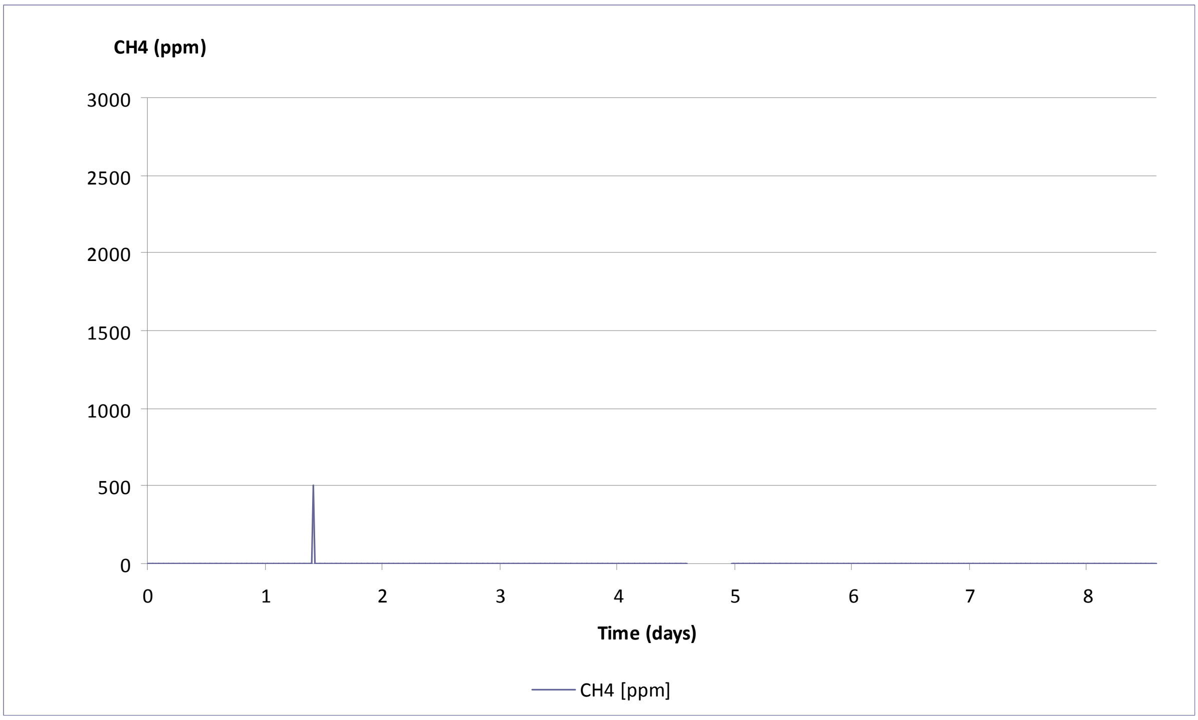


This Figure shows that the total amount of carbon dioxide produced by both stages of each run varied from 15.1 tonnes to 40.3 tonnes.

13.10 Methane detected in MSW runs producing CLO

As the composting process is fully aerobic, the presence of methane in the recirculated air would not be expected. However, in the early part of the first stage of some runs, small quantities of methane were detected. As an example, the methane levels in MSW run 1 are shown in Figure 109.

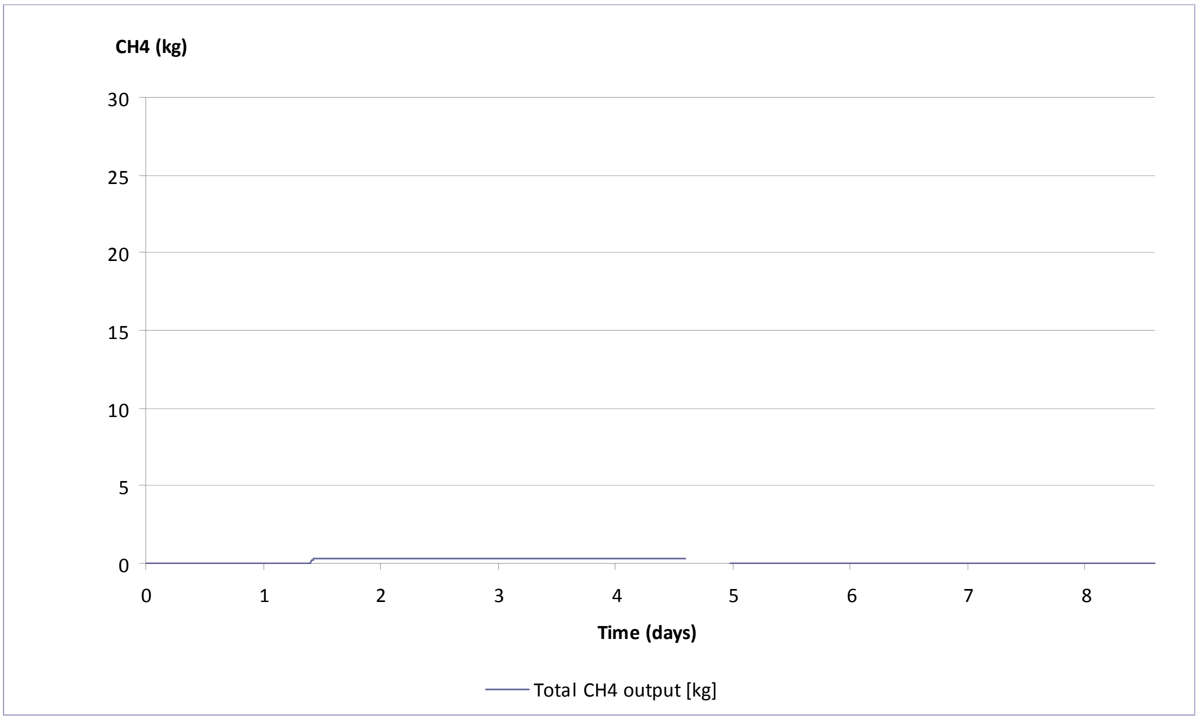
Figure 109: Methane levels detected in MSW run 1 producing CLO



This Figure shows that for a single reading methane was detected at 506 ppm in the recirculating air as the composting material warmed up in the first stage.

The tunnel computer also measured the total quantity of methane produced during a run. As an example, Figure 110 shows the amount of methane produced during MSW run 1.

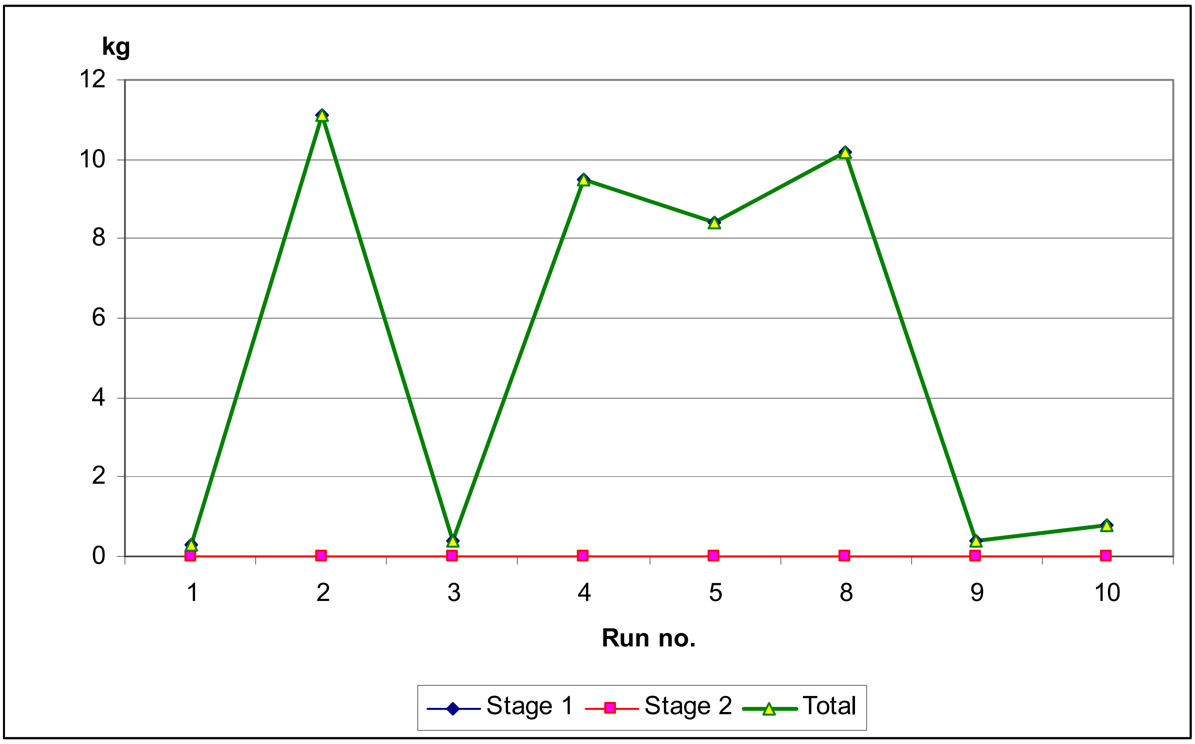
Figure 110: Methane produced during MSW run 1 producing CLO



This Figure shows that during the first stage of MSW run 1 0.3 kilos of methane were detected.

Figure 111 shows the quantity of methane detected for all the MSW runs producing CLO.

Figure 111: Methane detected in MSW runs producing CLO

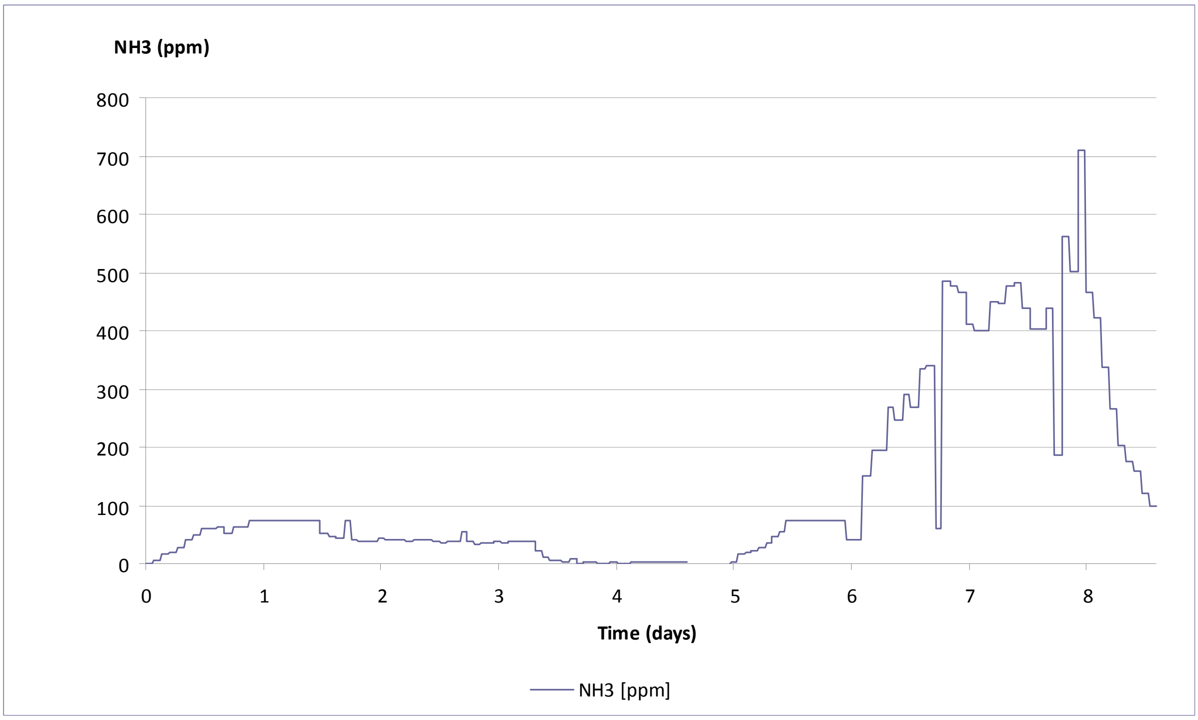


This Figure shows that the quantity of methane detected in the first stage varied from 0.4 to 11.1 kg. No methane was detected in the second stage of any run.

13.11 Ammonia produced by MSW runs producing CLO

As an example. The ammonia levels detected during MSW run 1 are shown in Figure 112.

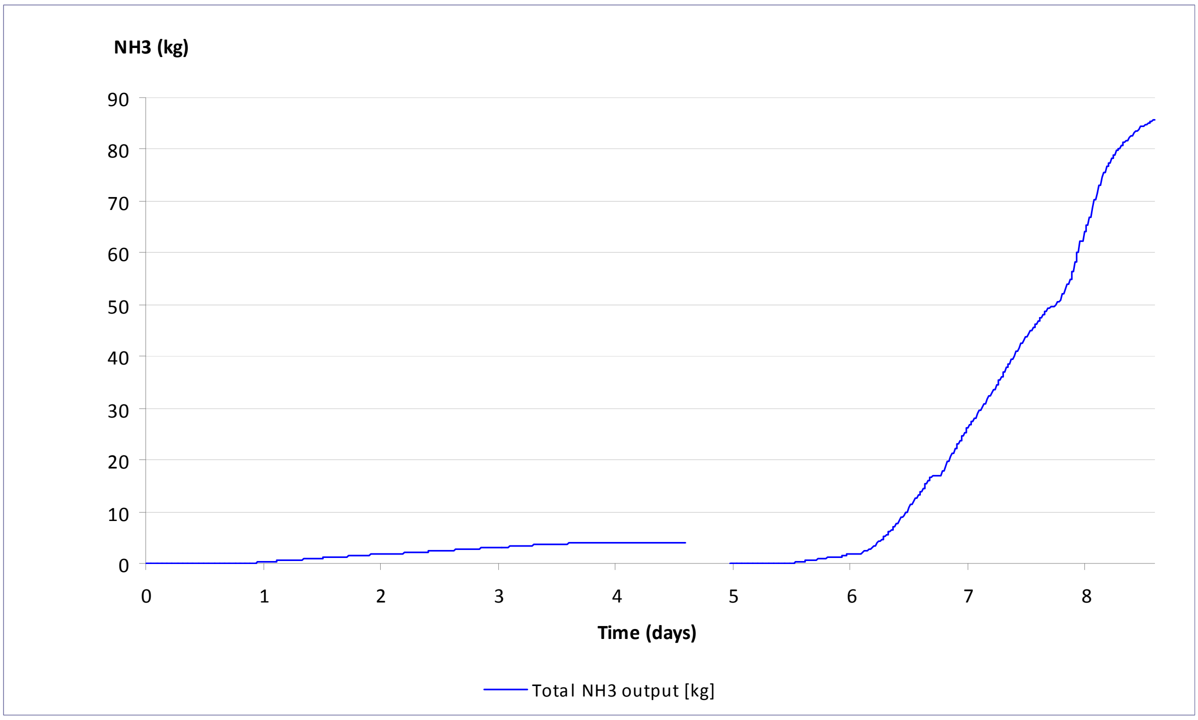
Figure 112: Ammonia levels in MSW run 1 producing CLO



In this run, ammonia was mainly produced during the latter half of the second composting stage.

The tunnel computer also calculated the total quantity of ammonia produced during MSW run 1 as shown in Figure 113.

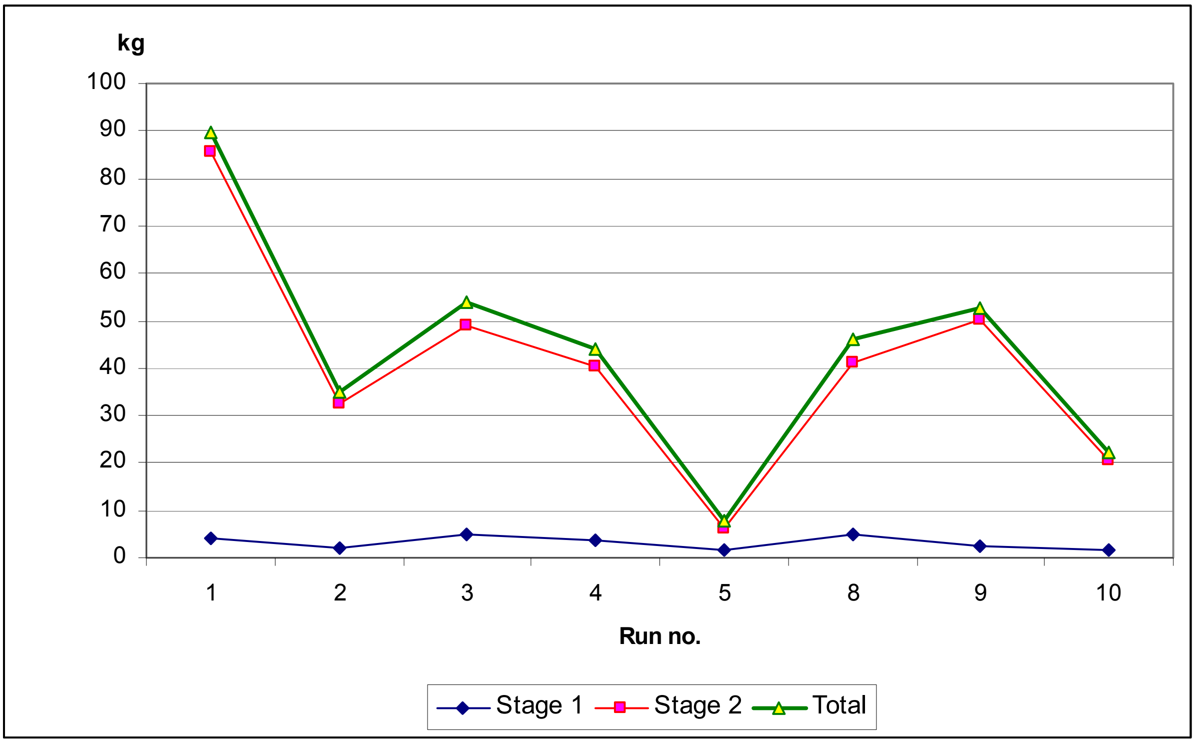
Figure 113: Ammonia produced during MSW run 1 producing CLO



In MSW run 1 4.1 kilos of ammonia was produced during the first stage and 85.7 kilos in the second stage.

The tunnel computer also recorded the amount of ammonia produced during all of the MSW runs producing CLO. The results are shown in Figure 114.

Figure 114: Ammonia produced in MSW runs producing CLO

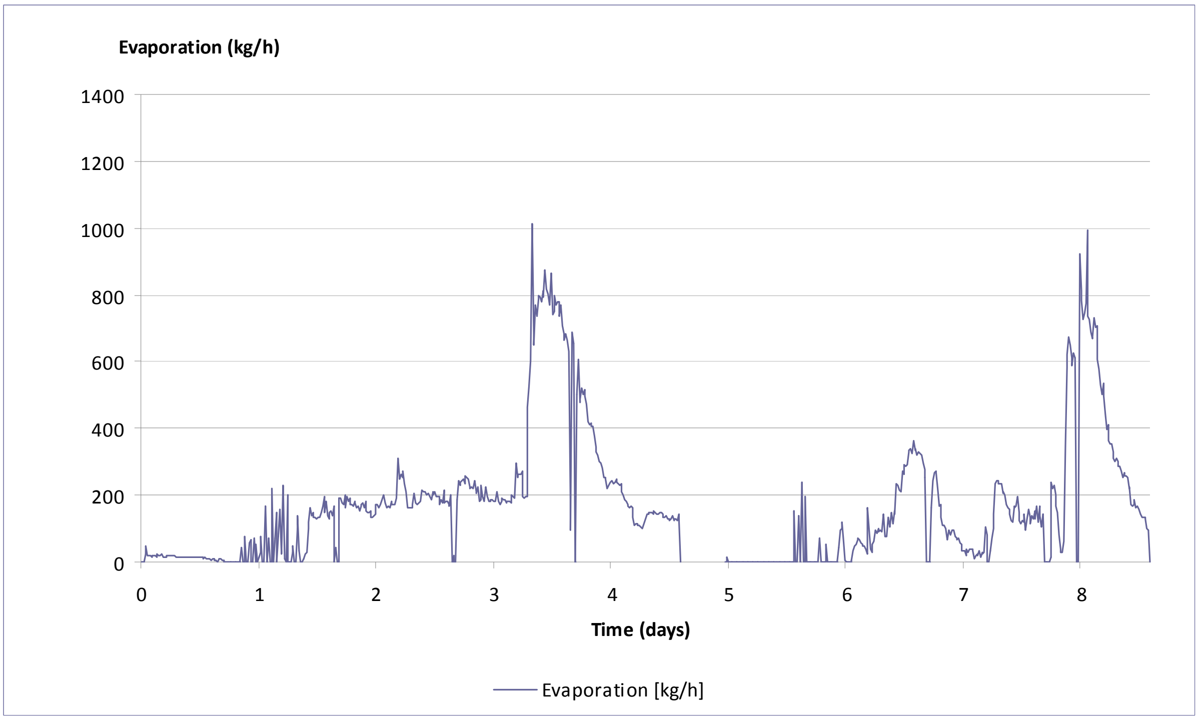


The amounts of ammonia produced during the first stage varied from 1.6 to 4.8 kg, and the amount produced during the second stage varied from 6.3 to 85.7 kg. The total amount of ammonia produced varied from 7.9 to 89.8 kg.

13.12 Water evaporation and spraying during MSW runs used to produce CLO

Because of the high temperatures maintained during the composting process, and because of the high volume of air passing through the composting material, a considerable amount of water is lost during the composting process. As an example, Figure 115 shows the rate of water evaporated during both stages of MSW run 1.

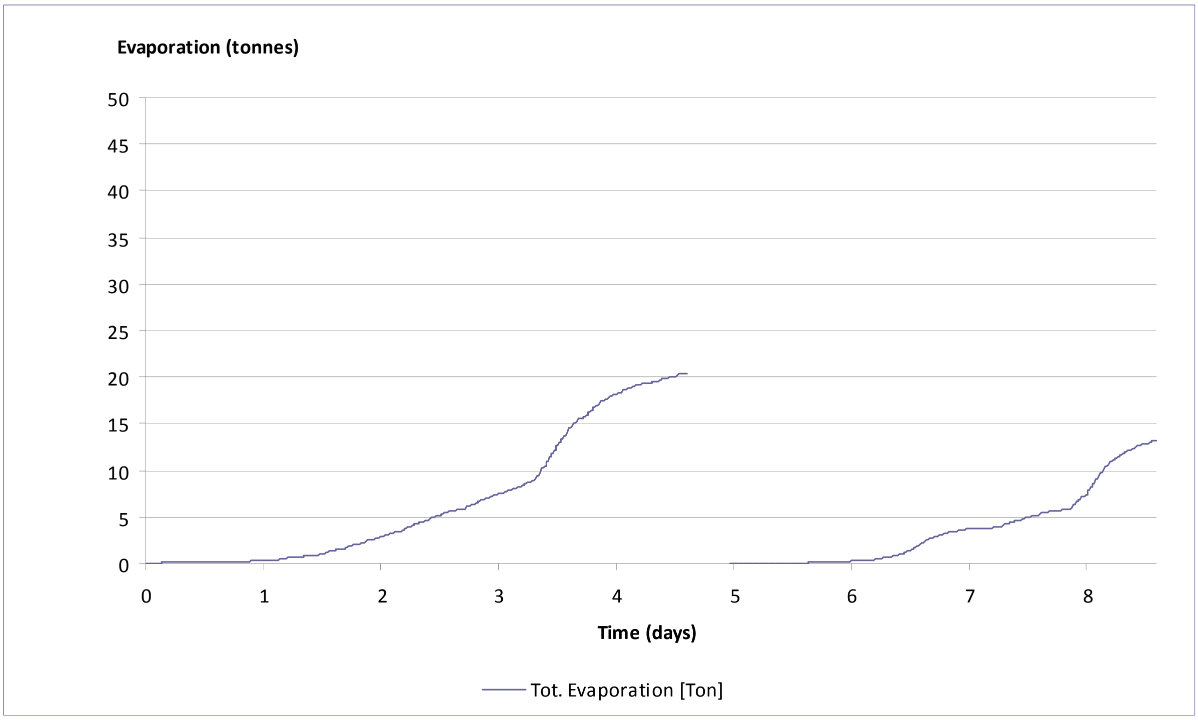
Figure 115: Rate of evaporation during MSW run 1 producing CLO



The Figure shows that the maximum rate of water loss for both stages occurs when the volume of fresh air being delivered to the tunnels is greatest during the cool down section.

The quantity of water evaporated is also calculated. The result for MSW run 1 is shown in Figure 116.

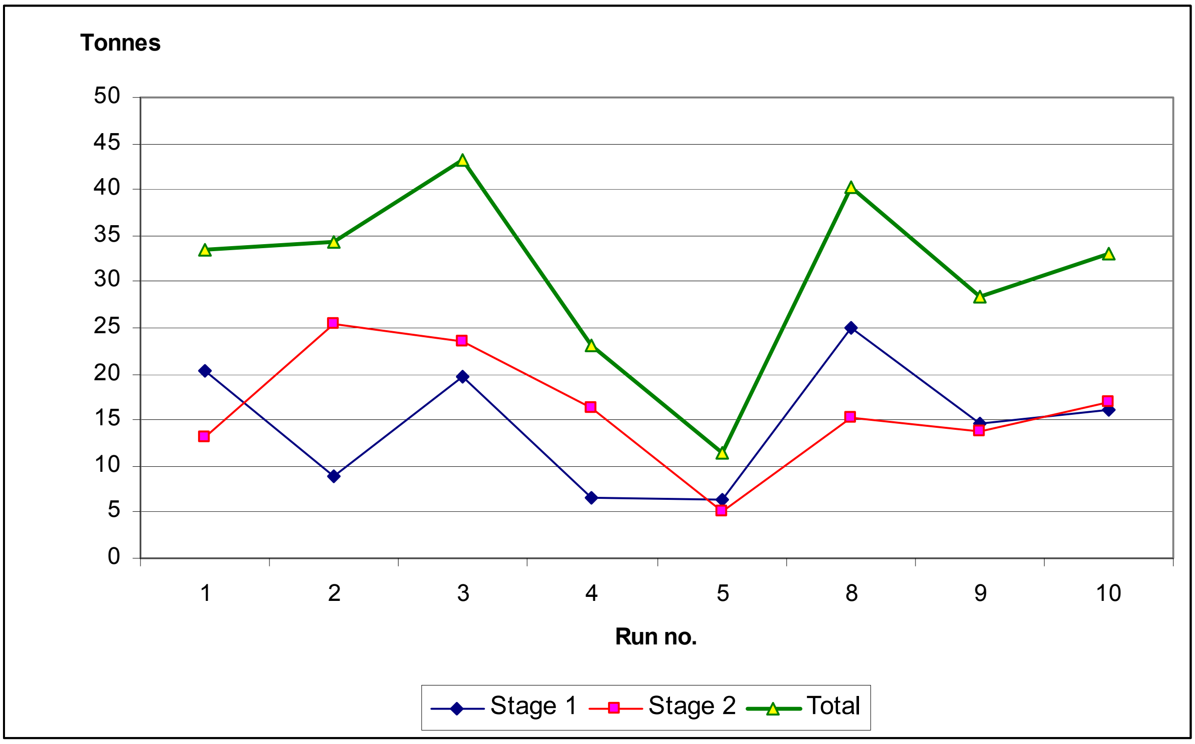
Figure 116: Evaporation during MSW run 1 to produce CLO



This Figure shows that during the first stage of MSW run 1 20.4 tonnes of water were evaporated, while during the second stage 13.1 tonnes were evaporated.

The tunnel computer also recorded the loss of water by evaporation during all the MSW runs producing CLO. The results are shown in Figure 117.

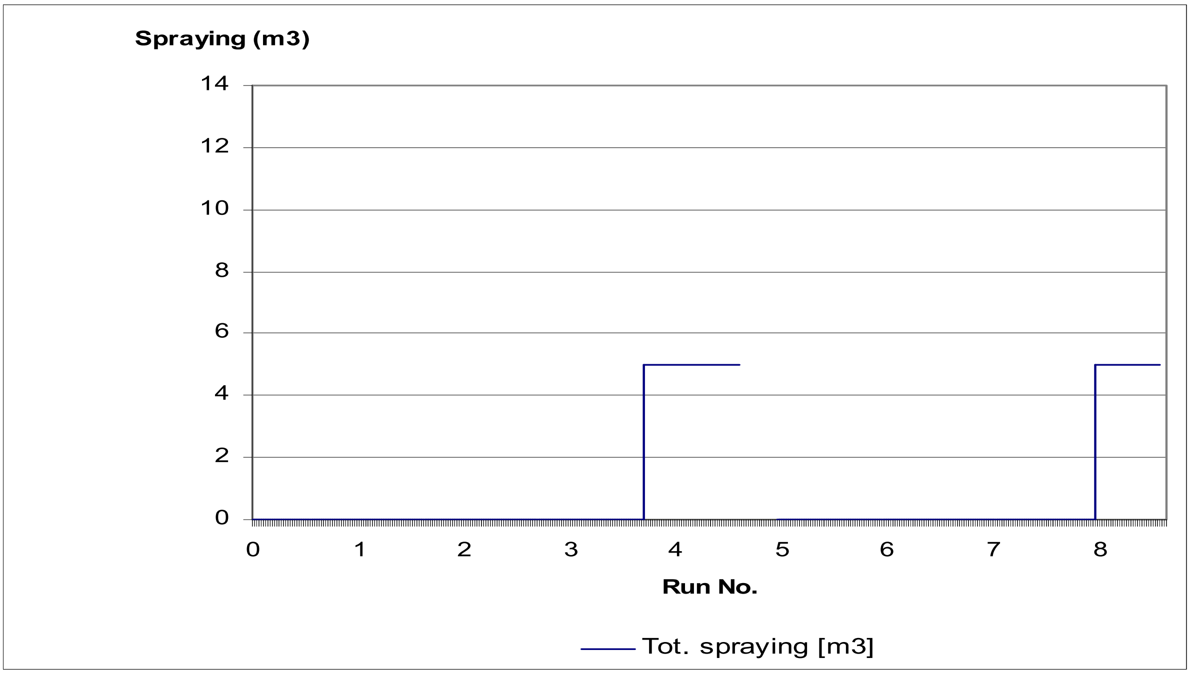
Figure 117: Water loss by evaporation during MSW runs producing CLO



The amount of water lost by evaporation during first stages of the runs varied from 6.4 to 20.4 tonnes, while during the second stage the amount lost varied from 5.0 to 25.4 tonnes. The total amount of water lost for the entire run varied from 11.4 to 43.2 tonnes.

In order to compensate for the water losses described above, water was sometimes sprayed on to the composting material through spray bars located on the tunnel roof. For example, the volume of water sprayed during MSW run 1 is shown in Figure 118. The addition of water at this stage is a management decision based on the estimated moisture levels of the feedstock filled into the tunnels.

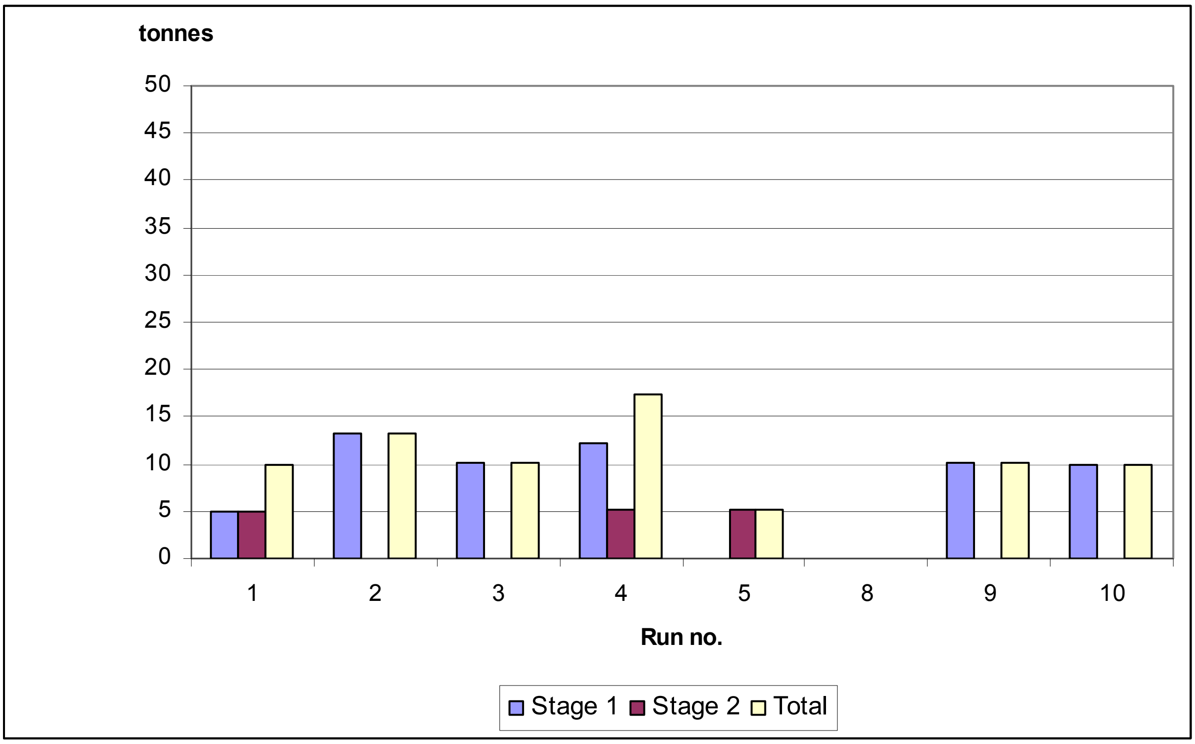
Figure 118: Water added by spraying during MSW run 1 producing CLO



This Figure shows that during the first stage of MSW run 1 5.0 tonnes of water were added, while during the second stage another 5.0 tonnes were added.

The tunnel computer also recorded the amount of water added by spraying for MSW runs producing CLO, as shown in Figure 119.

Figure 119: Water added by spraying during MSW runs producing CLO

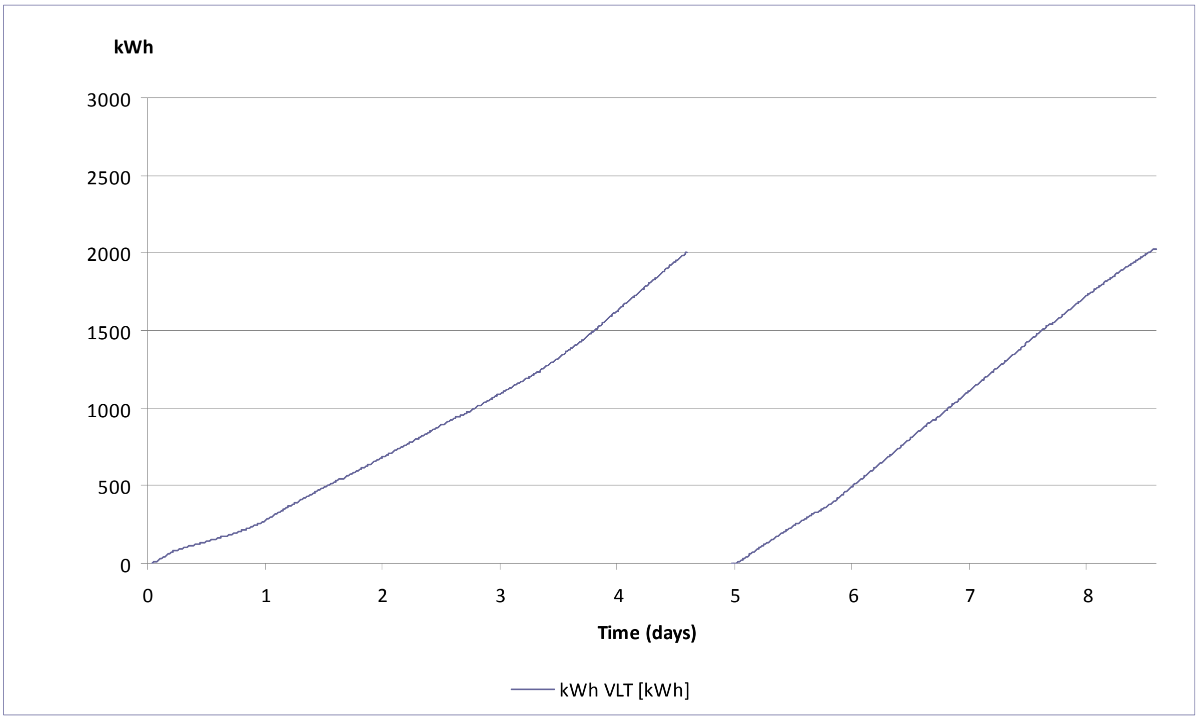


This Figure shows that the amount of water added by spraying during the first stage varied from 0 (2 runs) to 13.2 tonnes. The amount of water added by spraying during the second stage varied from 0 (5 runs) to 5.1 tonnes. The total amount of water added by spraying for the entire run varied from 0 (1 run) to 17.3 tonnes**.**

13.13 Electricity utilisation by MSW runs used to produce CLO

Most of the electricity used to operate the tunnel system is employed in running the large tunnel fans. The tunnel computer measured the usage of electricity by the fans throughout the composting process. As an example, the electricity usage during MSW run 1 is shown in Figure 120

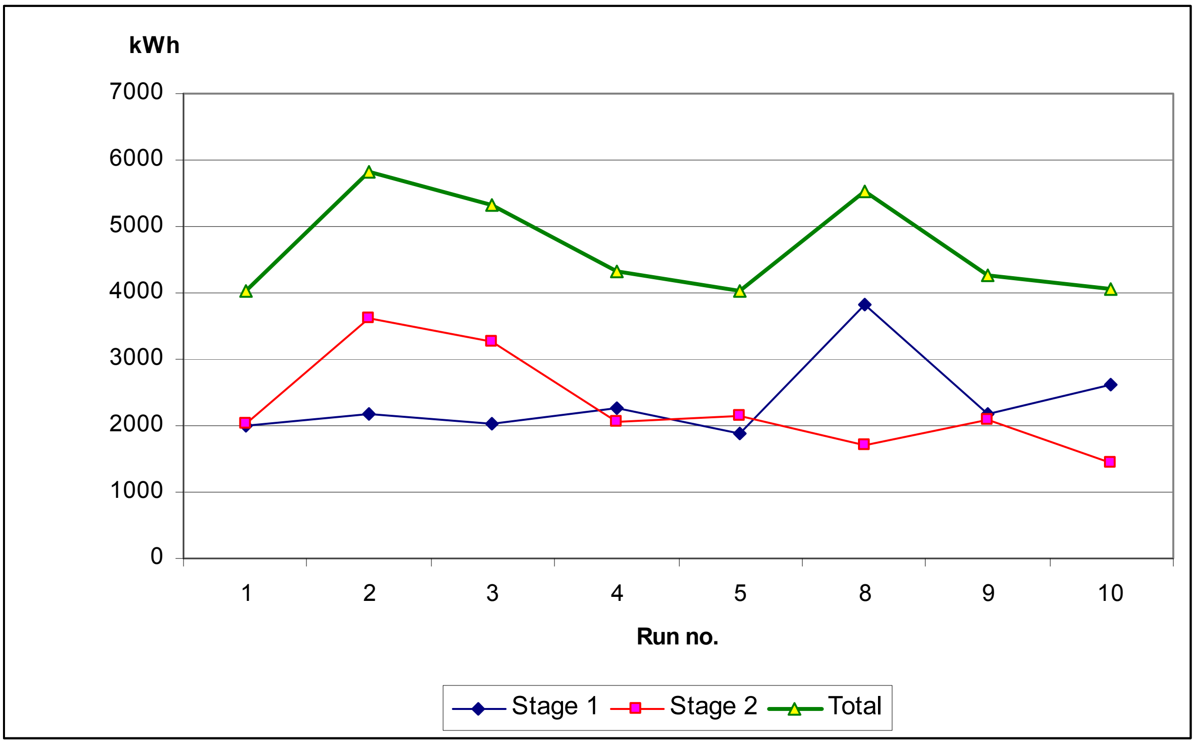
Figure 120: Electricity consumption during MSW runs producing CLO



This Figure shows that 2,005 kWh were used in the first stage and 2,027 kWh were used in the second stage.

The tunnel computer also measured electricity consumption for all of the MSW runs producing CLO, as shown in Figure 121.

Figure 121: Electricity consumption during MSW runs producing CLO



This Figure shows that the electricity consumption by the first stage varied from 1,874 kWh to 3,809 kWh. Consumption during the second stage varied from 1,435 kWh to 3,629 kWh. The total electricity consumption for each run varied from 4,031 kW h to 5,809 kWh.

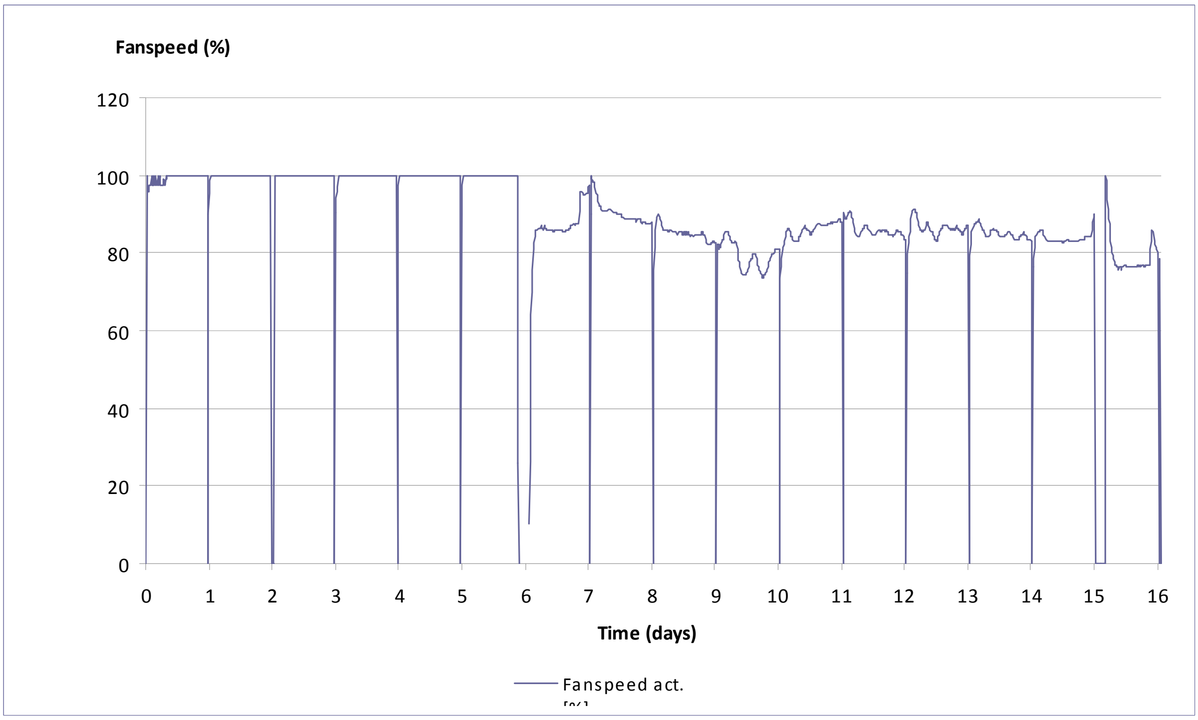
13.14 Process control for MSW runs producing RDF

MSW runs 6 and 7 were used to produce RDF. The method of tunnel composting varied from the other eight MSW runs by having extended second stages and with no water being added during this stage. By this method, the moisture of the material in the tunnel was reduced as much as practically possible.

13.15 Residence time in tunnels for MSW runs producing RDF

Figure 122 shows the residence time for the two stages of one particular run (MSW run 6). This run illustrates in detail the data collected for each run carried out by the project.

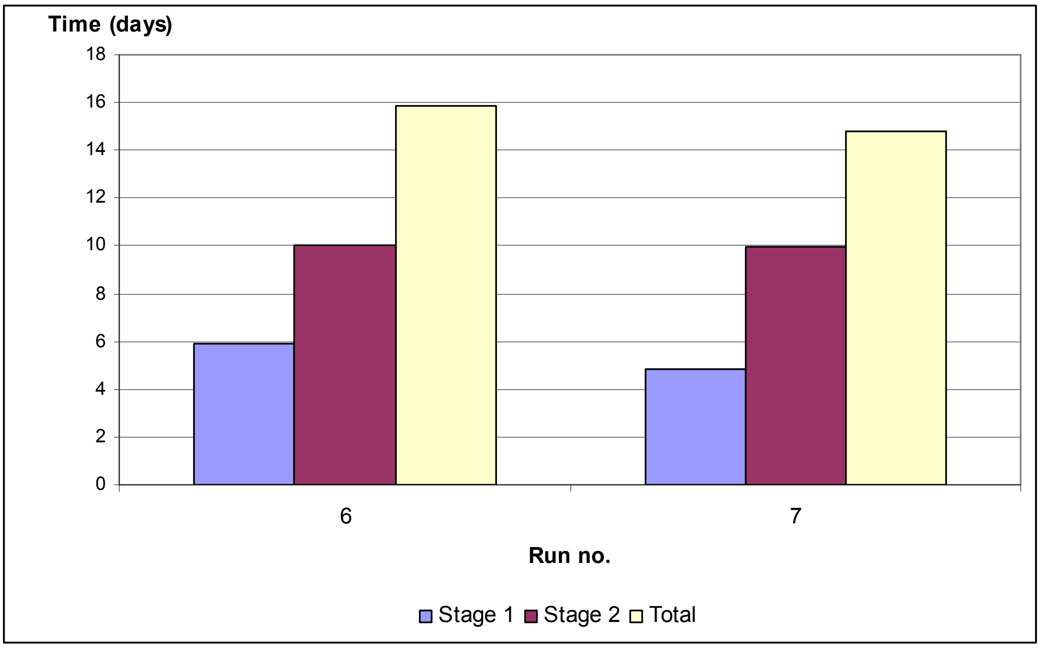
Figure 122: Residence time for MSW run 6 producing RDF



The figure shows that the material spent 5.90 days in the first stage and 10.00 days in the second stage.

Figure 123 shows the residence times for both MSW runs.

Figure 123: Residence time for MSW runs producing RDF

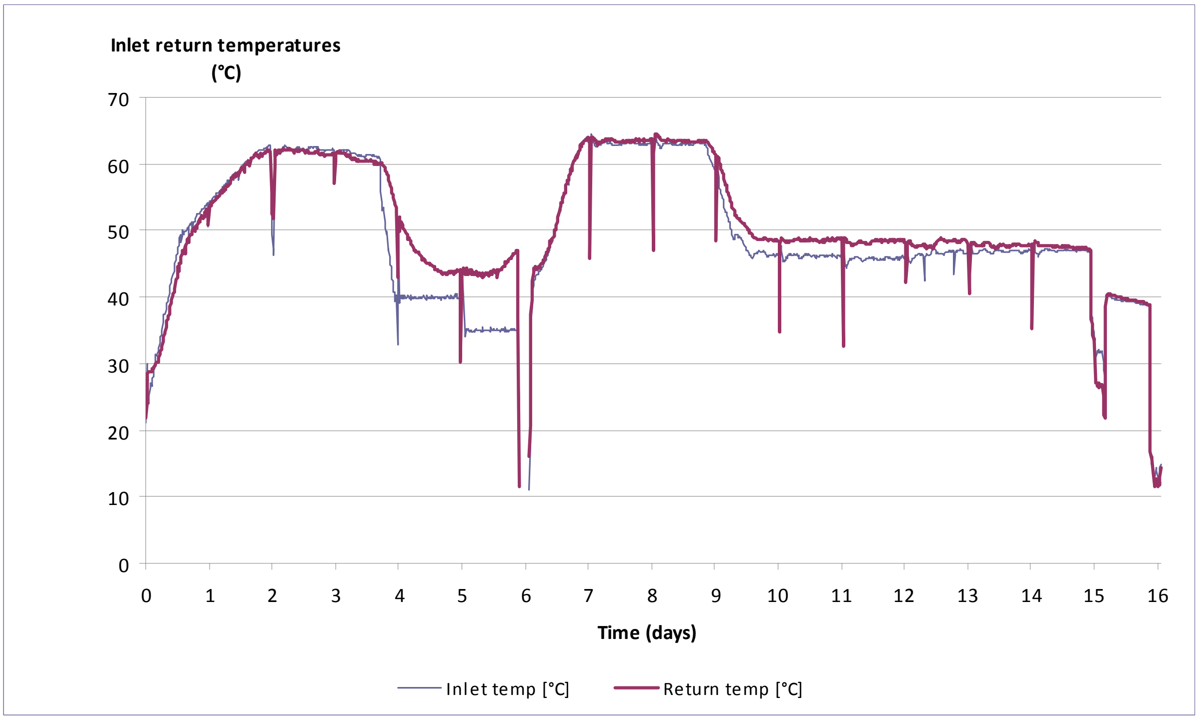


The residence time for the first stage varied from 4.85 days to 5.90 days. The residence time for the second stage varied from 9.93 days to 10.00 days. The combined residence time for both stages varied from 14.78 days to 15.90 days.

13.16 Temperatures – Air inlet and return for MSW runs producing RDF

As an example, Figure 124 shows the air inlet and air return temperatures for MSW run 6.

Figure 124: Air inlet and return temperatures for MSW run 6 producing RDF

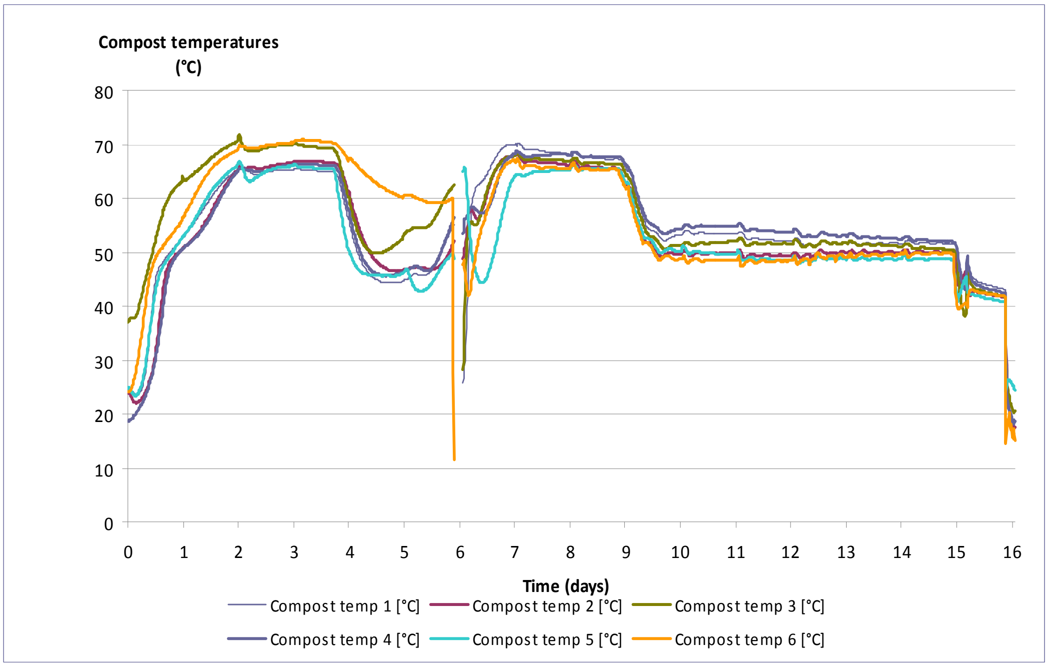


This Figure shows a very close correlation between the air inlet and air return temperatures for both stages of the run, indicating a very uniform composting environment.

13.17 Compost temperatures for MSW runs producing RDF

Six temperature probes were inserted into the compost for both stages of each run. Figure 125 shows the results MSW run 6.

Figure 125: Compost temperature for MSW run 6 producing RDF

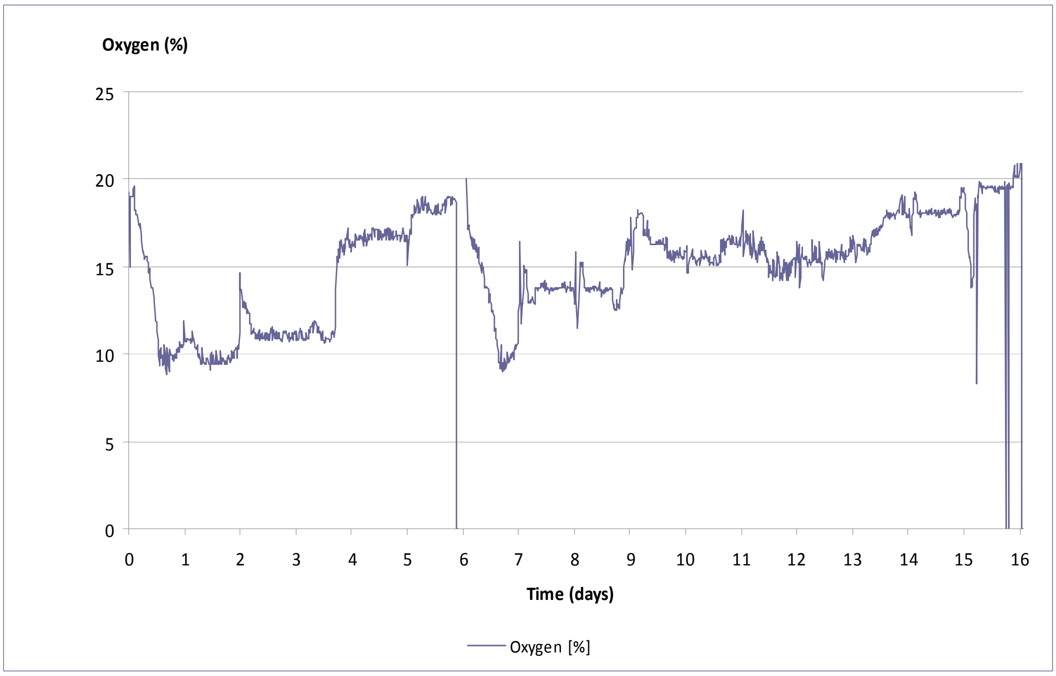


It can be seen that all 6 compost temperature probes exceeded 60° C for at least 48 hours for both stages of the composting process, thereby complying with ABPR.

13.18 Oxygen consumption for MSW runs producing RDF

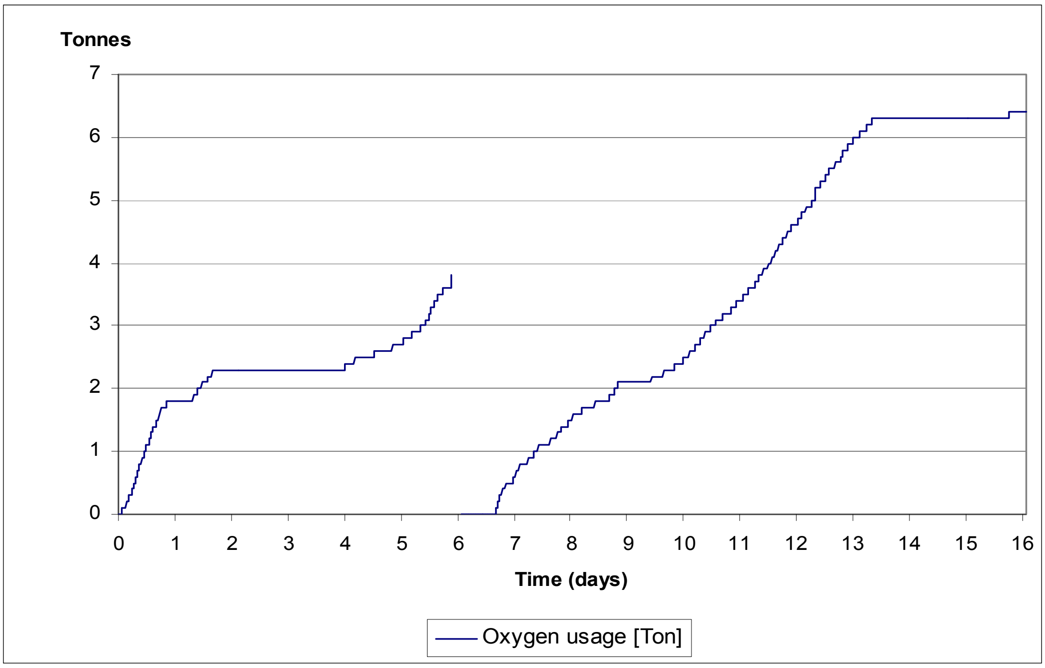
Figure 126 shows the percentage oxygen recorded in the recirculating air for MSW run 6.

Figure 126: Oxygen levels during MSW run 6 producing RDF



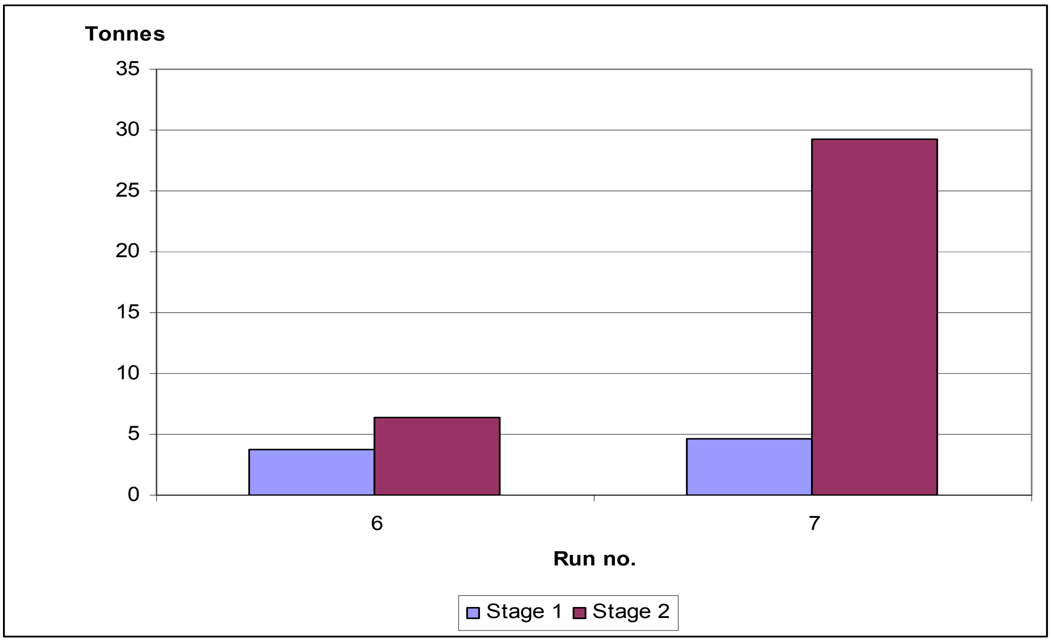
This Figure shows that oxygen levels were maintained above 7% during both stages. The apparent momentary drop in oxygen levels at the end of the second stage is an artefact caused by the momentary shorting of the oxygen probe. The tunnel computer also records the quantity of oxygen consumed during each run. Figure 127 shows the accumulative amount of oxygen consumed during both stages of MSW run 6.

Figure 127: Oxygen consumed during MSW run 6 producing RDF



This Figure shows that during the first stage of this run 3.8 tonnes of oxygen were consumed, and during the second stage 6.4 tonnes were consumed. Figure 128 shows the amounts of oxygen consumed during both stages of both MSW runs producing RDF.

Figure 128: Oxygen consumed during MSW runs producing RDF

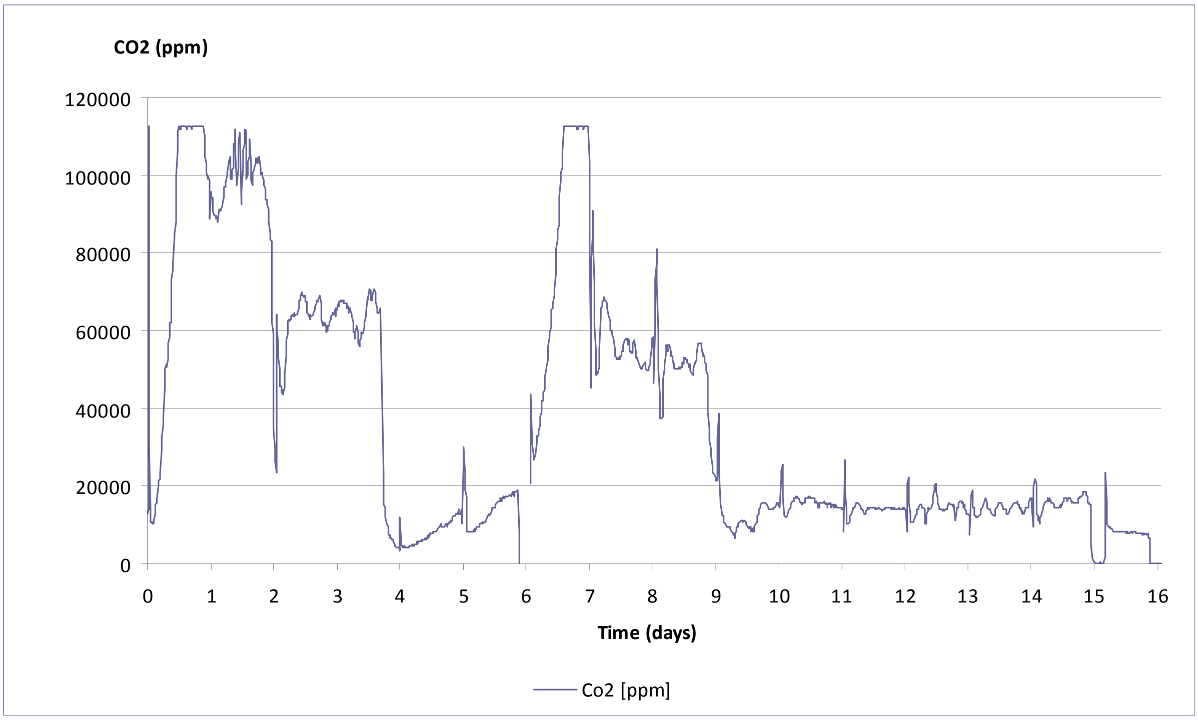


This Figure shows that the oxygen levels consumed during the second stage in each run, varied considerably, while the levels of oxygen consumed in the first stage were comparable. The recorded levels of oxygen consumed by both stages were 10.2 and 33.80 tonnes.

13.19 Carbon dioxide produced by MSW runs producing RDF

The tunnel computer monitored the carbon dioxide levels in the recirculated air for each run. As an example, the carbon dioxide levels in MSW run 6 are shown in Figure 129.

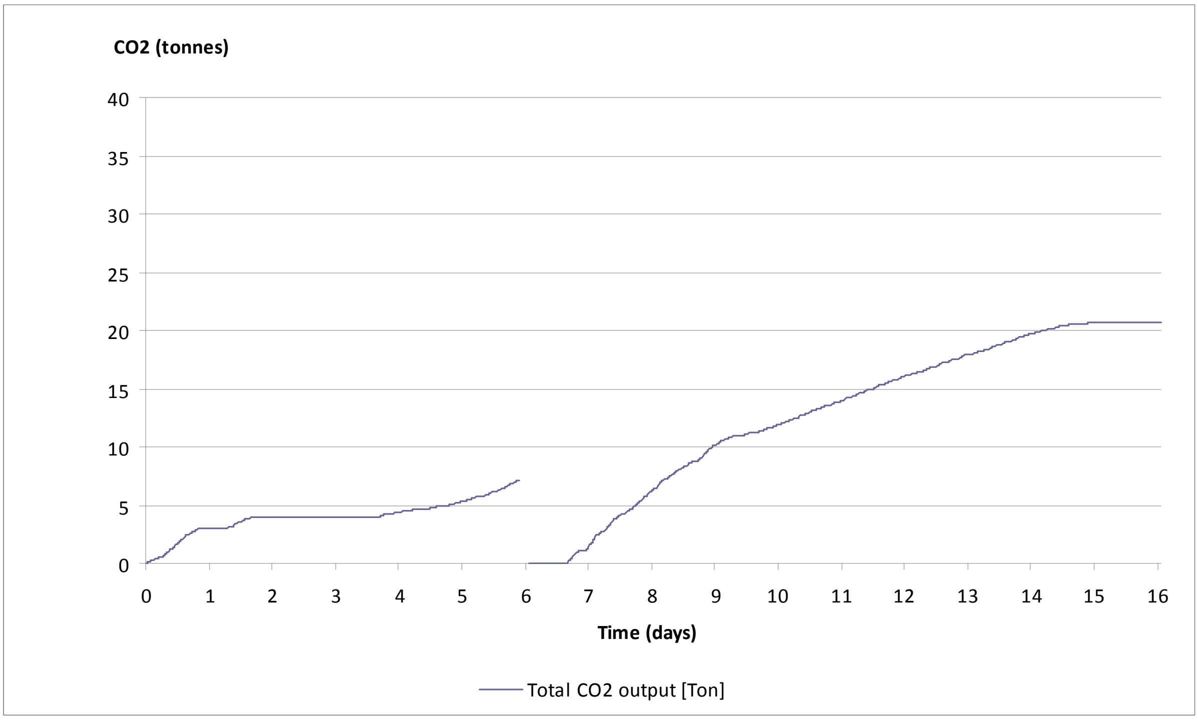
Figure 129: Carbon dioxide levels in MSW run 6 producing RDF



This Figure shows that carbon dioxide levels in excess of 110,000 ppm were generated during the most active sections of both stages. The graphs plateau at the maximum levels of carbon dioxide detection with this system. For each stage, the levels of carbon dioxide dropped off when large quantities of fresh air were introduced during the cooling down sections of the runs.

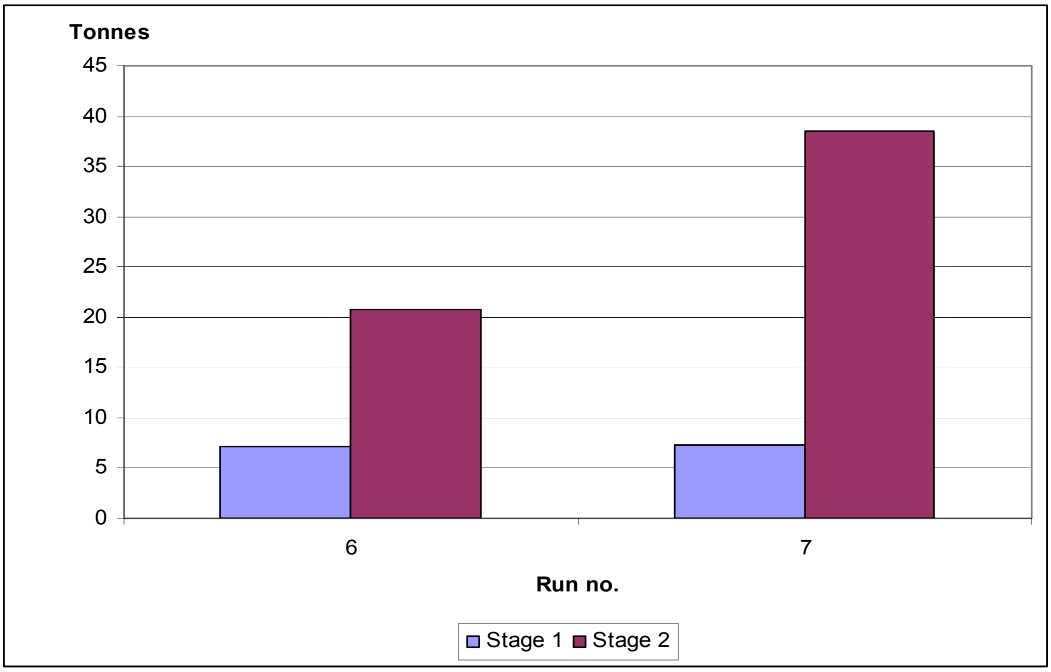
The tunnel computer also recorded to total quantity of carbon dioxide produced during each run. As an example, Figure 130 shows the total quantity of carbon dioxide produced during MSW run 6.

Figure 130: Carbon dioxide produced during MSW run 6 producing RDF



This Figure shows that during the first stage of MSW run 1 7.1 tonnes of carbon dioxide were produced, and during the second stage 20.7 tonnes were produced. The amount of carbon dioxide produced for each of the 2 MSW runs producing RDF is shown in Figure 131.

Figure 131: Carbon dioxide produced during MSW runs producing RDF

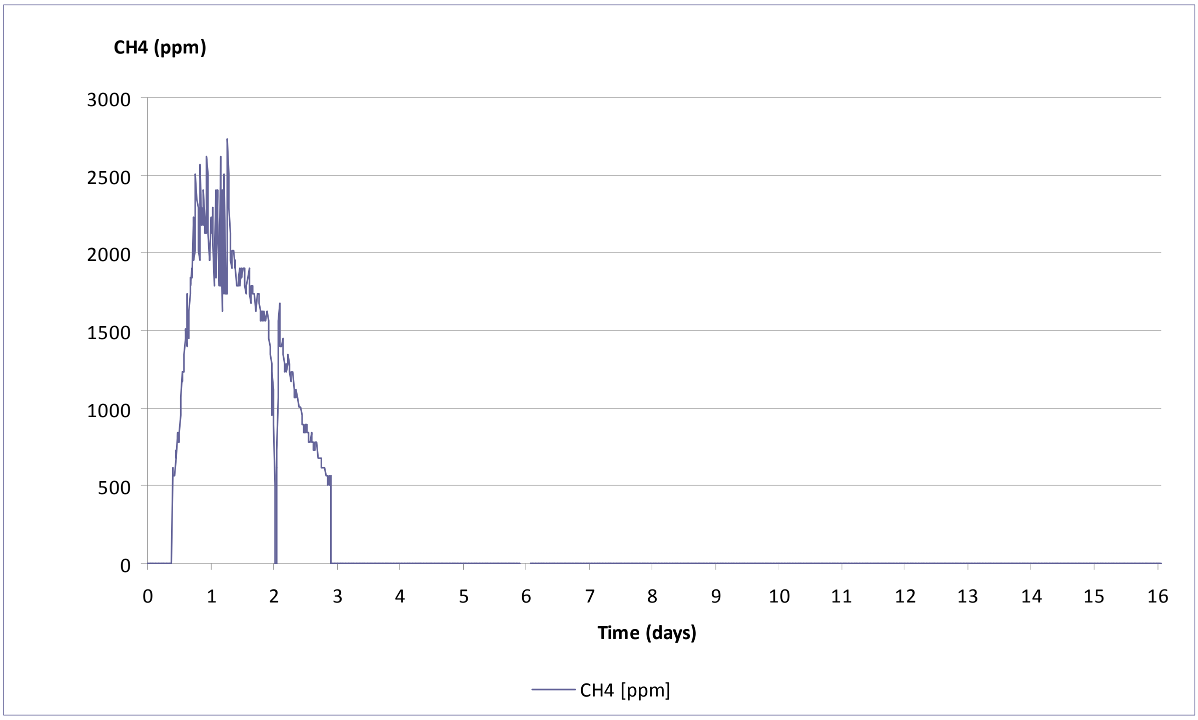


This Figure shows that the carbon dioxide levels produced during the second stage in each run, varied considerably, while the levels of carbon dioxide produced in the first stage were comparable. The recorded levels of carbon dioxide produced both stages were 27.8 and 45.8 tonnes.

13.20 Methane detected in MSW runs producing RDF

As the composting process is fully aerobic, the presence of methane in the recirculated air would not be expected. However, in the early part of the first stage of some runs, small quantities of methane were detected. As an example, the methane levels in MSW run 6 are shown in Figure 132.

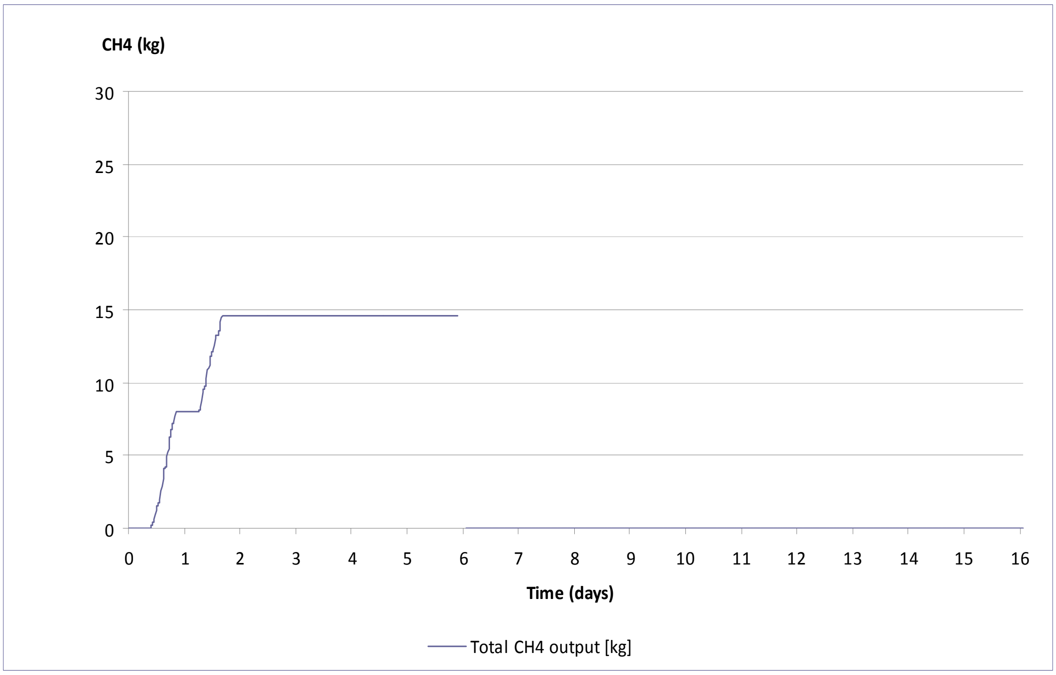
Figure 132: Methane levels detected in MSW run 6 producing RDF



This Figure shows that for a short time levels of methane up to 2,734 ppm were detected in the recirculating air as the composting material warmed up in the first stage.

The tunnel computer also measured the total quantity of methane produced during a run. As an example, Figure 133 shows the amount of methane produced during MSW run 6.

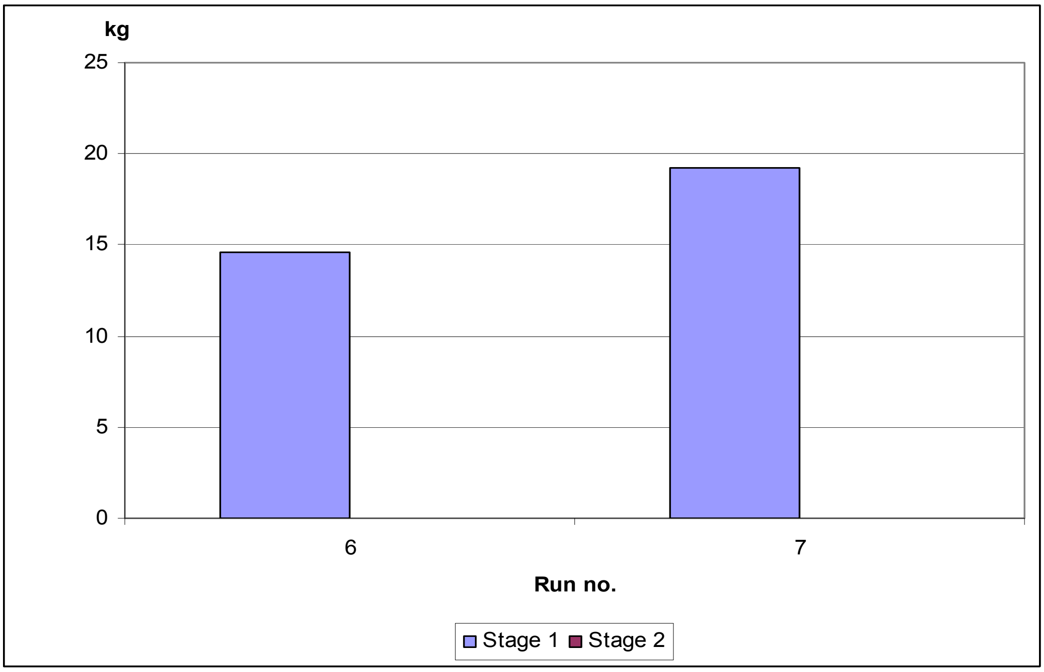
Figure 133: Methane produced during MSW run 6 producing RDF



This Figure shows that during the first stage of MSW run 6 14.6 kilos of methane were detected.

Figure 134 shows the quantity of methane detected for both the MSW runs producing RDF.

Figure 134: Methane detected in MSW runs producing RDF

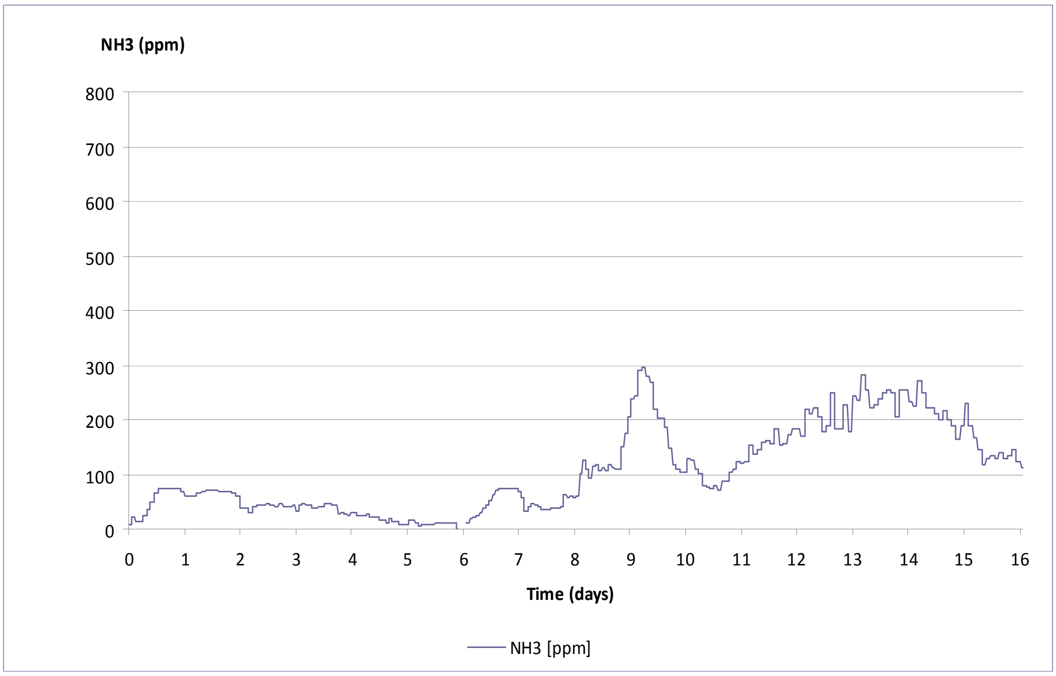


This Figure shows that the quantity of methane detected in the first stage varied from 14.6 to 19.2 kg. No methane was detected in the second stage of any run.

13.21 Ammonia produced by MSW runs producing RDF

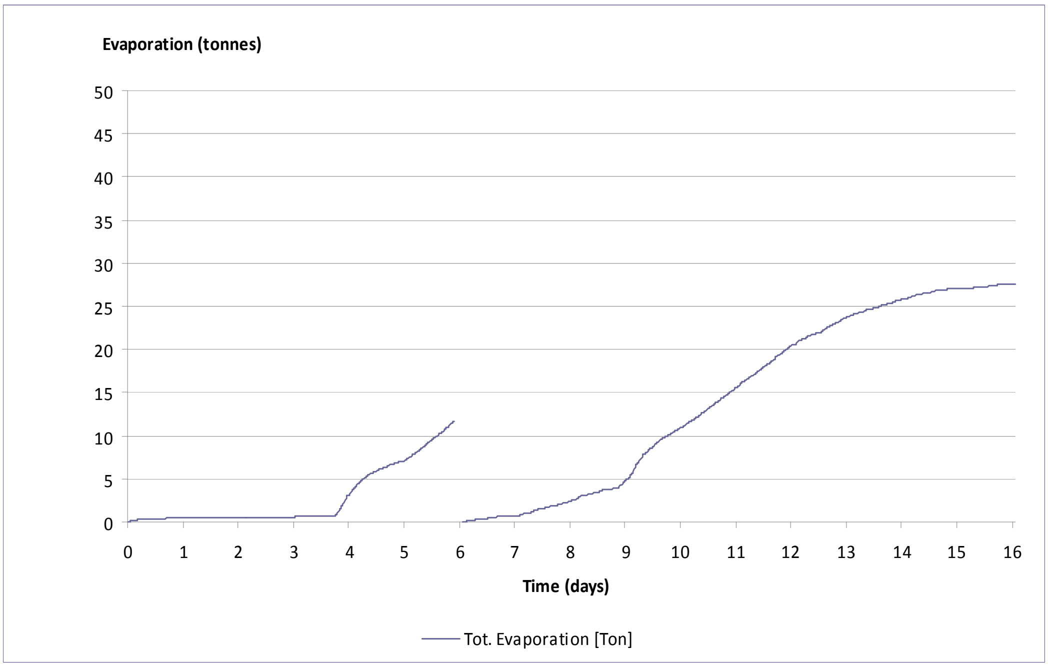
As an example. The ammonia levels detected during MSW run 6 are shown in Figure 135.

Figure 135: Ammonia levels in MSW run 6 producing RDF



In this run, ammonia was mainly produced during the latter half of the second composting stage. The tunnel computer also calculated the total quantity of ammonia produced during MSW run 6 as in Figure 136.

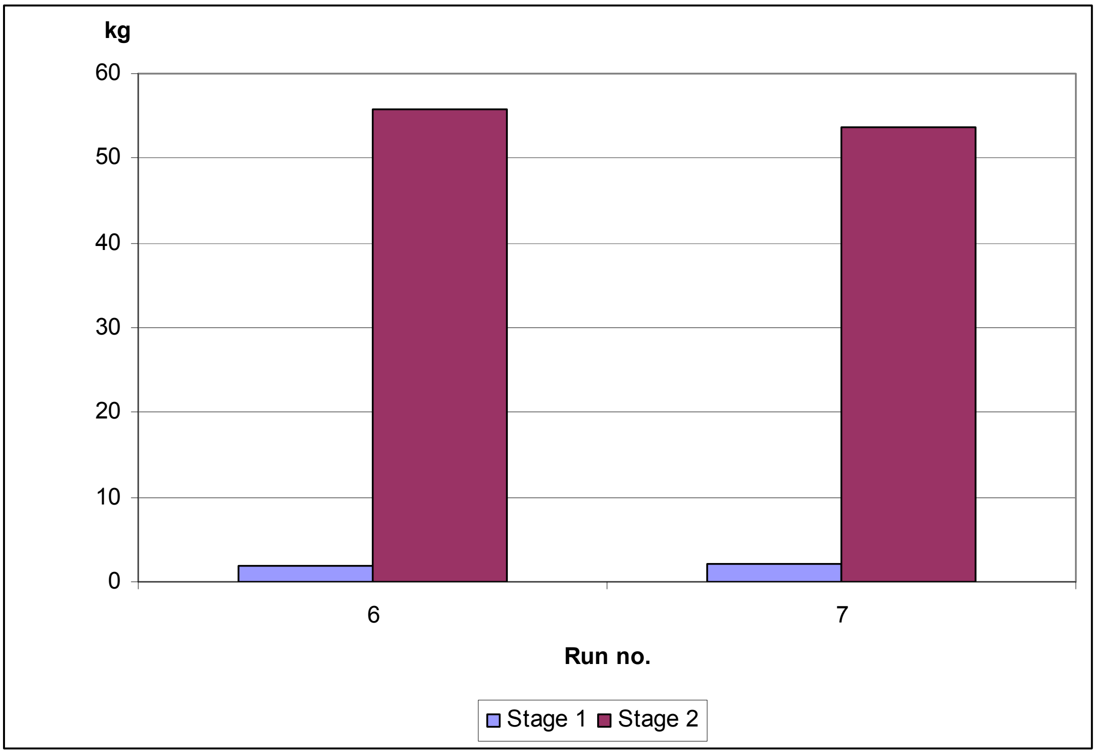
Figure 136: Ammonia produced during MSW run 6 producing RDF



In MSW run 1 1.8 kilos of ammonia was produced during the first stage and 55.7 kilos in the second stage.

The tunnel computer also recorded the amount of ammonia produced during all of the MSW runs producing RDF. The results are shown in Figure 137.

Figure 137: Ammonia produced in MSW runs producing RDF

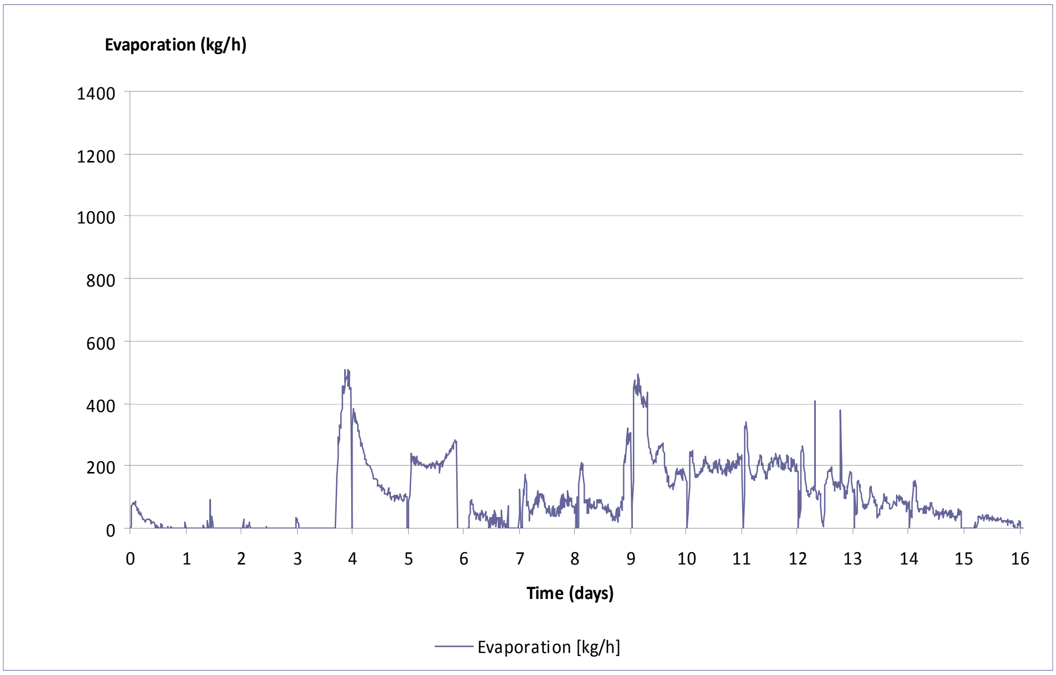


The amounts of ammonia produced during the first stage varied from 1.8 to 2.2 kg, and the amount produced during the second stage varied from 55.7 to 53.6 kg. The total amount of ammonia produced varied from 55.8 to 57.5 kg.

13.22 Water evaporation and spraying during MSW runs used to produce RDF

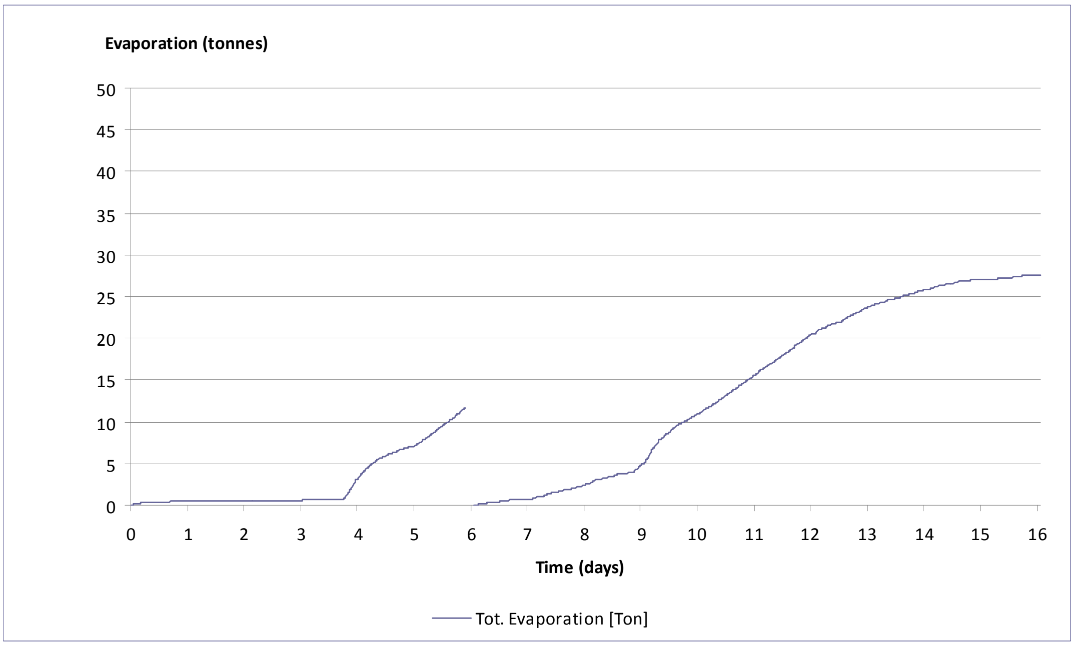
As stated earlier, an extended second stage was utilised to remove more moisture from the MSW feedstock and no water was sprayed on the material in the second stage. As an example, Figure 138 shows the rate of water evaporated during both stages of MSW run 6.

Figure 138: Rate of evaporation during MSW run 6 producing RDF



The Figure shows that the maximum rate of water loss for the first stage occurs when the volume of fresh air being delivered to the tunnels is greatest during the cool down section. During the second, extended stage, the water loss reduces to zero towards the end of the second stage. The second stage run was stopped at this time for this reason: no significant amount of extra water was going to be lost. The quantity of water evaporated is also calculated. The result for MSW run 6 is shown in Figure 139.

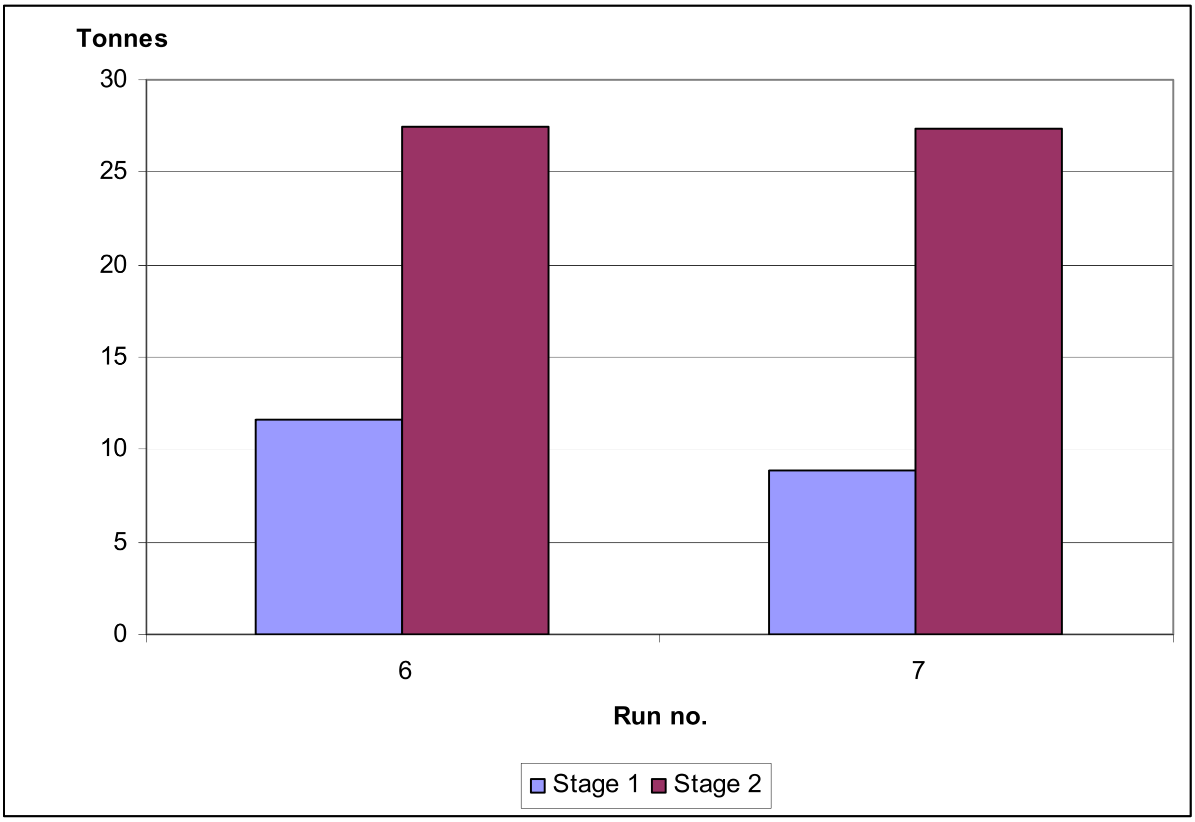
Figure 139: Evaporation during MSW run 6 to produce RDF



This Figure shows that during the first stage of MSW run 6 11.6 tonnes of water were evaporated, while during the second stage 27.5 tonnes were evaporated.

The tunnel computer also recorded the loss of water by evaporation during both the MSW runs producing RDF. The results are shown in Figure 140.

Figure 140: Water loss by evaporation during MSW runs producing RDF



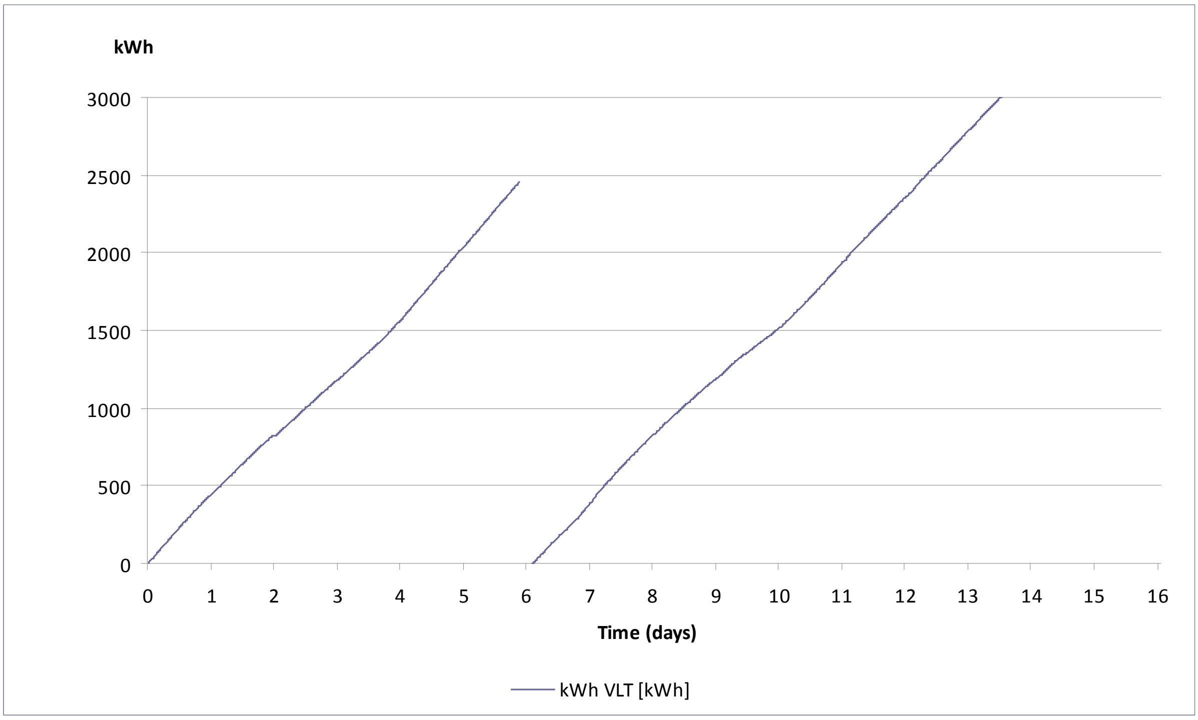
The amount of water lost by evaporation during first stages of the runs varied from 8.9 to 11.6 tonnes, while during the second stage the amount lost varied from 27.2 to 27.5 tonnes. The total amount of water lost for the entire run varied from 36.3 to 39.1 tonnes.

No water was sprayed on to the compost in the tunnels during the second stage.

13.23 Electricity utilisation by MSW runs used to produce RDF

Most of the electricity used to operate the tunnel system is employed in running the large tunnel fans. The tunnel computer measured the usage of electricity by the fans throughout the composting process. As an example, the electricity usage during MSW run 6 is shown in Figure 141.

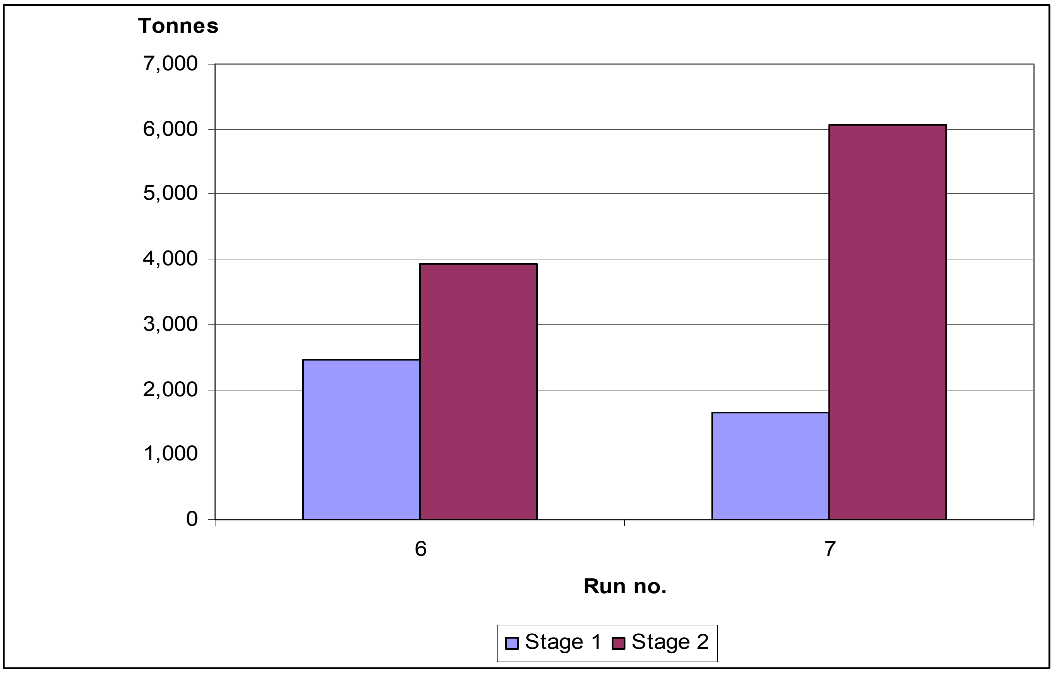
Figure 141: Electricity consumption during MSW runs producing RDF



This Figure shows that 2,451 kWh were used in the first stage and 3,937 kWh were used in the second stage.

The tunnel computer also measured electricity consumption for both of the MSW runs producing RDF, as shown in Figure 142.

Figure 142: Electricity consumption during MSW runs producing RDF



This Figure shows that the electricity consumption by the first stage varied from 1,638 kWh to 2,451 kWh. Consumption during the second stage varied from 3,937 kWh to 7,704 kWh. The total electricity consumption for each run varied from 6,3881 kW h to 7,704 kWh.

13.24 Analysis of RDF product

An analysis of the output material from the two RDF runs is presented in Table 24.

Table 24: Analysis of refuse derived material

Parameter	Units	RDF (MSW run 6)	RDF (MSW run 7)
Gross Energy	MJ/kg (DM)	12.97 (±1.85)	14.03 (±0.32)
Net Calorific Value (NCV)	MJ/kg	11.85 (±1.85)	12.86 (±0.36)
Dry Matter	%	75.73 (±2.64)	70.80 (±4.78)
Ash Content (calculated)	%	45.79	44.19
Organic Matter	%	51.80 (±3.58)	53.33 (±3.37)
Chloride	mg/kg (DM)	3,646.67 (±55.08)	3,706.67 (±254.03)
Total Sulphur	mg/kg (DM)	6,360.00 (±365.10)	10,066.67 (±7168.84)
Total Nitrogen	mg/kg (DM)	2.73 (±0.14)	1.99 (±0.33)
Total Potassium	mg/kg (DM)	6,639.00 (±592.91)	6,046.67 (±258.16)
Total Sodium	mg/kg (DM)	3,650.00 (±358.02)	4,022.00 (±387.98)
Total Copper	mg/kg (DM)	87.37 (±11.54)	145.00 (±58.28)
Total Zinc	mg/kg (DM)	384.00 (±96.81)	414.33 (±57.66)
Total Lead	mg/kg (DM)	471.00 (±42.33)	529.33 (±235.73)
Total Cadmium	mg/kg (DM)	0.59 (±0.21)	0.78 (±0.38)
Total Mercury	mg/kg (DM)	0.8 (±0.29)	0.36 (±0.06)
Total Nickel	mg/kg (DM)	29.57 (±7.90)	26.90 (±0.36)
Total Chromium	mg/kg (DM)	23.80 (±4.90)	28.53 (0.93)
Total Copper	mg/kg (DM)	87.37 (±11.54)	145.00 (±58.28)

Parameter	Units	RDF (MSW run 6)	RDF (MSW run 7)
Total Arsenic	mg/kg (DM)	4.64 (±0.35)	4.60(±0.90)
Total Manganese	mg/kg (DM)	307.33 (±32.25)	367.00 (±71.34)
Total Aluminium	mg/kg (DM)	6,263.33 (±1434.21)	6,936.00 (±516.54)

For comparison purposes Table 25 gives the typical properties of other potential sources of energy.

Table 25: Calorific value of selected fuels

Fuel	Units	Calorific Value		Contaminants %		
		Gross	Net	Sulphur	Water	Ash
Steam Coal	MJ/kg	30.60	29.70	1.20	10.00	8.00
Wood Waste	MJ/kg	15.80	14.40	0.40	15.00	trace
Gas-Oil	MJ/litre	38.30	36.00	0.15	0.05	0.01
Natural Gas	MJ/m^3	38.00	34.20	-	trace	-
Landfill Gas	MJ/m^3	20.00	18.00	trace	trace	-
Mine Gas	MJ/m^3	21.00	18.90	trace	5.00	-

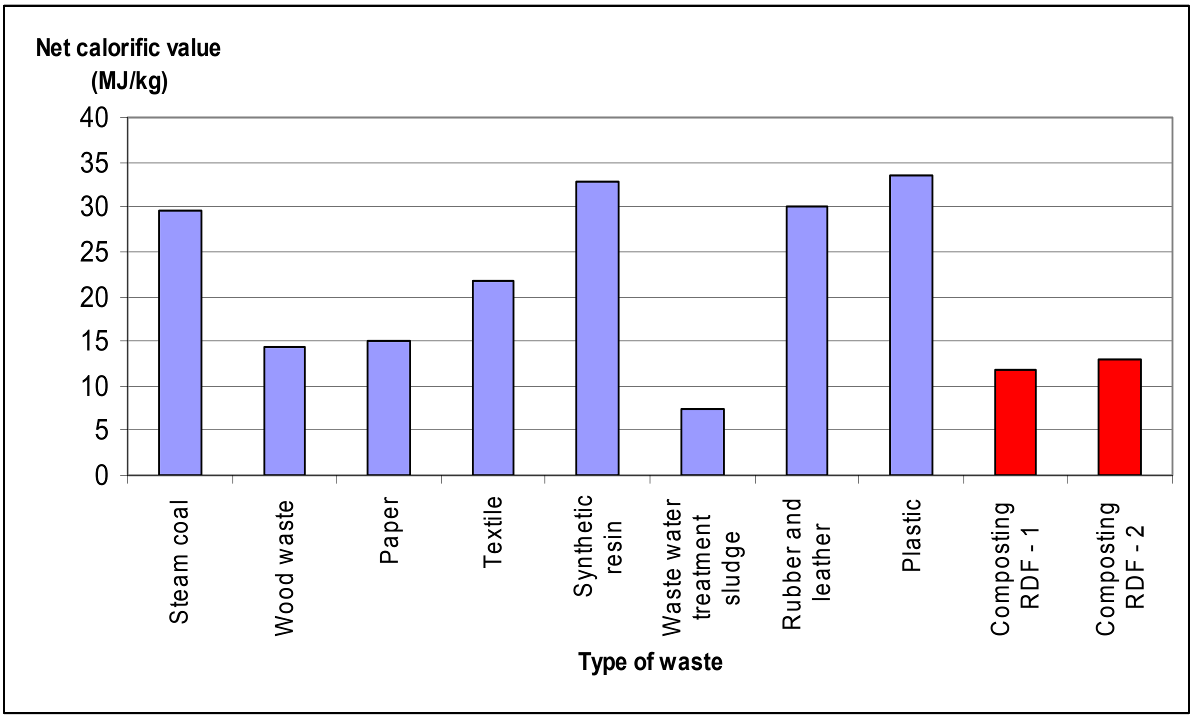
The net calorific values of other waste materials are listed in Table 26.

Table 26: Heating values of different waste materials

Waste Component	Units	Net Calorific Value
Paper	MJ/kg	15.02
Textile	MJ/kg	21.77
Synthetic Resin	MJ/kg	32.90
Waste water Treatment Sludge	MJ/kg	7.54
Rubber and Leather	MJ/kg	30.14
Plastic	MJ/kg	33.49
Process Sludge	MJ/kg	12.56

The average net calorific value of two triplicate samples of RDF material from the first run (MSW run 6) and the second run (MSW run 7) was 11.85 MJ/kg and 12.86 MJ/kg respectively. If compared with waste materials from Figure 143 it can be seen that the net calorific value of RDF produced in Gicom tunnels is similar to paper, process sludge and wood, but has only half of the calorific of steam coal. Plastics were included in this material.

Figure 143: Comparison of the calorific values of compost RDF and other wastes



14 PROJECT COSTS

14.1 Processing costs

The in-vessel composting of catering waste (including kitchen waste co-mingled with green waste) followed by windrow composting involves a number of readily identifiable stages that are common to most or all in-vessel composting facilities. These include:

1. Weighing in of waste.
2. Waste input.
3. Pre-treatment such as contamination removal.
4. Shredding.
5. Moisture adjustment.
6. Mixing with other feedstocks.
7. Washing down.
8. Transfer to the in-vessel composting units.
9. In-vessel composting (one or two stages depending on whether the catering waste is meat included or meat excluded) with associated electricity and, for some runs, gas costs.
10. Transfer to a windrow composting stage.
11. Windrow formation.
12. Windrow composting including windrow turning.
13. Transfer to a screen.
14. Screening (possibly including plastic removal).
15. Product storage.
16. Product weighing on removal from site.
17. Landfilling of oversize and inert contaminants.
18. Treatment and disposal of leachate.

In addition, there are a number of associated activities that carry costs. These include:

1. Chemical, physical, compositional and microbiological analysis for process control.
2. Chemical, physical, compositional and microbiological analysis to ensure compliance with a product standard, such as PAS 100.
3. Site, feedstock or process specific activities.

Each composting site is different and has its own unique set of processing costs. These have to be calculated for each stage that is applicable to the particular site.

All of the above types of cost applied to the current project, and each is considered in turn. In order to make this analysis useful to other composters, wherever possible, the costs are expressed in a way that can be applied to other composting facilities, e.g. the rate of usage of diesel per hour by a machine is given rather than the time taken to carry out each stage during the project. Also, labour costs vary from one facility to another. Therefore these costs are expressed in terms of the number of operators required for each process.

1. **Transfer of shredded feedstock into first stage tunnel**
   This was carried out by means of a Volvo L70F loading a tractor and trailer with the front loader using 6.57 l/hr of diesel for this activity.
2. **Filling of first tunnel**
   This was carried out using a CASE 621XT front loader that used c. 6.34 l/hr of diesel for this activity. The process took about 4 hours.
3. **Transfer of material from first stage to second stage of tunnel composting**
   This was carried out using a CASE 621XT front loader that used c. 6.34 l/hr of diesel for this activity. The process took about 3 hours.
4. **Emptying of second stage tunnel and formation of windrow**

   This was carried out using a Volvo L70F front loader that used c. 6.57 l/hr of diesel for this activity. The process took about 3 hours.
5. **Windrow composting including windrow turning**

   Windrow composting was carried on intensive runs with each windrow being turned once a week typically using a Volvo L70F front loader that used c. 6.57 l/hr of diesel for this activity. A single front loader could turn at lease 1,000 tonnes in a one shift day.
6. **Transfer to a screen**

   This was carried out using a Volvo L70F front loader that used c. 6.57 l/hr of diesel for this activity.
7. **Screening**
   Screening was carried out using a McCloskey 621 trommel screen fitted with a 10 mm mesh screen and a Komptech Windsifter to remove plastic and stones.
8. **Product weighing and removal from site**

   Compost product was loaded on to bulk lorries for removal from the site using a Volvo L70F front loader that used c. 6.57 l/hr of diesel for this activity.

9. **Landfilling of oversize and inert contaminants** Inert contaminants such as plastic, glass and stones were landfilled at the local landfill gate fee plus Landfill Tax.

10. **Treatment and disposal of leachate**

    Leachate was taken through the site's water treatment plant, which is licensed by the Environment Agency, before being released off site. This involved regular analysis of the water leaving the site by an accredited laboratory at a monthly cost of £700.

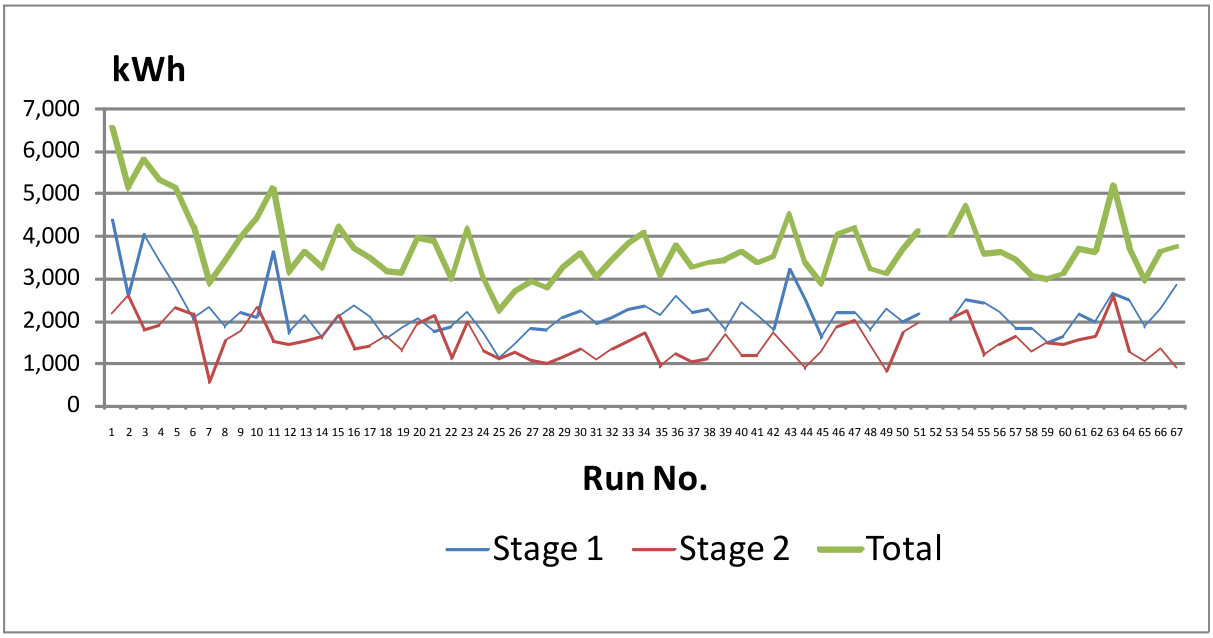
11. **Chemical, physical, compositional and microbiological analysis to ensure compliance with a product standard, such as PAS 100.**

    This was carried out at an accredited laboratory at a unit cost of £50.

The exception to this is the processing costs applicable to the Gicom batch tunnels which are examined in detail.

In excess of 90% of the electricity consumed during tunnel composting was used by the tunnel fans (b to e above), with 8% used by the scrubber fans (f to g above) with the remaining 2% used by other equipment. The usage of electricity during the runs processing co-mingled kitchen waste and green waste are given in Figure 144.

Figure 144: Electricity consumption during runs 1-67



Using an average electricity price of £0.07663 per kWh, it can be determined that the cost of processing a tonne of feedstock through the first stage of tunnel composting is c. £0.81 per tonne of feedstock. Assuming an average loss of c. 20.9% of the mass during the first stage of composting, the electricity costs of processing the material through the second stage of composing is c. £0.69 per tonne of first stage material.

Table 27: Electricity costs of tunnel composting

	First stage	Second stage
kWh	145,077	100,058
Cost/kWh	£0.07663	£0.07663
Electricity cost	£11,117	£7,667
Tonnes processed	13,798	10,914
Cost/tonne	£0.81	£0.70

The total electricity cost of tunnel composting the 13,798 tonnes of feedstock was £18,784, giving an average cost of £1.36 per tonne of feedstock. It is to be expected that cost per tonne of fill will be slightly less for the second stage than the first stage, as the material being filled into the second stage will be drier and warmer than the feedstock filled into the first stage tunnel, and the residence time is significantly shorter.

All of the performance parameters discussed in the technical sections of this report help to increase feedstock throughput and improve compost quality. These changes in procedure help to reduce the processing cost per tonne of feedstock and increase the value and market size of the compost product.

14.2 Capital costs

The total cost of the four tunnels used in the project, plus the reception area, associated fans and computer control system, floor and wall heating assembly, boilers, composting building and scrubber and biofilter system cost c. £1,300,000. This cost was higher than normal because of the additional heating and monitoring equipment installed specifically for the project.

The cost of a shredder can vary considerably from £150,000 to £250,000. The cost of a screen can vary from £120,000 – to £200,000. The cost of a system to remove stones and plastic from screened material can cost £80,000 to £100,000. Front loaders are normally leased with a maintenance contract costing in the order of £2,000/month.

Concrete costs can be very site specific, depending upon how much ground work is involved. £400,000 per hectare can be considered a typical figure.

14.3 Wider site costs

As stated previously, many costs involved in composting are site specific. However, there is a fairly common approach to determining all of the capital and operating costs associated with a composting site. This section sets out a model for determining these costs.

Capital costs

The following are the main capital cost items associated with a an in-vessel – followed by windrow composting - composting facility

Composting tunnels
Reception shed
  Main works
  Electrical
  Water supply
Ground works
Concrete
Windrow turner
Shredder
Screen
Windsifter
Reception shed
  Main works
  Electrical
  Water supply
Water treatment plant

Site costs and overheads

The following are the main site costs and overheads items.

1	**Payroll**	Salaries
		Operators
		Operations manager
		Site foreman
		Site manager
2	**T & S**	Staff expenses
3	**Property costs**	Rent
		Rates
		Water
		Electricity
		Gas
4	**Office costs**	Telephone & fax, stationery
5	**Marketing**	Conferences, brochures
6	**Depreciation**	Depreciation
7	**Professional fees**	Legal fees
8	**Site costs**	Vehicle repairs and maintenance
		Equipment repairs and maiantenance
		Hire of Site Machinery
		Site lab costs
		Site pre-notes
		Water disposal
		Landfill costs
		Fuel and oil
9	**Insurance**	Insurance

Revenue

The following revenue calculations can then be carried out.

Input of feedstock	Tonnes
Contracts	Gate fee/tonne
Compost sales	£/tonne
Total revenue	£
Site Costs	£
Contribution	£
Capital expenditure depreciation	£
Return on capital	%
Unit cost of production	£

15 DISSEMINATION OF PROJECT RESULTS AND EXPERIENCE

15.1 Project launch - opening of the Envar Visitors Centre

The Visitors Centre was officially opened on Friday 5th October 2007 by Mr Shailesh Vara, Member of Parliament for Northwest Cambridgeshire,. Other special guests included Mr John Burns, Defra, Mr Patrick Pierrepont, Envar, the local Site Liaison Committee and Mr Jeremy Jacobs, Composting Association (now the Association for Organics Recycling).

The opening ceremony also signified the beginning of the project and was followed by a tour of the Visitor Centre and the New Technology Demonstrator Programme composting operation.

Figure 145: The opening of the Envar Visitor Centre.

15.2 Articles in printed publications

Since the project inception Envar has disseminated information on the construction and operation of the composting tunnels, and information on the progress of the project,. Initial technical data was released into the public domain via publications, presentations and open days. The complete technical data will be published in the Final Report and in a series of technical articles.

Technical publications

Webb, A.L. (2007) An innovative in-vessel tunnel composting system. Waste and Resource Management: Vol: 160 (1). A technical overview of the operations of the NTDP system, including technical diagrams and specifications during the construction phase of the tunnels.

A series of technical articles will also be published following the completion of this report.

Industry publications

Envar launches new solution to the landfill problem: Composting News, Spring 2007 Volume 11, issue 1. An initial short article giving an overview of composting under the NTDP, including details of the tunnels under construction, the planned operations and feedstocks.

Boeke, J. (2007) Demonstration of an in-vessel composting system: Public Services Management. A **s**ingle page article giving a detailed overview of the NTDP tunnel design, operation, construction, feedstocks and technical assessments. There is also a short overview of ADAS and Envar.

Freyburg, T (2007) Light at the end of the composting tunnel: Recycling and Waste World, February 2007. A 2-page photo write-up of a visit to the St Ives site by the author, with an external perspective on the new tunnel system along with how it fits into the current waste management industry in the UK. There is detail towards the end of the NTDP funding and tunnels.

Boeke, J. (2007) Unique composting system opens for business: ADAS Insight Magazine, May 2007. An article on the opening of the NTDP project and an overview of the programme, written for the ADAS External magazine.

Fowles, M. (2007) Envar opens new Visitor Centre: ADAS Network magazine, Winter 2007. A summary of the key points from the Visitor Centre opening event, attended by Mr Shailesh Vara, MP for North-West Cambridgeshire. Written for the ADAS internal magazine.

Fowles, M. (2007) The idea that mushroomed: CIWM Journal, December 2007. A 2-page overview of NTDP and the composting system at St Ives.

Webb, A (2007) Heat at the end of the tunnel: Materials Recycling Week, September 28th 2007. A 2-page central spread focussing on the NTDP and the processes at St Ives.

Fowles, M. (2008) Investigating the performance of double-ended batch tunnel composting: Composting News, Vol. 12, Issue 1. A 3-page summary of the NTDP operations and the opening of the Visitor Centre at St Ives.

Robinson, G (2007) Heading up the class: Biowaste management in the UK: Waste Management World, Nov-Dec 2007**.** An 8-page comparison of the Envar NTDP composting system and Biogen Anaerobic Digestion. Both systems were based within the South-East of England and integrate imported existing technology into new developments. The article found that both technologies offered important diversion of wastes from landfill, and demonstrated the ability of imported technology to integrate into the UK waste market.

Recycling Action Yorkshire (2008) DEW visit to In-vessel Composter: Local Government Yorkshire and Humber, www.recyclingaction-yorkshire.org.uk. A 5-page overview of the NTDP site tours from the perspective of RAY and the Local Authorities who visited. The article addresses many FAQs regarding composting operations and issues surrounding the operations.

Newspaper articles

What a waste to go: Huntingdon Town Crier, 11/10/07. A public interest write-up of the composting system and the opening of the new Visitor Centre at St Ives. This article was written by local journalist Hazel Slade to give the local area an update on the activities going on at the St Ives site.

15.3 Internet websites

Envar: www.envar.co.uk

Information has been displayed on the Envar website throughout the NTDP project. The main news articles have included an overview report of the NTDP, an invitation to stakeholders to visit the stand at CIWM 2007, and the opening of the Envar Visitor Centre at St Ives.

Lets Recycle: www.letsrecycle.com

Envar Reveals new In-Vessel Composting Technology Project (05/01/2007): This article was published on Lets Recycle following contact by the website with the then Project Manager Jochem Boeke. The article was written during the construction of the tunnel system, and before any waste was accepted into the tunnels. The report gave a summary of the intentions of the system to process biodegradable municipal waste by batch tunnel composting, and highlighted several links to the other NTDP demonstrators and the Defra Web Pages for the Programme.

Acorus: www.acorus.co.uk

Compost site designed to avoid landfill: A brief summary of the site, specifically mentioning the NTDP. Acorus were responsible for the planning applications to ensure the on-time construction of the system.

15.4 Open Day events

Open Days and visits

After the official opening event, the Visitor Centre was used extensively for open days and individual visits from a wide variety of industry stakeholders.

Aim of the Open Days

The focus of the open days was to highlight the effective operation of the composting system to the relevant industry stakeholders. This was to increase the available knowledge of in-vessel composting, and to encourage further development of such composting systems throughout the UK. It was anticipated that the NTDP would encourage Local Authorities to develop more waste treatment technologies, based upon those demonstrated in the programme, in order to ensure a significant reduction of the volumes of biodegradable waste sent to landfill.

Stakeholders

Under the terms of the service agreement with Defra, Envar was required to host a total of 75 visits from individual Local Authorities or other relevant organisations selected from the following list of industry stakeholders:

- Local Authorities (planning departments or waste officers).
- Environment Agency.
- Animal Health.
- Relevant commercial organisations from the waste industry.
- Universities.

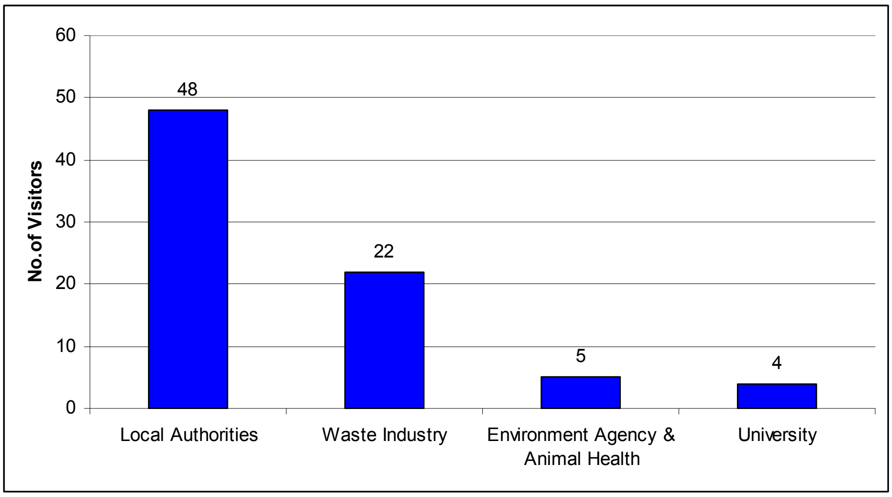
In addition, Envar received delegates from the following list of organisations that were not counted towards the 75 for specific stakeholders:

- WRAP.
- Defra.
- NTDP - Technical Advisory Committee.
- Association for Organics Recycling.
- Other Government organisations.

During 2007/2008 eighteen separate events were arranged. A total of 79 different specific stakeholders were received, with over 239 individual visitors (including non counted visits) by the completion of the open days. A visitor log was recorded. The key information gathered included: delegate name, organisation type, English or Welsh region, and date of visit.

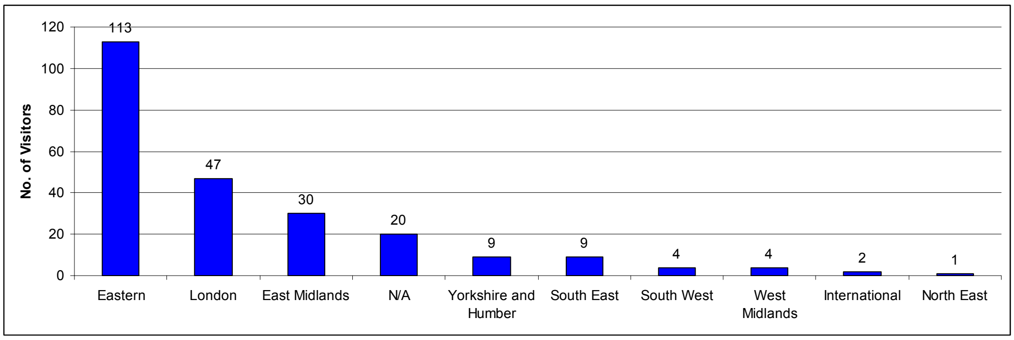
Figure 146 provides an analysis of the visitors by stakeholder group.

Figure 146: Analysis of NTDP open day visitors by stakeholder group



The visitors were also classified in terms of geographical location, as shown in Figure 147.

Figure 147: Classification of Envar NTDP open day visitors by location



Open Day agenda

For each of the open day events, an agenda was prepared to illustrate the progress of the project. The agenda consisted of an introduction to the NTDP, a technical overview of the Envar Composting System, and a tour of the composting facility. A typical agenda is given in Figure 148.

Figure 148: Typical agenda for an Envar NTDP open day event

Demonstration of an In-Vessel Composting System -
Defra New Technologies Demonstrator Programme (NTDP)

Agenda

10.30	Arrival, Registration and Refreshments
10.55	Introductions, housekeeping and Health and Safety
11.00	Welcome to Envar and Industry Perspective Andrew Urquhart, Envar/ CIWM
11.15	Background to the NTDP Programme Enviros
11.40	The Envar Site, Process and Gicom Technology David Border, Envar
12.00	Questions/ Discussion
12.15	Premier Waste (NTDP demonstrator exchange) Tony Hitchens, Premier Waste
12.45	Lunch
13.00	Site tour (in groups)
14.30	Questions/ Discussion and refreshments
15.00	Departure

The agenda was modified on each occasion to show changes to the guest speakers, and was used for the four main open days held during August, September and October 2008. As part of an information exchange between the demonstrators, Envar invited Premier Waste to provide a presentation on their NTDP system at the open days.

All presentations were conducted in the Envar Visitor Centre conference room. One or two site tours were arranged for each open day, with approximately 15 visitors per tour. These were escorted by a minimum of two Envar Staff. Time was provided throughout the tours for visitors to raise relevant questions about the technology and the composting process.

Each visitor was presented with a pack containing contact details, further information on Envar, the Defra Waste Implementation Programme, and an information leaflet on the Envar composting system.

General feedback

The open days were deemed to be very successful, with project milestones being achieved at a relatively early stage. A positive feedback was received from the visitors. This included comments on the Visitor Centre, the efficiency of the facility, the standard of the presentations, and the expertise of the technical team. Several visitors were also surprised at the lack of odour during the site tour, despite normal composting operations including screening and windrow turning taking place at the same time as the tour.

A list of frequently asked questions was compiled for the four large-scale open days, based upon questions asked by previous visitors. Several questions were of a commercially sensitive nature (i.e. gate fees) and were therefore not answered directly but as a range of values. Most questions focussed on the treatment capacity of the site, the availability of wastes, the ease of compost relocation to end-markets, and the carbon footprint of the entire operation. Visitors were provided with time to question the technical team over the course of the day, both during the dedicated question sessions and during the site tours themselves.

The open day format will be utilised by Envar beyond this project as part of a strategic approach to help further promote Gicom tunnel composting systems to interested Local Authorities.

15.5 Road shows

Envar has attended a series of conferences as part of the dissemination programme. The road show element included the design and development of relevant literature, the production of poster boards, and attendance at key events with a stand and exhibit.

A screen with a large-scale diagram of the Envar NTDP system was prepared. This screen is now used in the Visitor Centre at St Ives, and is regularly taken to exhibitions and conferences to advertise the Gicom Technology. An A0 poster board was also designed to provide a greater depth of textual information than the graphic-heavy screen. Envar also designed an NTDP specific handout for delegates at each of these events.

The Composting Association Conference (2006)

Members of Envar's technical team attended the Compost Association Annual Conference, held in Brighton on the 6/7th December 2006. The aim of the stand was to highlight the start of construction of the tunnels at St Ives, and the subsequent work to be undertaken under the banner of the NTDP. It was designed to initiate the dissemination portion of the project.

The stand consisted of a slideshow of construction and composting photos, the large screen and Envar literature.

Figure 149: Envar at the Composting Association Conference 2006.

Alternative Waste Treatment Technologies Conference (2007)

Project Manager Jochem Boeke attended this event on 26th April 2007 at the Brit Oval in London. The large screen was on display, alongside Envar literature on the composting system. A handout was designed to go in the delegate pack provided by the organisers.

CIWM (2007)

Envar attended the CIWM Annual Conference in Paignton on 12-15th June 2007. The stand was set up with the large screen, and the slideshow was updated to include new photos and videos of the tunnels in operation throughout the commissioning phase.

Figure 150: Envar at the CIWM Annual Conference, 2007.

RWM (2007)

The third event attended was RWM 2007, held in Birmingham NEC in September 2007. Although the open days were not being run at the time, contact details were taken for several potential open day visitors.

RWM (2008)

The RWM event for 2008 was manned by the Envar development team, with the large screen and NTDP literature available. This event was attended to advertise the upcoming open day and to highlight the Gicom tunnel composting system as an effective technology to process biodegradable municipal waste, working with the major aim of the NTDP to encourage uptake by Local Authorities.

15.6 Future publication of technical and general articles

The quantity of data collected in the course of this project is too voluminous to be fully described in this report. It is therefore intended that a series of technical articles will be published showing a detailed analysis and interpretation of this data. A number of general articles describing the lessons learned by the project and its relevance to the UK composting industry will also be published.

16 DISCUSSIONS AND CONCLUSIONS

16.1 Introduction

This project has examined in great detail one particular form of in-vessel composting, *viz*. batch tunnel composting. Section 1 of this report describes in outline the other main in-vessel composting systems available. The batch tunnel system was selected by Envar for the study because of the high degree of control possible over the environmental conditions during composting and its clear compliance with the Animal By-Products Regulations (ABPR).

The batch tunnel composting system used in the project was unique in that the tunnels were fitted with heated walls and floors. This was carried out in order to determine if this development would reduce the residence time in the tunnels, especially during the winter months, thereby increasing throughput.

The tunnel system used by the project consisted of four computer-controlled composting tunnels and a computer-controlled air scrubber and block of biofilters. This system was used to monitor and control composting procedures for a variety of Municipal Solid Waste (MSW) based feedstocks, and to determine and minimise the effect of the composting process upon the environment. The project was carried out within a commercial composting site and at a commercial-scale.

It was intended that the techniques developed by this project, and the technical data generated, could be utilised by designers and operators of other commercial-scale in-vessel composting systems in the UK.

This section of the report discusses the results of the project activities.

16.2 Feedstock composition

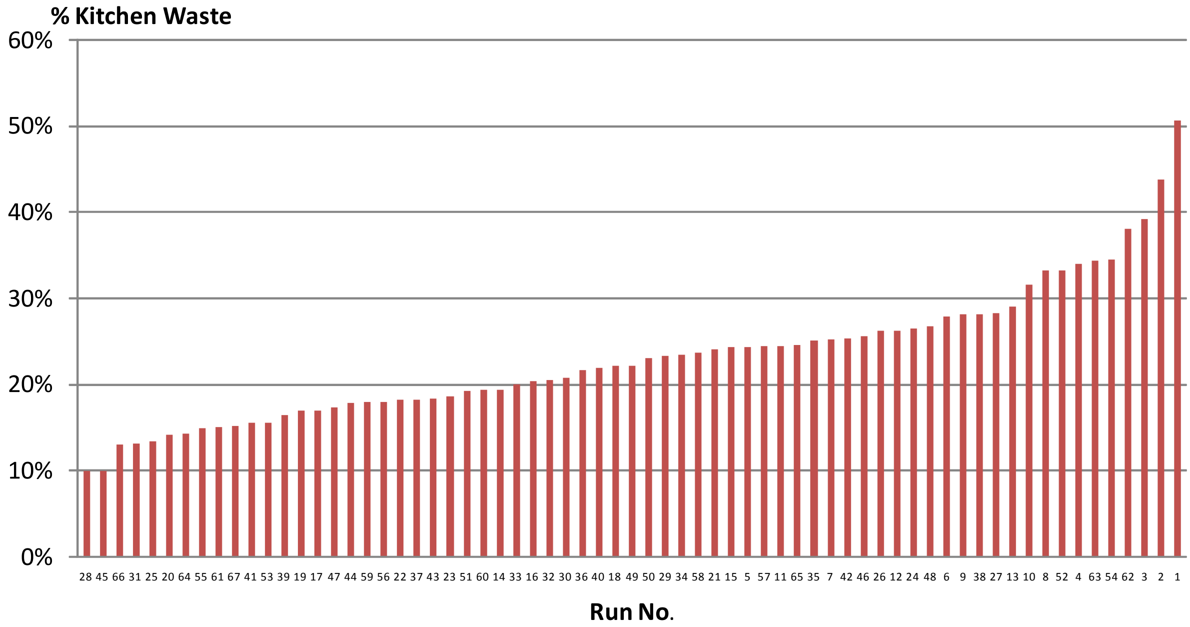
At the start of the project it was quickly realised that because of the wide variety of collection methods used by local authorities, the collection of kitchen waste and green waste formed a continuum of feedstock. This continuum ranged from almost 100% green waste to 100% kitchen waste.

It was decided that the project should process 10 runs with the kitchen waste component representing <15% of the kitchen waste/green waste mixture, 10 runs with the kitchen waste component representing >35% of the mixture, with the remaining runs falling between these two extremes. It was agreed that this approach would cover all of the different collection policies used by local authorities and would generate data of maximum interest to the industry.

For each project run, the amount of feedstock type contributed by each local authority to a fill was calculated. This was made possible by the routine procedure of weighing each load of feedstock as it arrived and identifying which loads were used to fill each tunnel. A degree of control was possible in the waste reception area that allowed the creation of a range of proportions of kitchen waste in the feedstock.

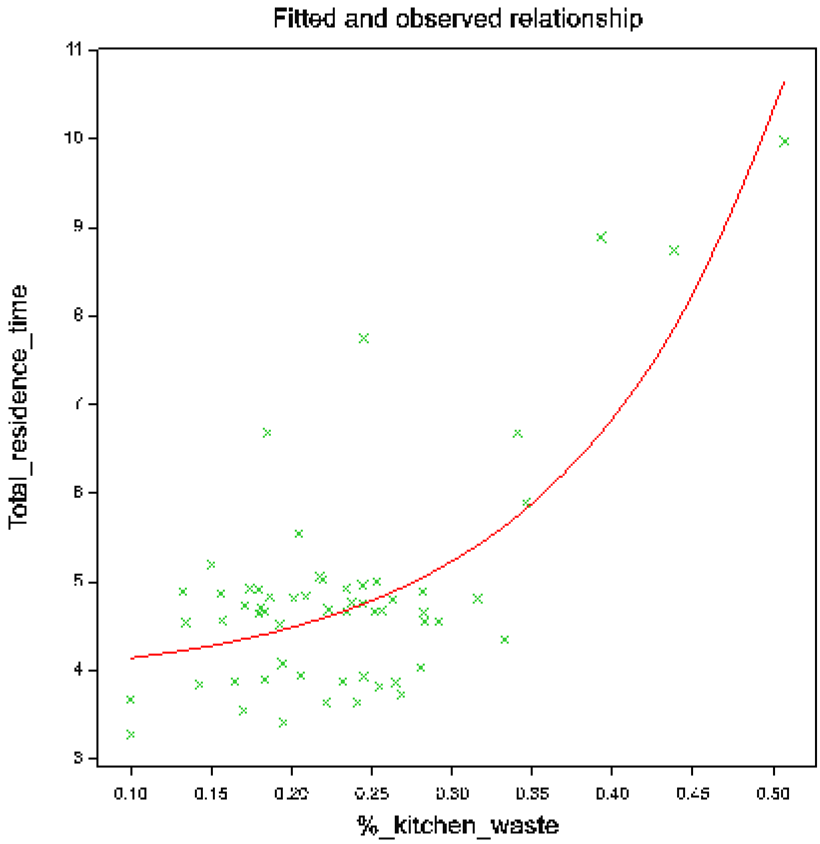
Figure 151 shows the range of proportions of kitchen waste in the feedstock mixture used throughout the project.

Figure 151: Proportion of kitchen waste to green waste – increasing proportion



It was found that the residence times for the first stage of composting within the composting tunnels, using feedstock mixtures containing less than 30% (by weight) of kitchen waste, were essentially unaffected by variations in the proportion of kitchen waste. However, with percentages of kitchen waste greater than 30% the residence time increased significantly. This is shown in Figure 152. The X axis in this graph represents a 30% mixture as 0.30.

Figure 152: Relationship between residence time and percentage kitchen waste in feedstock



Therefore on the basis of these results it is recommended that in order to carry out processing as quickly as possible and to use the tunnels to their maximum capacity, feedstock mixtures being processed by this technology should not exceed 30% of kitchen waste. Alternatively, the tunnels can be filled with a quantity of wastes lower than the nominal capacity with feedstocks containing higher levels of kitchen waste. Increasing the proportion of kitchen waste in the feedstock mixture increases the bulk density. There is a limit to how high the bulk density can be before there is a limitation of air flow through the feedstock. Efficient air flow is essential in order to keep the feedstock aerobic and to control temperatures.

The tunnels used in this project have a nominal capacity of 180 tonnes. However, results showed that the residence time of the first stage of composting was not significantly affected by fills of up to 248 tonnes as long as the proportion of kitchen waste does not exceed 30%. The actual capacity of the tunnels is determined to a great extent by the bulk density of the feedstock.

During the summer months, when there is much green waste available, the bulk density of mixtures can be kept quite low, and air flow is not a problem. During the winter months, when green waste is less available, there is a risk that the proportion of kitchen waste in the mixture will become too high, resulting in a mixture with too high a bulk density resulting in problems with air flow. This can be countered by adding other, low density material, such as oversize material removed during product screening, back into the feedstock mixture. Using this method it is possible to successfully compost mixtures of kitchen waste and green waste in the tunnels throughout the year.

The section of the project has enabled the tunnel operators to optimise this part of the composting process by enabling them to set an upper limit for the proportion of kitchen waste in the feedstock to ensure that the residence time in the tunnels is not lengthened. It also enables the composter to have confidence in the total amount of feedstock, within limits of composition that can be filled into the tunnels. Both of these improvements help to increase the throughput of the site and decrease the unit processing cost per tonne of feedstock.

The composting of MSW organic fines was successfully carried out with mixtures containing up to 28% (by weight) of the fines combined with co-mingled kitchen waste and green waste. However, the tonnages of mixtures filled into the tunnels were kept nearer the nominal tunnel capacity of 180 tonnes in order to avoid problems with air flow caused by the high bulk density of the fines.

The proof that the tunnels are capable of processing MSW fines as part of a feedstock mix enables composters to increase the range of feedstocks that they can compost with confidence. This in turn increases the potential income for the site from accepting additional feedstocks.

16.3 Feedstock quantity processed, number of runs, and operating time

The project, under the terms of the contract agreement, was required to process a minimum of 10,500 tonnes of biodegradable municipal waste (BMW) during a minimum of 8,000 operational hours, processing a minimum of 70 batches of feedstock material.

In practice, the project composted 13,798 tonnes of co-mingled kitchen waste and green waste, and 1,976 tonnes of MSW fines. The tunnels operated for 14,534 hours processing co-mingled kitchen waste and green waste, and 2,561 hours processing MSW fines. Sixty seven runs were carried out on co-mingled kitchen waste and green waste and a further 10 runs with MSW fines.

The project therefore met the contract requirements with respect to the tonnage processed.

16.4 Site operations monitoring

This project examined many aspects of the composting process, from the reception of waste on to the site, through the composting process itself, to the screening of the compost product.

It is important to recognise that this aspect of the project is very site-specific. Each composting site has its unique advantages and disadvantages, whether designed and constructed for optimal performance on a green field location, or, as in the case of the St Ives site used in this project, developed from a pre-existing site used for other purposes. The results obtained for this section should, therefore, be interpreted in this context. The following comments, while referring to the specifics of the St Ives site, also attempt to look at site operations in a wider context that is applicable to all composting facilities.

Feedstock

It is very important in any composting site to control, as much as possible, the timing of the delivery of the feedstock to the reception area. If deliveries are not controlled adequately this can result in too much feedstock arriving at the site at any one time or on any one day. Reception areas have a limited capacity for feedstock storage, and there are normally tight restrictions under the site's Environmental Permit on how long feedstock can remain in the reception are before being processed. In the case of the project this was 48 hours. Also, if feedstock is allowed to remain unprocessed for longer than 24–48 hours, there can be problems with malodours. It is, therefore, essential that the site management develops a good relationship with the supplying companies or local authorities in order to control the flow on feedstock into the site.

The level of contamination of the feedstock with plastics, particularly kitchen waste, has a significant effect upon the cost of processing. Plastic contamination can be removed at the start of the process by the use of picking lines, or at the end of the process by means of screening, with or without the use of a wind sifter. The acceptable level of plastic in feedstock is a matter for negotiation between the composter and the supplier. Typically, levels are set at 2 – 5% by weight depending upon the individual contract with the local authority. These are low figures but nevertheless represent a considerable quantity of plastic and can cause a significant problem for the composter.

In the case of this project, plastic was removed at the end of the process using a McCloskey trommel and a Komptech Windsifter. A 10 mm mesh screen was used in the trommel. This process was very effective at removing the plastic contamination. The resultant compost product was well received by local farmers for use as a soil improver. The demand by farmers for the compost was at times greater that the ability to supply the material. In terms of comparison with the cost of artificial fertilisers, even allowing for spreading costs, the use of composting was an attractive option. In addition, the organic matter in the soil was appreciated by the farmers as being of additional value.

Plastic contamination also involves an increased cost for the composter in that once removed from the feedstock or the compost product it has to be landfilled. However, when using the tunnels for the preparation of RDF it would be possible to consider leaving the plastic within the material.

The most effective way of reducing, or avoiding, the above problems is to educate the public or supplier to avoid putting plastic bags and other plastic items into the kitchen waste and green waste in the first place. This is normally not a problem where the source of the material is a commercial company, but the problem is much greater when the supplier is a local authority collecting waste from the public. The best way forward is for the composter to work with the local authority to get the message across that putting non-compostable plastics into the collected material should be avoided. In addition, and as carried out within this project, local authorities, councillors, and the public can be invited to visit the composting site to see for themselves the problems that plastic contamination can cause.

Shredding

There is a very wide range of shredders available for processing the types of feedstocks used in this project. Shredders vary considerably in terms of throughput and the particle size of the shredded material generated. In this project a low speed shredder (Powerscreen 1800) was used very effectively in producing shredded material of a particle size that complied with the requirements of ABPR (< 40 cm) and also produced material of a bulk density suitable for batch tunnel processing.

An alternative approach to shredding in compliance with ABPR is to use a shredder that produces material with a particle less than 12 mm in one dimension. This will enable compliance with ABPR pasteurisation requirements if all of the feedstock reaches at least 70°C for one hour.

Shredding material to <12 mm results in a feedstock with a higher bulk density than the material produced by the Powerscreen used in this project. Because of the importance of ensuring adequate air flow through the tunnels the Powerscreen approach, producing coarser material, was favoured. However, there is no inherent reason why the <12 mm approach could not work in batch tunnels as long as there is control over the composition of the feedstock, its moisture, and the depth to which it is filled into the tunnels.

Movement of material

Once shredded, the feedstock has to be transported to the batch tunnel processing area. In the case of this project, this was carried out using a tractor and trailer combination. In a green field facility the reception area should adjoin the ‘dirty’ end of the tunnels to enable the fastest possible filling of the tunnels.

Although semi-automatic conveyor systems are available to fill the tunnels, front loaders were used for this project. Front loaders are very versatile machines that can be used for a wide number of applications throughout the site and can be replaced quickly if mechanical problems occur. Front loaders were also used to empty the tunnels, to transfer material from one tunnel to another, to construct and turn windrows, and to feed the trommel screen.

Washing down and general hygiene

The levels of cleanliness demanded by ABPR for the project runs and all the commercial runs carried out by the company required the frequent cleaning of concrete surfaces and equipment. In the case of this project an individual operator was given responsibility for maintaining a tight control over the hygiene of all sections of the site. He was responsible for washing down concrete when required, washing vehicles and vehicle wheels, and replenishing disinfectant foot baths. It is considered essential that in all composting sites one individual is made responsible for hygiene monitoring and control.

Batch tunnel composting

Front loaders were used to fill and empty the tunnels. This was found to be a very cost effective process. The drivers of the front loaders were very experienced and could, to an extent, judge the depth to which the tunnels could be filled depending upon the perceived bulk density of the shredded feedstock. They were supported in this role by the site foreman and the site operations manager. The site operations manager at Envar is a very experienced composter with a particularly detailed knowledge of batch tunnel composting. Such a person is essential in order to ensure that the tunnels operate efficiently allowing maximum throughput of feedstock, and also compliance with ABPR and EP. This experience is also invaluable in ensuring that the correct mixtures of feedstocks are prepared, at the correct bulk density and moisture. An experienced operations manage will also draw up a series of standard operating protocols for each stage of the composting process covering everything from the reception of the feedstock to the removal of the product from the site.

The tunnels were operated using the same procedures as used for commercial runs. Apart from an intermittent fault with one of the oxygen probes, which was rectified, each part of the computer-controlled system worked very well. Only one run of co-mingled kitchen waste and green waste did not reach the required ABPR time/temperatures first time. This situation was readily rectified by reprocessing the material through a tunnel. The problem was that the density of the fill was slightly too high.

Overall, the tunnels were demonstrated to be very reliable and predictable and could process all of the feedstock mixtures used by the project. The proportion of kitchen waste in the kitchen waste/green waste mixtures could be increased to 30% by weight before residence times started to significantly increase.

Windrow composting

Windrows produced from the intensive runs in the project (6 with co-mingled kitchen waste and green waste as feedstock, and two with MSW fines added to this material) were constructed from material taken from individual tunnels, i.e. the windrows were 150 – 200 tonnes. The windrows set up as part of the normal operation of the St Ives site are c. 1,000 tonnes each.

Because of the small size of the project windrows there was a greater edge effect than normal. This means that the ratio of the surface area of the windrow to its mass was greater. The surface of the windrow tended to dry quicker than in a normal size windrow.

There has been much discussion in the industry on the optimal height and width of a windrow, how it should be turned (front loader, side-turner, straddle-turner), how frequently it should be turned, and for how long the windrow composting stage should be carried out. Although a detailed discussion of this stage of the composting process is beyond the remit of this project, a few general comments can be made.

It is vital that the windrow should remain aerobic at all times and that all the material within the windrow should be taken through an effective composting environment for the required amount of time.

The above is accomplished by ensuring that:

- The windrow is not too high or too wide to prevent air movement to all parts of the windrow.
- The moisture content of the windrow is not so low that composting activity is reduced or stopped, or so high that air movement into the windrow is compromised.
- The windrow is turned sufficiently frequently to ensure that all parts of the windrow are taken through a high temperature stage and that new surfaces are exposed for microbial action.
- Windrow composting is continued until the required level of stability is obtained.

In the case of windrows constructed for this project, the windrows were c. 3 m high and 5 m wide and were turned weekly for at least 8 weeks. This produced a product, after screening, which was acceptable to local farmers as a soil improver.

Screening

The project used a McCloskey 621 trommel screen fitted with a 10 mm mesh screen. The trommel was attached to a Komptech Windsifter to remove plastic contaminants. This process produced material of a quality readily acceptable to local farmers.

If the level of plastic contamination in the feedstock could be reduced, it would be possible to use a 25 mm mesh screen at the end of the windrow composting stage. This would allow a faster screening process producing a coarser end product, but one that would still be acceptable to farmers for use as a soil improver. There would also be a greater yield of end product and less oversize material produced.

16.5 Batch tunnel composting of co-mingled kitchen waste and green waste

This feedstock was processed in runs 1 to 67.

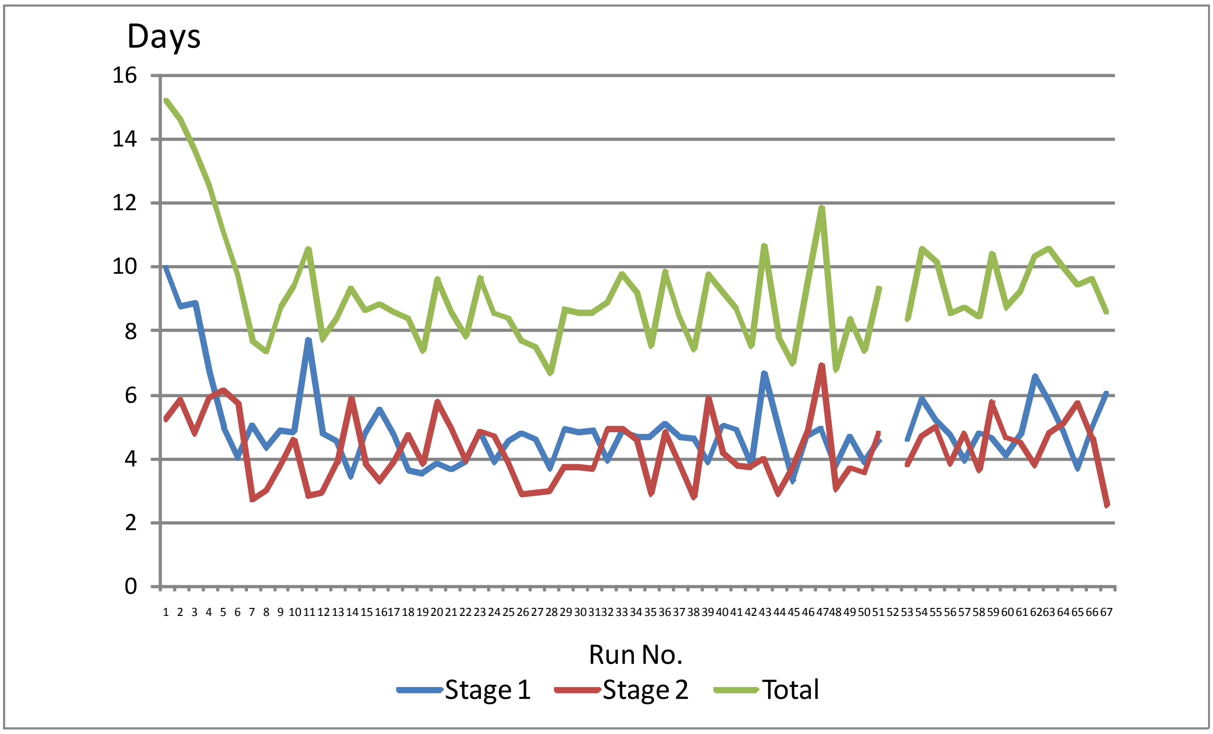
The Gicom system proved to be excellent in monitoring and controlling the composting process within the tunnels. The software controlling the tunnels measured or calculated over 150 different parameters, some of which were used to control the composting operation while others were used to generate data for subsequent analysis.

Residence time

The residence time in the tunnels required to take this type of feedstock through a process compliant with ABPR was not significantly affected by the proportion of kitchen waste in the feedstock, as long as it was 30% or below. Nor was it affected by the quantity of feedstock processed during any particular run at least up to c. 248 tonnes. The operators filling the tunnels were experienced in ensuring that dense feedstock was not overfilled.

The average time for the first stage of tunnel composting was 4.90 days (st. dev. 1.26) and the average time for the second stage was 4.28 days (st. dev. 1.02). The average for completing both stages was 9.18 days (st. dev. 1.67). It is to be expected that the second stage would be quicker than the first stage in that the required composting micro-organisms are already present in high numbers, and that the material filled into the second stage tunnels is uniform and warm.

Figure 153: Residence time for Runs 1 – 67 – date order



With the exception of the first 3 runs during the winter months when high the highest levels of kitchen waste were used at the start of the project, the time taken for each of the tunnel composting stages was fairly predictable and uniform. This enabled the project in particular, and the site as a whole, to successfully control the timing of each stage of the production process. The tunnel composting runs during the winter months near the end of the project did not repeat the extended time seen in the first 3 project runs during the first winter of the project and did not contain such high proportions of kitchen wastes. This reflected the experience gained in processing this type of feedstock and a tight control over the feedstock composition.

A tight control over the bulk density of the feedstock and the depth to which it is filled within the tunnels will ensure that the tunnels are used to their maximum capacity. This ensures that the final stabilised compost product is produced as quickly as possible.

Effect of heated walls and floors

An analysis of the data for the 67 runs using kitchen waste and green waste mixtures as feedstocks shows that the mean residence time for runs with the heated walls and floors turned on was 4.71 days (st. dev. 0.80) while that for the runs with the heating turned off was 5.02 days (st. dev. 1.5).

An analysis of data for the eight runs using MSW fines combined with kitchen waste and green waste to produce CLO showed that the mean residence time in the first stage for runs with the heated walls and floors on was 5.26 days (st dev 1.04) and the residence time when the heated walls and floors were turned off was 7.04 days (st dev 1.92). This showed a significant reduction in residence time but with a total of only eight runs generating the data.

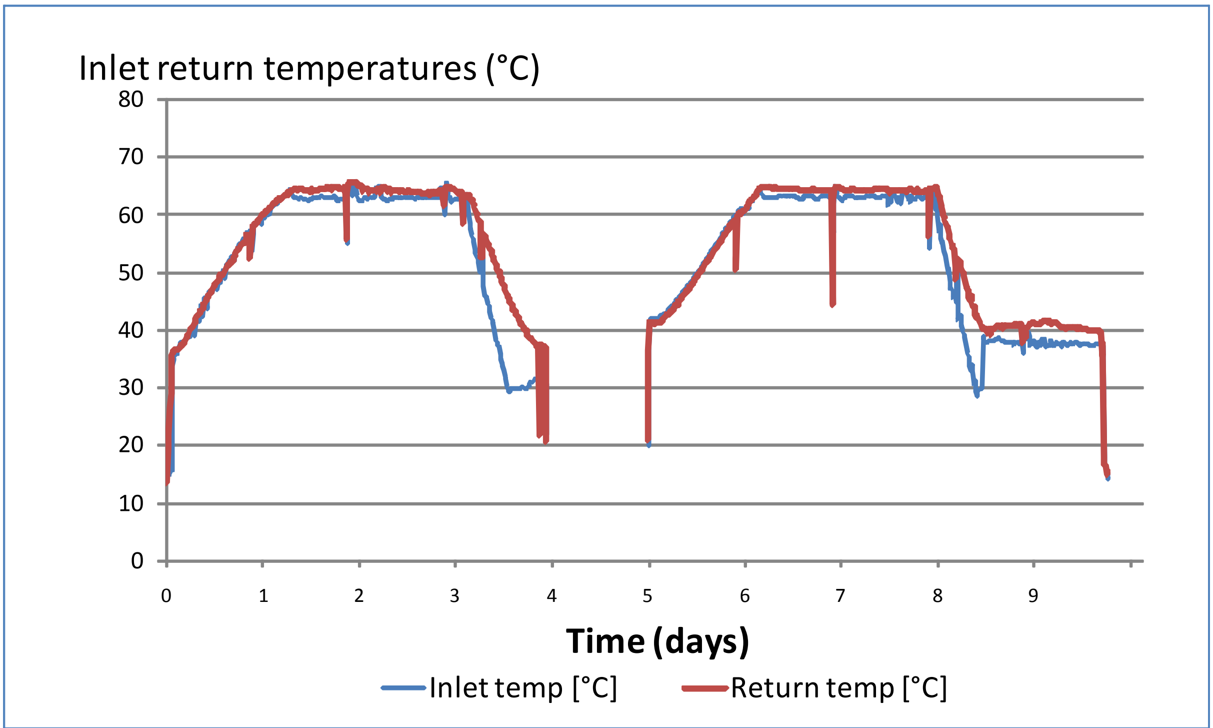
The data generated by the project demonstrated that the use of heated walls and floors is not necessary in order to ensure that all parts of the composting matrix reach the time/temperature regime required by ABPR. The results of the project clearly showed that the required conditions could be met whether the wall and floor heating was turned on or off.

Temperatures – air inlet and return

In order to ensure that the composting environment within the tunnels is uniform it is essential that the temperature gap from the bottom to the top of the composting mass is as small as possible. If the gap in temperature between the bottom and the top is more than a few degrees there will be a variation in the composting process throughout the composting mass and there will be difficulty in ensuring that all parts of the composting mass are taken to 60°C for 48 hours as required by ABPR.

The project has shown that the difference in air temperature entering the base of the tunnel (the coolest area) is within a couple of degrees of the exhaust air leaving the tunnels (the hottest area) and that all of the composting mass is taken through the required ABPR time/temperature regime. The results from run 57 illustrate this point.

Figure 154: Air inlet and air return temperatures for run 57

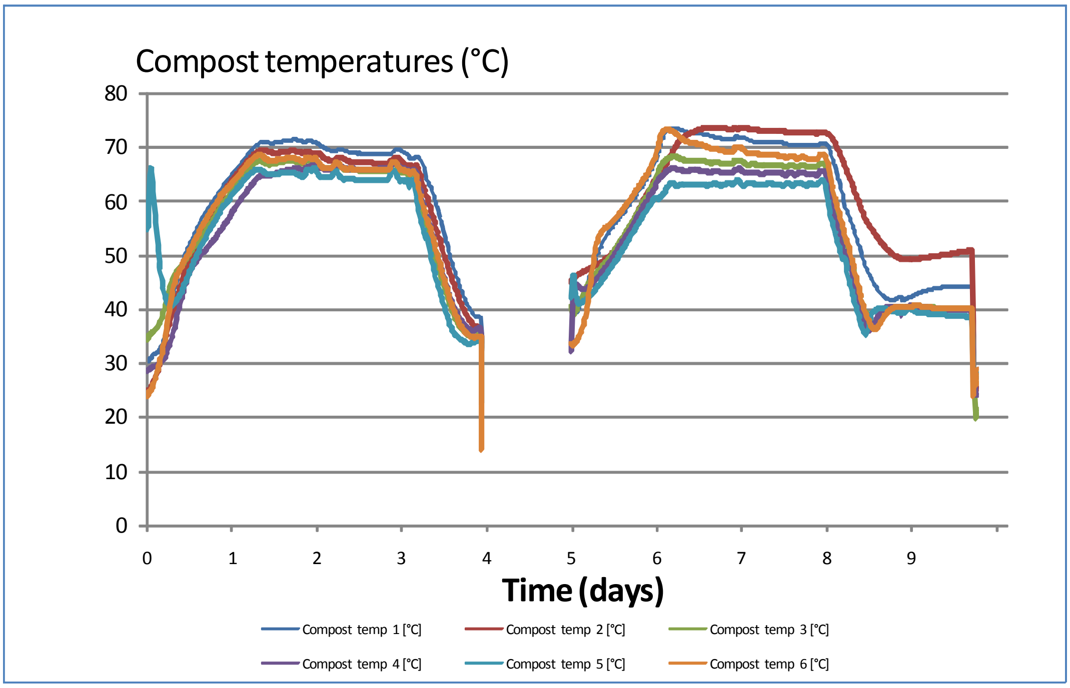


The gap between air inlet and air return temperatures is controlled by the volume of air passing through the composting matrix. The large fans in the Gicom tunnels (37 kW) ensure that sufficient air movement occurs to keep the temperatures uniform from top to bottom. Other systems with much smaller fans would struggle to attain this degree of uniformity.

Temperature – compost

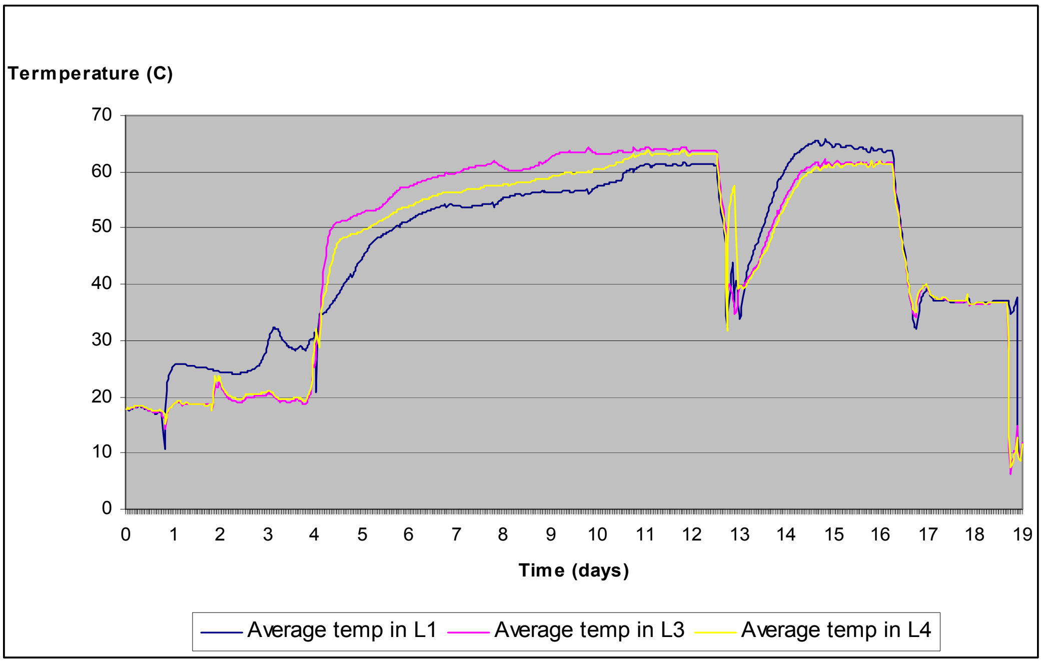
The temperatures recorded by the 6 compost temperature probes indicated that all of the measured regions of the composting mass in the tunnels exceeded the required time/temperature regime of ABPR. Two of the compost temperature probes were situated near the doors of the tunnels in a position agreed with Animal Health as representing the coolest part of the composting material within tunnels. The results from run 57 illustrate this point.

Figure 155: Compost temperatures for run 57



In addition to the 6 tunnel compost temperature probes, for the intensive runs, TinyTag temperature recording devices were placed on the floor of the tunnels, against the tunnel walls, and in the tunnel corners to measure compost temperatures before, during and after the pasteurisation stage.

Figure 156: TinyTag temperature monitors – run 57



These temperature results give confidence that the Gicom batch tunnel system can more than adequately ensure compliance with ABPR in terms of the time and temperature requirements for pasteurisation.

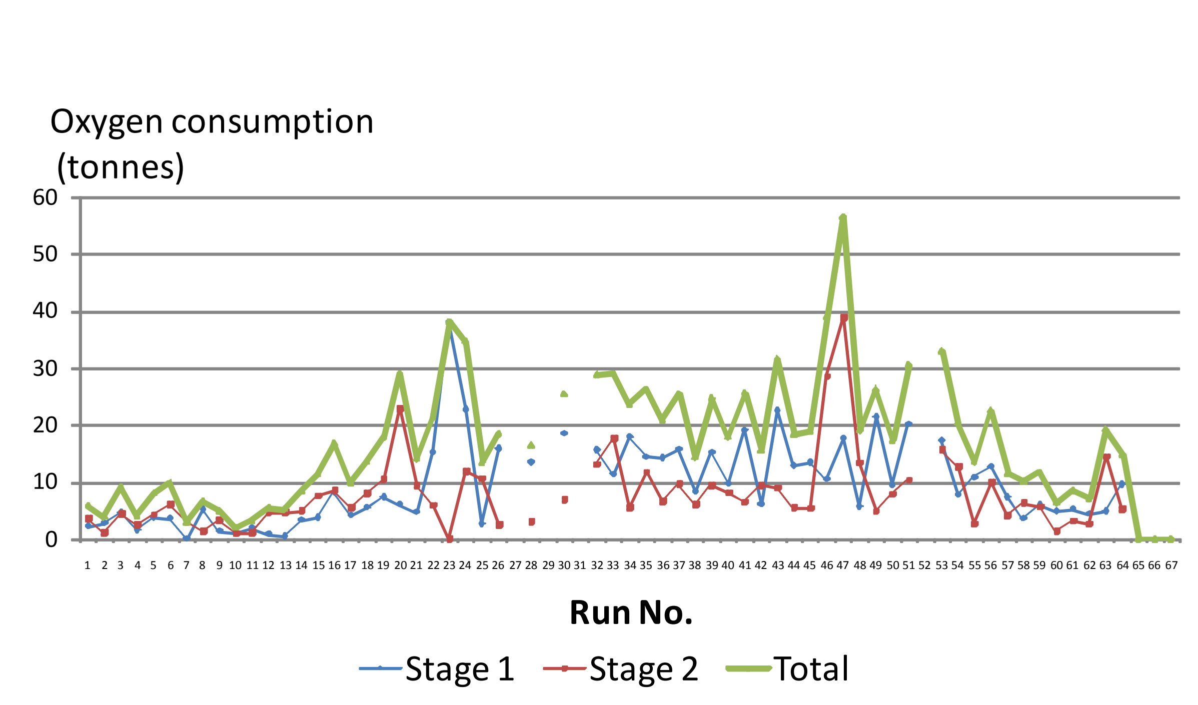
Other composting systems, with lower aeration levels, should be examined in equal detail to determine the level of compliance with ABPR in all parts of the composting system. The coolest part of the system should be identified, temperature probes should be inserted at this point, and temperatures recorded through the pasteurisation stage.

Oxygen consumption

The tunnel computer controlled aeration to ensure that oxygen levels did not drop below 7% at any time, thereby guaranteeing aerobic conditions at all points within the tunnel.

The quantities of oxygen consumed by the composting process showed considerable variation from one run to another.

Figure 157: Oxygen consumed during runs 1 – 67



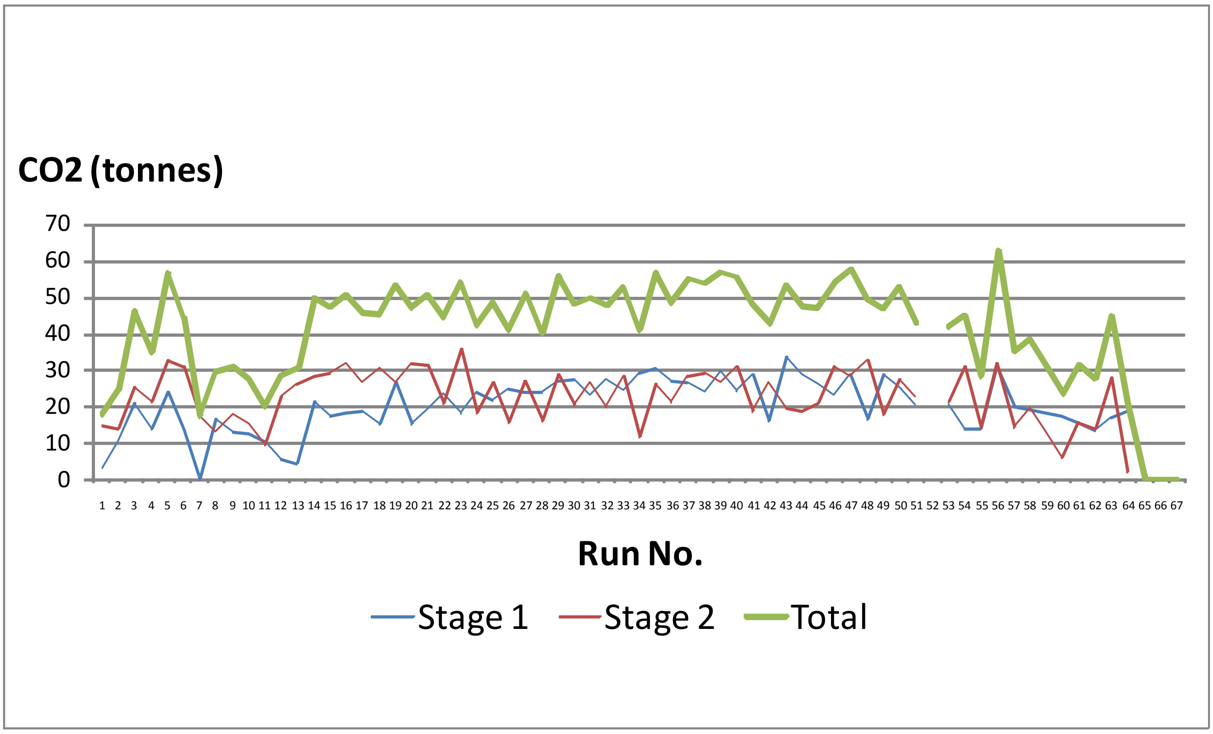
The consumption of oxygen during the summer months was significantly greater than during the winter months, indicating a much more active compost. This is probably due to the changes in composition of the feedstock, especially the relative proportion of easily biodegradable components such as grass. The feedstock during the winter months tends to have very little grass in it and can be quite dense. It is clear that efforts have to be made during the winter months to increase the activity of the compost as much as possible. This is often accomplished by the addition of oversize material to open up the structure of the composting matrix.

However, it should be emphasised that every one of these runs passed the required time/temperature regime for ABPR compliance.

Carbon dioxide production

It was also found that considerably more carbon dioxide was produced during the summer months compared to the winter months. This mirrored the utilisation of oxygen and was probably caused by the same variation in the activity of the compost. Carbon dioxide levels were not recorded for runs 65,66 an 67 because of a downloading problem.

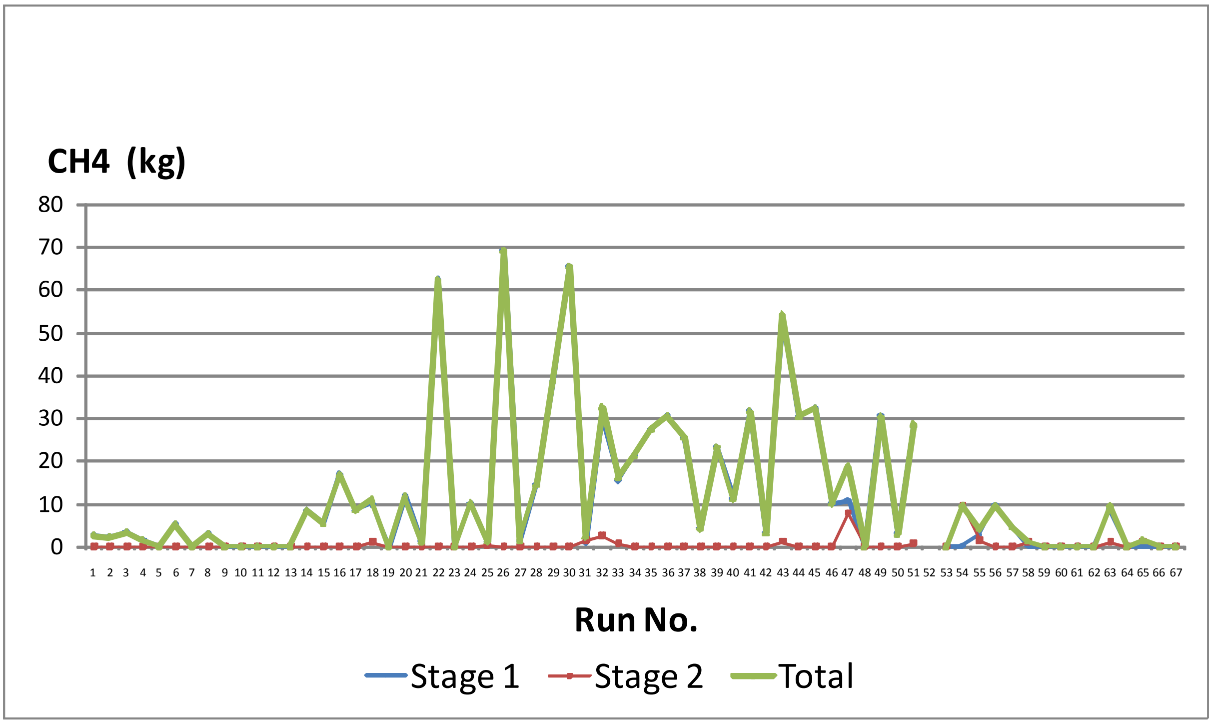
Figure 158: Carbon dioxide produced during runs 1 – 67



Methane production

Methane was normally detected for only a short period during the first stage of tunnel composting. The quantities detected were very small and it was concluded that this methane was likely to be the result of anaerobic conditions within some parts of the feedstock delivered to the site. This was to be expected as there was some variation in the time the feedstock was stored prior to delivery to the site, and in the amount of kitchen waste present in the feedstock. The small amounts of methane produced were quickly oxidised by the aerobic conditions within the tunnels.

Figure 159: Methane detected in runs 1 – 67



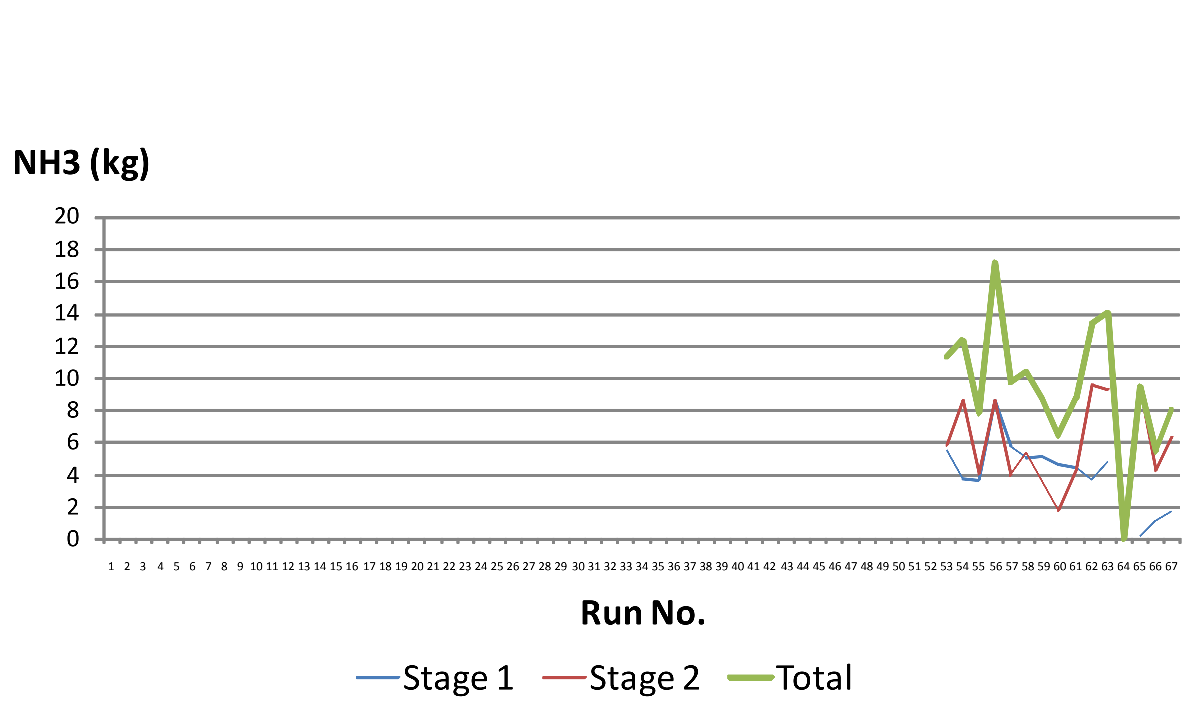
More methane was detected in the summer months than during the winter. This would be expected as the higher storage temperatures of the feedstock prior to delivery to the site would encourage the development of anaerobic conditions.

This data has shown that the tunnels always operated under aerobic conditions and give the composter confidence that no anaerobic odours will be produced during the tunnel composting part of the process, and that the tunnel composting process will not generate amounts of methane above those that are generated by the feedstock itsel.

Ammonia production

For technical reasons, ammonia was only measured by the tunnel computers from runs 53 to 67.

Figure 160: Ammonia produced in runs 52-67



The presence of ammonia within the exhaust gases from the tunnel was expected as the breakdown of the volatile components within the feedstock takes place. On the basis of previous experience, the amount of ammonia produced will vary considerably from one type of feedstock to another. Feedstocks containing manures, such as horse or poultry manures, produce considerable quantities of ammonia. Feedstocks such a co-mingled kitchen waste and green waste produce relatively small quantities of ammonia compared to other types of compost such as mushroom compost made from straw and poultry manure. In mushroom composts ammonia levels in process air are often ten times higher than the levels seen with these feedstocks.

The use of the scrubber has shown that the release of ammonia to atmosphere by the tunnel part of the composting process can me minimised, but only if the scrubber water is replaced at an adequate frequency.

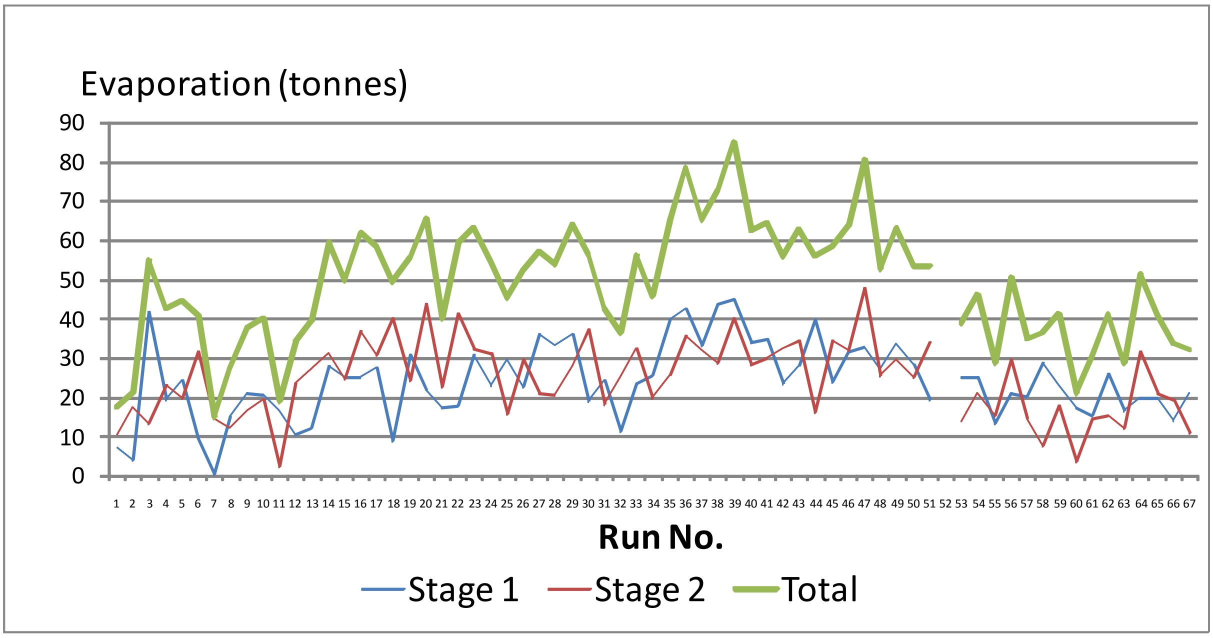
Water evaporation

Because of the large volumes of air forced through the composting material within the tunnel, and the high temperatures generated throughout much of the process, the rate of evaporation from the composting material is high.

The amount of water evaporated from each of the two stages of the tunnel composting process was approximately the same, but the amount of water lost during the summer months was greater than during the winter months. Again, this indicates a more active compost during the summer.

The control of compost moisture levels within the tunnels is critical in ensuring that the rate of composting is not limited by dry conditions. The ability of the Gicom tunnels to add water through spray bars in the tunnels while composting is taking place is a very important feature. Although the actual moisture levels of the composting material are not measured while the material is inside the tunnel, the site operators are sufficiently experienced to determine whether or not the feedstock at any one time will require the addition of extra water. It is not necessary, or desirable, to replace all of the water lost by evaporation. Sufficient water has to be added during composting to ensure that composting is not limited by reduced moisture levels within the tunnels or afterwards during the windrow composting stage. More water needs to be added by spraying within the tunnels during the summer months than in the winter months.

Figure 161: Water loss by evaporation during runs 1 – 67

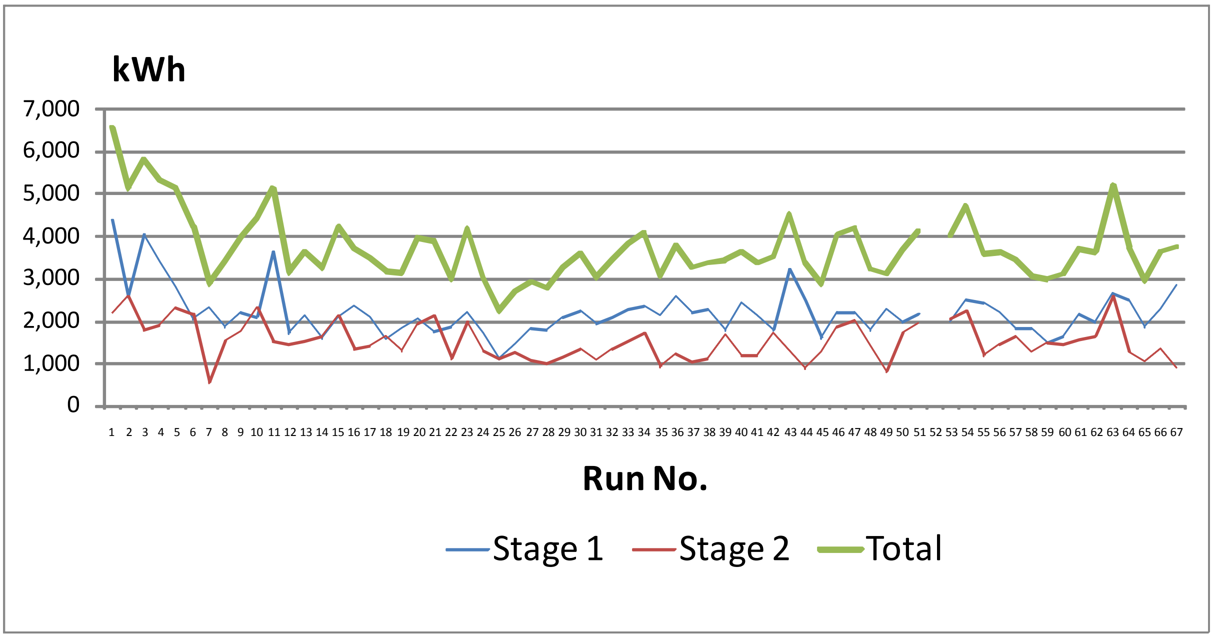


The water evaporation data and the spraying data assist the composter in optimising the tunnel composting process by indicating when and how much water needs to be added to the material composting in the tunnels. This ensures that the composting matrix does not become too wet and thereby restrict air movement and temperature control, or too dry so that the composting process slows down. This degree of control over moisture ensures that composting in the tunnels is always near optimal conditions for this parameter and hence throughput is as high as possible.

Electricity utilisation

Most of the electricity used by the tunnel operation is employed to run the large aeration fans. Apart from the first few runs of the project where the highest kitchen waste percentages were used, the electricity utilisation rate was fairly uniform throughout the project.

Figure 162: Electricity consumption during ring 1-67



Using an average electricity price of £0.07663 per kWh, it can be determined that the cost of processing a tonne of feedstock through the first stage of tunnel composting is c. £0.81 per tonne of feedstock. Assuming a loss of c. 20.9% of the mass during the first stage of composting, the electricity costs of processing the material through the second stage of composing is c. £0.69 per tonne of first stage material.

Table 28: Electricity costs of tunnel composting

	First stage	Second stage
kWh	145,077	100,058
Cost/kWh	£0.07663	£0.07663
Electricity cost	£11,117	£7,667
Tonnes processed	13,798	10,914
Cost/tonne	£0.81	£0.70

The total electricity cost of tunnel composting the 13,798 tonnes of feedstock was £18,784, giving an average cost of £1.36 per tonne of feedstock. It is to be expected that cost per tonne of fill will be slightly less for the second stage than the first stage, as the material being filled into the second stage will be drier and warmer than the feedstock filled into the first stage tunnel, and the residence time is significantly shorter.

The work reported on feedstock mixtures, moistures and quantities filled into the tunnels also informs the composter on how to minimise the electricity costs associated with tunnel composting. Electricity costs for tunnel operation can be minimised by ensuring that the structure of the composting matrix readily allows the movement of air and does not have too high a moisture content or bulk density.

Effect of heated walls and floors

An analysis of the data shows that the mean residence time for runs using kitchen waste and green waste mixtures with the heated walls and floors turned on was 4.71 days (st. dev. 0.80) while that for the runs with the heating turned off was 5.02 days (st. dev. 1.5).

Although the residence time is slightly less in the heated runs the difference is not thought to be significant. The extra cost of installing the floor and wall heating pipes, the cost of the boiler and the cost of gas to run the heating system is thought to exceed any minor improvement in throughput of the feedstock during the first stage of tunnel composting.

The eight runs using MSW fines combined with kitchen waste and green waste to produce CLO showed that the mean residence time in the first stage for runs with the heated walls and floors on was 5.26 days (st dev 1.04) and the residence time when the heated walls and floors were turned off was 7.04 days (st dev 1.92). This showed a significant reduction in residence time but with a total of only eight runs generating the data.

However, in a facility with a rapid movement of batches of feedstock through the composting tunnels, the walls and floors of the tunnels are frequently still warm from the previous run when the next batch of feedstock is filled into the tunnel and additional heating is not necessary. The use of heated floors may be advantageous at times of the year when the supply of feedstock is such that the tunnels cool down completely between fills.

The data generated by the project also demonstrates that the use of heated walls and floors is not necessary in order to ensure that all parts of the composting matrix reach the time/temperature regime required by ABPR. The results of the project clearly showed that the required conditions could be met whether the wall and floor heating was turned on or off.

Mass balance

It was determined that the data from the first 60 runs using this feedstock was sufficient to enable an analysis of mass losses within the tunnels to be carried out. The analysis showed that there was an average of 20.9% loss in mass during the first stage of tunnel composting and a further loss of 24.3% of the material filled into the second stage tunnel. The total reduction in mass of the original feedstock during the two stages of tunnel composting was 38.6%. These figures allow for the water added by spraying during tunnel composting.

The mass balance model shown in this report enables the modelling of each of the two stages of tunnel composting. The inputs in terms of volatile solids, total solids, ash, water, sprayed water, dry air and air moisture are included and are used to calculate the predicted losses and output in terms of the same parameters. An assumed degradation percentage can be changed in order to reflect variations in composting activity.

This model should also be useful in predicting the performance of composting systems other than batch tunnels. The particular characteristics of a composting system can be allowed for in fine tuning the model.

Energy balance

Energy consumption is an important consideration in determining the cost effectiveness of an in-vessel composting system. It is therefore important to calculate how much energy is used by such a process and to estimate the associated costs.

The energy balance model described enables the calculation of the various sources of energy entering the batch tunnel system, the energy generated by the compost in the tunnel, and also the energy leaving the system. While this model is specific to batch tunnels, it can be modified to look at the energy balance of other in-vessel composting systems.

Factors affecting residence time in the tunnels

The time required for tunnel composting obviously plays an important role in determining the throughput of a composting facility and the cost of processing a tonne of feedstock. The shorter the time in the tunnels, without compromising compliance with ABPR, the more cost effective is the process.

The project has shown that the electricity consumption during the first stage and the second stage of tunnel composting is directly proportional to the residence time. There is a closer correlation in the first stage than in the second stage.

The results show that the percentage of kitchen waste in the feedstock mixture can be as high as 30% (by weight) before the residence time significantly increases. This indicates that the batch tunnel system can handle a wide variety of wastes and waste mixtures without compromising the throughput of the facility.

The results also showed that the nominal capacity of the tunnels can be considerably increased as long as the bulk density of the feedstock mixture is controlled so that the movement of air is not compromised.

All of these results illustrate the versatility of the batch tunnel composting system in terms of the types of feedstock processed and its capacity to handle varying batch sizes.

After the end of the project the site obtained an ABPR license that enabled it to comply with the regulations using a single pasteurisation stage rather than the two pasteurisation stages previously required. This development halves the required residence time in the tunnels.

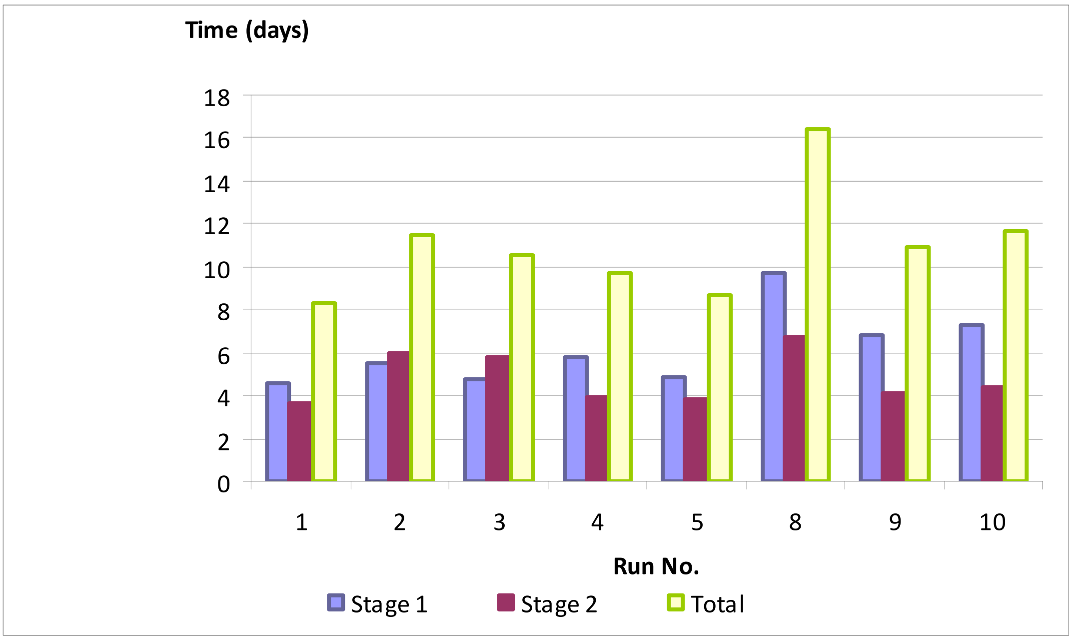
16.6 Batch tunnel composting of MSW with co-mingled kitchen waste and green waste to produce CLO

The MSW fines (derived from a Shanks Waste facility) were added to shredded co-mingled kitchen waste and green waste prior to being filled into the composting tunnels. Ten composting runs were carried out using this feedstocks. Eight runs were carried out in exactly the same way as with the co-mingled kitchen waste and green waste feedstocks described earlier in order to produce a CLO. Two runs were carried out with an extended second stage in order to dry out the material to produce an RDF. The Gicom system proved to be excellent in monitoring and controlling the composting process of these feedstocks.

Residence time

The residence time for the first stage varied from 4.60 days to 9.67 days. The residence time for the second stage varied from 3.68 days to 6.75 days. The combined residence time for both stages varied from 8.28 days to 16.42 days. MSW run 8 had a very long first stage as it was slower than normal in reaching pasteurisation temperatures. The two stages of tunnel composting with MSW fines included took on average 1.78 days longer to process than material without the fines included. The feedstock including the MSW fines would certainly have a higher bulk density than feedstock without this component. This may well explain the longer time need to take the feedstock through the tunnel composting process.

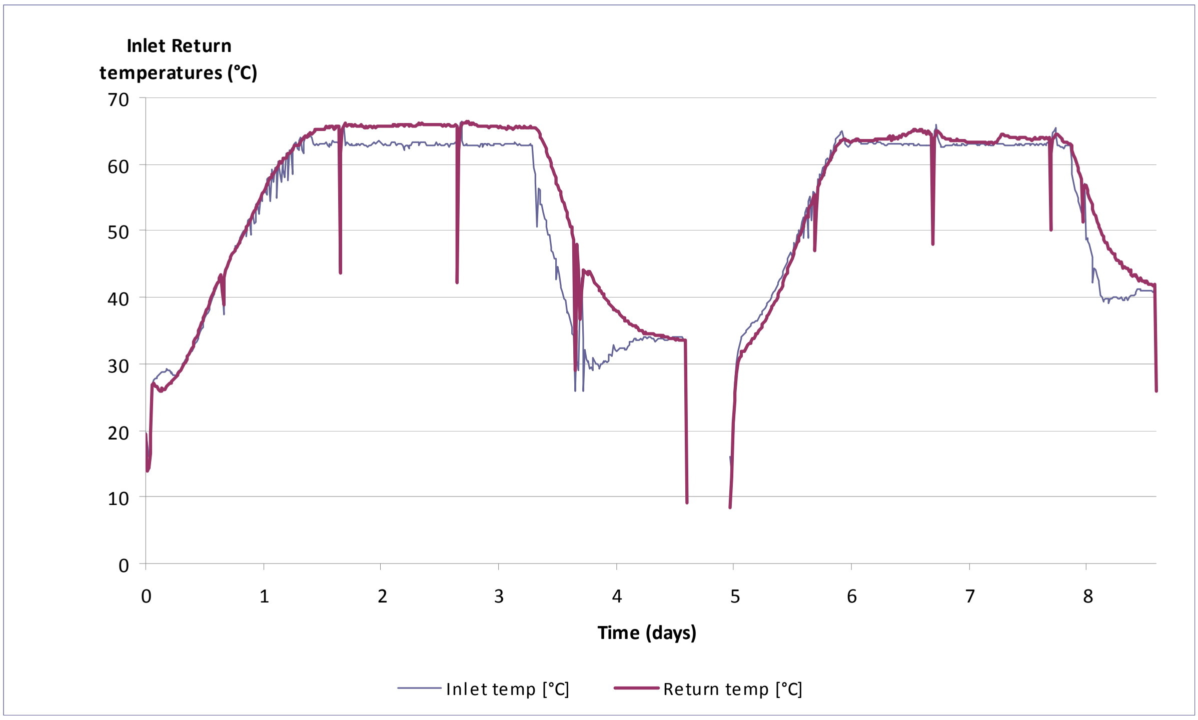
Figure 163: Residence time for MSW runs producing CLO



Temperatures – air inlet and return

The feedstock containing MSW fines behave in a very similar way to feedstock not including fines in regard to the ability to maintain small differences between the air inlet and air return temperatures despite the higher bulk density of the feedstock mixture. There was also no difficulty in ensuring that both air temperatures were above 60°C for the required 48 hours.

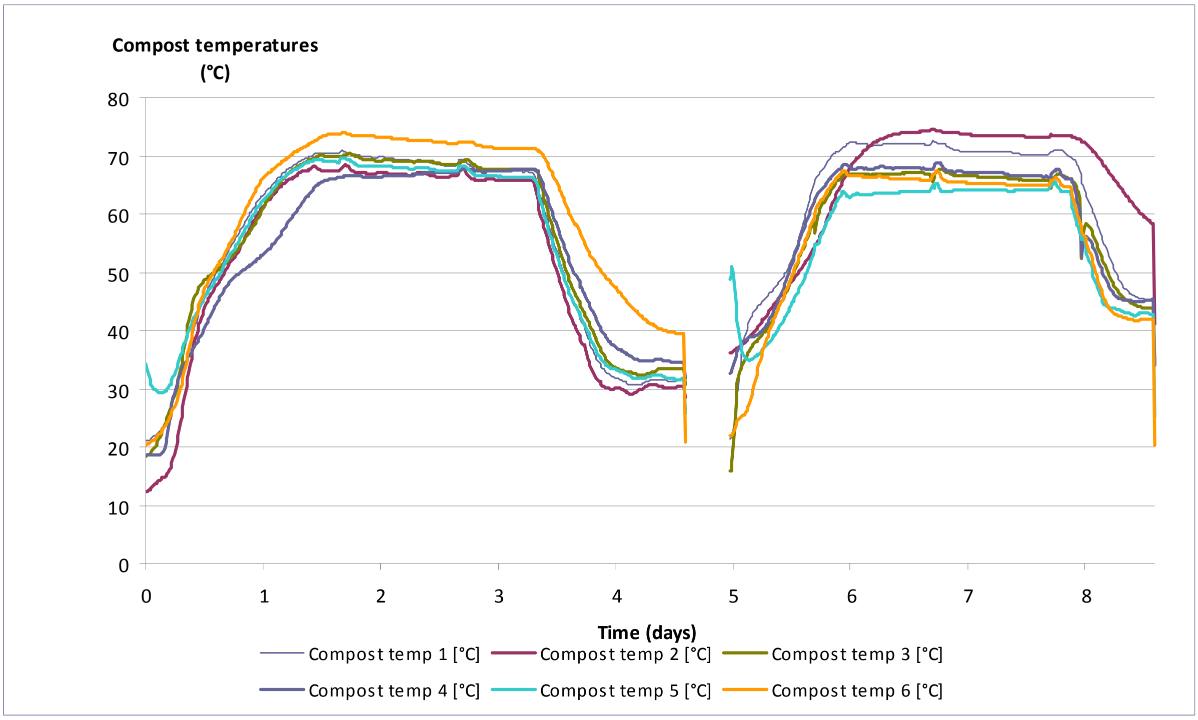
Figure 164: Air inlet and air return temperatures for MSW run 1 for producing CLO



Temperature – compost

With this feedstock the temperatures recorded by the 6 compost temperature probes indicated that all of the measured regions of the composting mass in the tunnels exceeded the required time/temperature regime of ABPR. Again, two of the compost temperature probes were situated near the doors of the tunnels in a position agreed with Animal Health as representing the coolest part of the tunnels.

Figure 165: Compost temperatures for MSW run 1 for producing CLO



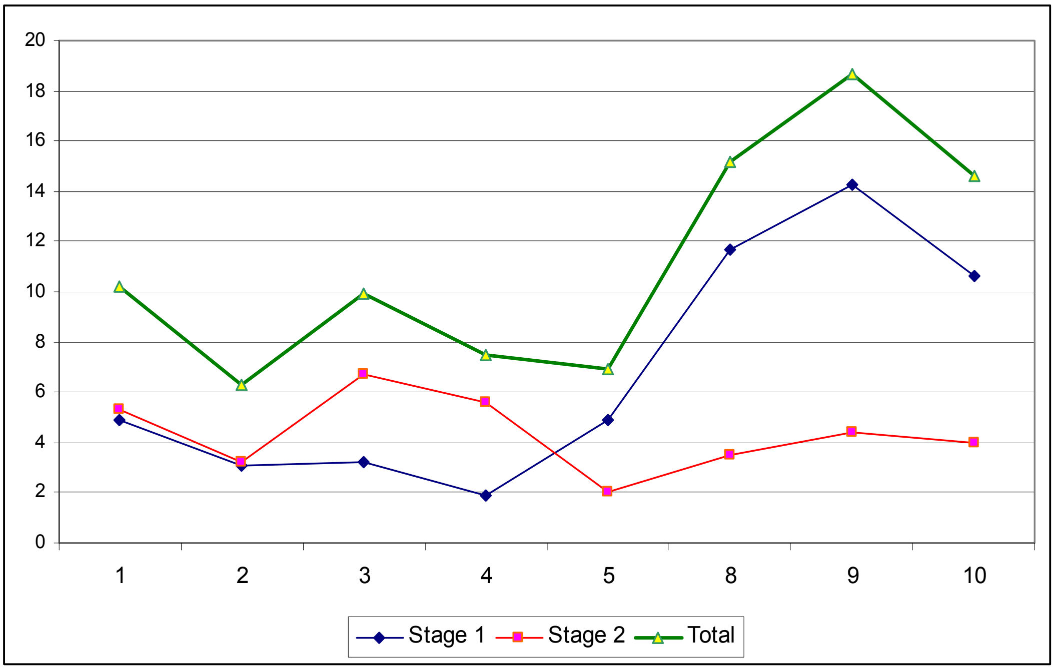
These temperature results give confidence that the Gicom batch tunnel system can more than adequately ensure compliance with ABPR in terms of the time and temperature requirements for pasteurisation using feedstock that includes MSW fines, at least up to the inclusion rate of 28%.

Oxygen consumption

The tunnel computer controlled aeration to ensure that oxygen levels did not drop below 7% at any time, thereby guaranteeing aerobic conditions at all points within the tunnel.

The quantities of oxygen consumed by the composting process showed a considerable variation from one run to another, varying from 1.9 tonnes to 19.1 tonnes for an individual stage of a run. However, the degree of variation was much lower than that seen for feedstock without the inclusion of MSW fines. This may well be due to the fact that the 10 MSW fines runs were carried out over a short period of time (10th December 2008 to 25th February 2009) and did not incur the wider variation in feedstock encountered over the much longer period (31st December 2007 to 19th March 2009) over which the feedstocks not including MSW fines were composted.

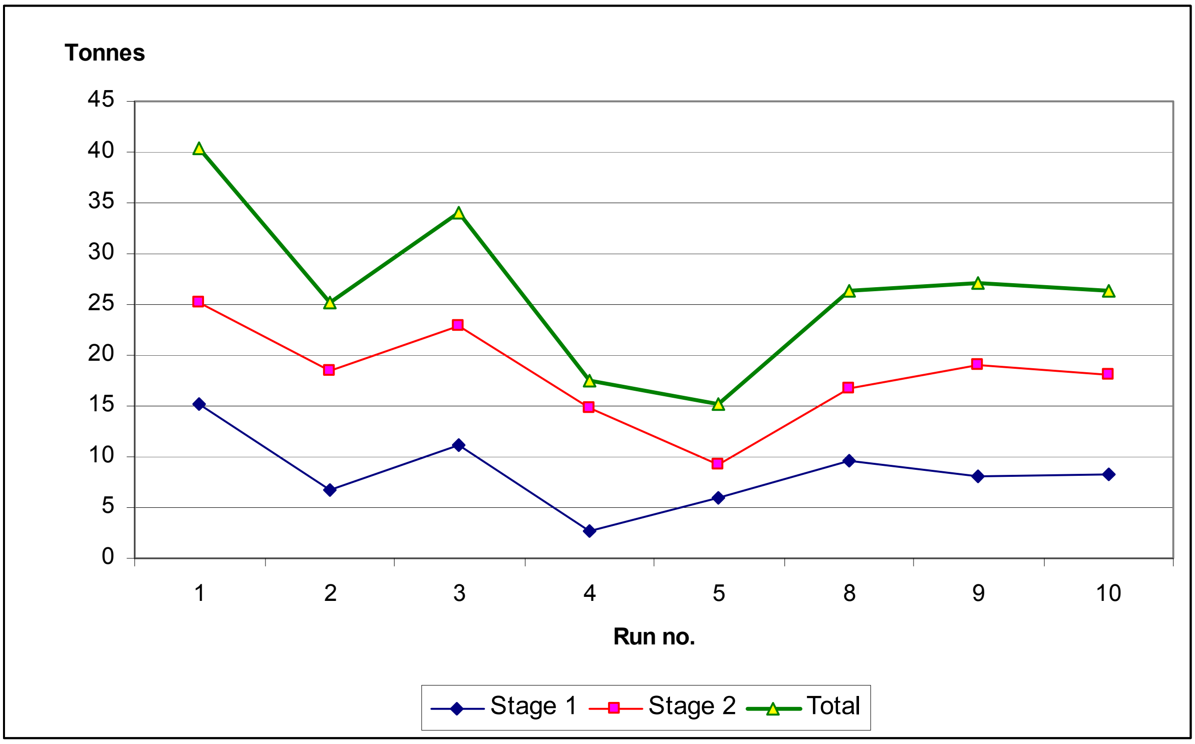
Figure 166: Oxygen consumed during MSW runs producing CLO



Carbon dioxide production

The rate of carbon dioxide production closely mirrored that of oxygen utilisation for the 10 MSW runs and was of a similar level to that generated by feedstock without the MSW included.

Figure 167: Carbon dioxide produced during MSW runs producing CLO

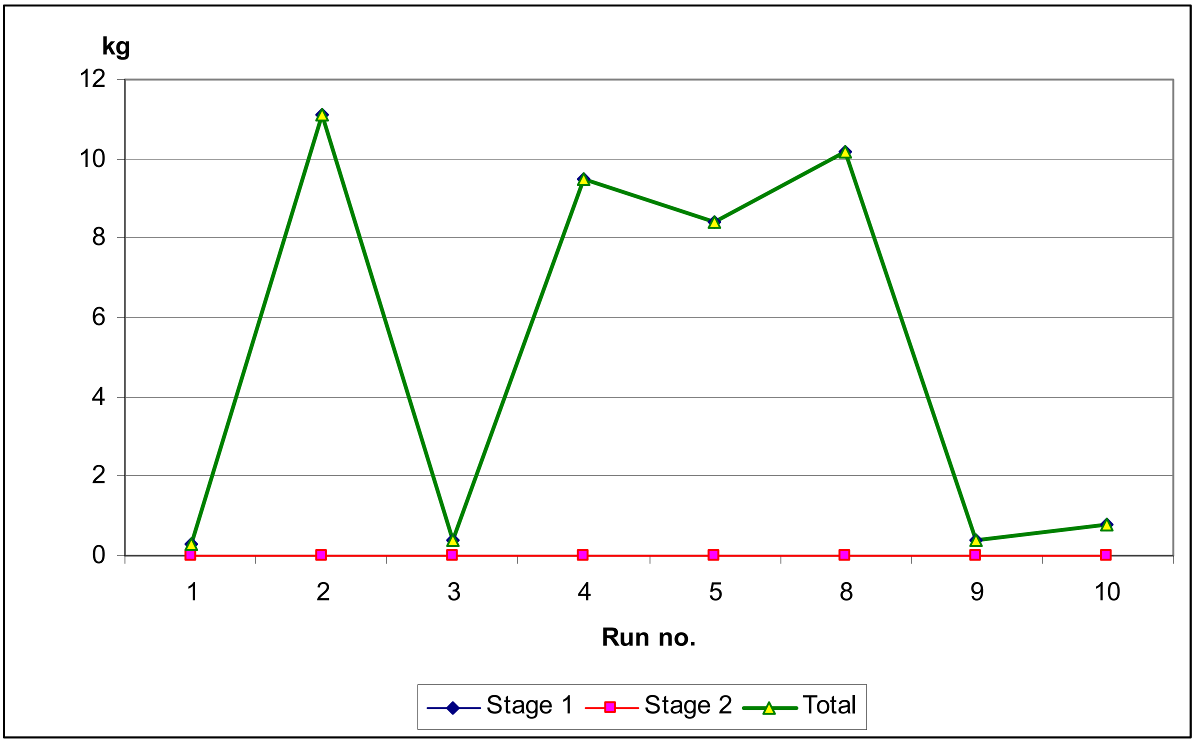


As the sensitivity of the tunnel carbon dioxide resulted in a cut off above 110,000 ppm the total figures for carbon dioxide production are underestimated to a limited extent.

Methane production

The pattern of methane production followed that of feedstock without MSW fines included. There was no detectable increase in the levels of methane encountered through the addition of the MSW fines to the feedstock mixture.

Figure 168: Methane detected in MSW runs producing CLO



It is clear that feedstock should be delivered to the composting site as quickly as possible after collection to avoid the generation of anaerobic conditions.

Ammonia production

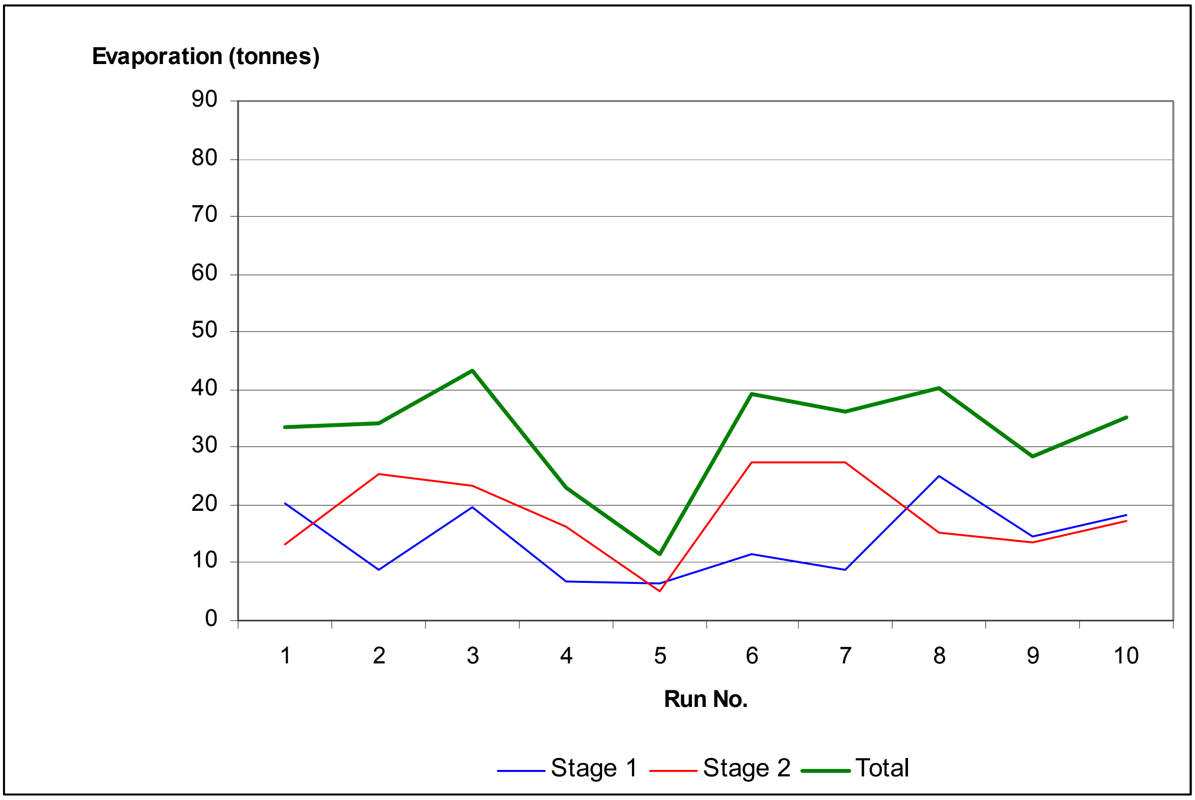
Ammonia levels were measured using the tunnel infrared probe for all 10 MSW runs. The levels of ammonia produced were much higher than that found in the processing of feedstock not including MSW fines. The maximum level with non-MSW material was 17.2 kg for both stages with an average of 10.2 kg. The maximum level for the MSW runs producing CLO was 89.8 kg for both stages. The exact reasons for these higher ammonia levels are not clear but clearly relate to the volatile components in the MSW fines.

As the sensitivity of the tunnel ammonia detection system resulted in data producing a plateau at 70 ppm the amount of ammonia generated by the system is underestimated to some extent.

Water evaporation

The levels of water loss by evaporation of feedstock containing MSW fines is similar to that of feedstock not including MSW fines at a similar time of year, i.e. during the winter months.

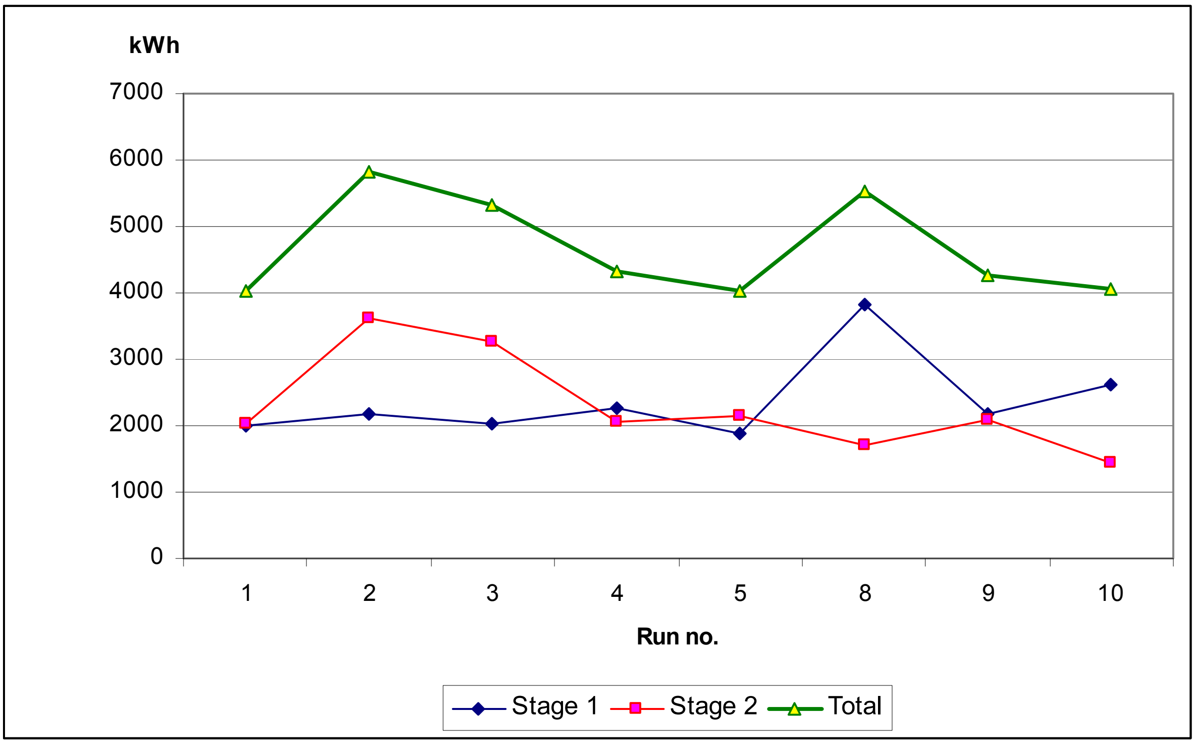
Figure 169: Water loss by evaporation during MSW runs producing CLO



Electricity utilisation

The minimum utilisation of electricity for both stages of composting with feedstock containing MSW fines producing CLO was 4,031 kWh with a maximum of 5,809 kWh and an average of 4,875 kWh. With feedstock not containing MSW fines the minimum for both stages was 2,247 kWh, with a maximum of 6,533 kWh and an average of 3,714 kWh.

Figure 170: Electricity consumption during MSW runs producing CLO



Effect of heated walls and floors

An analysis of the data shows that the mean residence time for the first stage of MSW runs producing CLO with the heated walls and floors turned on was 5.26 days while that for the runs with the heating turned off was 7.04 days. Unlike the runs using feedstocks not including MSW fines, this difference is statistically significant. However only four runs with MSW were carried out with the heating on and only four with the heating off, so this result has to treated with caution.

In a facility with a rapid movement of batches of feedstock through the composting tunnels, the walls and floors of the tunnels are frequently still warm from the previous run when the next batch of feedstock is filled into the tunnel.

Product analysis

The quality of a compost produced is affecting to a considerable extent by the quality of the feedstock, especially the level of contamination with plastic and other inerts. Every effort should be made to minimise this level of contamination as significant costs are incurred by the composter in removing and landfilling them. This is also essential in order to enable the composter to achieve the PAS 100 and Compost Quality Protocol standards.

The degree of control over the composting process, including the control of moisture, aeration, particle size and temperature also have a major effect on compost quality, along with the use of sufficient time to ensure that the compost has been sufficiently stabilised.

As expected, material derived from the two windrows produced during the intensive runs using this feedstock failed a number of the PAS 100 tests. Levels of glass and heavy metals exceeded permitted limits. This result re-enforces the case for source-separated feedstocks being used to produce high-quality compost. However, the material was suitable as a CLO and was used in one of the company's restoration projects under a paragraph 9 exemption.

Comparison with the composting of co-mingled kitchen waste and green waste without the inclusion of MSW fines

Feedstock containing MSW fines behaved in a similar way to feedstock without MSW fines with the significant exceptions that ammonia production was much higher as was the electricity consumption. These differences are likely to be caused by the volatile composition of the MSW fines and the bulk density of the material, the latter affecting the time to take the material through the two-stage composting process. The implications of these results are that greater care has to be taken in ensuring that unacceptable levels of ammonia are not released to atmosphere, and that consideration has to be given to the potentially increased electricity costs in processing this type of material.

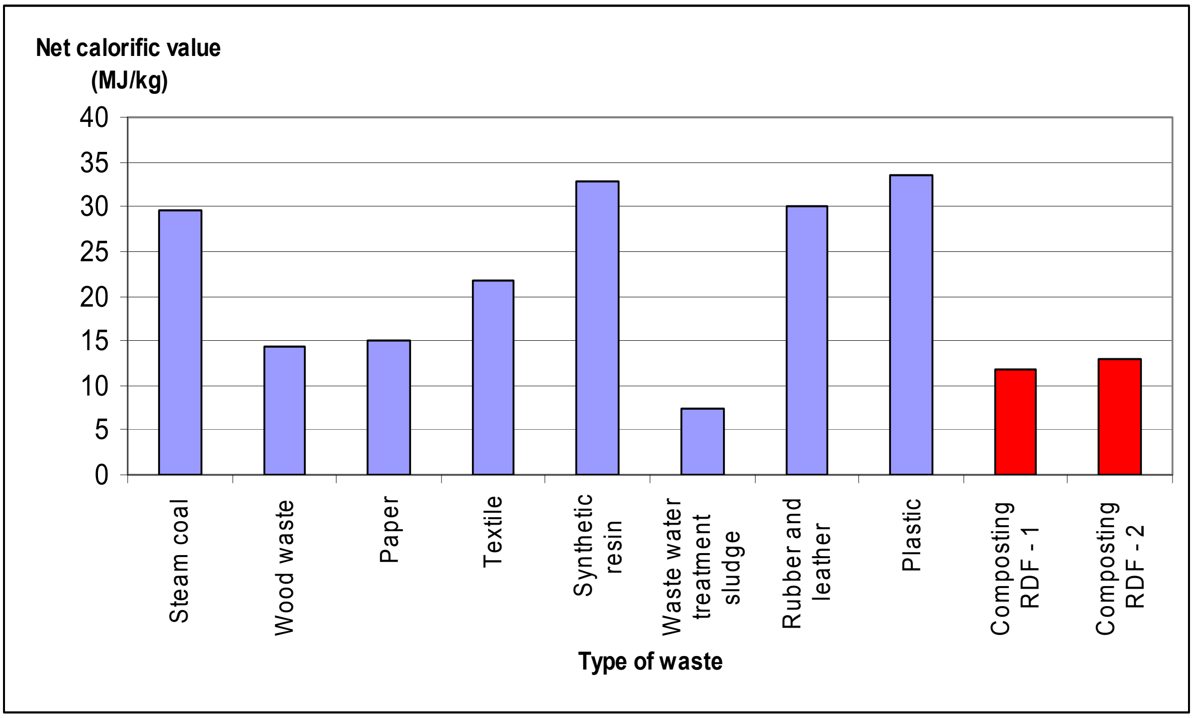
16.7 Batch tunnel composting of MSW with co-mingled kitchen waste and green waste to produce RDF

The use of batch tunnel composting to produce RDF material has been carried out for a number of years in a number of ways. It is an effective way of quickly reducing the moisture of material that is subsequently to be burned to generate electricity. The lower the moisture the more attractive is the material as a fuel.

The two composting runs used to produce RDF, from a mixture of co-mingled kitchen waste, green waste and MSW fines, (MSW runs 6 and 7) produced material that enabled the calorific value to be calculated. The average net calorific values of triplicate samples of RDF material produced by runs 6 and 7 were 11.85 MJ/kg and 12.86 MJ/kg respectively.

The following figure compares these results with the calorific value of other possible fuels. It be seen that the net calorific value of the RDF produced in Gicom tunnels is similar to paper, process sludge and wood, but has only half of the calorific of steam coal.

Figure 171: Comparison of the calorific values of compost RDF and other wastes



Although this material may well have a role to play in generating energy by combustion, there are a number of increased cost factors to consider. The residence time in the composting tunnels found necessary to produce the RDF material was more than 12 days longer than the normal second stage of tunnel composting. This extended residence time would reduce the throughput of the tunnel composting facility and would also involve a greater use of electricity.

The gross and net calorific values of the RDF material generated by the project suggest that it can be successfully combusted or co-combusted with conventional fuels but the ash content suggests that separation of the non-combustible fraction (stones, glass and metals) may be necessary to improve its calorific value further.

This type of fuel could be used in energy plants, cement kilns, incinerators or thermal treatment facilities (pyrolysis and gasification technology). These technologies are equipped with exhaust air treatment systems which allow combusting of fuel contaminated with heavy metals.

16.8 Emissions monitoring – the composting of co-mingled kitchen waste and green waste

Leachate

The biological oxygen demand (BOD) of the leachate produced by the tunnel composting of this feedstock varied from 264.00 and 9,236.67 mgl^{-1}(ppm), indicating the need for this material to be taken through a water treatment plant before release off site. This process is regulated by a Discharge License obtained from the Environment Agency who require regular analysis of the water leaving the site. The volume and BOD of the leachate has to be considered in determining the size and throughput of the water treatment plant. The leachate produced by the project was processed effectively by the existing water treatment plant at the facility.

Volatile organic compounds (VOCs)

Twenty four VOCs were detected in the exhaust gases from the processing of this feedstock. The VOCs present in the highest concentration during the tunnel warming up stage were (in decreasing concentration) 2-butanone (MEK), limonene, 2-butanol, and pinene. During the pasteurisation stage the main VOCs were (in decreasing concentration) limonene, pinene, and 2-butanone (MEK). During tunnel cool down the main VOCs were (in decreasing concentration) limonene and pinene. These are all VOCs commonly found in composting operations.

By far the highest concentrations of VOCs were found at the warming up stage of tunnel composting, with levels reducing during pasteurisation and much lower still during cool down. VOC production appears to be much higher at the start of the composting process when the feedstock is unprocessed or when its temperature increases.

Samples of air taken after the scrubber had much reduced levels of VOCs present. For example, 2-butanone (MEK) was present at 620,000 ngl^{-1} during warming up and 56 ngl^{-1} after the scrubber. Similarly, limonene was present at 390,000 ngl^{-1} at the warming up stage and at 6,400 ngl^{-1} after the scrubber. The scrubber was therefore quite efficient at reducing the levels of VOCs released to atmosphere.

The levels of VOCs emitted by the process were well within any levels set by the Environmental Permit of the facility.

Ammonia

The three methods of quantifying ammonia in the tunnel exhaust gas (Dräger tubes, bubbler method, and infrared probe) produced varying results when used to determine the efficiency of the scrubber in removing ammonia. On theoretical grounds the bubbler method should be the most accurate. It appeared that on some occasions the water in the scrubber was saturated with ammonia and that it was not always removing ammonia from the exhaust air before the air entered the biofilter. It was determined that the replacement of the water should take place on a weekly basis.

The levels of ammonia released by the batch tunnel system after passing through the scrubber and biofilter were well within any limits set by the site Environmental Permit.

Odour

Samples of exhaust air were analysed for odour concentrations before and after the scrubber, and after the biofilter. An estimate was made of the efficiency of the scrubber and biofilter systems in removing odours from the exhaust air.

The efficiency of odour removal by the scrubber varied from 18% to 67%. At its most efficient the scrubber reduced the odour level of the tunnel exhaust air from 67,123 ou_Em^{-3} to 22,018 ou_Em^{-3}.

With the exception of one anomalous result, that showed negative efficiency, the efficiency of further odour removal by the biofilter varied from 42% to 96%. At its most efficient the biofilter reduced the odour concentration of the tunnel exhaust air from 66,100 ou_Em^{-3} before the biofilter to 2,605 ou_Em^{-3} after the biofilter. Variations in the moisture levels of the biofilter undoubtedly had an effect on biofilter efficiency. It is clear that moisture levels within the biofilter must be kept high enough in order to allow efficient microbial activity.

The overall efficiency of the scrubber/biofilter system in reducing odours from the tunnel exhaust air ranged from 33-98%. This variation may have been in part due to the difficulty of obtaining representative odour samples from the tunnel exhaust air.

The levels of odour released by the batch tunnels after passing through the scrubber and biofilter were well within any limits set by the Environmental Permit of the site. No odours generated by the project were detected as unacceptable either in the region of the batch tunnels or at the site boundary.

Conclusions

This data provides useful information to help fill in the gaps in our knowledge of solid, liquid and gaseous emissions from composting facilities as indicated in the Defra report.

The small volumes of leachate produced by the tunnel composting process have high levels of BOD and require processing by a water treatment plant before being released off site. The scrubber system used to process exhaust air from the tunnels was shown to be very effective in reducing the levels of VOCs released to atmosphere. A regime of more frequent changing of the scrubber water may be necessary to improve its efficiency in removing ammonia from the exhaust air. The scrubber/biofilter combination was effective in reducing odour concentrations in the tunnel exhaust air.

The levels of all types of emissions were well within any limits set by the site's Environmental Permit.

16.9 Emissions monitoring – the composting of Municipal Solid Waste with co-mingled kitchen waste and green waste

Leachate

The BOD of the leachate produced by the tunnel composting of this feedstock varied from 194.70 and 207.00 mgl^{-1}(ppm), indicating the need for this material to be taken through a water treatment plant before release off site.

As with the composting of feedstock not containing MSW fines the small volumes of leachate produced by the tunnel composting process have high levels of BOD and require processing by a water treatment plant before being released off site.

This data assists in filling the information gap indicated in the Defra report.

Volatile organic compounds (VOCs)

Twenty seven VOCs were detected in the exhaust gases from the processing of this feedstock. The VOCs present in the highest concentrations during the tunnel warming up stage were (in decreasing concentration) limonene, ethanol, ethyl acetate, and pinene. During the pasteurisation stage the main VOCs were (in decreasing concentrations) limonene, pinene, and mercyne. During tunnel cool down the main VOCs were (in decreasing concentration) limonene and pinene. These are all VOCs commonly found in composting operations.

As with the composting of feedstock not containing MSW fines, by far the highest concentration of VOCs was found at the warming up stage, with levels reduced during pasteurisation and much lower during cool down. VOC production appears to be much higher at the start of the composting process when the feedstock is unprocessed and warming up.

Samples of air taken after the scrubber had much reduced levels of VOCs present. For example, 2-butanol was present at 22,500 ngl^{-1} during warming up and 210 ngl^{-1} after the scrubber. Similarly, limonene was present at 250,000 ngl^{-1} at the warming up stage and at 30,000 ngl^{-1} after the scrubber. The scrubber therefore seemed quite efficient at reducing the levels of VOCs released, through the biofilter, to atmosphere.

The scrubber system used to process exhaust air from the tunnels was shown to be effective in reducing the levels of VOCs released to atmosphere. A regime of more frequent changes of the scrubber water may be necessary to improve its efficiency in removing ammonia from the exhaust air. The scrubber/biofilter combination was generally effective in reducing odour concentrations in the tunnel exhaust air.

This data contributes to the limited amount of information available on the VOCs released during composting.

Ammonia

As with the composting of feedstock not containing MSW fines the three methods of quantifying ammonia in the tunnel exhaust gas (Dräger tubes, bubbler method, and infrared probe) produced varying results when used to determine the efficiency of the scrubber in removing ammonia. It appeared that on some occasions the water in the scrubber was saturated with ammonia and that it was not always removing ammonia from the exhaust air before the air entered the biofilter. A regime of more frequent changes of the water within the scrubber maybe necessary.

The data generated on the levels of ammonia produced during composting help to quantify the importance of the control of the release of this chemical into the atmosphere.

Odour

Samples of exhaust air from the tunnels were analysed for odour concentrations before and after the scrubber, after the biofilter. An estimate was made of the efficiency of the scrubber and biofilter systems in removing odours from the exhaust air.

Of the three sets of samples taken with this feedstock, two were anomalous in indicating that the efficiency of odour removal by the scrubber was negative. The only positive result showed an efficiency of 61%. At this efficiency the scrubber reduced the odour level of the exhaust gas from 65,080 $ou_E m^{-3}$ to 25,231 $ou_E m^{-3}$.

The efficiency of odour removal by the biofilter varied from 20% to 79%, with an average of 55%. At its most efficient the biofilter reduced the odour level of the exhaust gas from 29,340 $ou_E m^{-3}$ before the biofilter to 6,260 $ou_E m^{-3}$ after the biofilter. Variations in the moisture levels of the biofilter undoubtedly had an effect on biofilter efficiency. It is clear that moisture levels within the biofilter must be kept high in order to allow efficient microbial activity, and as described above, it became apparent that it is not possible to rely on the incoming high humidity of air off the scrubber to achieve this.

The odour levels above the windrows made from MSW feedstock were much higher that those above the windrows made from kitchen waste and green waste. However, the odour levels were still so low that they would not increase odour levels at the site boundary. Constructing windrows of the correct size, regular turning of the windrows, and a control over the bulk density of the composting material, ensure that aerobic conditions are maintained within the windrow. If any of these characteristics exceed normal limits then anaerobic conditions can be created and odour problems result.

This data should assist Defra in enabling an estimate to be made of the degree of control that is possible in minimising potential problems with odours associated with composting facilities and the importance of scrubbers and biofilters.

16.10 Processing costs

Many of the processing costs identified by the project are site-specific in that they vary considerably with the throughput of the facility, its layout, the nature of the in-vessel composting technology, the method of turning windrows, and the choice of equipment for shredding, moving material around the site and screening.

The composting processes from waste reception, through shredding, in-vessel composting, windrow composting and screening have been previously described. These are standard processes and were the basis of the composting runs used in the project. Each composter has to look at each of these activities in terms of the number of operators needed, diesel consumption, and electricity consumption. Other information such as equipment and facility maintenance, depreciation, leasing costs must also be taken into account.

One of the purposes of this project has been to identify processing costs associated with the batch composting tunnel used to process the various feedstocks. Most of the costs associated with the batch tunnels are associated with the use of electricity to drive the large fans used to aerate the composting material and to control composting temperatures. Other costs, such as labour and diesel costs associated with the filling and emptying of the tunnels are common to most or all other in-vessel composting operations.

A determination of the electricity costs associated with running the tunnels using kitchen waste/green waste mixtures and kitchen waste/green waste/MSW mixtures used to produce CLO has shown that there is an overall cost of c. £1.36 per tonne of feedstock (co-mingled kitchen waste and green waste) composted. This is considered a low cost to take the feedstock through a two-stage pasteurisation process to comply with ABPR. Electricity costs associated with kitchen waste/green waste/MSW mixtures converted into RDF were higher at c. £2.05 per tonne of feedstock composted.

Tunnel electricity costs can be reduced by ensuring that the structure of the feedstock is open enough to allow the free movement of air with the minimum of resistance.

The batch tunnels used by the project have recently been licensed under the 2006/208 ABPR regulations to comply with ABPR with just a single pasteurisation stage instead of two stages. This has been made possible by proving that all of the composting material is taken through the required 60°C for 48 hours with no bypass by a single pass through the tunnels. This effectively halves both the electricity costs, and other costs such as labour and diesel, in order to take the feedstock through the ABPR process. This makes the batch tunnel composting process even more cost efficient.

The development of a single pass system is a major step forward in hte

16.11 Dissemination

The dissemination activities of the project have been extremely successful in utilising a number of techniques to inform stakeholders of the aims of the project and the results obtained.

Open days and presentations at the composting site using the purpose-built Visitors' Centre, publications in the technical and trade press, attendance at exhibitions, presentations at technical conferences, and the use of web sites have all enabled news of the project to be taken to the widest possible audience.

The responses to the results of the project have all been very positive with great interest being shown in the detailed technical and process data generated.

The raw data generated by the project has been assembled into a series of Excel databases. In addition, the analysed data and charts have also been brought together in a series of Excel databases classified according to topic. The databases are being burned onto to CDs to enable easy distribution for other to access and analyse.

16.12 Lessons learned by the project

A number of important lessons have been learned by the project.

It is clear that a successful in-vessel composting system such as the Gicom batch tunnel operation must be managed by a range of staff that are adequately trained and experienced in all stages of the composting process.

It is also clear that the composting process is best carried out when there is an agreed set of standard operating procedures that cover every important aspect of the process. The use of SOPs enforces a discipline on those carrying out the composting process and enables the generation of high quality data that can be used to control and optimise the process and ensure the composting site stays within the requirements of ABPR and EP.

Much was learned about the effect of processing a wide range of feedstock mixtures and the limits that have to be adhered to if the processing time is to be kept to the minimum and problems avoided.

The collection of data from the tunnel computer was straight forward and generated very useful and detailed information. The collection of data relating to the time taken to carry out particular operations around the site or the amount of fuel used for a particular process was much more difficult to collect. The collection of this data required a considerable amount of management and checking to ensure that the data was collected in the first place and that the data collected was accurate and meaningful.

The quality of control measures to limit emissions from the composting operation was found to be quite critical and required some modification to the methodology and equipment.

The importance of protecting finished compost from microbial contamination and wind-blown seeds was also appreciated by an examination of the PAS 100 analyses.

The importance of communicating with local authorities, regulators, farmers and other stakeholders was shown to be very important. The interest shown in the project was gratifyingly large.

The importance of holding a final seminar was also learned. This enabled the results of the project to receive an initial interrogation by experts in the composting industry and generated a lively discussion with many useful contributions being made.

The final lesson learned by the project is that the composting process must be looked at in its entirety, from specifying the quality of feedstock, through every stage of the composting process, and the sale of compost into the market place. Each stage of the operation has an effect on the following stages. As one stage is optimised it becomes evident that another stage is limiting throughput pr quality or adding to costs. The process of optimising a composting site is one of continual examination and effort.

17 PROJECT PROTOCOLS

17.1 Introduction the Project Protocols

This protocol forms the central control document for delivery of the project. It lists all other documents, spreadsheets, sub-protocols, and Standard Operating Procedures (SOPs) that were used in connection with the project. This document was reviewed regularly throughout the course of the project.

Versions – Developing the Protocol

The initial protocol was written as part of the application to Defra for financial support for the project under NTDP. It was prepared before the Gicom tunnels used by the project had been built or even fully designed.

Once the tunnels had been constructed and began operation, a number of changes were made to the protocol to take into account the final specification of the tunnels, the biofilters, and the controlling software.

Changes in the way that source-separated and mixed municipal solid waste was collected in the UK also required modifications to the protocol.

Two significant changes to the project were undertaken with the agreement of Defra:

Initially, only 2 of the block of 4 Gicom tunnels constructed on the St Ives site during 2007 were used for the project. For the latter half of the project the two remaining tunnels were brought within the project. This enabled the required number of runs to be carried out more quickly and also enabled the project to exceed its targets regarding the tonnage of feedstock that had to be processed and the number of hours the tunnels had to operate.

At the start of the project it was quickly realised that because of the wide variety of collection methods used by local authorities, the collection of kitchen waste and green waste formed a continuum of feedstock. This continuum ranged from almost 100% green waste to 100% kitchen waste. With the agreement of Defra it was determined that the project should process 10 runs with the kitchen waste component representing <10% of the kitchen waste/green waste mixture, 10 runs with the kitchen waste component representing >30% of the mixture, with the remaining runs falling between these two extremes. It was agreed that this approach would cover all of the different collection policies used by local authorities and would generate data of maximum interest to the industry.

The protocol described in this Section is the final version (version 8, August 2008).

Definitions used in the protocol

Run –a unit of material composted in a tunnel, and tracked throughout the monitoring phase of the project. All runs consist of a minimum of two stages in the tunnels. Two of the runs of each feedstock type will be followed by a windrow stage.

Set – a number of runs of the same waste feedstock.

Stage 1 – a unit of material composted in the first stage tunnel (G3 or G5) for a minimum of 48 hours at 60ºC.

Stage 2 – a unit of material composted in the second stage tunnel (G4 or G6) for a minimum of 48 hours at 60ºC.

Stage 3 – a unit of material undergoing windrow composting after the completion of stages 1 and 2.

Labelling

The above definitions were used to label samples and analyses. For example, samples taken on the first run of the first set will be labelled S1:R1.

Project monitoring activities

The monitoring activities were split into three areas:

Section 1 – Operational monitoring

labour time for each stage of the process

labour costs for each stage of the process

fuel usage for each stage of the process

fuel costs for each stage of the process

weight of feedstock filled into tunnels

weight of feedstock transferred between G3 and G4, and between G5 and G6

weight of material emptied from G4 and G6

weight of windrow at screening stage

volume of water used at each stage of the process

Section 2 – Process monitoring

all data recorded automatically by the G3 , G4, G5 and G6 composting tunnels, including temperature, air flow, oxygen, and water usage

the effect of using heated tunnel walls and floors

additional temperature recording during composting using Tiny Tags

chemical, physical and compositional analysis of feedstock, composting material, and compost product

the stability of feedstock, composting material, and compost product

quality of end product with reference to PAS 100 overall costs of processing expressed per tonne of feedstock

Section 3 – Emission and abatement monitoring

leachate analysis

leachate volumes

volatile organic compounds

odour

scrubber efficiency

biofilter efficiency

Data recording

All operational data were initially recorded on appropriate forms. The data was then be transferred to the Primary Database on the ADAS shared drive.

Waste types

The composting trials processed various combinations of the following feedstocks (see earlier Section):

kitchen waste (meat included) (KW)

green waste mixed with kitchen waste (meat included) (GW/KW)

municipal solid waste fines (MSW)

green waste (GW)

Calibration of equipment

All equipment used to generate data for the project was regularly calibrated (see SOPs). Equipment calibrated included:

compost temperature probes

ammonia probes

ammonia control box

oxygen probes

weighbridge

weigh cells

pH meter (plus temperature probe)

Standard procedures

Composting and monitoring was carried out in line with PAS 100 principles. The site operators adhered to their composting protocol and HACCP, carrying out corrective action where parameters were outside the limits defined in the plan.

17.2 Operational monitoring

Operational monitoring was carried out for each stage of the composting processes.

Shredding

The performance of the shredder was assessed for one run of each waste type.

The driver of the front loader moving feedstock into the shredder recorded the time spent on the activity.

The time for which the shredder operates in preparing material for filling into G3 or G5 was recorded.

The fuel used by the front loader and the shredder was recorded.

The shredder performance was recorded in terms of throughput per hour of operation.

The feedstock was sampled and sent to the appropriate laboratory for analysis.

Washing down

The activities involved in the process of washing down at each stage of the composting process were recorded by the operator for one run of each waste type and the appropriate form completed:

the size of the area washed down or the number of vehicles washed and the parts of the vehicles washed

the time spent on this activity

the volume of water used for this activity

the time spent on this activity

the volume of water used for this activity

Filling and emptying the tunnels

The operator recorded the following information:

each time Tunnels G3, G4 , G5 or G6 were filled or emptied, the time spent on the activity

each time material was prepared for filling into G3 or G5, filled into G3 or G5, transferred from G3 to G4, or transferred from G5 to G6, or emptied from G4 or G6, or the reception area washed down, or lorry wheels were washed, the time spent on the activity

the weights (determined by weigh cells on the front loaders) of the material filled into G3 or G5, transferred from G3 to G4 and from G5 to G6, emptied from G4 or G6, and, when appropriate, taken from the windrow for screening

Windrow turning

The activities involved in forming and turning a windrow were monitored for two runs of each waste type. The operator will record the following information:

the time spent in constructing a windrow

the time spent in turning a windrow

the fuel utilised in turning a windrow

the initial volume of the windrow

Screening

Two runs of each feedstock type were windrowed separately and screened.

The operator of the front loader recorded the following:

the mesh size used for screening the compost product

the time spent on this activity

the fuel utilised by the front loader on this activity

the fuel utilised by the screen on this activity

the weight of compost product that passes through the screen

the weight of compost product that was rejected by the screen (i.e. oversize)

any blockages or breakdowns that occurred during the screening process

the number of hours for which the screen operated in screening the entire windrow

17.3 Process monitoring of tunnel composting

The following activities were undertaken in monitoring the composting process.

Process control

The following information will be recorded on the tunnel computer:

Temperature, air-flows and oxygen levels were recorded automatically by probes integrated into the tunnel control system

Water usage figures (water sprayed on the composting material within the tunnels)

After each composting run the data were transferred to a sub-Section of the Primary Database on the shared drive and imported into Excel format

Each of the parameters recorded by the tunnel computer were analysed to indicate changes during the course of each run

The temperature and oxygen profile of each run were recorded graphically to demonstrate that the time and temperature requirements of ABPR (Animal By-Products Regulations) are being achieved under aerobic conditions

Water usage figures in the G3-G6 reception area were recorded by a water meter

Heated walls and floors

The effect of the heated walls and floors on the time required to reach pasteurisation temperature and any increase in throughput were assessed.

The heated walls and floors were turned on for the stage before pasteurisation for approximately half of the runs for each feedstock type and off for the other half of the runs. The data was examined to assess whether the time taken to reach the required pasteurisation time/temperature profiles, or the total residence time within the tunnels, is less with the heated walls and floors on.

Tiny Tags were positioned within the compost during two runs of each waste type when the heated walls are on.

The Tiny Tags were positioned in the coolest parts of the tunnel, i.e. the corners on the floor.

Data from the Tiny Tags was be downloaded via the dedicated software and the data input into Primary Database.

Tiny Tags were positioned within the compost during two runs of each waste type when the heated walls are off.

The Tiny Tags were positioned in the coolest parts of the tunnel, i.e. the corners on the floor.

Data from the Tiny Tags was downloaded via the bespoke software and the data input into Primary Database.

Waste input

The waste was analysed in the following manner.

Waste was sampled before shredding.

Waste was sampled after shredding and before being filled into the composting tunnels.

For two runs of each feedstock type, the analyses shown in Table 1 were carried out.

Samples were taken in triplicate after shredding and mixing and before filling onto a tunnel.

The quantity of sample required was 3,500 g.

The analyses was carried out by a UKAS accredited laboratory.

Table 1: Waste analysis

Analysis	Units
Dry matter	%
Moisture content	%
Air-filled porosity	%
Compost stability	mg CO_2 g^{-1}
Nitrogen	mg g^{-1}
Carbon	mg g^{-1}
Organic matter	%
Bulk density	g l^{-1}
Physical contaminants	%

The data from the analyses was recorded in the Primary Database.

Biodegradation

For two runs of each feedstock type weekly temperatures were taken in the windrow.

For two runs of each feedstock type two-weekly samples (1,000g), in triplicate, were taken from the windrow to assess biodegradability.

The analyses indicted in Table 2 were carried out by a UKAS accredited laboratory.

Results were recorded in the Primary Database.

Table 2: Biodegradability assessment

Analysis	Units
Dry matter	%
Organic matter / Ash Content	%
Compost Stability	$mgCO_2/gOM/d$

Mass balance

Weigh cells on the front loaders were used to record the following information:

the mass of material loaded into the tunnels

the mass of material coming out of the tunnels

the oversize mass (for two runs of each feedstock type)

the compost product mass (for two runs of each feedstock type)

details recorded in the Primary Database.

Compost quality

For two runs for each feedstock type the quality of the end product was assessed against PAS 100.

On each sampling occasion a triplicate sample was sent to a UKAS accredited laboratory for PAS100 analysis.

The quantity of each sample required was 7,000 g.

The quality of both product and oversize in terms of physical contaminants was determined.

Data was recorded in the Primary Database.

Energy

The use of fuel, gas and electricity in the composting process was recorded.

Fuel (diesel)

The typical usage of fuel per hour for each machine was obtained from the equipment manufacturer.

The data was recorded in Primary Database.

Electricity

The electrical energy consumption for the composting tunnel building and operation of tunnels G3, G4, G5 and G6 was monitored. The following data was recorded.

electricity used by the G3 fan

electricity used by the G4 fan

electricity used by the G5 fan

electricity used by the G6 fan

electricity used by the two scrubber fans

electricity used by the compressor

electricity used by other activities within the tunnel building

Gas

The volume of gas used by the heated walls and floors was determined.

Processing costs

The data gathered above was used to calculate the average cost of each run and, thereby, the cost of processing a tonne of each feedstock type. Only the fan costs were quantified as these represented the vast majority of the electrical costs.

17.4 Emissions and abatement monitoring

The following activities were carried out.

Leachate analysis and volumes

The following data was recorded for the leachate produced by the composting tunnels.

Leachate analysis

On two runs of each feedstock type triplicate samples of the leachate were take from the G3 sump.

The quantity required for each sample was 1,000 ml.

The following analyses, (Table 3), were carried out by a UKAS accredited laboratory.

Table 3: Leachate analysis

Variable	Units
Biological Oxygen Demand	mg l^{-1}
Chemical Oxygen Demand	mg l^{-1}
Total solids	mg l^{-1}
Ammonium-N	mg l^{-1}
pH	
Calcium	mg l^{-1}
Magnesium	mg l^{-1}
Sodium	mg l^{-1}
Chloride	mg l^{-1}
Sulphate	mg l^{-1}
Cadmium	mg l^{-1}
Chromium	mg l^{-1}
Copper	mg l^{-1}
Lead	mg l^{-1}
Mercury	mg l^{-1}
Nickel	mg l^{-1}
Zinc	mg l^{-1}
Nitrate	mg l^{-1}

Leachate volumes

The volume of leachate water disposed of was recorded.

Volatile Organic Compounds

For two runs of each feedstock type the volatile organic compounds released by the composting process were analysed.

The following analyses (Table 4) were carried out by a UKAS accredited laboratory.

Table 4: Analysis of volatile organic compounds

Parameter (mgl^{-1})
Trimethylamine
Dimethyl sulphide
1-Propanol
2-Butanone (MEK)
2-Butanol
Ethyl acetate
2-Methyl- 1-propanol
3-Methylbutanal
1-Butanol
2-Methylbutanal
3-Pentanone
Methyl butanoate
3-Methyl-1-butanol
2-Methyl-1-butanol
Dimethyl disulphide
Ethyl butanoate
2-Heptanone
α-Pinene
Sabiene ?
β-Myrcene
Limonene
2-Nonanone
Fenchone
Camphor

In addition, ammonia and methane were measured within the tunnel system at the following points.

- The exhaust outlet of tunnels G3, G4, G5 and G6.
- Before the scrubber.
- After the scrubber.
- After the biofilter.

Odour

The following activities were carried out to determine the level and nature of odour produced by the composting process.

Sampling

Samples were taken by pulling air from the ducting into Teflon bags placed within a sample barrel.

Odour was also be monitored in the windrows. Monitoring took place directly after the material has been turned.

Samples were taken at the following points:

- Before the scrubber.
- After the scrubber.
- After the biofilter.
- After a windrow is turned.

Samples were taken in triplicate at each point and sent to a UKAS accredited laboratory for analysis.

Analysis

Olfactometry was used in accordance with the European Standard BS EN 13725 to assess detectability of the odour.

Bioaerosols

Bioaerosol analysis was carried out by the University of Leeds.

Biofilter function

The biofilters will be monitored throughout the project.

The biofilters were visually inspected every month to check whether there had been any compaction, or formation of cracks and fissures.

The temperature of the biofilters were measured automatically by the tunnel software.

Scrubber

The following data were collected:

- Temperature of water in the process tank (weekly).
- pH of the water in the process tank (weekly).
- Triplicate samples of the level of ammonia and ammonium N in the process water (for two runs of each feedstock type).
- The volume of water used for the scrubber.

17.5 Production of refuse derived fuel

During the course of the project a number of runs were carried out to produce material that was examined for its use as a refuse derived fuel. The following activities were carried out.

The tunnels were operated as normal until the required time/temperature regimes for pasteurisation were achieved.

After pasteurisation, attempts were made to dry out the composting material as thoroughly as possible. This involved changing the rate of air passed through the material.

A triplicate sample of the final material was sent to a UKAS accredited laboratory for the analyses listed in Table 5.

Table 5: Analysis of refuse derived material

Parameter	Units
Gross Energy Bomb Calorimetry or Gross Energy	MJ/kg dry basis
Net Calorific value	MJ/kg
Dry matter	%
Ash content	%
Water soluble chloride	mg/kg (DM)
Sulphur	mg/kg (DM)
Nitrogen	mg/kg (DM)
Potassium	mg/kg (DM)
Sodium	mg/kg (DM)
Copper	mg/kg (DM)
Zinc	mg/kg (DM)
Lead	mg/kg (DM)
Cadmium	mg/kg (DM)
Mercury	mg/kg (DM)
Nickel	mg/kg (DM)
Chromium	mg/kg (DM)
Copper	mg/kg (DM)
Arsenic	mg/kg (DM)
Manganese	mg/kg (DM)
Aluminium	mg/kg (DM)

17.6 Standard Operating Procedures (SOPS)

The following SOPs were used throughout the course of the project.

SOP 1 – Collection of machinery, performance and water usage data

Edition: 01

Authorised by: Agnes Starnawska, 11/08/2008

INTRODUCTION

This document describes:

- Collection of machinery performance data methodology.
- Collection of tunnel performance data methodology.
- Collection of water usage data for washing down the reception area and lorry wheels.
- Data recording and processing.

REFERENCE DOCUMENTS:

D. Border (2008), Protocols to measure efficiency of the composting process

PROCEDURES

Operational monitoring

All site activities involved in the project operations are recorded on relevant recording sheets.

Collection of performance data includes following activities:

- Shredding of feedstock.
- Washing down the reception area of the shredding area and vehicles delivering waste on site.
- Filling and emptying the tunnels.
- Windrow turning.
- Windrow screening.

This data will provide information necessary to assess performance of the site equipment and machinery (shredder, front-end loaders and tractor) and water used during composting process in the tunnels.

Machinery operators must record the date when one of the activities listed above takes place, the type of machinery, the person name, the start and finish time of each task, and the weight of material being filled/emptied to and from a tunnel or screen.

Collection and transferring of data into Primary Database

Forms with machinery and tunnels performance data as well as water usage data are collected by the site management team and kept in a 'red folder' in the Envar Reception Office in St. Ives.

All forms and recording sheets gathered are transferred on weekly basis to the Primary Database, located on the shared drive.

All manually recorded data is filed in relevant run folders that are kept in a filing cabinet located at the Envar Heathtop House Office in St Ives.

SOP 2 – Calibration of weigh cells using a weigh bridge

Edition: 01

Authorised by: Agnes Starnawska, 06/08/2008

INTRODUCTION

In order to verify a loader's weigh cell readings, calibrations of the weigh cells with the site's weighbridge is carried out on a quarterly basis.

MATERIALS AND EQUIPMENT

Calibration sheet

PROCEDURES

Weigh cell calibration

Each time a weigh cell is calibrated a loader driver will:

- Scoop up a portion of material (e.g. oversize, compost product, etc.) and note the machine weight readings on the 'Calibration sheet'.
- Drive the loader onto the weigh bridge.
- Empty the loader's bucket and drive with the empty loader again onto the weighbridge.

The above actions will be carried out in triplicate.

Recording the data

The date of calibration, the calibrating person, the start and finish times of the exercise as well as the weigh cell and weighbridge readings will be recorded onto the 'Calibration sheet' and transferred to the Primary Database (located on share drive at Envar St Ives).

All 'Calibration sheets' are kept at the Envar Heathtop House Office in St. Ives.

WEIGH CELL CALIBRATION RECORDING SHEET

Recording person	
Calibration date	
Start time	
Finish time	

	Weigh cell readings (1) (kg)	**Weigh bridge readings**		**(1)-(2) kg**
		Full loader (1) (kg)	**Empty loader (2) (kg)**	
1				
2				
3				

SOP 3 – Windrow construction and turning

Edition: 01

Authorised by: Agnes Starnawska, 06/08/2008

INTRODUCTION

This document describes:

- Windrow formation/turning equipment.
- Windrow construction process.
- Windrow turning process.
- Data recording and processing.

Definitions of terms used in this Standard Operating Procedure

All the composting runs are divided into intensive and non-intensive runs. Each feedstock type will have two intensive runs.

Non-intensive run – is a unit of composted material during which following variables are monitored:

- Operational hours for loader, shredder and tractor.
- Fuel usage for loader, shredder and tractor.
- Water usage for washing down the reception area of the tunnels and lorry's wheels.
- Energy and water usage during the run.
- Ammonia emissions sampling.

Intensive run – is a unit of composted material 'intensively' monitored. Monitoring and sampling of this run includes all monitoring for non-intensive runs plus:

- Sampling and analysis of feedstock material (pre and post-shredded material).
- Measurements of temperature in potential cold spots (tunnel corners) using TinyTags data loggers.
- Sampling and analysis of process water and leachate produced from particular run.
- Odour emissions sampling and analysing.
- Bioaerosols monitoring.
- Monitoring of the temperature and biodegradability of material during maturation phase of composting.
- Sampling and analysis of product samples for PAS100 tests.

- Analysis of the physical contamination of oversize material.

REFERENCE DOCUMENTS:

The Composting Association, *“Large-scale composting A practical manual for the UK”*

PROCEDURES

Windrow formation

Composted material after processing in the tunnels is send onto the pad for the maturation stage, which may take up to 12 weeks.

Material leaving the tunnels is transported by front-end loader and formed into a long windrow, shaped as an elongated triangular prism.

Front-end loaders are equipped with weigh cells which allow the recording of the tonnage of composted material sent for maturation.

A typical windrow is around 2 meters in height, 6 meters in width and is up to 25 metres long.

All the windrows have a unique batch number which contains the date of windrow formation and the number of the tunnel where first stage of composting process took place.

All information regarding windrow management is recorded on the ‘Windrow formation and monitoring recording sheet ‘.

Windrow turning

In order to aerate the windrow, to allow the release of carbon dioxide, water vapour and heat, and to help to separate closely-packed particles, compost windrows need to be turned regularly. Regular turning is carried out on a weekly basis throughout the 8-12 weeks of windrow composting.

Table 6: Conditions for maturation

Condition	Optimal Range
Moisture	40-50%
Aeration	Low level, variable
Temperature	Below 70°C

The windrows are turned on a weekly basis by a FEL CASE 621XT front-end loader. The loader is used to lift and turn the windrow over into the space immediately adjacent to the existing windrow. The advantage of using the loader is that material from the middle can be exchanged easily with material from the outer edges.

All turning exercises are recorded by loader operators on ‘Operators recording sheets’.

Recording data

All the data collected during the emptying of the tunnels and the turning of the windrows is recorded by the site operation staff using ‘Operators’ recording sheets’.

All the paperwork is collected on a weekly basis and transferred to Primary Database located on the share drive, to ‘windrow monitoring and operator hours spreadsheets’.

Paper copies of this gathered data are stored at the Envar Heathtop House Office in St Ives, in relevant run folders.

SOP 4 - Ammonia measurement in the composting tunnels

Edition: 01

Authorised by: Agnes Starnawska, 03/06/2008

Introduction

This procedure describes:

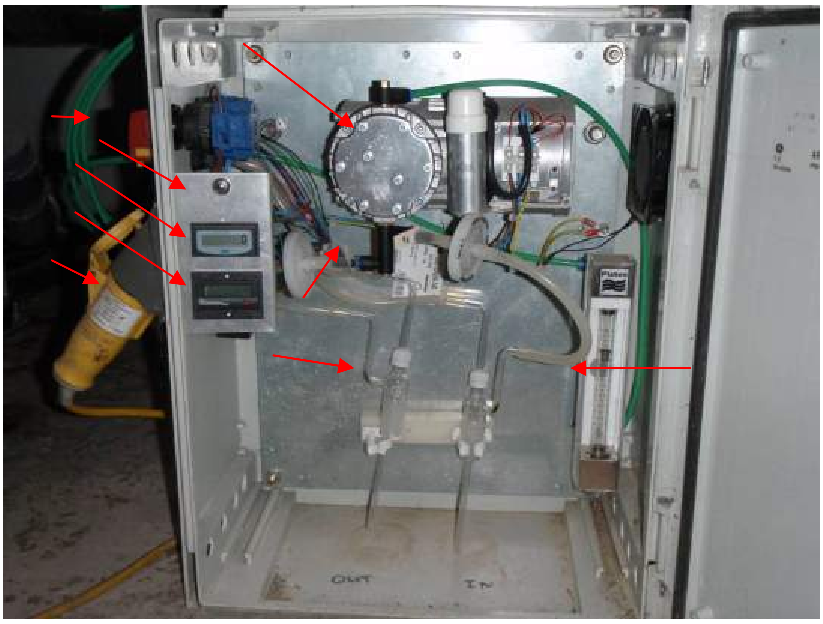
- Ammonia sampling equipment used in the composting tunnels.
- Calibration, maintenance and set up of this equipment.
- Data recording.

Materials and equipment

The material used in this procedure includes the following:

- A control box for each sampled point containing.
- Diaphragm pump (6).
- Platon flow meter (9).
- Inlet and outlet 'bubbler' heads (8).
- Two critical orifices (one for inlet and outlet air lines) (7).
- Counter (3).
- Timer (4).
- Reset button (2).
- Switch (1).
- Power inlet (5).
- Set of bubblers (14 x 250 ml conical flask bubblers containing 80 ml of 0.02 M orthophosphoric acid).
- Key to open control boxes.
- Transformer 1.5 kVA, model No. 15002.
- Stop-watch.
- Extension cables.
- Ammonia 5/a and 2/a Dräger tubes.
- Dräger pump.
- Protective equipment: gloves and safety glasses.
- Permanent marker pen.
- Sample recording sheet.

Figure 1: Control box for ammonia measurement



Time

It takes 10-15 minutes for one person to set up 3 control boxes and about the same time to collect bubbler flasks and record data.

Because samples are taken in triplicates, up to 3.5 hours are required for one person to carry out the ammonia sampling at the required positions.

One person will take approximately 2 hours to renew 20 bubbler flasks and prepare 20 samples for analysis (refer to SOILS/075 SOP).

It takes approximately 1-2 minutes to measure ammonia emissions using Dräger safety tubes.

Reference documents

SOP SOILS/075 Measuring ammonia emissions using small-scale wind turbines, Lizzie Sagoo, ADAS, 05/09/2005;

Fisher Scientific UK, Material safety data sheet. Orthophosphoric acid, 85%, http://www.catalogue.fisher.co.uk/scripts/search.dll?ViewMSDS&SheetNumber=91620;

Dräger safety tubes instructions manual for 5/a and 2/a tubes, www.dreager.com.

Equipment maintenance and calibration

Field Instrumentation Group (FIG) at ADAS, Boxworth, Cambridgeshire, carries out general maintenance of the ammonia sampling equipment, which includes:

critical orifice calibration

checking the diaphragm in the diaphragm pump and changing it if necessary

changing the filter between the bubblers and the critical orifice

The Platon flow meters in the control boxes are not calibrated, but can be used as a visual indicator in the field of potential problems. The value given by the air flow meter should stay approximately constant over the time (within approximately 1 l/min variation over the course of a study). Each orifice should pump approximately 3.5 to 4.0 l/min. Because the control box contains two critical orifices, Platon flow meter readings should vary between 7 and 8 l/min.

Control box calibration details are kept in an equipment file in Boxworth and can be provided by noting the control box reference number (recorded on the Sample Recording Sheet during every test).

For calibration details refer to SOILS/075.

Procedures

Safety considerations

Care must be taken when working on site near moving machinery.

Bubbler flasks contain 0.02 M orthosphoric acid which when in contact with skin can cause skin rush (Fisher Scientific UK, Material safety data sheet - Orthophosphoric acid 85%). Therefore, protective gloves should be worn.

Normal hygiene precautions should be observed.

Setting up control boxes

All 3 control boxes are located in the technical area of the tunnels. One box samples air coming from the G3-G6 tunnels (exhaust air which is send to the scrubber). The second box is located next to scrubber fan 1 to sample air coming out of the scrubber. One control box is designated to sample ambient air. Sampling point locations are shown below.

The duration of the sampling period is 3.5 hours and the sampling exercise is carried out on weekly basis.

The control boxes should be plugged into the transformer and the counter zeroed, by pressing simultaneously the top reset button and the reset button counter (red button located below counter). All pipes should be checked that they are re-connected to the inlet of the control box.

Each bubbler flask should be uncorked and plugged into the air inlet line. Sampling should be started by turning on the control box. The Sample Recording Sheet should be used to record when the air sampling is started, along with the sampling point and the control box number.

A check should be made that the air is flowing freely through the bubbler and that the timer and counter are working correctly. Platon flow meters should show readings between 7 and 8 l/min, which means that the orifice pumps are pumping approximately 3.5 to 4.0 l/min.

If one of the boxes is not working properly and needs changing, it can be replaced with a spare box located in Bungalow.

Ammonia monitoring using Dräger safety tubes

Ammonia sampling using control boxes will be carried out in conjunction with Dräger safety tubes measurements.

Exhaust air leaving the 4 tunnels, and the air sent to biofilters (after scrubber) will be monitored.

Before measurements are taken, the Accuro pump needs to be checked for any leaks and damage.

To check leak-proof of pump, squeeze the pump and insert an unopened tube.

To determine ammonia in exhaust air:

- Break off both tips of the tube in the tube opener.
- Insert the tube tightly in the pump in the way that arrow points towards the pump.
- Suck the air or gas sample through the tube (10 strokes using 5/a tubes and 5 strokes using 2/a).
- Read the entire length of the discoloration.
- Multiply the value by factor F (F = 1013/actual atmospheric pressure, hPa) for connection of the atmospheric pressure. Atmospheric pressure can be obtained from xcweather.co.uk website, for Wyton weather station.
- Flush the pump with air after operation.

Recording data

All the data collected during sampling should be recorded on the Sample Recording Sheet and despatched with ammonia samples to Boxworth.

Ammonia sampling results should be transferred to the ‘Volatile Organic Compounds’ and Dräger tubes spreadsheet under Primary Database.

Changing bubblers

The optimum sampling duration for this test is an hour. To stop sampling the control box should be turned off and the bubble flask removed from the control box. The timer readings should be recorded on the Sample Recording Sheet, as well as any changes in the amount and clearness of the liquid (comment column). The flask should be labelled according to the method provided later in this document.

The rinsed bubbler head should be inserted into a new labelled bubbler flask and sampling started by switching the control box on. It is advisable to reset the counter and timer at each bubbler change. A visual assessment should be made of the bubblers and a check made that they are bubbling properly.

Labelling

After turning off the control box, the flasks should be labelled according to the following system, e.g. 2A, where the '2' indicates number of sampling point (2-4), 'A' indicates the set of samples (number of test).

Sample preparation

After sampling, the bubbler flasks need to be prepared prior to sending to the ADAS laboratory at Boxworth for ammonia analysis. The bubbler sample preparation for analysis is described in SOILS/075.

Despatch of samples to the laboratory

Bubbler flasks should be kept in a refrigerator, at temperatures between 1 and 4°C, before and after sampling.

Ammonia test samples with the Sample Recording Sheet should be despatched to Boxworth laboratory on the same day the sampling was undertaken.

Ammonia measurements for in-vessel composting tunnels

Sample recording sheet

Date:…………………………………………
Recorder:……………………………………..

Set and run of feedstock:……………………..

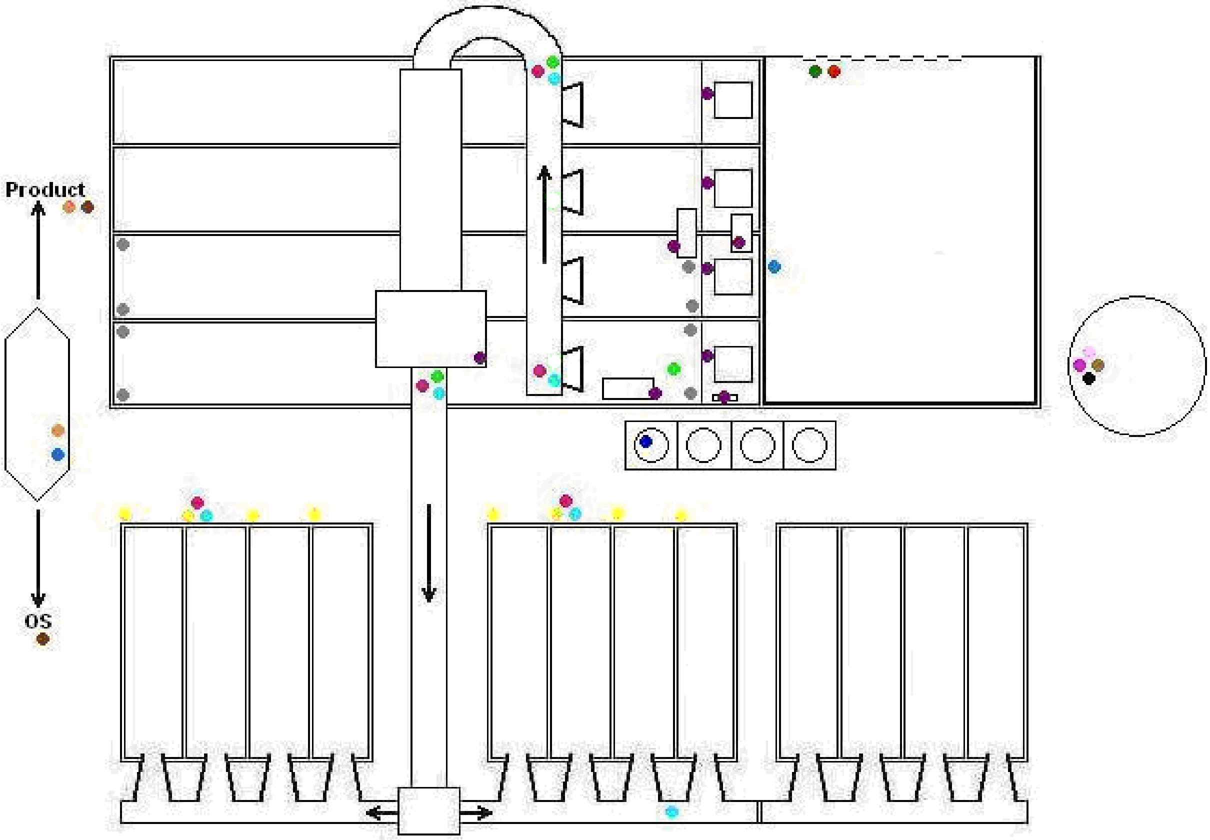
Sampling point	**Tunnel G3-G6 (2)**	**After scrubber (3)**	**Ambient (4)**
Equipment Number			
Sample Number			
Time ON			
Time ON			
Time OFF			
Time OFF			
Comments			
Sampling point	**Tunnel G3-G6 (2)**	**After scrubber (3)**	**Ambient (4)**
Equipment Number			
Sample Number			
Time ON			
Time ON			
Time OFF			
Time OFF			
Comments			

Dräger safety tubes readings

Actual atmospheric pressure:………………………………….

Sampling time	**Dräger tube reading before scrubber (ppm)**	**Dräger tube reading after scrubber (ppm)**

Figure 2: Ammonia sampling points



SOP 5 – Leachate and process water sampling and analysis

Edition: 01

Authorised by: Agnes Starnawska, 08/07/2008

INTRODUCTION

This document describes:

- Process water/leachate monitoring and sampling equipment.
- Temperature and pH measurements process.
- Leachate and process water sampling process.
- Sample shipment instructions.
- Data recording and processing.

MATERIALS AND EQUIPMENT

The following materials and equipment are required for this procedure:

- Process water monitoring sheet.
- Eutech EcoScan pH/mV/°C meter.
- Polyethylene bottles (1,000 ml) with caps.
- Vinyl disposable gloves.
- Sampling pole.
- Hooks for removing manhole cover from the sump.
- NRM analyse request forms.
- NRM boxes.
- Marker pen.
- Key to Bungalow.

TIME

One person will take approximately 10-15 minutes to measure the process water tank temperature and pH and the same amount of time to transfer data to the Primary Database.

It will take approximately 15 minutes to collect triplicate sample of leachate and the same amount of time for process water sampling.

REFERENCE DOCUMENTS

Instruction manual for pH 5/6 & Ion 5/6 (pH/mV & Ion/pH meter series).

LAB/019 Taking samples for microbiological analysis

EQUIPMENT MAINTENANCE AND CALIBRATION

The calibration of a pH/mV/°C meter is carried out every 1-2 months.

It is recommended to perform at least a 2-point calibration at room temperature (25°C) using standard buffers provided by the supplier, starting with first buffer at pH 6.86 (NIST) and followed by pH 4.01 (NIST).

A pH electrode glass bulb should be always stored in electrode storage solution. Deionised water should be never use for the electrode storage.

Probes should be washed with distilled water after each use and cleaned every 1 to 2 months depending on extent and condition of use.

It is recommended to clean the pH electrode using a mild detergent. Wipe it with a soft tissue paper and recalibrate the meter after cleaning the electrode.

CALIBRATION

Before calibration, remove the plastic protective cap of pH electrode and condition the glass bulb by soaking it in tap water for 1-2 hours. This hydrates the glass bulb if the electrode is too dry or has not been used for a long period of time.

Always rinse the probes with tap water or rinse solution before and after each calibration/sample measurement to avoid cross-contamination.

After pouring pH 6.86 buffer solution into a clean and dry container, dip both the pH electrode and temperature probe in it, swirl gently and wait for the reading to stabilise.

Press CAL key to enter the pH calibration mode. A “CA” displays momentarily and the display shows the current un-calibrated reading flashing while in the calibration mode.

To abort or cancel calibration without accepting the new value, press CAL key. The meter then reverts to pH measurement mode.

To continue calibration, allow the reading to stabilise. The meter automatically recognises pH 4.01 and 6.86. Press ENTER to confirm calibration and the LCD display will “CO” momentarily.

Repeat all steps with the pH 4.01 buffer solution.

PROCEDURES

Safety considerations

Care must be taken when working on the site near to site machinery.

Because of the weight of the manhole cover, at least two people are required to sample leachate from the sump.

Temperature and pH monitoring

The process water tank temperature and pH should be monitored on a weekly basis (every Friday, starting from 11/01/2008).

Monitoring equipment can be found in the Bungalow office.

The process water tank is fitted with a tap to enabling sampling. The sampling point is located in the building next to the tank.

In order to flush the pipes, the tap should be run for approximately 10 seconds and the collected liquid disposed.

After re-filling the bottle with process water, dip both the temperature and pH probe in it. Wait for the reading to stabilise and record the reading. The pH and temperature mode can be chosen using MODE button on pH/mV/°C meter.

Empty the container and repeat all steps twice to obtain triplicate measurements of pH and temperature.

Data, along with date and time, should be recorded on the process water monitoring sheet.

Process water sampling

Take triplicate samples of process water during intensive runs and after the pasteurisation stage of first pass of composted material. Run the tap for 10 seconds prior sampling.

Fill three bottles leaving 1 cm of air at the top taking care to avoid splashing and close the bottles firmly to ensure there is no leakage during transport.

Label samples clearly with a marker pen with set number, run number and sampling location: e.g. 1S2R3LT – where 1 is a sample number, S2 is the second set of composted material, R3 is the third run of set 2 feedstock and LT is the leachate sample collected from process water tank.

Fill in the NRM analysis request form with 'Ammonium –N' quotation reference and sample IDs.

Arrange for the Natural Resource Management Ltd (NRM) courier to collect the samples on the same day as the samples were taken. If it is not possible to book a courier for the same day, store the samples in a fridge.

Leachate sampling

Take triplicate samples of leachate from the tap during intensive runs and after the pasteurisation stage of the first tunnel composting stage.

Remove the manhole cover using the hooks located in the building.

Screw the bottle to cap attached to expandable pole and dip it in leachate. Wait for the container to fill with liquid, unscrew full bottle, and attach a new container, repeating exercise until all the samples are taken.

Label samples clearly with a marker pen with set number, run number and sampling location: e.g. 1S2R3LS – where 1 is a sample number, S2 is the second set of composted material, R3 is third run of set 2 feedstock, and LS is the leachate sample collected from sump.

Fill in the NRM analyse request form with Q12986/08 quotation reference number and sample IDs.

Arrange with the NRM courier for the collection of samples on the same day they are taken. If it is not possible to book a courier for the same day store samples in a fridge.

Sample collection

All samples should be labelled, packed in cardboard boxes provided by NRM laboratories and send to:

NRM Ltd.

Coopers Bridge

Braziers Lane

Bracknell

Berkshire

RG42 6NS

The collection point for the samples is located in front of the main Envar site office.

Recording data

All the data collected during monitoring should be recorded on Process water monitoring sheet and transferred to the Primary Database.

NRM laboratories results from analysing leachate and process water samples should be transferred to the Primary Database and saved under ‘Leachate Lab’ and ‘Scrubber’ spreadsheets.

PROCESS WATER MONITORING SHEET

	Date	Time	pH	Temperature (ºC)	Comments
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					

SOP 6 - Collection and processing of power consumption data

Edition: 01

Authorised by: Agnes Starnawska, 27/05/2008

Introduction

In order to estimate energy costs associated with the running of the composting tunnels, the total energy consumption for the building and the separate equipment will be measured.

Materials and equipment

- Energy consumption sheet.
- Key to the technical area to Gicom tunnels.

Time

One person will take about 10-15 minutes to gather and record data from electricity meters located in technical area of Gicom tunnels. An additional 10-15 minutes will be required to transfer data from the recording sheet to the Primary Database.

Collection of data

The electricity consumption of seven pieces of equipment, along with a reading for the total electricity consumption for the entire composting tunnel building, will be monitored. Also the gas consumption required by the heating of the tunnel walls and floors will be recorded.

Electricity usage reading points are:

12. Main meter (shows total electricity consumption for G3-G6 tunnels)
13. Tunnel Fan G3
14. Tunnel Fan G4
15. Tunnel Fan G5
16. Tunnel Fan G6
17. Scrubber Fan 1
18. Scrubber Fan 2
19. Air compressor

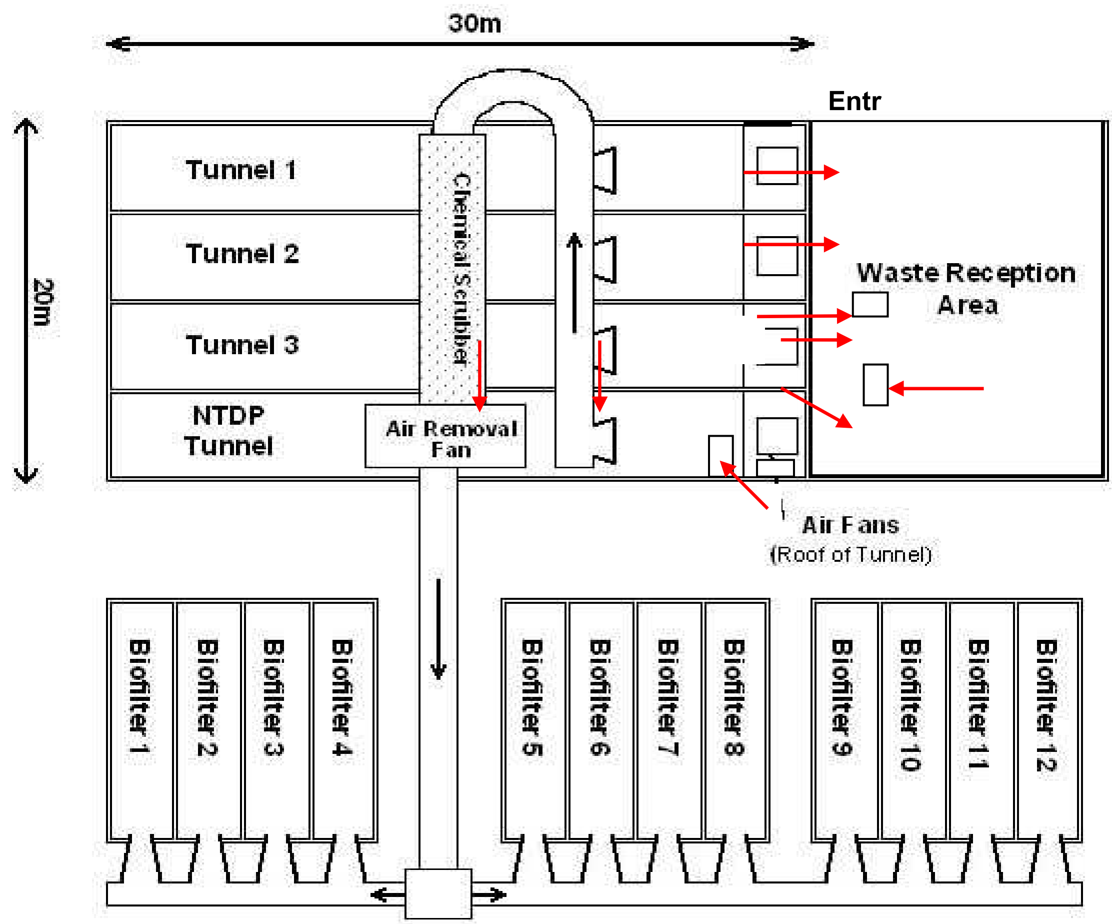
The reading point for gas consumption is:

Gas meter

Reading points number 2-7 are equipped with LCD screens. The main meter, air compressor and gas meter are analogue meters.

Utility consumption readings need to be taken before start of a new run before the doors of G3 or G5 are closed, again after G3 or G5 are emptied, and before G3 or G5 are filled again. Readings also have to be taken before the doors of G4 and G6 are closed for the second stage, and again when the run is finished after emptying tunnels G4 or G6 and before they are filled again.

Figure 3: Location of power consumption reading points



ENERGY CONSUMPTION SHEET

Date:…………………………..…. Run No……………………………..

Time:…………………………..… Composting phase……………….……

Recorder:………………………..…

	Reading point	Units	Readings	Comments
1	Main meter	kWh		
2	Tunnel fan G3	kWh		
3	Tunnel fan G4	kWh		
4	Tunnel fan G5	kWh		
5	Tunnel fan G6	kWh		
6	Scrubber fan 1	kWh		
7	Scrubber fan 2	kWh		
8	Air compressor	h		
9	Gas meter	m^3		

SOP 7 - Temperature monitoring using data loggers

Edition: 01

Authorised by: Mark Fowles, 17/08/2007

Introduction

Tiny Talk Range G™ and Tiny Talk PT100™ data loggers are made by Gemini Data Loggers UK Ltd. Tiny Talk Range G™ has a temperature range of -40 ºC - +85 ºC, whilst the Tiny Talk PT100™, using an attached probe, has a temperature range of -50 ºC - +300 ºC. If the logger is fully immersed in a harsh environment such as a composting tunnel, or in a freezer, the Tiny Talk Range G™ should be used and placed into a Gemini logger protection case. These are yellow in colour to enhance visibility and are robust and sealed to protect the loggers' chip and battery.

Key features of the temperature data loggers include:

- Ability to customise logger IDs.
- Logging Intervals of 1 second to 4.5 hours.
- Programmable delayed start.
- 3 stop options.
- Non-volatile memory capable of storing 1800 readings.
- 2 alarm settings.
- Accuracy to ± 0.2 ºC.

Reference documents

SOP COMP/001 Guidelines for the backup of data held on computer , Des Sarjant, ADAS Ltd, J:\NTDP\SOPs

See http://www.tinytag.info/ - For further details

Time

Set up Tiny Talk measuring parameters – 10 minutes for 1 person (based on 5 loggers being set).

Transfer Data to PC – 10 minutes (based on data from 5 loggers being transferred, excluding possible formatting of data).

Calibration – 15 minutes for 1 person (per batch – e.g. 5 loggers).

Materials and equipment

The following materials and equipment are needed for this procedure:

- Data logger/loggers.
- PC with TinyTag Explorer™ software application and desktop shortcut.
- USB data transfer cable (same cable for both Tiny Talk Range G™ and PT100™ models).
- Probe attachment (for Tiny Talk PT100™ model).
- Logger protection cases (for Tiny Talk Range G™ model).
- Spare SB-AA02, 3.6 volt batteries.

Procedures

Setting Reading Parameters

Connect the data transfer cable from the PC to the logger. On both models of Tiny Talk this is achieved by removing the logger protection case or film cap lid and connecting to the small socket.

Click on the TinyTag Explorer shortcut on the PC desktop to open the program. The main TinyTag Explorer screen will then be displayed.

Click on the Green GO icon to confirm connection. The system then proceeds into the start up menu.

In the start menu, page 1 asks for the desired logger description – enter your desired logger identification (e.g. Compost Run 1). Once completed click 'NEXT'.

Select the logger start time using the Hours, Minutes and Seconds boxes. Select the logger time (seconds). A time/date delay can be applied at this point if required. Once completed click 'NEXT'.

On this page (3) choose 'temperature measure at the end of each interval'. Once completed click 'NEXT'.

Chose the temperature logging intervals. Units of minutes or seconds can be chosen and then specific time intervals can be chosen. For example the logger can be set to record a temperature figure every 30 minutes. Once completed click 'NEXT'.

On this page (5) choose 'stop when full'. Once completed click 'NEXT'.

On the Final page (6) ensure that no alarms are chosen then choose launch to start the logger.

A Launch Confirmation screen will then appear. It is useful to print this screen as a summary.

Logging

- The data loggers (units) are fitted with green LEDs. These indicate the logging status as follows:

Awaiting delayed start:	2 flashes every 4 sec
Logging:	1 flash every 3 sec
Storing a reading:	1 short, bright flash
When logger stops:	1 half second bright flash
Power up:	LED on for several seconds

Place the logger in the desired place for logging. Tiny Talk Range G™ models should be secured in individual logger protection cases. The probe attachment for the Tiny Talk PT100™ will record the temperatures from the desired location. The logger unit itself therefore should not be immersed into harsh environments.

Ensure that no dirt or moisture can get into the unit, as this may cause readings to stop and cause corrosion.

If the unit is being used in cold conditions, it must be allowed to restore to room temperature prior to opening, to avoid a potential condensation build up.

Stopping the logger

Connect the data transfer cable from the PC to the logger. Click on the connect icon.

Click on the Red Stop icon.

Exporting and processing the data

Once the logger has been stopped click on the Table Icon (to the right of the Red Stop Icon).

A graph containing the logger readings will then be shown. To view the table of readings click on the Blue Table icon. To Export the data to Excel highlight the required columns then right click the mouse and select 'export-selected cells'.

To view recorded time and temperature data choose the Red Table icon. Logger run information (time and temperature of readings) should be copied to Primary Database to Tiny Tag temperature spreadsheet.

Time and temperature data recorded by Tiny Tags are converted to graphs.

Troubleshooting

The following trouble shooting guidelines apply to the Tiny Talk Range G™ and the Tiny Talk PT100™. If the methods below are unsuccessful contact Gemini directly for further instructions.

If the Tiny Talk has stopped logging without being instructed to, remove the lid and check for moisture or dust within the logger protection case (Range G) or canister (PT100 model). The small sachet of silica helps maintain a moisture free environment and should be renewed at least annually. If there is evidence of either free moisture or dust remove the battery immediately.

To remove the workings unscrew the logger protection case (Range G) or gently squeeze the sides of the opened canister (PT100), take care when handling the chip unit once out as it may be damaged by static electricity.

Clean the chip unit with fresh water and dry completely before re-installing the battery. If the unit still does not work it is likely that the battery needs replacing. Always stop the logger prior to battery changes.

Refer to the logger instruction manual as to size, longevity and replacement schedules for batteries.

Calibration

For GLP studies a logger should be UKAS calibrated at manufacture; this must be pre-arranged with Gemini. Loggers used for GLP studies should be returned to the manufacturer annually to be serviced and re-calibrated.

Once the recently UKAS calibrated logger is returned, this can be used to check other loggers for accuracy. Place the calibrated and non-calibrated loggers together in areas of varying temperature and humidity i.e. a refrigerator and a normal room.

Allow the loggers to record for at least 8 hours.

Download both loggers. Produce the data in table form. The two data sets can then be compared and accuracy established.

Insertion procedures into Gicom tunnels

For each point which requires temperature measurement, three tags will be used.

The three tags will be inserted into a mesh bag to allow the tags to be separate yet in contact with the compost.

A rope will be tied from each bag, leading up to the bespoke holes in the ceiling of the tunnel.

The tags will be positioned in the ‘cool spots’ near the walls, floor and doors as the tunnel is being filled.

As the tunnel is emptied, the bags will be removed and the ropes pulled back through the holes in the ceiling. This will allow the tunnel to be emptied with no obstructions.

Bags with loggers will be prepared by ADAS staff and passed to site operators , who will place loggers in potential ‘cold spots’ and retrieve them from the tunnel after every intensive run.

SOP 8 - Tunnel data recording

Edition: 01

Authorised by: Alison Webb, 07/12/2007

Introduction

Data must be collected and handled in the same way throughout the project to ensure consistency. As data is being collected from such a wide range of sources, all these must be pulled together into a final database.

This SOP covers the collation and file handling procedures for the tunnel data files.

Gicom Tunnel Data

The tunnel data is collated on the shared drive.

Data will be downloaded manually once a week from the Gicom computer using a USB drive. All data files are recorded in 'grafiek' files in 'Shortcut to data Tun 3-6' folder located on Gicom computer desktop. The 'grafiek' files will be separated into folders according to Table 6:

Table 7: Naming procedures for the Gicom systems

Grafiek file number	Corresponding System
1	Tunnel 3
2	Tunnel 4
3	Tunnel 5
4	Tunnel 6
5	Biofilter
6	Exhaust
7	Pumps
8	Heating System

The Gicom 'grafiek' files will be converted from CSV to Excel format and stored in the Primary Database.

Gicom File naming procedures

File types – Tunnels

Files from the two tunnels start with .numeric. (e.g. the very first file created for each system starts .000. Each new run receives the next consecutive number in the series, i.e. .001, .002 etc.

For example grafiek1.000 corresponds to the first run carried out in tunnel 3; grafiek 2.003 corresponds to the fourth run carried out in tunnel 4.

File Types – Systems

Files from the four ancillary systems (biofilter, exhaust, pumps, heating system) are also labelled as a ‘grafiek’ file for the numbers listed in Table 1. These files are produced on a monthly basis. The first file for the biofilter (grafiek 5.000) listed all the information for the biofilter in April 2007. The following files correspond to the following months.

.dat files – Tunnels

The run currently within the tunnel will not have a .numeric file but a .dat file instead. This file is continually updated every 15 minutes as the process computer records the data from the integrated probes. Once the tunnel program is complete, this .dat file will convert to a .numeric and can be copied; a new .dat file will be created for the next composting run.

As a result, if the .dat file is copied onto another computer system it automatically becomes void as it is incomplete.

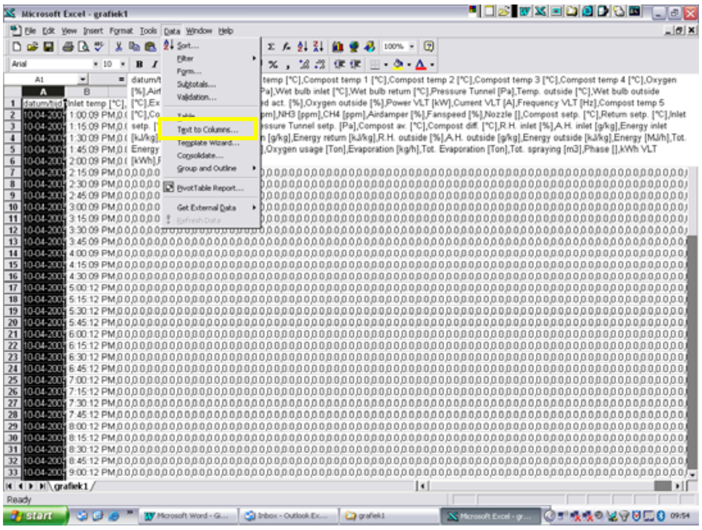
.DAT files – Systems

The current month will not have a .numeric file but a .dat file instead. This file can be copied monthly with the others, but it must be noted (see later) that the file is incomplete.

Converting tunnel files to Excel Format

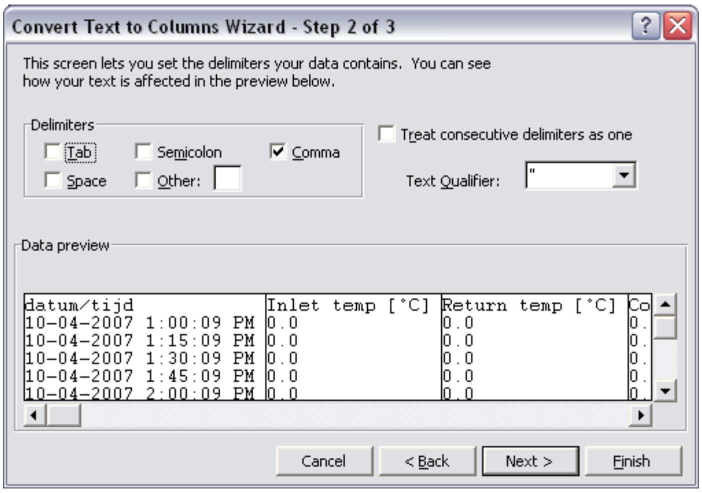
The data on the system for the tunnels biofilter, pumps, heating system and exhaust must be saved to the shared drive in Excel format. Right click on the file and select ‘open with’ and click Excel. The file will be opened, with all the data grouped into the first column. Highlight the first column (A). Click on the Data Menu, and select ‘Text to Tables’.

Figure 4: Converting tunnel files to Excel format – first dialogue box



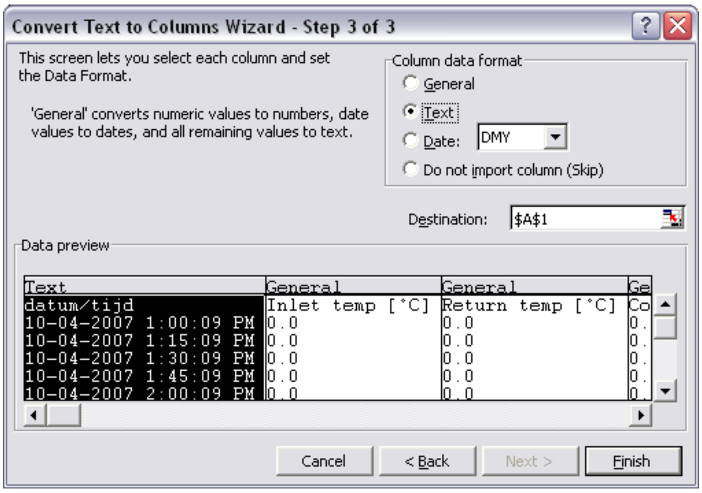
When the dialogue box opens, choose the file type as 'delimited', press next. On the next dialogue box, choose the separators as a comma, deselect tab.

Figure 5: Converting tunnel files to Excel format – second dialogue box



Click 'next'. On the final screen, highlight the first column 'datum/tijd' and select this column as text not general. Click Finish and the data will be converted to ordered columns.

Figure 6: Converting tunnel files to Excel format – third dialogue box



All headings will be changed to English and the columns widened as necessary. An Excel macro will be used to perform these actions.

Saving files on J: Drive

Files are saved on the J: drive under NTDP/Data. All recorded data are kept together in individual folders for exhaust, tunnel 3 data, tunnel 4 data, biofilters, pumps and heating system. Tunnel data should be named ‘Tunnel Y Run X Year/Month/Day Year/Month/Day’. The first date is the day the tunnel program was loaded and the second date the day the program was complete. Labelling the dates in this way automatically sorts them into chronological order.

Biofilter, pump, heating system and exhaust data are recorded monthly. Each month has its own file within the folders on the J:Drive. During each data backup to the J: Drive, the .dat file should be labelled as ‘incomplete’ as a reminder that the file does not contain the data for the whole month.

NTDP Primary Database

Data from manual sampling will be recorded in the field and then input immediately into the NTDP Primary Database, found at J:\NTDP\DATA\Primary Database. Any comments or observations on sampling will be recorded in the relevant spreadsheet. If there are large numbers of comments, these will be saved to a word file and saved with the sampling date, name of sampler, sampling method and location e.g.: Alison Webb Odour Windrow 20080101

All other data will be recorded in the NTDP Primary Database under the relevant worksheet. This database will be backed up weekly onto J:\NTDP\Data\Primary Database\ Primary Database Backup [DATE].xls

The date is included in the filename to identify the time of the last backup. It will be input in the format Year/Month/Day.

SOP 9 – Windrow temperature monitoring and biodegradation sampling

Edition: 01

Authorised by: Agnes Starnawska, 09/06/2008

Introduction

This document describes:

- Windrow monitoring equipment.
- Windrow core temperature measurements and taking samples from windrowed material process.
- Data recording and processing.

The methodology is based on PAS 100 specification for monitoring the composting process of ABPR input materials.

Materials and equipment

- Hand-held TES 1312A Dual K-type Thermometer with probe.
- Batch formation and monitoring record sheet.
- NRM Analysis Request Forms book.
- Spade.
- PPE – protective gloves, stole cup boots and Hi Vis clothes.
- Sampling polythene bags, cardboard box, marker pen and brown cellotape.

Time

One person will take around 10-15 minutes to measure compost windrow temperature and the same amount of time to collect windrowed material samples.

Reference documents

BSI PAS100:2005, Specification for composted materials.

BS EN 12579:2000, Soil improvers and growing media – Sampling.

Equipment maintenance and calibration

Calibration of the hand-held TES 1312A Dual K-type Thermometer is carried out on an annual basis.

The calibration certificate of the TES 1312A Dual K-type Thermometer with temperature probe, used to measure windrow temperatures, showed -0.4 °C reading error.

Procedures

Safety considerations

Care must be taken when working on the site near moving site machinery. Compost material may be contaminated with glass and other sharp objectives. Protective gloves should be worn. Normal hygiene precautions should be observed.

Temperature monitoring

Temperature monitoring for windrowed material should be carried in accordance with the PAS 100 specification guidance.

It has been estimated that the volume of windrow formed from one batch of material composted in the Gicom composting tunnels is around 220 m3. Although, according to existing standards, this volume of material requires monitoring of core temperature using only a single monitoring point, it was decided that windrow core temperature will be monitored using 3 monitoring points: front, middle and end of the windrow.

Windrow core temperature monitoring should be carried out one day before turning of the windrow and on a weekly basis. The windrow is normally turned once a week.

Ambient air temperature, the number of windrow turns and weather conditions will also be recorded during monitoring.

Ambient air temperature readings for weather type/temp column in the recording sheet can be found on www.xcweather.co.uk (Wyton Royal Air force Base).

Turning details are recorded by site operators and transferred to Primary Database (J:\NTDP\Data\Primary Database\NTDP Primary Database) under 'Operators hours' spreadsheet.

Taking samples of windrowed material

Samples will be taken in accordance with BS EN 12579:2000 Soil improvers and growing media – Sampling, and should take place within one day after windrow turning. Compost samples should be sent off by courier on the same day to NRM laboratories.

The sampling points will be designated at intervals along the windrow with an incremental sample being taken at each point.

The number of sampling points (nsp) should be calculated using following equation:

nsp = 0.5(V1/2) rounded to the nearest whole number where:

V is the nominal quantity of the sampled portion in cubic metres

With a minimum nsp = 12

And a maximum nsp = 30.

To form a final sample the incremental samples should be combined. If necessary, the combined sample should be reduced in size by quartering, or by coning, to produce triplicate samples of 1000g.

The same method will be applied to the collection of triplicate samples of compost product after windrow screening (for PAS100 analysis) and triplicate samples of oversize material (for physical contamination analysis).

All samples should be collected in labelled polythene bags, packed in cardboard boxes and send to:

NRM Ltd.

Coopers Bridge

Braziers Lane

Bracknell

Berkshire

RG42 6NS

The collection of samples should be booked over the phone (tel.: 01344 886 338, ADAS account code: F633) before 12 pm on the sampling day.

The collection point for the samples is located in front of the main Envar site office.

Recording data

All the data collected during monitoring should be recorded on the batch formation and monitoring record sheet and transferred to the Primary Database.

A copy of the Analysis Request Form should be taken and filed in the relevant run folder.

Quotation reference for sending samples for laboratory analysis:

Q12985/08 - biodegradability assessment for windrowed material

Q12990/08 - physical contamination analysis for oversize of screened windrow

Q12989/08 – PAS100 test for compost product

Sample labelling

Samples to be sent off for biodegradability test should be labelled in following way: e.g. 1S2R7T, where:

- 1 is sample number.
- S2 is set 2 of processed material.
- R7 is 7th composting run of set 2 of composted material.
- T describes biodegradability test.

Samples of compost product to be sent off for PAS100 test should be labelled in following way: e.g. 1S2R7P, where:

- 1 is a sample number.
- S2 is set 2 of processed material.
- R7 is 7th composting run of set 2 of composted material.
- P describes quality of the end product assessment using PAS100 test.

Samples of oversize material to be sent off for PAS100 test should be labelled in following way:

e.g. 1S2R7C, where:

- 1 is a sample number.
- S2 is set 2 of processed material.
- R7 is 7th composting run of set 2 of composted material.
- C describes physical contamination assessment for oversize carried out in accordance to PAS100 specification.

Figure 7: Batch formation and monitoring sheet

BATCH FORMATION AND MONITORING RECORD SHEET

ST. IVES COMPOSTING OPERATED BY ENVAR LTD.

BATCH CODE

BATCH FORMATION

BATCH TONNAGE

Started

Oversize from batch

Finished

Feedstock Assessment

and Treatment (as applicable)

Week	Week	Date [1]	Core zone temperatures [2]							Turn	Weather
No.	day		1	2	3	4	5	Average	Watered [3]	number	type / temp
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
Comments											

1 Do not start monitoring until batch formation is finished.

2 Add more columns as appropriate to windrow length and update formulas for calculating averages. Take temperatures before turning, if possible.

3 Information here could include water source and approximate gallons.

SOP 10 - Odour sampling

This document covers the procedures undertaken to measure the odour produced by the composting process, and the efficiency of the scrubber and biofilter odour abatement system. It covers the sampling procedures and equipment that will be used, as well as the locations and procedures of the tunnel systems during sampling.

Sampling locations

Odour will be sampled at four different locations during the process:

- At the inlet of the scrubber serving the tunnel.
- At the outlet of the scrubber serving the tunnel.
- Treated air off the biofilter. (Emissions collection from inside the biofilter tunnel headspace.
- From the surface of the formed windrows.

Samples will be taken from a single batch for each set of composting feedstock. Sample collection will take place during the pasteurisation phase of the tunnel cycle. Odour will be sampled from the same material during the windrow maturation stage.

Three replicates will be taken at each of the four sample locations for the feedstocks under investigation.

Sampling Kit

The odour kit includes the following components:

- Sample barrel.
- PET sample bags, to be secured to the black sample valve in the barrel.
- PTFE sample tubes with stainless steel fittings.
- Vacuum pump with plastic tube to connect to the barrel.
- Spanner x 2, duct tape, spare ferrules, spare sample tube & knife.
- Lindvall hood - for use when sampling odour from a surface source (windrow).
- Air fan – hood sampling only.
- Activated carbon filter - hood sampling only.
- Plastic spiral hosing to join the scrubber and the hood - hood sampling only.
- Disposable 'layflat' air tubing to join the carbon scrubber and the fan as well as to prevent air entering the exit aperture of the hood - hood sampling only.

Odour sampling schedule

Table 8: Odour Sampling Schedule

Set Number	Material	Tunnel Loading Date	Tunnel Sampling Date	Biofilter Sampling Date	Tunnel Emptying Date	Windrow Formation Date	Windrow Turning Date	Windrow Sampling Date

Odour samples taken from the scrubber inlet ducting, scrubber outlet ducting, biofilters and windrow are to be taken using a number of techniques. Sampling from the inlet ducting will require the standard use of the sample barrel; the outlet ducting is under positive pressure and therefore requires no barrel. The impracticalities involved in biofilter sampling mean that bags should be filled manually. Samples from the windrow will require the barrel as well as the Lindvall hood and associated equipment.

Preparation

Pre - Sampling Day

The pump should be put on charge for two days before odour testing is carried out to ensure maximum charge in the batteries and prevent variability in pump operation through loss of power. If possible, ensure that the charging equipment and extension leads are available should they be required.

Making Up Boxes for Delivery

The correct number of large cardboard boxes (normally 4 full odour sample bags per box) should be made up with parcel tape ensuring that joints are secure and the tape provides sufficient overlap. Take care to remove all traces of previously used bar codes and address labels. Ensure no sticky faces of tape are exposed inside the box by lining it with newspaper or equivalent. (This is to ensure that the full sample bags are not ripped open when they are removed at the laboratory).

Boxes will be required during sampling to store odour bags once full. However, ensure that they are kept somewhere dry and wind free.

Laboratory Address

L. McCartney & R. Sneath
Silsoe Odours Ltd
Building 42
Wrest Park
Silsoe
Bedford
MK45 4HP

Ensure that the Silsoe Laboratory address is clearly written on the box. Any address labels already on the box to Silsoe can be left providing old dates and consignment numbers are not visible.

Labelling the Sample Bags

Label the sample bags ‘In1 – In3’, ‘Out1 – Out3’, ‘Bio1 – Bio3’ & ‘Win1 – Win3’. Put all the sample bags into the barrel for safe transport to where the sampling is to take place. Each sample bag should also have the date and company clearly written on the label.

Sampling – Scrubber inlet and outlet

Preparation for Sampling

Scrubber inlet and outlet samples must be undertaken at the same time. Biofilter samples should also be taken during the same period. The time sampling commenced and ceased should be recorded on the results sheet.

Samples from the ducting will be taken directly from monitoring points at the scrubber outlet (where the sample will be well mixed due to fans) and at the inlet in a position applicable to the operating tunnel. The odour kit should be set up close to the inlet sampling point near the ducting. The outlet is under positive pressure and does not require the barrel.

Clean any residue from both the inlet and outlet sampling holes with a cloth. Cut clean pieces of sample tube to the desired lengths using a penknife. In the case of inlet sampling, the tube should be long enough to easily reach from the sample hole to the barrel. For outlet sampling, a small length of tube (~ 20 cm) should be used that connects directly to the sample bag and extends into the ducting. Previously used tubing can be recycled providing each Section serves the same task as before and was immediately flushed out using a vacuum pump for approximately 20 minutes after its last use.

Before the samples can be collected, the sample tubes should be briefly flushed with the sample odour for approximately 2 minutes. At this point do not attach the sample bags to the barrel or tubing.

Secure the inlet sample tube to the barrel. Firstly, place a nut over the sample tube, then a small ferrule, and then the front / tapered ferrule. This can now be screwed onto the valve using two spanners. Place approximately 20 cm of the other end of the sample tube into the inlet hole and secure with duct tape. In all sample locations try to prevent the open end of the sample tube touching the inside surfaces of the duct. For the outlet sample tubing, add the nut, ferrules and adapter to allow connection directly to the sample bag fittings. Insert into the outlet duct and secure with duct tape.

The outlet tubing will flush itself due to the positive pressure; the inlet tubing requires the use of the pump. Open the pump box and if necessary, connect the flexible vacuum tubing to the suction side of the pump. Turn the pump on via the external switch or by connecting the battery (red to positive, black to negative). Check for suction by placing a finger on the tube inlet/outlet. Connect the vacuum tube to the top of the barrel and press the lid firmly onto the barrel, clamping it place. Allow the pump to flush the tube for approximately 2 minutes and then switch off. Ensure that if the sampling tube fitting on the barrel has a valve, it is open at all times (handle in vertical position).

If the outlet sampling requires a vacuum, the same procedure as the inlet sampling should be followed.

Sampling

Sampling requires two people. There should be one person at the inlet and one person at the outlet. Three samples should be acquired from both the inlet and outlet (six in total). Sampling from the inlet and outlet should be concurrent. Start and end times should be recorded on the log sheet.

Sample bag 'In1' should be fitted to the inside of the barrel and the lid should be re-sealed using the clamp. The metal sample bag stopper should be stored somewhere safe, clean and dry. Sampling can commence by restarting the pump. Ensure it is connected to the barrel. The bag should be supervised until it has become full with odour. Once the sample bag looks to be full and bulges towards the lid, remove the pump line from the barrel and switch off the pump. Remove the lid of the barrel, unscrew the sample bag and firmly replace the stopper onto the bag fitting.

Sample bag 'Out1' should be connected directly to the fittings on the sample tubing at the scrubber outlet. Store the stopper somewhere safe, clean and dry. The bag will start to fill and should be removed and sealed with the metal stopper when it is full.

Full sample bags should be stored in one of the boxes already prepared where they cannot blow away or be punctured by sharp objects. (Unused sample bags can be stored in the base of barrel or in the cardboard boxes until required).

Repeat this sampling procedure for In2, Out2 & In3, Out3.

Sampling – Biofilters

Preparation for Sampling

If four people are available for the sampling period, biofilter and scrubber (tunnel exhaust) sampling should be simultaneous to eliminate inconsistency caused by process variations.

The structure of the biofilters does not allow use of the Lindvall Hood on what is effectively an area source. Therefore, as emissions are largely enclosed, samples should be collected manually from inside the tunnel headspace.

Sampling requires two people. Entry to the biofilters should be via a carefully placed ladder, held in position by the second sampler stood at the base. The sampler entering the biofilter must wear a hard hat and boiler suit.

The sealed end of sample bag 'Bio1' should be opened by cutting away the plastic fastener and therefore opening up the full width of the bag. Make sure the metal fitting remains in place.

Sampling

The bag should be handed to the sampler in the biofilter. The bag must held open, taking care not to contaminate the inside by touch, and the emissions should be forced inside by rapidly moving the open bag through the space above the media. It is important to fill the bag as much as is possible. The bag should be securely sealed using duct tape taking care not to lose any odour and stored in the previously prepared boxes.

This procedure should be carried out a further two times inside separate biofilters for Biofilter 2 & Biofilter 3.

Sampling – Windrow

Preparation for Sampling

It is important to maintain consistency when sampling in order to interpret results. Monitoring on the windrow should take place at the same stage of windrow maturation and the same time before or after turning for each sampling session. Formation, turning and sampling dates should be recorded to ensure these occur at the same intervals for all sets.

The fan and air pump will be put on charge two days prior to sample collection to ensure full charge and reduce variability in fan and pump operation during sampling.

The hood should be placed on a flat area of the windrow and pushed down into the material to seal the edges. To prevent entry of air that has not passed through the windrow material, it is necessary to pack material around the hood using a shovel. The exit aperture must be covered with a small Section of disposable ‘layflat' tubing primarily to prevent odorous air escaping, but also to prevent interaction in the hood from external sources. This tubing should be secured with duct tape.

Air is blown by the fan through a ‘layflat’ connecting duct to the carbon filter. Air from the exhaust of the filter then passes through a 4” spiral tube to the inlet of the Lindvall Hood.

The plastic spiral tubing should be secured to the filter and hood with 4” spiral clamps and duct tape to ensure a perfect seal. This tubing is not disposable since air passing through it will be cleaned by the filter before passing through the hood. The fan should be placed several metres away from the windrow to avoid collecting odorous air from the surrounding environment.

It is important that air passes through the carbon filter and the hood in the same direction on each sampling run during each sampling occasion.

The barrel should be set up as per the scrubber inlet sampling. However, the sample tube should be fixed in position with a nut and ferrules through the sampling hole near the hood exit aperture.

The fan should be turned on for 2 minutes before any sample is taken in order to flush the system.

Sampling

The sample will be taken following the same procedure as sampling from the tunnel exhaust ducting.

The procedure should be carried out a further two times at different places on the windrow for Windrow 2 & Windrow 3.

Completion of Sampling

Check sample bag stoppers are secure (hand tightened) and not cross-threaded.

All full sample bags should be packed carefully ensuring there is no strain on the cardboard boxes. Where possible, put one bag from each source in each box rather than all the bags from one source point in one box. Lay newspaper or equivalent over the top of the samples to prevent contact with parcel tape leading to damage. Ensure all delivery details are viewable.

The box is now ready for courier collection.

Analysis

Olfactometry will be carried out accordance with the European Standard BS EN 13725. On one sampling occasion the intensity of odour (strong / weak) will be assessed. Samples will be delivered to Silsoe on the day of collection, and the results will be sent back.

SOP 11 – Backup of computer data

Summary

Data, including email, held on computer, whether a Desktop PC, laptop or network server, can be at risk from a number of sources, the main dangers being:

- Hard disk failure.
- Theft or loss.
- Accidental deletion.
- Corruption.
- Computer 'virus'
- Malicious. damage

Throughout ADAS much valuable data is stored on computer. It is the responsibility of every member of staff to ensure the data and email held on their local PC or laptop drive (usually C: or D:) is regularly backed up.

This SOP outlines the procedures and facilities available for the backing up of data held on computers. It replaces the previously issued DATA/019 which has been withdrawn.

Procedure

PC/laptop users

Data, including email stored in Personal Folders in Outlook, held on the local drive of any ADAS PC/laptop (usually C: or D:) is not backed up automatically. It the responsibility of the user of the PC/laptop to ensure the data and email is regularly backed up. The backup strategy you choose will depend upon the value of the data. High value data must be backed up frequently (and possibly on to multiple media devices). A backup of any high value data should also be stored in a separate location away from the source computer.

If there are any problems with backing up data or email the ITC Help Desk must be contacted for assistance.

Office based staff at sites with a network server

Staff must save all data to a drive on the network server. Data on the server is backed up overnight and copies are held off-site. Backups are not done on weekends or bank holidays.

Email, held in Personal Folders in Outlook, is stored on the local drive of the PC/laptop and must be backed up manually to the network server. A 'backup' icon is provided on the desktop for this purpose.

Office based staff at sites without a network server

Email held in Personal Folders in Outlook, and data will be held on the local drive of the PC/laptop and it is the responsibility of the user of the PC/laptop to ensure it is backed up regularly.

Most offices have backup facilities available, such as Network Attached Storage and external USB Hard Drives. Advice on using these is available from the ITC Help Desk.

In addition, most laptop users will have CD/DVD writers, which can be used for the backup of data and email. CDs can hold around 700 Mb of data, and DVDs around 4.5 Gb. Instructions on how to backup to a CD or DVD can be found on the Intranet under ‘Procedures>IT’.

Field based staff

Email held in Personal Folders in Outlook, and data will be held on the local drive of the PC/laptop and it is the responsibility of the user of the PC/laptop to ensure it is backed up regularly.

Most computers, particularly laptops, will have CD/DVD writers, which can be used for the backup of data and email. CDs can hold around 700 Mb of data, and DVDs around 4.5 Gb. Instructions on how to backup to a CD or DVD can be found on the Intranet under ‘Procedures > IT’.

The network servers, at the larger offices, and Network Attached Storage and external USB drives, at other offices, are available for use by field based staff. The ITC Help desk can advise on the use of these.

Staff who do not regularly visit an office and have large amounts of data to backup, which will not fit on a CD or DVD, should purchase an external USB disk drive for this purpose. The help desk can give advice.

LAN (Local Area Network) servers

ITC have responsibility for ensuring the LAN servers are backed up daily to tape. ITC will ensure there are no more than two consecutive backup failures on a server.

At each server location a nominated person will take responsibility for the changing, storing and archiving of the backup tapes, following the procedures detailed in the ‘ADAS LAN Server Backup Strategy’ (see appendix). The nominated person will sign the relevant procedure to confirm that they have read and understood it, and return a copy to ITC.

It is the responsibility of the nominated person to ensure that another competent person is available to carry out these procedures in the event of their absence.

Archive tapes

Archive tapes should be retained for a minimum of seven years.

ITC will check the latest archive tapes from every LAN server, three times annually, to ensure they can be read and data could be successfully restored.

ADAS LAN server backup strategy (DLT/ULTRIUM)

As the person responsible for the changing and storage of tapes on the LAN server at please can you read, and ensure you understand, the ADAS backup policy detailed below. One signed copy of this policy should be returned to ITC, and another held locally.

Tape Rotation Cycle

Twenty tapes should be used in the cycle labelled appropriately e.g. Tape 1 – Tape 20 Week 1 Day 1 – Week 4 Day 5

A new tape must be inserted each day, and the tape number recorded on the local backup record sheet.

Tape Drive Cleaning

The tape drive must be cleaned once each week using a cleaning cartridge, and this should be recorded on the local backup record sheet. Note: Cleaning cartridges only have a limited lifespan so ensure you always have a new one available. Ensure you mark off each time you use the cleaning cartridge and dispose of it after the last clean.

Tape Storage

All tapes must be stored away from the server. The most recent full weeks' tapes must be stored 'off-site'. Off-site' means somewhere well away from the building where the server Is housed. Should a disaster occur in the vicinity of the server, e.g. a fire or plane crash, that weeks' tapes would be available for recovering data.

Archiving of tapes

At the end of every other 20 day cycle, one tape must be archived and replaced with a brand new tape. This serves two purposes. Firstly, it enables the recovery of older data which may have since been deleted from the server. Secondly, tapes wear out over time and archiving ensures they are regularly replaced. These tapes must be stored away from the server.

In order to ensure rotation of tapes it is essential you replace a different tape after every other cycle. This can be achieved, either by writing a date on the tape as it is added to the cycle and always replacing the tape with the oldest date, or by replacing them in order e.g. day 1 week 1, this time, day 2 week 1, next time and so on.

You must always archive a tape which contains a successful backup. If a backup has failed ITC will have notified you on the morning following the backup.

I have read and understand the details of the ADAS LAN Server Backup Strategy. I will ensure this strategy is followed at .

I will ensure that another competent person is available to carry out these procedures in the event of my absence.

NAME:

SIGNED:

DATE:

SOP 12 – Data transfer to Excel

INTRODUCTION

This SOP describes the procedure for transferring data from paper records into a computer spreadsheet or worksheet by manual keying. The same principles apply to the transfer of data into an electronic database.

It is critical that the keying process is carried out carefully and checked systematically to avoid transcription errors.

The following definitions apply to the terms used in this SOP:

- Record sheet - the form or other paper record containing the raw data.
- Computer worksheet - the spreadsheet, database form, or other electronic data entry 'screen' into which data etc. are entered.
- Data entry record - a paper record giving the location and description of data etc. on the computer worksheet, also used to record confirmation that the entered values have been checked.
- N.B. There is no standard data record entry form on AIMS. KEYWORDS: As per SOP title.

PROCEDURES

Data should be entered onto computer using an ADAS approved program e.g. Excel, Access or Minitab, other project specific database software or into a comma (or tab) separated ASCII text file. Electronic data files should be named and organised in a logical way (see SOP DATA/035 or computer category – COMP successor for guidance).

Setting up the computer worksheet

To aid analysis or electronic query of the data, it is important that computer worksheets, or database design and table structures, are set up in a consistent and logical way. For multi-site studies worksheets and databases should be set up in the same way for all sites. If one has already been set up, retrieve the relevant file and go to Section 2 of this SOP.

If not, refer as necessary to any program specific SOPs or manuals, and in the case of data from designed experiments to 1.2 - 1.3 below, to set up the worksheet or database.

The Study Director may have provided computer worksheets, or specified a particular data entry format in the protocol/study plan. In the absence of specific guidance:

- Enter the experiment structure into columns in a logical order e.g.:
- Site number/code (for multi site experiments).
- Plot/animal number.
- Block number.

- Factor 1 levels (treatment numbers for single factor experiments).
- Factor 2 levels (for factorial or split-plot structures).

When the experiment structure has been entered, obtain a print out and check that the number of plots and blocks are correct, and that the treatment code for every plot/animal is the same as on the final site plan/list of animal groups. Sign the print out (or the appropriate box(es) on a data entry record where this is used) to confirm this check has been made.

N.B. For large experiments the Excel pivot table is a useful tool for summarizing and cross checking data, and database software inherently support query and reporting functions useful for checking data quality.

Entering the data

Depending on the program used, document the names of variate columns, dates, units etc. on the working file e.g. using a data entry record, or within the computer worksheet. In the case of Excel the first page of the workbook can usefully be used to record the necessary details.

Before entering the data, check that the study/contract number and the variate

Description on the record sheet and on the computer worksheet match, and are the same as on the data entry record (where this is used).

Enter all data in the same units as they appear on the record sheet, and all values within a column to the same number of decimal places.

In Excel format the cells to show a defined number of decimal places by selecting Format, Cells, Number. The same can be applied to 'fields' within database software.

Missing values should be entered as '*' unless the software being used requires an alternative code (some statistical packages use - 9999).

If a code other than * is entered to indicate missing values, the code used must be recorded on the data entry record or in the computer worksheet. All other characters within the body of the worksheet should normally be numerical values.

This may require the coding of observations or assessments e.g. pregnancy status or fat class. Where the original raw data values include '<' or '>' signs these may need to be converted to a plain number or missing value, in such cases the converted values should be in a separate column (see Section 4), the original recorded raw data value should be retained.

At regular intervals while inputting data, and when all of the values for all of the variates have been entered, save the file.

For experimental data record the electronic location of the data on the original record sheet or in a separate note in the study file.

Checking the entered data

When all of the values for any particular batch have been entered, check that the data have been correctly entered. There are two acceptable options for doing this; manual checking whereby the entered values are checked against the original data, ideally by another person, or by one person reading to another; and checking by double entry and subtraction.

N.B. Where large amounts of data are entered the latter approach may be more efficient.

Manual checking

The computer worksheet must be checked, ideally by another person, before the data are analysed. This may be done either from a print out or on screen. In either case every raw data value on the computer worksheet must be checked against the original value on the record sheet(s) and any incorrectly entered values amended.

Numerical comparison by double entry

Once data have been entered each value should be re-entered, ideally by another person, into vacant columns. The difference of the two columns is then computed by subtracting one from the other.

All values in the resulting column should be zero.

Values which are not zero or are shown as missing values are then double checked against the original data. Any mistakes should be corrected and the calculation rerun to check the corrected data.

Confirmation of checks

When each column of entered data has been confirmed as correct, the person checking must record this by initialling that column on the printout (where one was taken), and/or the appropriate box of the data entry record. This confirmation that the entries have been checked must filed on the study/job file.

Calculations

If any variates need calculating from the raw data, the calculated data should go in a new column, which should be given an appropriate heading.

Do not overwrite raw data or convert it before entry onto the computer worksheet.

Document fully the method of calculating or the formulae used, either on the study/job file or within the computer worksheet. In the case of Excel the formulae used for calculations may best be recorded on the first page of the workbook together with a list of all column names and details of what they contain (see Section 2 above).

SOP 13 – Calibration of temperature probes

INTRODUCTION

It is important that the integrity of thermometers is checked on a regular basis, by a method both appropriate to the thermometer and to the purpose of temperature measurement.

Calibration of thermometers used to measure freezers, particularly ultra-low temperature freezers, is a specialist activity outside the scope of this SOP. It may be necessary to contract the calibration out to an organisation with the appropriate expertise and equipment. An in-house calibration would necessitate the use of a reference thermometer which is capable of operating within the appropriate temperature range.

Definitions

This SOP covers both calibration and accuracy checks of thermometers (within this SOP, the term ‘thermometer’ also refers to thermocouples).

Full Calibration – Certified checks against a reference thermometer, across the range of use, for thermometers used on studies where precise, and authenticated, temperature measurement is required. Calibration must be performed at least annually, unless manufacturer’s recommendations indicate otherwise. Where thermometers used for critical measurements are ‘in calibration,’ interim check(s) should be made at the temperature of use, no more than one month prior to use on a study. This is particularly important when using battery operated thermometers, since a low power reserve in the batteries will often affect accuracy.

Accuracy check – Checks performed at the temperature of use at least annually, where less stringent levels of accuracy are required or when precise monitoring is not required. For example accuracy checks may be undertaken on the environment monitor used in a freezer, (where the only requirement of that freezer is that it maintains frozen samples); or in animal accommodation, (where temperatures are not a component of critical study data).

Health and safety

Take care when handling glass/mercury thermometers. Glass thermometers can be easily broken and mercury is hazardous. In the event of a thermometer breaking: clean up immediately - ventilate the area; wear chemical resistant gloves and eye protection; carefully pick up the glass and place it in a zip bag; pick up the mercury using a disposable pipette, duct tape and/or some card and place with the glass in the self-seal bag. Enclose the bag in two more bags and seal tightly before placing the whole package in a sharps bin or stout plastic container; label the container clearly to indicate that it contains sharps and hazardous waste (mercury (Hg)). The waste is classed as hazardous waste and should be disposed of according to current waste disposal legislation.

Take care to avoid scalds when boiling water is being used during a calibration.
KEYWORDS: As per SOP title.

PROCEDURES

Calibration & accuracy check frequency

Calibration of thermometers, temperature probes or thermocouples should be carried out at least annually by the manufacturer or an approved agent, or if practicable within ADAS against a suitable, certificated, reference thermometer (unless manufacturer's recommendations indicate otherwise).

Thermometers used for critical temperature recording must be accuracy checked no more than one month prior to study start and at appropriate intervals thereafter, depending upon how long the equipment is going to be in use.

Reference thermometers (certified or referenced to national standards) should be sent for a full calibration check every five years, or earlier if a problem is suspected.

Full calibration for positive temperatures

Before calibrating battery powered thermometers, consider changing the batteries. It is not generally recommended that battery powered thermometers are calibrated using the water bath method, since wetting the battery may damage the thermometer.

Determine the operating range of the working thermometer to be calibrated. For example, for measuring the body temperatures of farm livestock an operating range of between 30 °C to 47 °C is appropriate.

Select points within the operating range to calibrate the thermometer. Ten different temperatures are recommended.

Where it is only necessary to calibrate for temperatures above freezing point, it may be possible to calibrate the thermometer using the water bath method as follows:

Fill the water bath to a working level, set the temperature to heat the water to the lowest calibration temperature and switch on. When the temperature of the water in the water bath has remained constant for one minute (check using any thermometer), carefully place the reference thermometer in the bath alongside the working thermometer. Read both thermometers (for glass/mercury thermometers, ensure that your eye is level with the fluid in the thermometer). Record the results against reading 1 on the Thermometer Calibration Certification form (Appendix 1).

Remove both thermometers, and heat the water bath to the next calibration temperature.

Repeat until all of the calibration point readings have been obtained.

If unable to use the water bath method, the same principles apply: calibration of the thermometers should involve a series of ascending temperatures, and no calibration should take place during a cooling down phase. The thermometer must be reset before being placed immediately alongside a similarly reset reference thermometer in each environment, where the temperature is relatively constant (and if possible may be modulated e.g. an incubator). Carry out the following steps:

Begin in an environment where the temperature is at the lowest end of the range to be measured, comparing the temperature displayed on the working thermometer against that displayed on the reference thermometer once the temperature displayed on both thermometers has stabilised (for glass/mercury thermometers, ensure that your eye is level with the fluid in the thermometer).

Record the results against reading 1 on the Thermometer Calibration Certification form.

Increase the temperature of the environment in which the thermometers are placed. If not undertaking the calibration in an environment where the temperature can be modulated, move both thermometers to a different, slightly warmer location. When the temperature displayed on both thermometers has stabilized, record the results against the next reading on the Thermometer Calibration Certification form.

Repeat until all of the calibration point readings have been obtained.

For both methods, continue as below.

Mean all ten of the temperatures recorded with each thermometer and compare the difference. If the difference is not within the agreed range for the purpose for which the thermometer is to be used, then the whole procedure must be repeated, but taking three sets of readings around each calibration point.

If more than one thermometer is to be calibrated, then provided that both are to be used within the same operating range, the additional thermometers readings can be taken immediately after the first working thermometer has been read. If the ranges are different, then calibration of the thermometers should be slotted in so that the procedures involve a series of ascending temperatures and that no calibration takes place during a cooling down phase.

The acceptable range of variation depends on the intended use of the thermometer and can be anywhere between 0.2 °C (for clinical thermometers) and 2 °C. However, unless otherwise stated in the study protocol, any working thermometer (except for clinical thermometers – see above) with a mean temperature reading more than 1 °C different from that of the reference thermometer must either be replaced, or (where cost effective and possible) sent away for re-calibration.

Calibration or accuracy checks of high temperature thermometers

If a reference thermometer is not available at the range required, it is acceptable to time calibrations to coincide with the calibration of laboratory equipment by external suppliers, using the engineer's thermometer or thermocouple. For example, maximum thermometers used to check autoclaves may be calibrated by placing them in the autoclave during its annual calibration, provided the calibration record includes the traceability details of the engineer's calibrated thermocouple.

Accuracy checks on thermometers

Thermometers used to monitor controlled environments

Check each working thermometer against a suitable reference thermometer in the normal environmental conditions that the working thermometer is exposed to, e.g. a thermometer used to monitor the temperature of a freezer running at – 18 °C should be checked at that temperature. Checks may be done individually or alternatively all the thermometers used to monitor e.g. freezers can be checked at the same time.

Reset the working thermometer and place the reset reference thermometer alongside it within the environment being monitored.

After 1 hr, record the temperatures indicated on the working and reference thermometers on the Thermometer Accuracy Check Record. If the temperature reading on the working thermometer differs by more than 1 °C from the reading on the reference thermometer, leave the thermometers *in situ* and record the temperatures indicated again about 3 hr and 5 hr after the start of the test; then calculate the mean temperatures for each thermometer. If the difference between the means is still greater than 0.1 °C, a full calibration must be carried out.

Clinical thermometers

Check each working thermometer against a suitable reference thermometer at a temperature within the range of temperatures that the working thermometer will be measuring. E.g. a thermometer used to measure the temperature of a cow whose normal temperature is 38.8 °C should be checked somewhere between 38 and 39.5 °C. Checks may be done individually, or alternatively all the thermometers used to monitor e.g. cattle temperature, can be checked at the same time.

Switch on (if necessary) and reset the working thermometer, and place it alongside the reset reference thermometer in an environment maintained at the required temperature.

Record the temperatures indicated on the working and reference thermometers on the Clinical Thermometer Accuracy Check Record. If the temperature reading on the working thermometer differs by more than 0.2 °C of the reading on the reference thermometer, repeat the exercise twice and then calculate the mean temperatures for each thermometer. If the difference between the means is greater than 0.2 °C, a full calibration must be carried out.

THERMOMETER CALIBRATION CERTIFICATION

Date of calibration:

ID of working thermometer calibrated:

ID of reference thermometer used:

Calibration carried out by:

	Reference thermometer values (°C)	**Working thermometer values (°C)**
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

Tolerance 0.2 °C for a clinical thermometer or 1 °C for all other thermometers

PASS	**FAIL**

NEXT CALIBRATION DUE
:
QC Checked By:

Date:

THERMOMETER ACCURACY CHECK FOR THERMOMETERS (OTHER THAN CLINICAL THERMOMETERS)

Accuracy check of the thermometer identified below was carried out in accordance with SOP LAB 005.

Working thermometer ID:

Reference thermometer ID:

Date of check:

Check carried out by:

If after the initial check there is greater than ±1 °C difference, refer to SOP LAB 005

Calibration thermometer value (°C) after 1 hour	Working thermometer value (°C) after 1 hour	OK (Y/N)? (Not more than ± 1°C), if N continues...	Calibration thermometer value (°C) after 3 hours	Working thermometer value (°C) after 3 hours	Calibration thermometer value (°C) after 5 hours	Working thermometer value (°C) after 5 hours	Mean of calibration thermometer values	Mean of working thermometer values	OK (Y/N)? (not more than ± 1°C)

PASS	FAIL

QC Checked By:

Date:

CLINICAL THERMOMETER ACCURACY CHECK

Accuracy check of the thermometer identified below was carried out in accordance with SOP LAB 005.

Working thermometer ID:

Reference thermometer ID:

Date of check:

Check carried out by:

If after the initial check there is greater than ±0.2 °C difference, refer to SOP LAB 005

Calibration thermometer value (°C)	Working thermometer value (°C)	OK (Y/N)? (not more than ± 0.2°C), if N repeat	Calibration thermometer value (°C)	Working thermometer value (°C)	Calibration thermometer value (°C)	Working thermometer value (°C)	Mean of calibration thermometer values	Mean of working thermometer values

PASS	**FAIL**

QC Checked By:

Date:

SOP 14 – Calibration of pH meters

SUMMARY

A pH meter can be used for quick and easy measurement of the pH of liquid samples, e.g. buffers, rumen fluid, silage effluent, water extracts of feeds, soils etc. This SOP covers the procedures for the regular maintenance and calibration of pH meters, which are essential to maintaining their accuracy. It does not include detailed instructions for the use of specific models for which users should refer to the manufacturer's instructions.

Time

- Buffer solution preparation - 10 minutes.
- pH meter calibration - 15 minutes.

Materials and equipment

The following materials and equipment are need for this procedure:

- pH meter and electrode.
- Deionised/distilled water for preparing buffer solutions.
- pH buffer tablets or pre-prepared pH buffer solutions (supplied by recognised suppliers, e.g. Fisher) for pH 7 plus, pH 4, pH 5, pH 9.2 or pH 10 as appropriate.
- Deionised/distilled water in wash bottle for rinsing.
- Tissues.
- Tongs.
- Calibration record form.
- Ball-point pen.

PROCEDURES

Wear overalls or a laboratory coat and rubber gloves when using buffer solutions to check the calibration of pH meters.

Preparation of buffer solutions

Prepare pH 7 buffer solution and one other either pH 4, 5, 9.2 or 10 according to manufacturer's instructions and store according to the instructions (volumetric flasks, magnetic stirrer, stirring bars and retrieval rods may be required).

Calibration of the pH meter

A two point calibration (covering the pH range of the samples to be tested) should be carried out regularly according to the manufacturer's instructions. If the meter is in regular use, calibrate daily and after every 50 samples; or if used irregularly calibrate prior to each use.

Calibrants should be at the same temperature as the samples to be tested or an auto temperature correction applied. Calibrants must not be used after their expiry date.

Record the date and time of calibration and the operator's initials on the calibration record form.

Measurement of pH

Measure pH of the samples according to the manufacturer's instructions.

In the event of failure of the pH meter, refer to the manufacturer's handbook for guidance.

Care of the pH probe

The electrode (pH probe) regardless of make should never be exposed to air for longer than necessary. Store the electrode in the solution recommended by the manufacturer, usually distilled water/buffer which requires regular replacement.

Clean the electrode regularly, particularly if used for biological samples using the solvents and techniques recommended by the manufacturer.

CALIBRATION RECORD

Equipment Reference/Identification number:

Description of Equipment:

Calibration interval:

Calibration method:

Acceptance criteria/tolerances:

DATE/TIME	INITIALS	DATE/TIME	INITIALS

SOP 15 – Sampling for microbial analysis

SUMMARY

This SOP describes the procedures to be followed when collecting samples for microbiological analysis. Correct sampling and sample transport are absolutely vital to ensure the results of analysis are valid and representative.

It is not possible to define absolute rules for all sampling situations; unusual circumstances may require modifications to the procedures below, however good practice can be applied to each case. For safety reasons, all samples for microbiological analyses are assumed to contain potential pathogens. Sampling procedures and transport must therefore protect the sampler, courier and the receiving laboratory from any possible health hazard. Some analyses require the addition of preservatives or other chemicals at the point of sampling, therefore it is important to ensure the correct bottles are used, and samples taken in the correct manner.

For further advice on any aspect of the procedures covered by this SOP contact the laboratory that will receive and analyse the samples.

REFERENCE DOCUMENTS

The Microbiology of Water 1994 part 1 Drinking Water - Report 71. BS 6068 Water Quality Part 6.2 Guidance on sampling techniques.

BS 6068 Water Quality Part 6.3 Guidance on the preservation and handling of samples. BS 7592 Sampling for Legionella organisms in water and related materials.

MATERIALS AND EQUIPMENT

Sampling

The following materials and equipment are needed for this procedure:

- Sterile disposable pots or bottles for microbiological analysis.
- Sterile disposable pots or bottles with sodium thiosulphate for microbiological analysis of chlorinated water.
- Disposable bottles for water samples for chemical analysis.
- Sterile disposable dipper pots.
- Sterile well sampling kits.
- Sterile polythene bags and closures.
- Sterile scalpels, spoons, chopping boards etc.
- Sterile disposable swabs and transport solution.
- Cotton wool and industrial methylated spirits (Azowipes or other alcohol - based wipes may be used provided they do not leave an antibacterial residue).

- N.B. Sterile equipment has an expiry date of six months, and must be stored in a cool, clean, dry, dark place.

Sample transport and submission

- Sterile disposable dipper pots.
- Cool box.
- Frozen ice packs or crushed ice.
- Packaging and polythene bags.

PROCEDURE

General considerations for taking samples for microbiological analysis

Samples must be fully representative of the item under investigation, and of adequate size for analytical needs; if in doubt, check with the receiving laboratory before sampling. Samples should not be so large they present a handling or storage problem for the courier or laboratory.

Aseptic procedures should be used, i.e. the sample must be taken without allowing transmission of bacteria or other contamination to or from the sample. The sample container and other sampling equipment (e.g. scalpels or well sampling kits) must be properly sterilised, by autoclaving, radiation or dry sterilisation. Avoid contaminating the sampling container, its lid, outside or inside while taking the sample. Do not put bottle tops down; they can be contaminated by dust or drops of water etc.

When sampling liquids, sample containers should be nearly filled. This prevents excessive churning or shaking during transport, whilst allowing proper mixing of the sample before testing.

Where analysis by two laboratory departments is required, turnaround times can be reduced by taking separate samples. To reduce the risk of contamination, the microbiology sample should be taken first; the same sample submission form may be used for both samples.

All samples must be clearly labelled with batch number (from sample submission form), date and time of sampling, client name and address and sample identification; transfer this information to the sample submission form.

Water samples – tanks, chambers and streams

EEC Standards and instructions for taking water samples are detailed in The Microbiology of Water 1994 part 1 Drinking Water - Report 71. For further guidance see BS 6068 Water Quality Parts 6.2 and 6.3. Select sampling points carefully, according to the nature of the investigation. Water samples should be taken as late as possible before sending them to the laboratory to ensure the minimum deterioration during transit. Samples should ideally be tested within six hours of sampling if possible, and certainly within 24 hours.

Take care not to contaminate the water by allowing material to fall into the tank or chamber while removing the cover. Do not touch the sides or disturb the sediment while taking the sample.

Remove the bottle top.

Plunge the bottle neck first into the water.

Invert the bottle underwater; point the neck into any current or move the bottle slowly forwards while it fills.

Remove the bottle, cap it quickly, label and complete paperwork as above.

When taking samples for Legionella analysis, note that safety precautions should be taken; gloves and a respirator should be worn. Chlorine in the samples must be inactivated before transporting to the lab, and samples should not be refrigerated. For further information refer to BS 7592.

Chemistry water samples

Consult with the receiving laboratory for information on which sample bottles to use; some determinations require additives or specially prepared bottles.

Chemistry samples should generally be taken after those for microbiological analysis; follow the instructions on the bottle concerning rinsing.

Clean the exterior of samples of dirty water before packing them to reduce the risk of health hazards/contamination in the laboratory.

Water samples should be cooled to 2 – 10 °C, and transported in a container which excludes light. Pack well to avoid excessive agitation and clearly label hazardous samples.

Completion of Sample Submission Form

If the sample is not representative of the bulk, state this clearly on the paperwork e.g. ‘Sample taken from mouldy patch’ or ‘sample taken from damaged package’. A sample submission form can be found on Intranet via AIMS > Topic > Forms. The version current when this SOP was last reviewed is appended.

The sample description, sampling point, client name and address etc. must be clearly stated on the sample submission form together with analysis required.

When submitting large batches of samples, enter details on the sample submission form in a logical order. Use at least one line per sample and do not use short cuts; paperwork must be fully completed before samples can be registered.

If the reason for sampling is a specific problem, state this on the sample submission form; the laboratory may be able to recommend more appropriate tests or report significant interim results if they are aware of the sample history.

It is very helpful, particularly in the receiving laboratory if a copy of the sample submission form can be faxed before the samples are despatched (as well as one included with the samples). This helps the laboratory to process the samples more rapidly, and ensures that any lost in transit are traced while they are still fit to test.

Sample transport

General guidance on packaging, and transport of samples is given in SOP LAB/01 0.

Samples begin to change microbiological composition as soon as a sub-sample has been removed from the bulk. Therefore, samples must be transported to the laboratory as rapidly as possible, and under conditions that slow down bacterial growth (i.e. refrigeration).

Standards for different sample types specify different temperatures for sample transport; a 'dummy' sample with a thermometer in liquid may be used to check the temperature of cool-boxes.

Pack samples in cool-boxes with sufficient ice packs or crushed ice to ensure they are still within the acceptable temperature range on receipt by the laboratory. Wrap the samples in polythene bags to prevent labels separating from samples; sample submission forms should be separately wrapped in a polythene bag, to prevent paperwork being contaminated by any leaking samples. Use newspaper or other insulating material to prevent samples moving about in transit. To aid processing large batches of samples should be packed in the same order as on the sample submission form; the laboratory may supply racks or sample boxes for this purpose.

Cool-boxes should be well labelled with the destination, 'fragile, with care', 'this way up' etc. and (inside the box) any return address for the cool box. N.B. Couriers must not be exposed to health hazards caused by incorrectly packaged samples.

Samples for microbiological analysis should generally be tested within 24 h of sampling; it is therefore important to liaise with the laboratory to ensure samples are expected. The laboratory can also advise on the most rapid or most convenient courier service.

ADAS SAMPLE SUBMISSION FORM

Despatch Ref. No:

Despatcher Name:
Despatcher Address:

DESPATCH TO:
Name:

Address:

SAMPLE DETAILS
Reason for
Sampling:

No. of Samples:
Type of Packaging:

LIST OF SAMPLES
(PLEASE SEE
ATTACHED
SHEETS)

(Include deadline for return of results where appropriate)

(Include hazard classification where appropriate)

***SAMPLE RECEIPT**

Received By: Name of

(signature) Company:

Date: Time:

(if applicable) Comments on sample condition

***Please complete and return (post or fax) this form (including the list of samples) to: [Name, address]**

Telephone:

Please also return any data loggers and ice packs. Thank you.

18 DEFINITIONS

Aerobic process

A microbiological process taking place in the presence of oxygen. Some microorganisms only function and break down substances in an environment containing oxygen. In the process, they release by-products such as carbon dioxide and water vapour. Composting is primarily an aerobic process.

Anaerobic process

A microbiological process taking place in the absence of oxygen. Some microorganisms only function and break down substances in an environment lacking in oxygen. In the process, they release by-products such as methane and volatile fatty acids. These can produce offensive odours. Anaerobic processing is normally referred to as anaerobic digestion.

Batch Processing

A processing method for in-vessel composting systems in which a discrete batch of feedstock is loaded, processed and unloaded from the vessel without the introduction of new material during the process.

Bioaerosols

Bacteria, actinomycetes and fungal spores suspended in the air that can cause respiratory problems. They are released during the composting process, especially when the composting material is moved or screened.

Biodegradable Municipal Waste (BMW)

A term used in the EU Landfill Directive to refer to biological wastes from households that consist of food and garden wastes, paper wastes, and other wastes in the Municipal Waste stream, that are capable of undergoing aerobic or anaerobic decomposition.

Biofilter

Normally organic, microbially active substrates (such as wood chips, peat and bark), that filter odorous air through the action of microorganisms that live in the medium.

Bulk Density

The mass per unit volume of a material, e.g. tonnes/m^3.

Compost

Biodegradable Municipal Waste that has been aerobically processed to form a more stable, granular material containing valuable organic matter and plant nutrients. This can be applied to land to improve soil structure, enrich the nutrient content of the soil, and enhance its biological activity.

Composting

The controlled biological decomposition and stabilisation of organic substrates, under conditions that are predominantly aerobic and that allow the development of thermophillic temperatures as a result of biologically produced heat. The resultant product is sanitised, partially stabilised, and is high in humic substances. It can be beneficially applied to land.

Feedstock

The general term for any organic material that is composted.

Forced Aeration

A method of providing air (and hence oxygen) to a composting mass, usually by pipes laid underneath. It can be carried out either by the use of positive pressure (which blows air into the compost) or negative pressure (which draws air down through the mass by suction).

In-vessel composting system

A term adopted to cover a wide range of composting systems in which the material being composted is contained and usually enclosed.

Heated walls and floors

A proposed method of warming the walls and floors of a contained composting system by the use of recirculated hot water, in order to reduce the time taken to reach the pasteurisation stage of composting, thereby increasing the throughput of material.

Leachate

Water that has percolated through the contents of a composting mass.

Maturation

The process whereby phytotoxic compounds in composts are metabolised by microorganisms into compounds that do not harm plants. Mature compost does not have a negative effect on seed germination or plant growth.

Olfactometry

A test method used to determine the extent to which substances are odorous, using human subjects as a sniff panel.

Oversize material

Material removed from the compost product by screening after the completion of the composting process.

Pathogen

A micro-organism that causes disease through infection.

PAS100

The UK voluntary standard for compost production, including details of maturation, weed seed propagules, heavy metals, pesticides and contaminants.

Product

The fraction of compost that passes through a screen with oversize material removed. The product can be spread to land as a soil improver.

Screening

The process of separating particles according to their size.

Scrubber

A water-based air filtering system designed to remove ammonia and other volatile components from the exhaust air stream of an in-vessel composting system before it enters a biofilter.

Shredding

The process of reducing large pieces of feedstock into smaller fragments so that the structural properties are more conducive for composting, e.g. by exposing a greater surface area for microbial activity.

Stability

The degree of biological decomposition that composting feedstocks have achieved.

VOCs

Volatile organic compounds.

Waste continuum

A term to describe feedstocks containing a range of percentages of kitchen waste and green waste feedstocks used in the project.

Waste reception area

The Section of a composting facility where new feedstocks are delivered and stored before being shredded and composted.

Windrow

A non-enclosed pile of composting material, usually shaped as an elongated triangular prism.