

Research Development and Design of a Simple Solid Waste Incinerator

Test-Rig construction and operation

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1 Introduction

The construction and testing stage of the LCI project follows technical and socio-economic studies, conceptual design and final design stages to develop the present concept of the low cost incinerator (LCI). Construction and testing were undertaken in the UK at a site owned and operated by EMC (formally the Coal Research Establishment, CRE) in Stoke Orchard near Cheltenham. The site has been used extensively for testing and monitoring the technical and environment performance of solid fuel combustion systems and is fully equipped with stacks and monitoring equipment to undertake comprehensive testing of the LCI.

As well as hosting the site, EMC were contracted to provide some supervision during the construction phase of the LCI and provide environmental monitoring services and general assistance during testing.

2 LCI design

The LCI consists of an inner refractory-brick built incinerator surrounded by an outer protective wall made from ordinary building brick or cement block (a cheaper option that was used on this test rig). There is a gap of approximately 300mm between the inner and outer construction. The incinerator is a simple two-chamber design with vertical sidewalls and a low sprung arch roof. The outer wall is a vertical wall, without a roof, that follows the contour of the incinerator.

The primary chamber is a simple tunnel design with a low arched roof. Combustion takes place on a stepped grate system consisting of three grates (drying, and two combustion grates) inclined at 20° from the feed (front) end of the incinerator and a burn out pit. The top grate is the drying grate and consists of a solid floor made from refractory brick. The two lower grates are combustion grates and are made from perforated refractory bricks sitting on top of a steel primary-air plenum. The secondary chamber starts as a tunnel with a low arched roof, situated above the middle combustion grate and at right angles to the primary chamber after which it forms an 'S' shape chamber which forces hot gasses to pass first vertically downward then vertically upwards. After the secondary chamber the hot gasses pass into the tertiary chamber, where the gases are cooled by mixing with cooling air. From the tertiary chamber a connector joins the system to the existing smoke gas stack of the EMC test boiler house.

The low arched roof of the incinerator is supported by buckstays, located within the gap between the incinerator and the outer wall, and tensioned using tie bars. Sheet steel is braced between the buck stays and the gap produced between the sheet steel and the incinerator wall is then backfilled with fine sand to provide a seal helping to reduce the likelihood of air ingress into the combustion chamber and also acts as a low cost insulation material.

The LCI is built under cover in an open sided shed approximately 6 meters from the stack being used. Therefore a horizontal section of ducting (the tertiary chamber) and a transition piece were required to connect the LCI to the stack.

A feeding platform is located at the front end of the incinerator approximately 2 meters above ground level. The platform has sufficient space for two operatives and intermediate storage for sorted MSW and support fuel. The incinerator is fed initially by biomass (wood-chip) and then fed with pre-sorted waste. Primary combustion takes place in the primary chamber under natural draught conditions secondary combustion using forced draught secondary air injection. Both the primary and secondary air is controlled manually, via dampers, according to combustion conditions.

2 Test-rig construction

The final design layouts, detail drawings, general arrangements and parts list were completed by September 2001. Attempts to identify a single company, which would construct the LCI, supply all materials and fabricate all steel components within a limited budget, were not successful. Therefore the fabrication of the steel components and construction activities of the project were separated and companies invited to quote for the work. T. Booth Engineering Ltd near Cheltenham and Ashwell Engineering Services Ltd near Leicester, were approached to quote for the steel fabrication work. Ashwell's quote was far cheaper than the other and after obtaining [verbal] references confirming the quality of their work an order was place with them.

Three specialist refractory engineering companies; Karafrac Ltd, S.E.M Construction Ltd, and Electric Furnace Repairs & Service, were approached to quote for the construction of the LCI including the supply of the refractory materials. Only Karafrac (verbally) and S.E.M (by letter) tendered for the work both of which quoted prices in excess of the total budget allocated for all materials (including steel components and bought outs) and construction.

It was therefore decided that the design team would manage the construction of the LCI and hire in skilled and general labour as required. Initially two persons, a mechanical engineer and a builder, were given short term contracts to undertake the construction of the LCI under the management of the design team. During the construction phase three other skilled craftsmen were employed on a daily basis to help speed up the work programme and/or undertake specialised work. EMC's specialised work force supplied electrical and instrumentation installations.

Work began on fabricating the steel components in October 2001 and was delivered to site by the 9th January 2002. Construction of the LCI started on the 7th January 2002 with all civil works completed by 20th March 2002 and steel work by 23rd April 2002.

The construction phase took much longer than originally scheduled. This was due mainly to the nature of the work, the LCI being a prototype, using non-standard, innovative materials and construction techniques. This was to be expected for R & D work and provided valuable lessons for the building and costing of future LCI's.

During the construction of the LCI a number of modifications and changes to the original design were made, as problems arose and solutions were found. Modifications to the civil works were undertaken onsite by the bricklayer with help

from other members of the team. Modifications to, and any additional, steel components were undertaken either on site by members of the construction team or off site by local fabrication engineering companies. The design of the transition piece for connecting the LCI flue to the stack was not finalised until just before it was required. Before the part could be designed the stack had to undergo an inspection and wind load calculations. These were undertaken to determine the dimension of the opening that needed in the existing stack and hence the shape of the connector piece.

The stack inspection was carried out by LA Steeplejacks of Bristol (EMC's usual steeplejack) and wind loading calculations by consulting structural engineers Michael Evens and Associates Ltd of Ilkeston in Derbyshire. The connector piece was designed and manufactured, in consultation with the design team, by the John Patrick Engineering Ltd of Ilkeston in Derbyshire. The transition piece was fitted to the stack by members of the construction team in accordance with a method statement issued by John Patrick Engineering Ltd.

A site construction logbook was kept throughout the construction phase with daily entries being made providing information on work done, work in progress, modifications carried out, details of prevailing weather conditions, and personnel on site.

3 Commissioning and Testing

Commissioning commenced on the 10th April and was complete 24th April 2002 and consisted of signal tests, MCC tests and test runs for E-consumers and calibration of primary, secondary and cooling air flow monitors. Special care was taken to check the even distribution of secondary air across the nozzles. A problem achieving equal (frontal/dorsal) distribution of the secondary air through the manifold resulted in a re-design and modification to the ductwork. Otherwise there were very few problems commissioning the LCI. Commissioning work is documented in the Operating Manual, lever arch file.

The LCI was tested on both biomass (wood chip) and municipal solid waste (MSW). Altogether 8 tests were carried out using wood chip and 6 using MSW. Wood chip was used initially to dry out the refractory materials before full testing was undertaken. Wood chip was used to warm up the incinerator the day before scheduled test using municipal solid waste (MSW) to simulate real conditions. In addition wood-chip was also used to fire up the LCI to achieve nominal operating conditions (i.e. temperature, O₂ and CO emission) before commencing operation on MSW. Throughout the testing on MSW, wood-chip was readily available to act as a support fuel if necessary and for the final burn out after using MSW.

MSW was sorted off-site by Grundon Waste Management at their Elmhurst site in South Oxfordshire and delivered to site in 1100 litre wheeled bins. The reason for the split operation of waste sorting and combustion tests was the refusal of the EA to give the tests an exemption from Waste Management Licensing at EMC/CRE. Grundon Waste Ltd organised the waste sorting team and provided general site supervision. The project team provided a short training session at the beginning of each day's sorting and provided a limited amount of supervision (approximately half a day). All

bins were numbered and the empty weight noted. Full bins were then weighed before delivery to the LCI test site. Each sorting session was documented with a sorting record, recording date of sorting and bin numbers, and weights. The MSW bins were individually covered with a tarpaulin and also covered with a large tarpaulin and stored in an open compound adjacent to the test rig site.

Waste sorting documentation is contained in the Test Results arch leaver file. The sorting operation was intended to provide the front end element of emission abatement for substances like heavy metals and HCl. Also the waste consistency and metal content should have been controlled by the sorting operations. Due to the remoteness of the sorting and the poor motivation of the staff this part of the test operations were disappointing (see comments under Section 4.) More attention has to be given to this aspect in the Pilot stage (for more detail, see Appendix 7).

When required each bin of MSW was, using a forklift truck, tipped and emptied directly into the bucket of a front-end loader. The bucket was then raised to loading platform level and the MSW manually transferred, using forks and spade, directly from the bucket into the feed chute. Originally it was envisaged that a conveyor would transport the MSW up to the platform but this method, used for wood-chips during the original biomass warm up test, is slow and requires greater manual handling of the MSW and additional operators.

Testing of the LCI started on the 29th April with an initial warm up using wood-chip to dry out refractory materials. This was followed the next day (1st May) by a second biomass fuelled test to ensure that full operating temperatures and conditions could be achieved. The first MSW test was carried out on the 2nd May 2002 followed by five more over the next seven weeks. On the day before each MSW test the LCI was operated on wood-chip to pre-heat it for the MSW test.

After each test the primary chamber was opened up and the ash removed, weighed and analysis (see Appendix 1 – 6: Test results and Appendix 10: Inspection reports). At the same time a visual internal inspection of the primary chamber and a partial inspection of the secondary chamber was undertaken. The partial inspection covered the downward section of the 'S' chamber only as this is all that could be seen from inside the primary chamber. After the last test (MSW6) the secondary chamber access tunnel was opened up and a full internal inspection undertaken. A summary of the inspection is given in Section 4 (Test Results) and copies of each inspection report appear in Appendix 10.

Having achieved full operating temperature it was found that six shovel loads of wood-chip every three minutes enabled the LCI to be operated effectively maintaining temperatures above 850⁰C. However, when operating on MSW the mixed nature of the waste meant that it was not possible to maintain steady state conditions by delivering a set number of shovels per unit time. In addition it is noted that the nature of the MSW did not allow the operators to pick it up in constant volume shovel loads, like the woo-chips. The feed rate was controlled (with difficulty) by partially filling the feed-chute with waste and then pushing it down on to grate 1 while ensuring that a plug of waste was always maintained inside the chute to minimise air ingress.

As a minimum the LCI requires 4 personnel for effective operation; one operator, one assistant operator and two feeders. The operator uses a combination of combustion air (primary and secondary) flow rates, MSW feed rate and stoking to maintain combustion temperatures and O₂ and CO emission levels. Visual inspection (through a site glass) of the combustion process on grates 2 and 3 assists the operator in making decisions. Temperatures, air flows and emission information is also at the operators disposal. Combustion air is controlled using simple butterfly valves fitted to all inlet air ducts.

Controlling the flow of material through the primary chamber proved problematic. The original raddles designed to provide stoking and agitation of waste on grates 2 and 3 did not last very long before they burnt out. The raddle on the main combustion grate (grate 2) burnt out on the first MSW test and on the burn out grate (grate 3) raddle lasted for three burns.

Test three commenced without any effective internal method of moving the MSW across grate 2. The use of 2 chains falling down the length of the 3 grates for agitation did not work and was therefore discarded as a solution. Stoking had to be carried out by pushing using long 'T' shaped tools from the feed chute. This method of stoking was difficult to undertake and lead to poor results for throughput, which was exacerbated by poorly sorted and very wet MSW.

Before test four was undertaken an agitator was designed and fitted on grate 2 and a heavy-duty steel raddle fitted to grate 3. The agitator is in effect a three-pronged fork (prongs running along the grate in waste flow direction) made from steel tubing. The prongs, set in line with the direction of the LCI primary chamber, are attached to a top tube that passes through the left hand wall of the LCI (see photo in Appendix 8). The agitator is then rotated back and fourth manually using a counterbalanced lever. To enable grate 2 to be cleaned the agitator can be rotated through 120°. Primary combustion air enters through the agitator helping to keep it cool in an attempt to reduce oxidation and the steel burning out. Air entered the agitator at around 72m³/hour (measured using hand held hot bulb anemometer) mitigating the need for side and under grate air. Each fork prong has a series of outlet jets enabling the combustion air to be evenly distributed across the grate.

Initial operation using the agitator proved inadequate due to over-rotation that eventually lead to the agitator prongs sitting on top of the MSW rather than below. By test 6 the correct operation the agitator had been learnt which involved a series of small, rapid reciprocating movements through no more than 10° of arc. However the airflow through the agitator was insufficient to cool it adequately resulting in partial oxidation and destruction of the steel. Also the improved method of operation was not so effective when incinerating very wet MSW and so alternative methods of stoking needs to be investigated. This is an ongoing task.

Provision to pre-heat primary air was added for the last run (MSW Test 6). This consisted of two electric element convection heaters placed in front of the primary air inlet duct so that they could blow hot air directly into the duct. The heaters were plugged into a standard 13A socket and switched on and off manually as required. Each heater was rated at 3kW and there was a tendency for them to cut out when used for extended periods. It was found that PA preheating was very beneficial with wet

waste (a well-known fact in EfW technology) and higher PA pre-heating (to 200°C) will form part of the design improvements for the Pilot.

Continuous monitoring for temperature, airflow, combustion gas emissions and particulates was carried out during each test:

Temperature: Primary, secondary and tertiary combustion zones and LCI structure temperature (roof arches, walls and sand seal) using K type thermal couples connected to a multi-channel Grant Squirrel data logger.

Air flow: Primary airflow using a Testo 445 fitted with a hot bulb anemometer. Forced airflow was measured using pitot tubes in secondary air duct and tertiary air duct. Airflow monitoring calibration was carried out during commissioning, ensuring an accurate reading by use of correction factors.

Emissions: O₂, CO, NO, NO₂, and SO₂ continuously measured at the end of the secondary combustion zone just before the addition of tertiary air using a Testo 33 multi-function gas analyser and a conditioning unit.

Particulates: Opacity was measured using PCME meter fitted across the main exhaust stack gave continuous readings through all the tests. (This unit was only calibrated against the gravimetric monitoring results during MSW6 run)

In addition CRE were contracted to undertake an assessment of emissions to atmosphere in accordance with the relevant British Standards and UKAS accreditation. For details see Measurement of Gaseous & Particulate Emission from a Low Cost Incinerator at CRE, Stoke Orchard, Cheltenham – Report No: G2018/020605. This monitoring exercise coincided with MSW 6 run.

4 Test results

Compiling and transferring monitoring data into a reportable format is time consuming and therefore only results for tests using MSW have been presented. Table 1 (below) presents a summary of the average test results for the operation of the LCI on MSW. For full test results see the individual reports for each MSW test presented in appendix 1 to 6. An electronic version of all operational and monitoring data for each test including those using biomass only is available from the ITC.

The test results show that the average MSW feed rates were between 47.5% and 75%, of the design rating of 425kg/hour. In all but one test the average power output was below the design rating of 826kW. The exception was test 2 where the average power output was 895kW. Here the apparently high power output is only due the report format: Burn time is very short therefore the effect of waste still burning after feeding stopped has a higher influence on pushing the power output figure up. On the other hand as power is calculated based on an estimate of CV; this was 9000KJ/kg in this run, higher than the others.

Table 1: Summary of results (test averages) for operation on MSW (Emission levels reported have not been corrected for reference conditions STP dry gas containing 11% by volume, dry oxygen)

	Units	Test 1 02/05/02	Test 2 09/05/02	Test 3 16/05/02	Test 4 30/05/02	Test 5 13/06/05	Test 6 20/06/02
MSW feed rate	kg/hour	319	298	197	206	256	284
Power output	kW	590	895	348	319	533	591
Combustion air:							
Primary	Nm ³ /h	348	347	540	360	270	235
Secondary	Nm ³ /h	148	204	177	321	257	346
Tertiary	Nm ³ /h	569	3469	3439	3026	3413	3666
Emissions:							
O ₂	%	12.3	11.9	12.7	12.5	13.5	13.2
CO	ppm	200	94	219	215	289	117
NO	ppm	95	103	89	94	109	92
NO ₂	ppm	1	0	1	1	0	0
SO ₂	ppm	14	30	15	15	2	22
Particulates	units	40	39	46	45	56	43
Temperature:							
Primary	°C	922	860	763	761	842	935
Secondary	°C	564	587	470	483	498	511
Tertiary	°C	205	227	187	194	204	197
Residuals:							
Total ash	kg	161	166	117	94	148.9	136
% of MSW	%	16	22	24	23	16	14
Loss on ign.	%	3.48	2.99	4.05	3.13	3.71	2.87

In general O₂ levels were above the 8 to 11% aimed for but were fairly consistent across all tests. CO levels were also higher than the legal requirement and the emission specifications but did on a number of occasions fall well below the threshold level of 100mg/m³. Controlling O₂ and CO levels required frequent and very vigorous agitation of the feedstock on grates 2 and 3, especially when the load is wet. Table 2 shows for test 6 that CO emission, corrected for reference conditions (dry gas @ 11% O₂) did for the last hour and a half of the test stay well below the permit level of 100mg/Nm³ and corresponds to the point at which primary air was pre-heated using the convection heaters used. Therefore this confirms that air pre-heating and good agitation, giving rise to greater combustion surface, are important factors in controlling and maintaining adequate levels of heat release from the feedstock and to ensure low O₂ values and low CO emissions. Other emissions such as NO, HCl and SO₂ are mainly a function of the feedstock composition and a reduction could be achieved through better pre-sorting.

Average primary combustion chamber temperatures were above the minimum 850⁰C required for four of the six test carried out. However, for two of the test (3 and 4) average temperatures were below 850⁰C. There were three contributing factors to the low temperatures in test 3.

First of all the LCI had not be warmed up adequately on biomass before the MSW was added and secondly the MSW used was very wet. Thirdly after about one and a half hours operation excessive feeding and stoking through the feed chute door (the

only stocking means available during this test (because the original raddle had burnt out and the new agitator had not yet been fitted) caused a wedge of wet MSW to be pushed directly on to grate 2 smothering the fire, resulting in almost complete cessation of the combustion process. Recovery from this situation took a great deal of time, requiring the biomass support fuel to be used exclusively for some time. Although this incident severely affected combustion temperatures it did provide the LCI team with an opportunity to test the remedial procedures developed for such occurrences (see operating manual, use of PA fan). Up until this point temperatures of over 900°C had been achieved (see Appendix 3 for details).

The low temperatures in test 4 were due mainly to very wet MSW (estimated at ~ 50% m.c.) in the second load used (bin 1.12) combined with over feeding and poor stoking technique due, this time, to incorrect operation of the agitator. This was the first time the agitator had been used and the original method devised was to move the agitator figure through a large arc so that good mixing would be achieved. However, the large movement enabled feedstock to fall under the fingers preventing the agitator fingers to return to their normal position. Eventually the fingers were completely above the bed of burning MSW and were rendered ineffective. This meant that stoking had to be carried out through the feed chute door using pushers. It also proved inadequate in providing good fuel/air mixing and sufficient combustion surface necessary for controlling the combustion process (especially as wet MSW does not flow easily).

The ignition losses data for residual ash indicates that for all MSW tests good burnout had been achieved despite the poor performance during tests 3 and 4.

Table 2 Test 6 - Comparison of corrected LCI emissions and EMC monitoring results on 20/06/02

Time		LCI corrected for dry air @11% O ₂ - (average)			Time		CRE reference conditions (average)		
From	To	CO mg/Nm ³	NO mg/Nm ³	SO ₂ mg/Nm ³	From	To	CO mg/Nm ³	NO mg/Nm ³	SO ₂ mg/Nm ³
11:30	11:59	432.07	318.77	103.10	11:39	12:08	285.0	223.5	212.5
12:00	12:29	187.83	290.77	100.05	12:09	12:38	178.5	203.5	189.5
12:30	12:59	269.18	195.37	114.97	12:39	13:08	208.5	122.5	192.5
13:00	13:29	69.37	256.80	83.94	13:09	13:38	37.0	174.5	135
13:30	13:59	109.25	229.89	103.66	13:39	14:08	48.5	157.5	132.5
14:00	14:29	177.25	360.15	75.38	14:09	14:38	61.0	209.5	147.5
14:30	14:59	239.67	301.96	68.64	14:39	15:08	207.0	201.5	120.5
15:00	15:30	222.16	344.85	78.03	15:09	15:15	93.0	200.0	85.0
Average 11:00 - 15:30		213.3	287.3	91.0	Average 11:39 - 15:15		145.0	186.0	158.0

Table 3 summaries the test average results measured by CRE during MSW test 6. These results show high levels of HCL and heavy metals such as lead and cadmium. The high levels of HCl are probably due to high levels of PVC in the waste, which should have been removed when the waste was sorted. The high levels of cadmium

and lead are probably due to the presence of cheap electronic components, such as musical greetings card and toys and their disposable batteries, in the waste.

Improved sorting protocols and training for ‘pickers’ will help to ensure the removal of these items from the waste stream. Also in developing countries the levels of cheap electronic toys and other component in the waste will be less than in the UK.

Table 3 Summary of CRE measurements of gaseous and particulate releases on 20/06/02¹

Determinand	Det. No.	Concentration				Release	
		Units	Ref. Cond.	STP	Uncertainty (6)	Units	Rate
SO ₂	GAS	mgSO ₂ /m ³	158	32	5	kgSO ₂ /h	0.16
NO _x	GAS	mgNO _x /m ³	186	38	5	kgNO ₂ /h	0.19
CO ₂	GAS	% CO ₂	8.1	1.7	0.3	kgCO ₂ /h	166
CO	GAS	mgCO/m ³	145	30	7	kgCO/h	0.15
HCl	HCL1	mgHCl/m ³	1524	311	25%	gHCl/h	1592
HCl	HCL2	mgHCl/m ³	1385	282	25%	gHCl/h	1446
HCl	HCL3	mgHCl/m ³	1509	307	25%	gHCl/h	1576
HF	HF1	mgHF/m ³	1.3	0.3	26%	gHF/h	1
HF	HF2	mgHF/m ³	2.9	0.6	26%	gHF/h	3
HF	HF3	mgHF/m ³	4.0	0.8	26%	gHF/h	4
VOCs	GAS	mgC/m ³	8	<5	100%	kgC/h	0.01
PCCDs PCDFs	PCDD	ng/m ³ (TEQ)	1.540	0.314	65%	ng/h (TEQ)	1608
Arsenic	TE	mgAs/m ³	0.0166	0.0034	31%	gAs/h	0.017
Cadmium	TE	mgCd/m ³	3.5707	0.7274	30%	gCd/h	3.728
Chromium	TE	mgCr/m ³	0.0650	0.0132	30%	gCr/h	0.068
Copper	TE	mgCu/m ³	0.8164	0.1663	30%	gCu/h	0.852
Lead	TE	mgPb/m ³	3.3374	0.6798	30%	gPb/h	3.484
Manganese	TE	mgMn/m ³	0.5892	0.1200	28%	gMn/h	0.615
Mercury	TE	mgHg/m ³	0.0185	0.0038	42%	gHg/h	0.019
Nickel	TE	mgNi/m ³	0.0469	0.0095	27%	gNi/h	0.049
Partic. Stack	TPM1	mg/m ³	265	54	10%	kg/h	0.28
Partic. Stack	TPM2	mg/m ³	178	36	10%	kg/h	0.19

1. Reproduced (in part) from Report – Measurement of gaseous & particulate emissions from a low cost incinerator at CRE, Stoke Orchard, Cheltenham.

Inspection of the primary chamber, undertaken after each test with MSW, showed that cracks had occurred in the structure. Two cracks appeared in the left hand wall and three in the right hand wall of the primary chamber and continued across the arch. in the primary chamber walls and across the arch roof. There were similar cracks in the downward section of the secondary chamber ‘S’ chamber and across the arched roof.

Most of these cracks were hairline in nature and followed both the joints in the bricks and also went through some bricks. The exception was one of the cracks in the left hand wall which was up to 3mm wide in places. The worst cracking occurred in the

corbelled wall above the ash end access arch which is up to 8mm wide in places. The crack has broken through bricks rather than follow the joints. This crack also leads up to, but not into, the arched roof of the primary chamber.

On inspection of the secondary chamber (only undertaken at the end of last test operation – MSW 6) it was noted that a significant amount of ash had built up on the floor, especially at the corners, between the downward and upward section. This build up of ash could have contributed towards the formation of dioxins during the cooling down period after testing or during warm up.

The inspections also showed that substantial shrinkage has occurred in some of the refractory cement joints between the refractory bricks allowing sand leak into both the primary and secondary chamber. Also sand leakage occurred at the joint faces between combustion chamber access arches and the access tunnels from the outer wall.

5. Conclusions and Recommendations

The UK test rig and monitoring results are a milestone in the project and results and findings must flow into the pilot design for the next stage of the project.

To summarise it can be said that although the test rig did not live up to the environmental specifications drawn up during the concept phase the performance is encouraging (see Table 4).

Table 4 Comparison of Environmental Specifications and CRE Results

Species/Other condition	Environmental Standards according to Specifications	Results from CRE Monitoring 20/06/02
Carbon monoxide	100mg/Nm ³ (half hourly average, continuous monitoring)	145mg/Nm ³
Total particulate	30mg/Nm ³ (half hourly average, continuous monitoring)	265/178 mg/Nm ³
Hydrogen chloride	30mg/Nm ³	1524/1385/1509 mg/Nm ³
Conditions of combustion	850°C with 6% O ₂ after last air injection, 2 seconds contact time	not determined by CRE
Use of auxiliary fuel (biomass)	below 850°C	This was done during the test
Visual inspection	No black smoke	Mostly no visible smoke from stack
Releases to Land limits		
Loss on ignition (550°C)	5% by weight	2.87%

The results suggest, that with some improvement measures it may be possible to meet most of the specifications. The only parameter where it is virtually impossible to achieve the values is HCl, as sorting the waste to exclude PVC has its limits. However it is believed that levels as low as 200-300mg/Nm³ should be achievable. Further reductions are possible through the use of an absorption type gas cleaning process followed by a particulate filter; this cannot be done without a dedicated ID fan to pull the gases through the system (this is however not a realistic prospect within the cost constraints of this project). A filter would also address the HM and particulate parameters.

Heavy metals were not part of the specifications, but very considerable improvements for reduction of releases of HM to air should be achievable through improved sorting and gas cooling before release. (The question is then what to do with HM contaminated fly ash). This measure would also cause overall particulate reduction.

Improving stoking and process controls can reduce carbon monoxide emissions. Better process control would also allow reducing particulate releases.

The formation of dioxins could be reduced by the changing the geometry of the floor in the secondary chamber so that there are no horizontal surfaces and by the addition of an ash box that enables ash falling out of the gas stream to be collected away from the hot surfaces in the incinerator and the combustion gases.

As a result of the test results and associated considerations the project team conclude as follows:

- The project should move on to the Pilot stage in the Gambia
- Some improvements and optimisations are necessary in the Pilot plant (see list in Appendix 9)
- Sorting needs to be radically improved (see Appendix 9)
- The data obtained from the test rig will flow into the EIA

It would have been preferable to test the improvement measures at EMC, but the LCI team believes that the current design is very robust and can be adapted to include small improvements.

The problems with cracking can be overcome by the addition of expansion joints into the structure. The number and position of expansion joints will be informed by the number and position of the cracks which have occurred. Additional buck stays will be fitted around the access arch to support the arch and minimise the risk of cracking occurring.

Innovative elements of construction for structural strength, heat lagging and air leakage prevention have been proven as well as the basic process.

One problem that we foresee however at this stage is that the funding will not be sufficient to overcome possible complications in the process of building and testing the pilot plant. Will the Gambian partners for instance have the funding to operate the plant and sorting operations over the lifetime of the Pilot plant? Will they be in a

position to carry out emission monitoring to enforce the required environmental standards?

We believe to compensate for these problems in the host country there is a need for institutional strengthening. This would ensure that the project can be carried to a successful conclusion in this most crucial part of the project.

Moreover there is now a need to liase with the Low Cost Landfill KAR project to ensure the best possible low cost option is used to dispose of the residuals of the process.

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- 4 Test results MSW 4
- 5 Test results MSW 5
- 6 Test results MSW 6
- 7 Report on sorting
- 8 Photo documentation
- 9 List of modifications for pilot plant (from DG meeting 6)
- 10 LCI Inspection reports (MSW 1 to MSW 6)

Appendix 1: Test Results MSW 1

Test Report Summary

Test: **MSW1** Date: **02/05/02**

Duration	From	To	Duration	Duration in minutes
Total	08:45	17:30	08:45	525.00
MSW	11:45	15:55	04:10	250.00
MSW + 1h	11:45	16:55	05:10	310.00

Feed	Total kg	per hour kg/h	moisture %	LCV (estimated) kJ/kg
BM	762	169	40	11000
MSW	984	319		9000
MSW + 1h	984	241		

Power	BM	BM + MSW	MSW	MSW + 1h
kW	266	547	590.4	476

Combustion Air Input (MSW)	Nm ³ /h	PA	SA	Tert. Air
MSW		348	148	594
MSW + 1h		331	146	589
Last hour MS		256	144	592

Emissions	O ₂ %	NO ₂ ppm	SO ₂ ppm	CO ppm	NO ppm	Partic units
MSW	12.3	1	14	200	95	40
MSW + 1h	12.7	1	14	186	92	40

Temperature Process	Deg C	Prim Ch	Sec Outl	Tert. Outl
MSW		922	564	205
MSW + 1h		918	552	202
Last hour M		949	543	190

Temperature Structure	Deg C	Arch Prim	Arch Sec	Wall	Sand
Start Burn		57.5	106	105.5	109
MSW		357	384	149	163
MSW + 1h		379	403	161	176
Last hour M		439	446	184	201

Residuals	Mass	Ash Total	Under Grate	Over Grate	Quality	Loss on Ign %
kg		161	22.5	138.5	Over grate	1.06
% of MSW		16	2	14	Under Grate	18.37
					Overall	3.48

Important Notes Log Book, Other Pages 6-7

Time	Note
10:10	start sec air
11:45	start feeding msw
11:55	increase PA 1110Nm ³ /h
12:29	reduce SA to 840Nm ³ /h; condensat starts to flow from PA plenums
13:15	material sits on grate with little reaction due to lack of stoking
14:50	bin 1.11 is completely unsorted (feeding difficult, many cans et.)
15:15	rattle action on grate 3 reduces O ₂ , CO
15:55	end feeding MSW

Important Conclusions

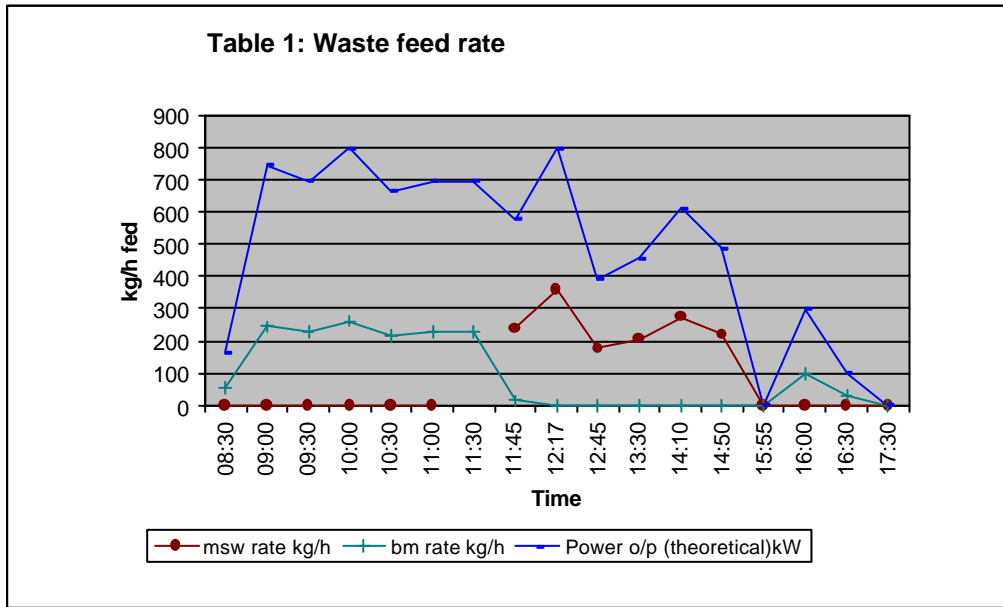
1	The basic thermodynamic principle of the LCI seems confirmed
2	The through put is below the expected 340 kg/h (comb diaar at 9000KJ)
3	The air flows need closer examination as they don't correspond to dimensioning

TEST MSW1 Date 02/05/02 Waste Feed Rate

time	msw kg	bm kg	bin ID	Dt min	msw rate kg/h	bm rate kg/h	Power o/p (theoretical) kW
08:30		27.11744		30.00	0	54	165.7177
09:00		122		30.00	0	244	745.7295
09:30		114		30.00	0	228	696.0142
10:00		130		30.00	0	260	795.4448
10:30		108		30.00	0	217	662.8707
11:00		114		30.00	0	228	696.0142
11:30		57		15.00		228	696.0142
11:45	127	8	1.1	32.00	238	15	575.7748
12:17	167	0	1.2	28.00	358	0	795.2381
12:45	132	0	1.3	45.00	176	0	391.1111
13:30	137	0	1.8	40.00	206	0	456.6667
14:10	183	0	1.9	40.00	275	0	610
14:50	238	0	1.11	65.00	220	0	488.2051
15:55	0	0		5.00	0	0	0
16:00		49		30.00	0	98	298.2918
16:30		33		60.00	0	33	99.4306
17:30		0			0	0	0

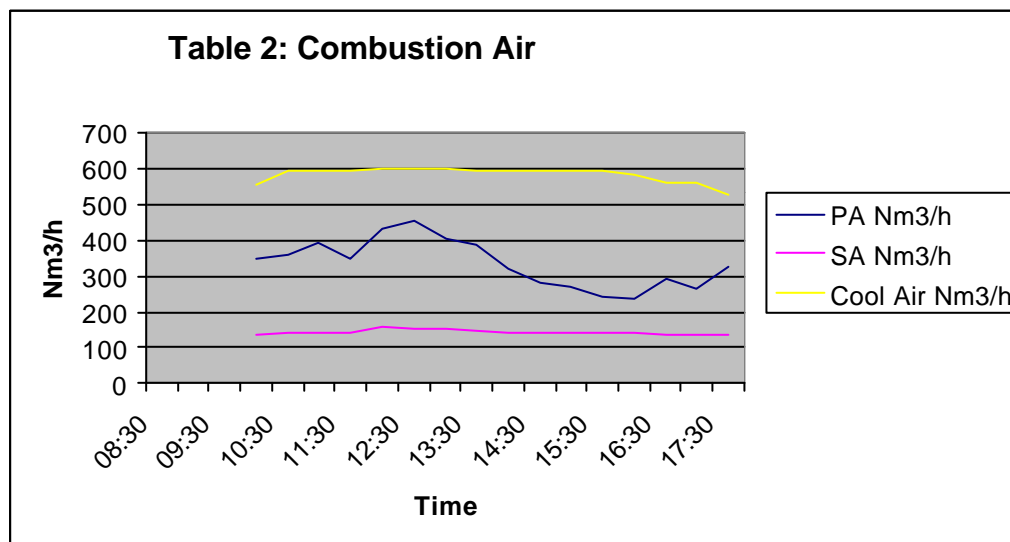
totals	984	762		0	540	1471.674	1604.335
total bm	762 kg		weight/shovel	2.71			

Total MSW	984 kg	in min	185	Average	319.1351 kg/h
Total bm	762 kg	in min	270.00	Average	169.3333 kg/h
Total MSW	984	in min	245	Average	240.9796 kg/h



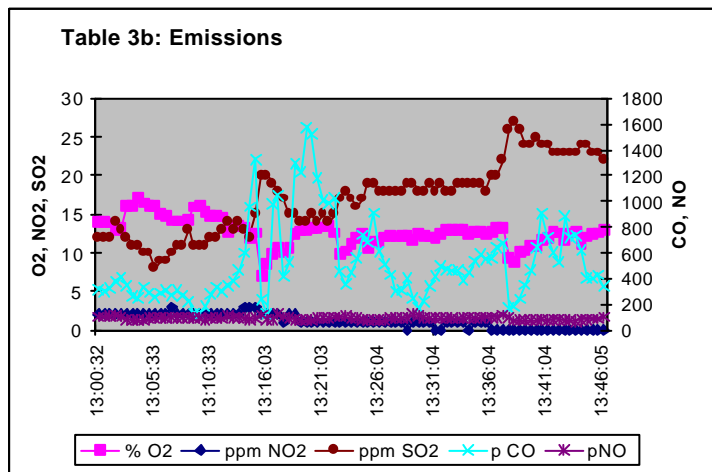
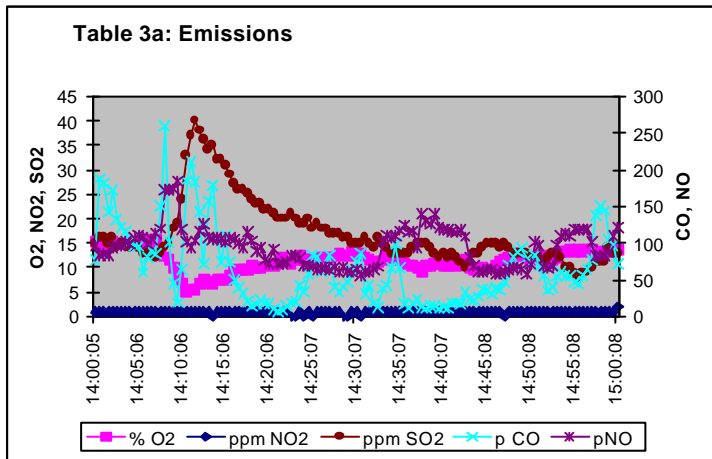
TEST MSW1 Date 02/05/02 Combustion Air

Average air flow in next 30 min			
time	PA Nm3/h	SA Nm3/h	Cool Air Nm3/h
08:30			
09:00			
09:30			
10:00	345	136	551
10:30	359	141	594
11:00	394	142	593
11:30	346	143	593
12:00	431	159	596
12:30	451	154	596
13:00	401	154	596
13:30	389	148	594
14:00	318	142	592
14:30	281	143	592
15:00	268	143	591
15:30	243	144	592
16:00	237	139	580
16:30	291	134	559
17:00	263	134	559
17:30	328	133.76	524
18:00			
Average	334	143	581
MSW	348	148	594
Average MSW +1h	331	146	589
Last hour MSW	256	144	592



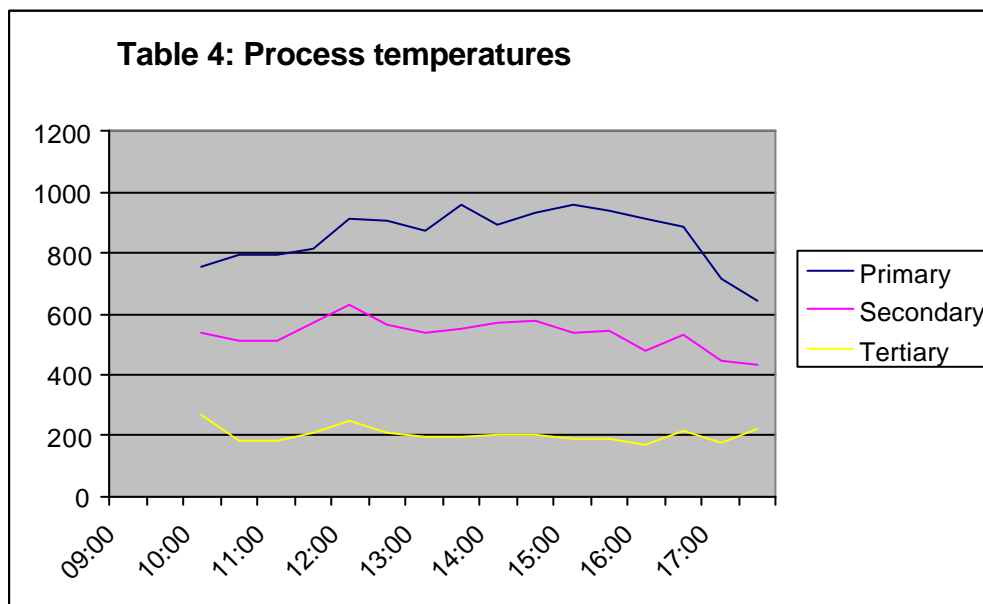
TEST MSW1 Date 02/05/02 Emissions

Average releases to air next 30 min						
time	O2 %	NO2 ppm	SO2 ppm	CO ppm	NO ppm	Partic units
08:30						
09:00						
09:30						
10:00	10.1	4	0	134	82	45
10:30	12.6	5	0	185	50	35
11:00	12.2	6	0	67	53	36
11:30	10.0	5	0	50	83	38
12:00	11.6	3	2	96	110	45
12:30	13.2	3	7	226	105	43
13:00	13.1	2	14	525	94	43
13:30	12.4	0	23	404	93	41
14:00	11.3	1	21	82	96	39
14:30	11.7	1	13	51	92	39
15:00	13.0	0	17	133	84	37
15:30	12.4	0	17	86	87	37
16:00	14.1	1	19	159	66	36
16:30	14.7	1	12	96	90	42
17:00	16.9	0	4	426	61	37
17:30	17.2	1	3	794	52	51
18:00						
Average	12.9	2.0	9.5	219.6	81.2	40.2
MSW	12.3	1.2	14.1	200.3	95.2	40.4
MSW +1h	12.7	1.1	14.4	185.7	91.8	40.1



TEST MSW1 Date 02/05/02 Temperature Process

Average temperature in next 30 min			
time	Primary	Secondary	Tertiary
09:00			
09:30			
10:00	755	536	264
10:30	797	511	184
11:00	797	511	184
11:30	817	572	206
12:00	912	631	251
12:30	907	563	209
13:00	870	535	196
13:30	961	553	196
14:00	896	569	202
14:30	934	576	204
15:00	959	539	189
15:30	939	547	190
16:00	914	478	166
16:30	885	529	217
17:00	719	448	178
17:30	641	434.1667	221
18:00			
Average day	856	533	204
Average MSW	922	564	205
Average MSW + 1H	918	552	202
Last hour MSW	949	543	190

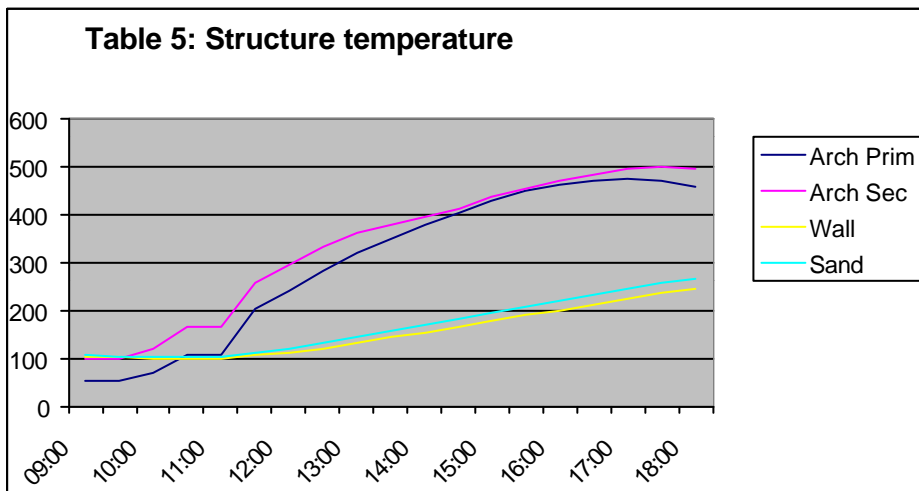


TEST MSW1 **Date 02/05/02**

Temperature Structure

Average temperature in next 30 min				
time	Arch Prim	Arch Sec	Wall	Sand
09:00	53	100	104	107
09:30	54	98	102	105
10:00	71	119	101	103
10:30	108	166	100	103
11:00	108	166	100	103
11:30	202	259	106	111
12:00	242	296	112	120
12:30	282	332	121	130
13:00	319	360	131	143
13:30	349	379	143	156
14:00	379	396	154	169
14:30	405	414	166	182
15:00	428	437	178	195
15:30	449	456	189	208
16:00	465	472	201	221
16:30	473	485	213	233
17:00	476	495	225	246
17:30	470	500	235	257
18:00	458	497	246	267
Average day	305	338	154	166
Average MSW	357	384	149	163
Average MSW + 1H	379	403	161	176
Last hour N	439	446	184	201

Temp at Start of burn(8:38)	57.5	106	105.5	109
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Discussion

Monitoring data, taken every 30 seconds, was downloaded at the end of each test operation, collated, and presented as half hourly averages in this report. The complete monitoring data set for the test is available separately from ITC.

Gas emissions (O_2 , CO, NO, NO_2 & SO_2) monitoring was carried out using a portable combustion gas analyser (Testo 33) with heated probe located at the exit from the secondary combustion chamber. Combustion and structure temperatures were monitored using K type thermocouples connected to a Grant Squirrel data logger and readout. Particulate monitoring was carried out using an opacity meter (PCME DV400) fitted into the stack. Primary air flow was measured using a hot wire anemometer (Testo 445) while secondary and tertiary combustion air was measured using Pitot tubes connected to electronic manometers.

Total burn time was 8.45 hours including the initial warm up and final burnout using biomass (wood-chip). A total of 762 kg of biomass and 984kg of pre-sorted MSW was used during the test giving average feed rates of 169kg/h for biomass and 319kg/h for MSW. This represents a MSW throughput of 75% of the design maximum continuous rating (mcr) of 425kg/hour. However, the LCI was designed for MSW with a calorific value (c.v.) of 7000kJ/kg and the MSW used had an estimated c.v. of 9000kJ/kg. Adjusting for MSW with a c.v. of 9000kJ/kg gives an mcr of 340kg/hour for the LCI resulting in a throughput of 94% of the mcr.

Average power output on MSW was 590kW with a peak of just over 795 kW and a low of 391kW. Both the peak and average power output is below the theoretical design mcr of 826kW. The average power output is approximately 71.5% of the mcr power output which is in keeping with the average MSW throughput of 75% of design mcr throughput. This would be expected as the LCI's power output is directly related to the feed rate of the MSW and this is shown in figure 1 on page 3.

Under stable operating conditions the primary, secondary and tertiary (cooling) air were all below the theoretical flow rates for the LCI. The measured flow rate for primary air was 348Nm³/h which is approximately 53% of the theoretical flow rate. Both measured secondary air at 148Nm³/h and tertiary air at 594Nm³/h are approximately 15% of the estimated theoretical flow rate. To some extent the difference can be explained by ingress air through the feed chute, cracks and gaps that started to appear in the structure after the initial warm up operations. Also the instrument readings for the secondary air may be inaccurate. Occasional readings taken manually, using a Testo 455 and hand held hot-wire probe, indicated that the flow rate through the secondary duct was at least twice that being measured by the insitu air flow measuring device (pitot tube interfaced with an electronic readout).

Emissions to air of O_2 , and CO were , at 12.3% and 200ppm respectively, higher than required by the design criteria. predicted.

The average primary combustion temperature was 922⁰C when operating on MSW, with temperatures above 950⁰C being achieved (see figure 4 page 7) at times. Temperature in the secondary chamber average 587⁰C with a peak temperature of above 631⁰C being recorded. With the use of cooling air the temperature of the

combustion gas in the tertiary chamber averaged 227⁰C and was kept below 300⁰C throughout the test operation.

At 161kg the residual ash represents 16% of the mass of MSW incinerated of which, 138.5kg was bottom, or over gate, ash and 22.5kg under grate ash. A visual inspection of the ash showed good burnout had occurred and that a large amount of ferrous metal (mainly food cans) with some glass and non-ferrous metals were present. The majority of the non-ferrous was from waste bin 1.11 which had been poorly sorted. The mass of cans was not measured but it is assumed that they account for a substantial proportion of the final mass of the residuals. Ash analysis from the over grate residuals (3 samples taken) indicate a loss on ignition of 1.06% confirming that good burn out had occurred. Analysis of under grate ash (1 sample taken) shows a higher degree of loss on ignition of over 18% which would be expected as any un-burnt material falling through the grate would cool quickly and would tend not to burn out adequately. Over all loss on ignition of all the ash is low at 3.48% by mass.

The high combustion temperatures achieved combined with relatively low O₂ and CO emission and good residual ash burnout suggests that good combustion conditions were achieved within the LCI. Low emission of NO and SO₂ indicate that the majority of the MSW had been well sorted (although the high levels of ferrous materials is of concern) confirming the importance of removing non-combustibles and potentially hazardous materials.

Appendix 2: Test results MSW 2

Test Report Summary

Test: **MSW 2** Date: **09/05/02**

Duration	From	To	Duration	Duration in minutes
Total	09:05	16:40	07:35	455.00
MSW	13:00	15:05	02:05	125.00
MSW + 1h	13:00	16:05	03:05	185.00

Feed	Total kg	per hour kg/h	moisture %	LCV (estimated) kJ/kg
BM	1179.9	262	33.5	11000
MSW	746	298		9000
MSW + 1h		213		

Power	BM	BM + MSW	MSW	MSW +1h
kW	475	721	895.2	605

Combustion Air Input (MSW)	Nm3/h	PA	SA	Tert.Air
MSW		347	204	3484
MSW + 1h		339	190	3469
Last hour MSW		270	134	3432

Emissions	O2 %	NO2 ppm	SO2 ppm	CO ppm	NO ppm	Partic units
MSW	11.9	0	30	94	103	39
MSW +1h	12.5	0	28	104	99	38

Temperature Process	Deg C	Prim Ch	Sec Outl	Tert.Outl
MSW		860	587	227
MSW + 1h		867	569	217
Last hour M		851	566	205

Temperature Structure	Deg C	Arch Prim	Arch Sec	Wall	Sand
Start Burn	48.5	122.5	125.5	129	129
MSW	288	415	157	170	170
MSW + 1h	310	437	169	184	184
Last hour M	363	489	191	211	211

Residuals	Mass kg	Ash Total	Under Grate	Over Grate	Quality	Loss on Ign %
		166	20.3	145.7	Over grate	98.9
	% of MSW	22	3	20	Under Grate	83.45
					Overall	97.01

Important Notes Log Book, Other Pages 6-7

Time	Note
09:05	Lighting with card board cradle
10:00	Passive cooling cooling air damper 90 deg
10:25	Cooling air fan on cooling to 20 deg
10:55	PA cofig.70/60/30/30 deg
12:00	sec air at 20deg (~150 m3)
13:00	Start MSW feed
13:29	PA config: 70/80/40/15deg (~250m3/h); SA to ~ 500 m3/h
13:59	Reduce CO by closing SA to) 15 deg (0m3 display)
14:33	PA config:40/90/30/10deg (~322m3/h); SA 15deg ,display 0, measured with HBA:~240m3/h
15:15	Replace CT01 sensor needlessly since it is only the display that stops indicating at T>1000 C, there is therefor a small error in the average
15:52	Finishe MSW feed

Important Conclusions

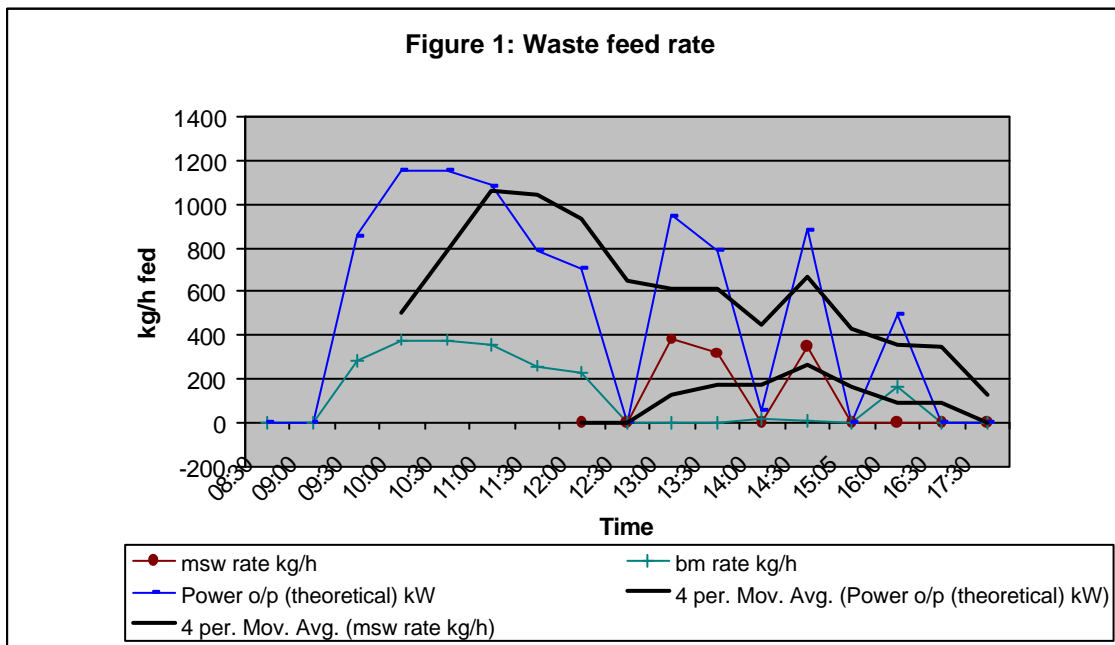
1	
2	
3	

TEST MSW 2 Date 09/05/02 Waste Feed Rate

time	msw kg	bm kg	bin ID	Dt min	msw rate kg/h	bm rate kg/h	bm shovels	Power o/p (theoretical) kW
08:30		0		30.00		0		0
09:00		0		30.00		0		0
09:30		140		30.00		281	52	858
10:00		189		30.00		378	70	1155
10:30		189		30.00		378	70	1155
11:00		178		30.00		356	66	1089
11:30		130		30.00		259	48	792
12:00		116		30.00	0	232	43	709
12:30		157		30.00	0	0	58	0
13:00	190	0	1.12	30.00	380	0		950
13:30	158	0	1.13	30.00	316	0		790
14:00		0		30.00	0	18		55
14:30	202	0	1.16	35.00	346	7		887
15:05	196	0	1.4	55.00	0	0		0
16:00		81		30.00	0	162	30	495
16:30		0		60.00	0	0		0
17:30		0			0	0		0

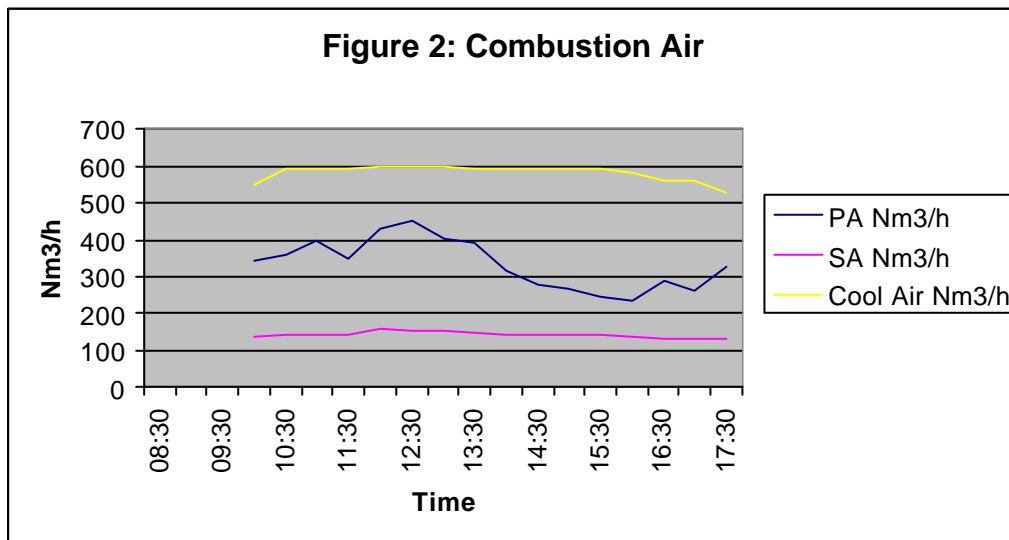
totals	746	1179.9		0	540	1042.286	2071.6	437	
total bm		kg		weight/shovel	2.70				
Total MSW	746	kg	in min	150	Average	298	kg/h	BM	11000
Total bm	1179.9	kg	in min	270.00	Average	262	kg/h	MSW	9000
Total MSW + 1h			in min	210	Average	213	kg/h		

BM Moist	A	B	C	Average
%	35	32		33.5



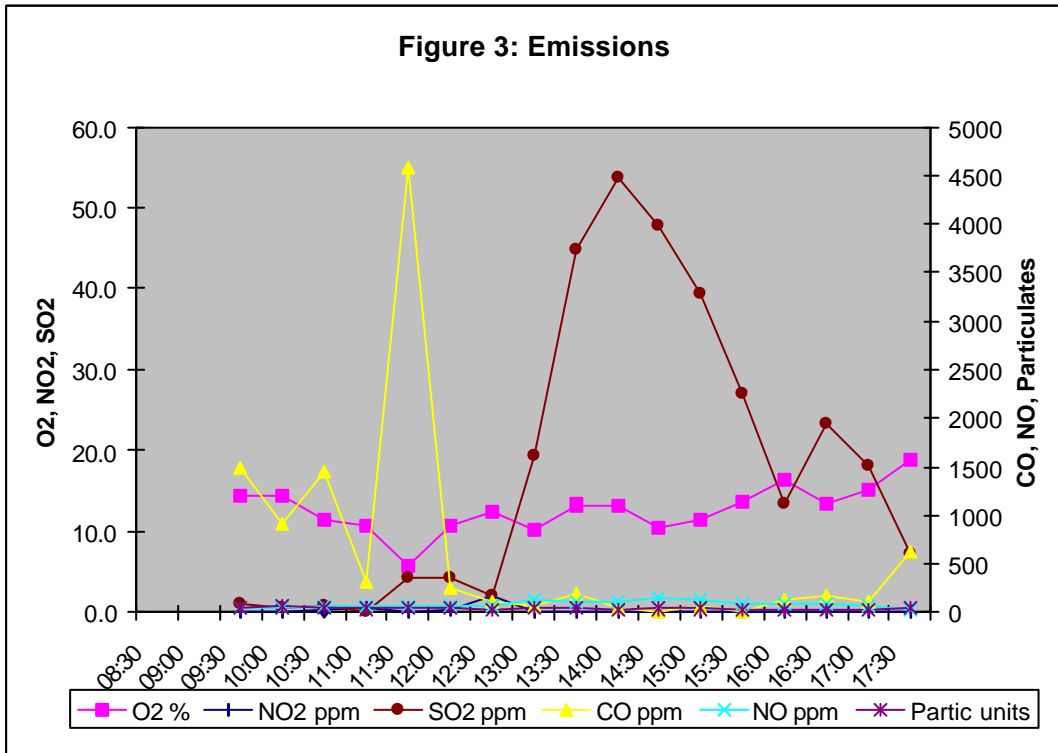
TEST MSW1 Date 09/05/02 Combustion Air

Average air flow in next 30 min			
time	PA Nm3/h	SA Nm3/h	Cool Air Nm3/h
08:30			
09:00	282	134	500
09:30	488	134	500
10:00	464	134	500
10:30	423	134	2724
11:00	517	134	3201
11:30	376	376	376
12:00	463	142	3472
12:30	427	160	3532
13:00	364	287	3538
13:30	325	480	3567
14:00	327	159	3462
14:30	328	134	3435
15:00	295	134	3436
15:30	246	134	3427
16:00	318	134	3413
16:30	293	134	3409
17:00	265	134	3394
17:30	234	134	1631
18:00			
Average	354	184	2907
MSW	347	204	3484
Average MSW +1h	339	190	3469
Last hour MSW	270	134	3432



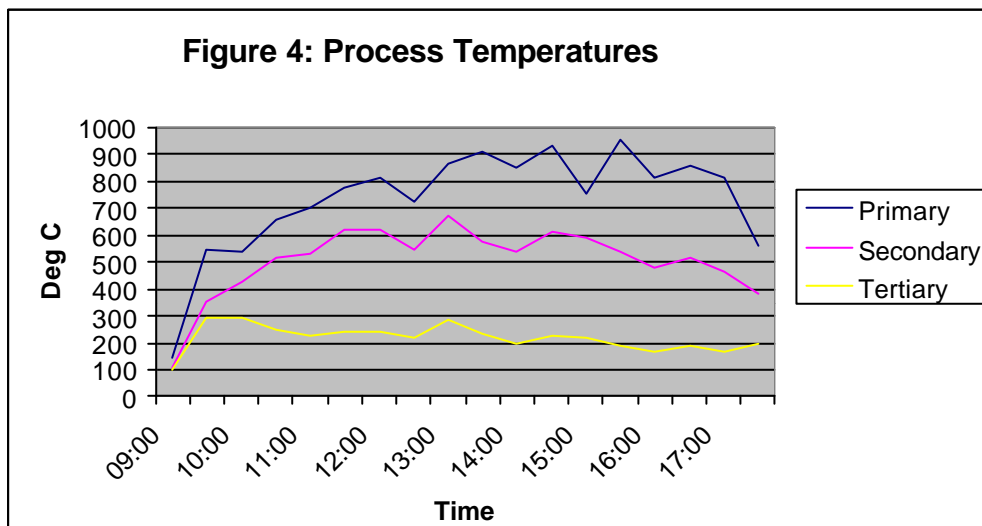
TEST MSW 2 Date 09/05/02 Emissions

Average releases to air next 30 min						
time	O2 %	NO2 ppm	SO2 ppm	CO ppm	NO ppm	Partic units
08:30						
09:00						
09:30	14.4	0	1	1499	55	57
10:00	14.3	0	1	916	54	60
10:30	11.5	0	1	1458	61	41
11:00	10.7	1	0	312	70	38
11:30	5.9	0	4	4587	75	42
12:00	10.6	0	4	257	68	42
12:30	12.6	2	2	114	66	36
13:00	10.3	0	19	63	121	44
13:30	13.3	0	45	200	101	42
14:00	13.1	0	54	45	114	37
14:30	10.5	0	48	7	143	38
15:00	11.5	0	39	60	122	39
15:30	13.7	0	27	5	91	35
16:00	16.3	0	14	124	80	33
16:30	13.3	0	23	164	84	36
17:00	15.2	0	18	117	66	34
17:30	18.9	0	7	624	30	50
18:00	0.0	0	0	0	0	0
Average	12.6	0.2	19.1	565.8	84.1	40.5
MSW	11.9	0.3	29.8	93.9	103.3	39.2
MSW +1h	12.5	0.2	27.5	103.9	99.0	38.3



TEST MSW 2 Date 09/05/02 Temperature Process

Average temperature in next 30 min			
time	Primary	Secondary	Tertiary
09:00	144	111	99
09:30	545	356	296
10:00	538	424	294
10:30	656	517	248
11:00	705	530	226
11:30	777	621	244
12:00	813	620	242
12:30	726	548	218
13:00	864	669	287
13:30	910	575	234
14:00	846	539	198
14:30	931	613	228
15:00	750	593	220
15:30	952	539	189
16:00	813	480	169
16:30	853	515	190
17:00	810	462	166
17:30	563	380	195
18:00			
Average day	733	539	222
Average MSW	860	587	227
Average MSW + 1H			
	867	569	217
Last hour MSW	851	566	205

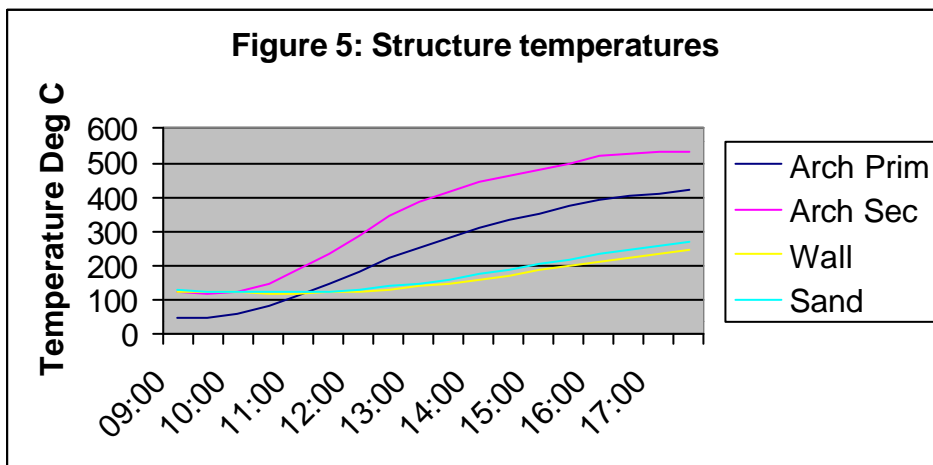


**Temperature
Structure**

TEST MSW 2 Date 09/05/02

Average temperature in next 30 min				
time	Arch Prim	Arch Sec	Wall	Sand
09:00	48	121	125	129
09:30	47	115	123	126
10:00	61	120	121	124
10:30	83	145	119	122
11:00	111	185	118	122
11:30	145	234	120	125
12:00	183	290	123	130
12:30	222	346	129	138
13:00	252	385	138	148
13:30	280	418	148	161
14:00	309	444	160	175
14:30	333	461	173	189
15:00	354	479	185	204
15:30	372	499	198	217
16:00	390	518	210	231
16:30	402	527	222	244
17:00	410	530	235	258
17:30	421	534	246	270
18:00	n/d	n/d	n/d	n/d
Average day	246	353	161	173
Average MSW	288	415	157	170
Average MSW + 1H	310	437	169	184
Last hour MS	363	489	191	211

Temp at Start of burn(9:05)	49	123	126	129
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Discussion

Monitoring data, taken every 30 seconds, was downloaded at the end of each test operation, collated, and presented as half hourly averages in this report. The complete monitoring data set for the test is available separately from ITC.

Gas emissions (O_2 , CO, NO, NO_2 & SO_2) monitoring was carried out using a portable combustion gas analyser (Testo 33) with heated probe located at the exit from the secondary combustion chamber. Combustion and structure temperatures were monitored using K type thermocouples connected to a Grant Squirrel data logger and readout. Particulate monitoring was carried out using an opacity meter (PCME DV400) fitted into the stack. Primary air flow was measured using a hot wire anemometer (Testo 445) while secondary and tertiary combustion air was measured using Pitot tubes connected to electronic manometers.

Total burn time was 7.58 hours including the initial warm up and final burnout using biomass (wood-chip). A total of 1179.9 kg of biomass and 746kg of pre-sorted MSW was used during the test giving average feed rates of 262kg/h for biomass and 298kg/h for MSW. This represents a throughput of 70% of the design maximum continuous rating (mcr) of 425kg/hour.

Average power output on MSW was 895.2kW with a peak of 950kW and a low of 55kW. The average power output is above the theoretical design mcr of 826kW which suggests a high c.v. for the MSW possibly due to the presence of high levels of plastic materials. The peaks and troughs in power output follows those for the MSW feed rate as would be expected as the LCI's power output is directly related to the feed rate of the MSW and is shown in figure 1 on page 3.

Under stable operating conditions the primary, secondary and tertiary (cooling) air were all below the theoretical flow rates for the LCI. The measured flow rate for primary air was $347Nm^3/h$ which is approximately 51% of the theoretical flow rate. At $204Nm^3/h$ secondary air is just over 19.5% of the estimated theoretical flow rate. The average tertiary air flow rate was 3484 which is just over 87% of the theoretical flow rate. To some extent the difference between the theoretical and measured flow rates for primary and secondary air is due to ingress air through the feed chute, cracks and gaps that started to appear in the structure after the initial warm up operations. Also the instrument readings for the secondary air may be inaccurate. Occasional readings taken manually, using a Testo 455 and hand held hot-wire probe, indicated that the flow rate through the secondary duct was at least twice that being measured by the insitue air flow measuring device (pitot tube interfaced with an electronic readout).

Emission levels reported have not been corrected for reference conditions (STP in dry gas containing 11% by volume, dry oxygen). Average emissions of O_2 were 12.5% with a peak of 13.7% and a low of 11.3%. Average CO emission was 215ppm with a peak of 546ppm and a low of 38.4ppm (see table 3 page 5). In the main levels of CO were well above those required from the LCI and are mainly due to the poor combustion conditions experienced and poor operation of the LCI throughout this test. Other gas emissions measured give average NO of 94ppm, NO_2 of 1ppm and SO_2 of 15ppm. which, within the sensitivity of the monitoring equipment, are within

acceptable limits. The average opacity was 45 units 51 and a low of 38.4 units. Visual inspection of the stack emission showed no visible plume at these levels of opacity.

Emission levels reported have not been corrected for reference conditions (STP in dry gas containing 11% by volume, dry oxygen). Average emissions of O₂ was 11.9% with a peak of 13.3 and a low of 10.5. Average CO emission was 94ppm with a peak of 200 and a low of 7 (see table 3 page 5). Generally CO emission levels were below 100ppm and as such acceptable. Other gas emissions measured gave average NO of 103ppm, NO₂ of 0ppm and SO₂ of 30ppm which, taking account of the sensitivity of the monitoring equipment, are within acceptable limits. The average opacity was 39 units with a high of 44 and a low of 37 units. Visual inspections of the stack emission showed no visible plume at this level of opacity.

When operating on MSW an average primary combustion temperature of 860⁰C was achieved which is above the design operating temperature of 850⁰C. The lowest half hourly temperature was 750⁰C and the maximum was 931⁰C (see data on page 7). The lowest temperature occurred during the incineration of last bin of MSW (bin 1.4). The reasons for this dip in combustion temperature is difficult assess but are thought to be due to a combination of poor fuel/air mixing (grate 2 raddle had completely burnt out and was not being used) and high levels of moisture in the waste.

Temperature in the secondary chamber averaged 587⁰C with a peak temperature of 669⁰C and a low of 613⁰C being recorded. With the use of cooling air the temperature of the combustion gas in the tertiary chamber averaged 227⁰C and was kept below 300⁰C throughout the test operation.

At 166kg the residual ash represents 22% of the mass of MSW incinerated of which, 145.75kg was bottom, or over gate, ash and 20.3kg under grate ash. A visual inspection of the ash showed good burnout had occurred and that a large amount of ferrous metal (mainly food cans) with some glass and non-ferrous metals were present. The mass of cans was not measured but it is assumed that they account for a substantial proportion of the final mass of the residuals. Ash analysis from the over grate residuals (3 samples taken) indicate a loss on ignition of 1.1% confirming that good burn out had occurred. Analysis of under gate ash (1 sample taken) shows a higher degree of loss on ignition of 16.55% which would be expected as any un-burnt material falling through the grate would cool quickly and would tend not to burn out adequately. Over all loss on ignition of all the ash is low at 2.99% by mass.

The high combustion temperatures achieved combined with relatively low O₂ and CO emission and good residual ash burnout suggests that good combustion conditions were achieved within the LCI. Low emission of NO and SO₂ indicate that the majority of the MSW had been well sorted (although the high levels of ferrous materials is of concern) confirming the importance of removing non-combustibles and potentially hazardous materials.

Appendix 3 – Test results MSW 3

Test Report Summary

Test: **MSW 3** Date: **16/05/02**

Duration	From	To	Duration	Duration in minutes
Total	08:55	16:45	07:50	470.00
MSW	13:15	16:00	02:45	165.00
MSW + 1h	13:15	17:00	03:45	225.00

Feed	Total kg	per hour kg/h	moisture %	LCV (estimated) kJ/kg
BM	1023.3	136	43.1	10000
MSW	492	197		7000
MSW + 1h	492	141		

Power	BM	BM + MSW	MSW	MSW +1h
kW	363	485	347.87879	255

Combustion Air Input (MSW)	Nm3/h	PA	SA	Tert.Air
MSW		540	177	3439
MSW + 1h		485	201	3462
Last hour MSW		878	139	3536

Emissions	O2 %	NO2 ppm	SO2 ppm	CO ppm	NO ppm	Partic units
MSW	12.7	1	15	219	89	46
MSW +1h	13.2	1	15	218	87	46

Temperature Process	Deg C	Prim Ch	Sec Outl	Tert.Outl
MSW		763	470	187
MSW + 1h		765	483	190
Last hour MSW		777	478	192

Temperature Structure	Deg C	Arch Prim	Arch Sec	Wall	Sand
Start Burn		0	0	0	0
MSW		203	305	112	121
MSW + 1h		227	337	122	132
Last hour MSW		297	409	138	153

Residuals	Mass kg	Ash Total	Under Grate	Over Grate	Quality	Loss on Ign %
		117	22.4	94.6	Over grate	2.98
% of MSW		24	5	19	Under Grate	8.57
					Overall	4.05

Important Notes Log Book, Other Pages 13, 14

Time	Note
12:00	Estimated moisture of dry bins (which were mixed with the 43% moisture material) is 10%.
13:15	Start feed MSW which is noted to be very wet (bin tar were wrong and needed to be corrected)
13:23	T dips below 850deg add dry biomass (this is not noted as BM input)
13:25	Test on CO rining because CO went too high-no reliable reading.
14:00	Added paper&plastic pelets (noted as BM, CV is higher though)
14:15	Other T-dip below 850deg: measures taken: add 0.1m3 BM dry plus P&P pelets
14:25	MSW heap colapses when manually pushed from feed end due to lack of stoking. Fire is very low
14:30	As fire recovers very slowly decide to restart on BM (stop momentarily feed of MSW)
14:35	Start PA fan (installed for emergencies) to blow forced draft air under grates
15:10	Situation improved PA:850 m3/h, Tprim: 940deg, O2~10%, CO~40ppm
15:30	Restart on MSW feed after T prim >850deg for 30min with FD PA (still bin 2.5)
15:50	Stop PA fan back to natural draft
16:00	Finish feeding bin 2.5
17:00	PA fan on for burn-out (MSW stays as a large lump, little break-up to smaller grain size)
17:20	Stop PA, SA fans
Inspection	Little klinker found on gr 2&3, but lots of aerosol cans cupper wire , batteries. Conclude poor sorting. Volume ash:~0.16m3

Important Conclusions

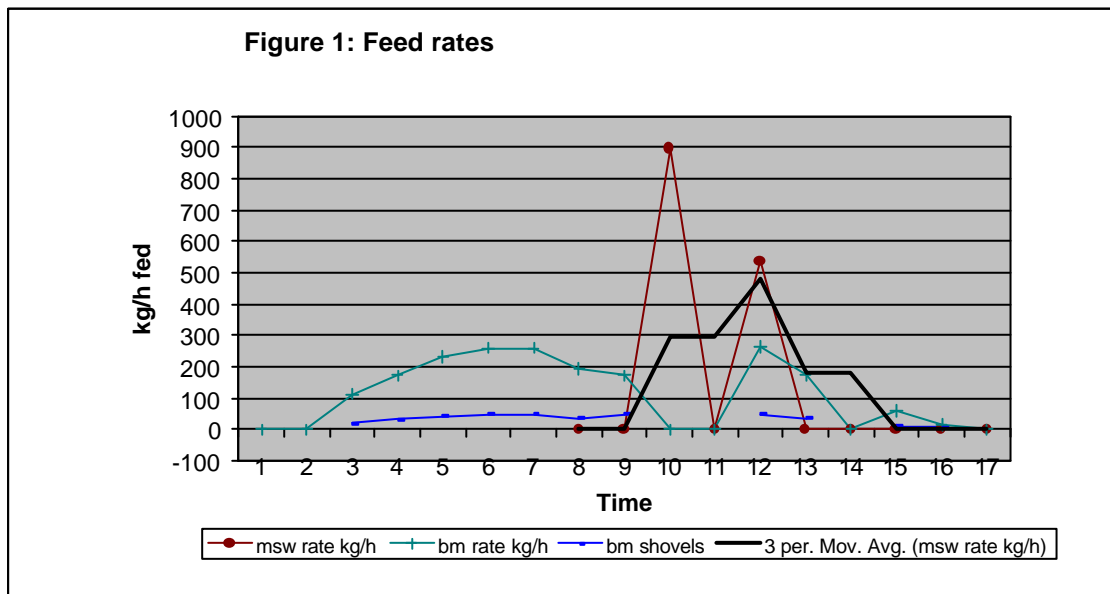
1	Stoking arrangements are not satisfactory
2	Problems with wet MSW
	Difficult to feed BM directly into fire when a T dip occurs - must devise a system were BM can be
3	fed directly onto grate 2.

TEST MSW 3 Date 16/05/02 Waste Feed Rate

time	msw kg	bm kg	bin ID	Dt min	msw rate kg/h	bm rate kg/h	bm shovels	Power o/p (theoretical) kW
08:30		0		30.00		0		0
09:00		0		30.00		0		0
09:30		57		30.00		113	21	315
10:00		86		30.00		173	32	480
10:30		116		30.00		232	43	645
11:00		130		30.00		259	48	720
11:30		130		30.00		259	48	720
12:00		97		30.00	0	194	36	540
12:30		130		45.00	0	173	48	480
13:15	224	0	2.2	15.00	896	0		1742
13:30		0		30.00	0	0		0
14:00	268	132	2.5	30.00	536	265	49	1777
14:30		100		35.00	0	171	37	476
15:05		0		55.00	0	0		0
16:00		30		30.00	0	59	11	165
16:30		16		60.00	0	16	6	45
17:30		0			0	0		0

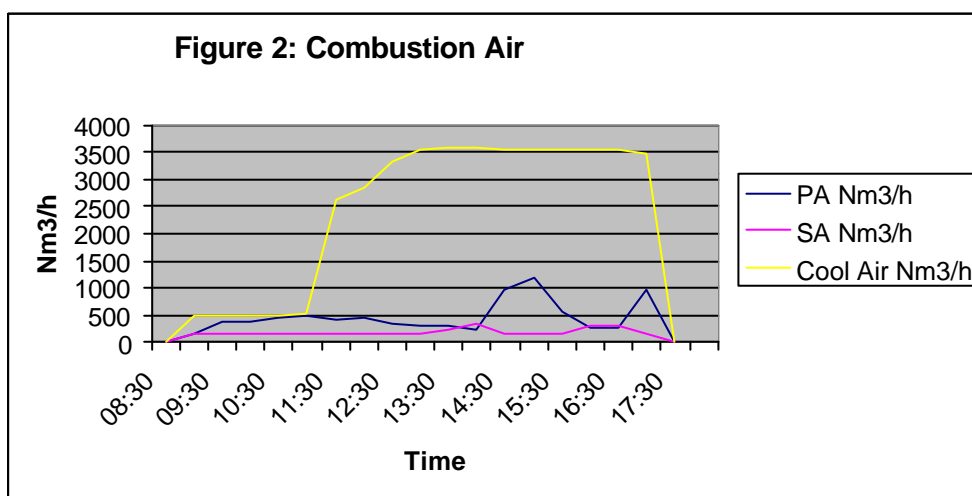
totals	492	1023.3		0	540	1432	1915.457	379
total bm		kg		weight/shovel	2.70			
Total MSW	492	kg	in min	150	Average	197	kg/h	Assumed CV kJ/kg
Total bm	1023.3	kg	in min	450.00	Average	136	kg/h	BM 10000
Total MSW	492		in min	210	Average	141	kg/h	MSW 7000

BM Moist	A	B	C	Average
%	43.1			43.1



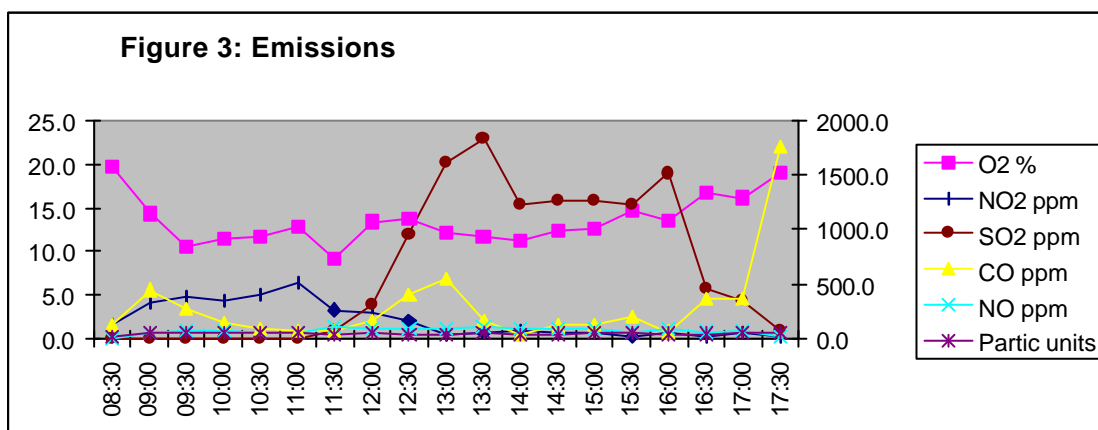
TEST MSW1 Date 16/05/02 Combustion Air

Average air flow in next 30 min			
time	PA Nm3/h	SA Nm3/h	Cool Air Nm3/h
08:30	n/a	n/a	n/a
09:00	152	134	500
09:30	353	134	500
10:00	369	134	500
10:30	458	134	500
11:00	493	134	508
11:30	416	134	2613
12:00	443	134	2860
12:30	330	134	3327
13:00	297	134	3532
13:30	303	239	3593
14:00	234	336	3586
14:30	954	163	3546
15:00	1195	139	3538
15:30	561	139	3533
16:00	277	288	3550
16:30	251	309	3556
17:00	966	149	3487
17:30	n/a	n/a	n/a
18:00	n/a	n/a	n/a
Average	503	180	2815
MSW	540	177	3439
Average MSW +1h	485	201	3462
Last hour MSW	878	139	3536



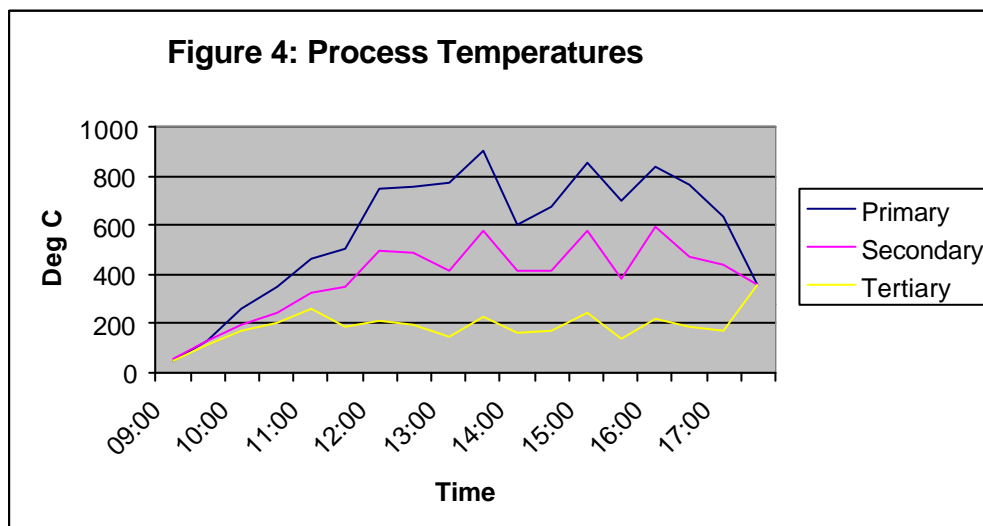
TEST MSW 3 Date 16/05/02 Emissions

Average releases to air next 30 min						
time	O2 %	NO2 ppm	SO2 ppm	CO ppm	NO ppm	Partic units
08:30	19.7	1.5	0.1	124.7	7.7	14.2
09:00	14.3	4.1	0.0	449.2	52.7	52.3
09:30	10.5	4.9	0.0	280.7	78.0	54.2
10:00	11.4	4.3	0.0	143.6	65.1	55.4
10:30	11.8	5.0	0.0	90.9	61.7	55.7
11:00	12.8	6.4	0.0	67.5	48.0	55.0
11:30	9.2	3.3	0.8	65.5	115.7	40.5
12:00	13.4	2.9	3.9	160.1	95.3	51.0
12:30	13.7	2.2	12.0	397.8	99.2	36.6
13:00	12.2	0.5	20.2	546.1	90.8	42.7
13:30	11.6	0.8	23.0	161.6	106.2	50.4
14:00	11.3	0.9	15.5	38.4	84.2	38.4
14:30	12.4	0.7	15.8	120.4	86.8	46.4
15:00	12.6	0.6	15.9	121.0	87.2	46.7
15:30	14.7	0.3	15.3	203.5	62.7	57.5
16:00	13.5	0.7	18.9	63.2	89.8	45.6
16:30	16.8	0.3	5.7	370.8	63.1	44.0
17:00	16.2	0.7	4.4	369.4	68.8	47.6
17:30	19.1	0.3	0.9	1762.0	22.5	61.5
18:00	n/a					
Average	13.3	1.9	9.5	292.6	77.9	48.4
MSW	12.7	1.1	15.2	218.6	89.0	46.2
MSW +1h	13.2	1.0	14.6	218.3	86.5	45.9



TEST MSW 3 Date 16/05/02 Temperature Process

Average temperature in next 30 min			
time	Primary	Secondary	Tertiary
09:00	49	55	48
09:30	133	129	109
10:00	258	197	173
10:30	350	241	203
11:00	468	321	261
11:30	507	353	183
12:00	754	499	209
12:30	757	486	194
13:00	776	413	149
13:30	907	581	229
14:00	602	411	163
14:30	675	415	170
15:00	856	576	245
15:30	697	380	139
16:00	838	597	222
16:30	766	474	183
17:00	637	439	168
17:30	359	359	359
18:00	n/a	n/a	n/a
Average day	577	421	203
Average MSW	763	470	187
Average MSW + 1H	765	483	190
Last hour MSW	777	478	192

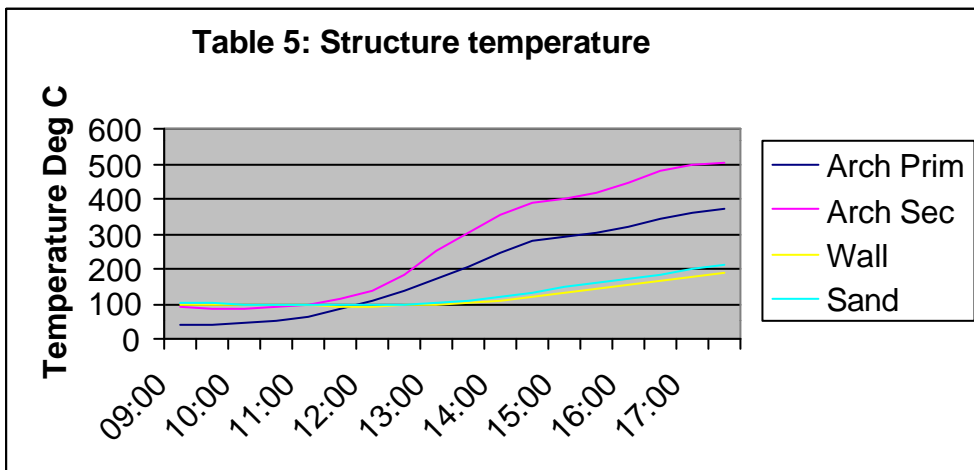


**Temperature
Structure**

TEST MSW 3 Date 16/05/02

Average temperature in next 30 min				
time	Arch Prim	Arch Sec	Wall	Sand
09:00	43	93	100	103
09:30	42	89	98	101
10:00	44	87	97	100
10:30	51	90	95	98
11:00	65	100	94	97
11:30	84	114	94	96
12:00	106	139	94	97
12:30	136	186	95	99
13:00	173	250	98	103
13:30	208	304	103	110
14:00	248	354	111	120
14:30	279	388	121	133
15:00	291	401	132	146
15:30	302	416	144	160
16:00	320	447	155	172
16:30	345	482	167	185
17:00	361	499	179	199
17:30	371	502	190	211
18:00	n/a	n/a	n/a	n/a
Average day	193	274	120	129
Average MSW	203	305	112	121
Average MSW + 1H	227	337	122	132
Last hour MS	297	409	138	153

Temp at Start of burn(9:05)				
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TEST MSW 3

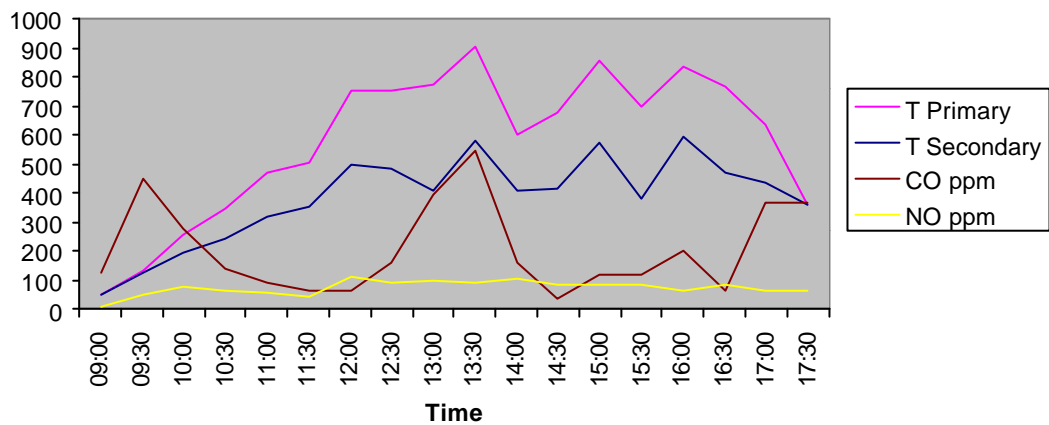
16/05/02

Correlations

T Process v Emissions

time	T Primary	T Seconda	CO ppm	NO ppm	Partic units	O2 %
09:00	49	55	124.7	7.7	14.2	19.7
09:30	133	129	449.2	52.7	52.3	14.3
10:00	258	197	280.7	78.0	54.2	10.5
10:30	350	241	143.6	65.1	55.4	11.4
11:00	468	321	90.9	61.7	55.7	11.8
11:30	507	353	67.5	48.0	55.0	12.8
12:00	754	499	65.5	115.7	40.5	9.2
12:30	757	486	160.1	95.3	51.0	13.4
13:00	776	413	397.8	99.2	36.6	13.7
13:30	907	581	546.1	90.8	42.7	12.2
14:00	602	411	161.6	106.2	50.4	11.6
14:30	675	415	38.4	84.2	38.4	11.3
15:00	856	576	120.4	86.8	46.4	12.4
15:30	697	380	121.0	87.2	46.7	12.6
16:00	838	597	203.5	62.7	57.5	14.7
16:30	766	474	63.2	89.8	45.6	13.5
17:00	637	439	370.8	63.1	44.0	16.8
17:30	359	359	369.4	68.8	47.6	16.2
18:00	n/a	n/a	1762.0	22.5	61.5	19.1

Figure 6: Correlation Temp/Emissions



Discussion

Monitoring data, taken every 30 seconds, was downloaded at the end of each test operation, collated, and presented as half hourly averages in this report. The complete monitoring data set for the test is available separately from ITC.

Gas emissions (O_2 , CO, NO, NO_2 & SO_2) monitoring was carried out using a portable combustion gas analyser (Testo 33) with heated probe located at the exit from the secondary combustion chamber. Combustion and structure temperatures were monitored using K type thermocouples connected to a Grant Squirrel data logger and readout. Particulate monitoring was carried out using an opacity meter (PCME DV400) fitted into the stack. Primary airflow was measured using a hot wire anemometer (Testo 445) while secondary and tertiary combustion air was measured using Pitot tubes connected to electronic manometers.

The total burn time was 7.83 hours including the initial warm up and final burnout using biomass (wood-chip). A total of 1179.9 kg of biomass and 746kg of pre-sorted MSW was used during the test giving average feed rates of 262kg/h for biomass and 298kg/h for MSW. This represents a throughput of 70% of the design maximum continuous rating (mcr) of 425kg/hour.

Average power output on MSW was 895.2kW with a peak of 950kW and a low of 55kW. The average power output is above the theoretical design mcr of 826kW, which suggests that the MSW had relatively a high calorific value (c.v.), which was probably due to a high level of plastic materials present in the waste. The peaks and troughs in power output follows those for the MSW feed rate as would be expected as the LCI's power output is directly related to the feed rate of the MSW and is shown in figure 1 on page 3.

Under stable operating conditions the primary, secondary and tertiary (cooling) air were all below the theoretical flow rates for the LCI. The measured flow rate for primary air was 347Nm³/h, which is approximately 51% of the theoretical flow rate. At 204Nm³/h secondary air is just over 19.5% of the estimated theoretical flow rate. The average tertiary airflow rate was 3484, which is just over 87% of the theoretical flow rate. To some extent the difference between the theoretical and measured flow rates for primary and secondary air is due to ingress air through the feed chute, cracks and gaps that started to appear in the structure after the initial warm up operations. Also the instrument readings for the secondary air may be inaccurate. Occasional readings taken manually, using a Testo 455 and hand held hot-wire probe, indicated that the flow rate through the secondary duct was at least twice that being measured by the in situ Pitot tube.

Average emissions of O_2 were 11.9% with a peak of 13.3% and a low of 10.5%. Average CO emission was 94ppm with a peak of 200 and a low of 7 (see table 3 page 5). Other gas emissions measured give average NO of 103ppm, NO_2 of 0ppm and SO_2 of 30ppm. The average opacity was 39 units with a high of 44 and a low of 37 units. Visual inspections of the stack emission showed no visible plume at this level of opacity.

When operating on MSW an average primary combustion temperature of 860⁰C was achieved which is above the design operating temperature of 850⁰C. The lowest half hourly temperature was 750⁰C and the maximum was 931⁰C (see data on page 7). The lowest temperature occurred during the incineration of last bin of MSW (bin 1.4). The reasons for this dip in combustion temperature is difficult assess but are thought to be due to a combination of poor fuel/air mixing (grate 2 raddle had completely burnt out and was not being used) and high levels of moisture in the waste.

Temperature in the secondary chamber averaged 587⁰C with a peak temperature of 669⁰C and a low of 613⁰C being recorded. With the use of cooling air the temperature of the combustion gas in the tertiary chamber averaged 227⁰C and was kept below 300⁰C throughout the test operation.

At 166kg the residual ash represents 22% of the mass of MSW incinerated of which, 145.75kg was bottom, or over gate, ash and 20.3kg under grate ash. A visual inspection of the ash showed good burnout had occurred and that a large amount of ferrous metal (mainly food cans) with some glass and non-ferrous metals were present. The mass of cans was not measured but it is assumed that they account for a substantial proportion of the final mass of the residuals. Ash analysis from the over grate residuals (3 samples taken) indicate a loss on ignition of 1.1% confirming that good burn out had occurred. Analysis of under grate ash (1 sample taken) shows a higher degree of loss on ignition of 16.55% which would be expected as any un-burnt material falling through the grate would cool quickly and would tend not to burn out adequately. Over all loss on ignition of all the ash is low at 2.99% by mass.

The high combustion temperatures achieved combined with relatively low O₂ and CO emission and good residual ash burnout suggests that good combustion conditions were achieved within the LCI. Low emission of NO and SO₂ indicate that the majority of the MSW had been well sorted (although the high levels of ferrous materials is of concern) confirming the importance of removing non-combustibles and potentially hazardous materials.

Appendix 4 – Test results MSW 4

Test Report Summary

Test: **MSW4** Date: **30/05/02**

Duration	From	To	Duration	Duration in minutes
Total	09:30	15:50	06:20	380.00
MSW	12:40	15:10	02:30	150.00
MSW + 1h	12:40	16:10	03:30	210.00

Feed	Total kg	per hour kg/h	moisture %	LCV (estimated) kJ/kg
BM	1023.3	157	32.45	13000
MSW	411	206		7000
MSW + 1h	411	137		

Power	BM	BM + MSW	MSW	MSW +1h
kW	583	710	319.66667	228

Combustion Air Input (MSW)	Nm3/h	PA	SA	Tert.Air
MSW		360	333	3053
MSW + 1h		365	321	3006
Last hour MSW		637	268	3026

Emissions	O2 %	NO2 ppm	SO2 ppm	CO ppm	NO ppm	Partic units
MSW	12.5	1	15	215	94	45
MSW +1h	12.8	1	16	197	90	47

Temperature Process	Deg C	Prim Ch	Sec Outl	Tert.Outl
MSW		761	483	194
MSW + 1h		792	514	203
Last hour MSW		766	495	208

Temperature Structure	Deg C	Arch Prim	Arch Sec	Wall	Sand
Start Burn		42.5	90.5	99	102
MSW		206	289	108	115
MSW + 1h		215	300	115	123
Last hour MSW		285	395	127	139

Residuals	Mass	Ash Total	Under Grate	Over Grate	Quality	Loss on Ign %
kg		94		94	Over grate	3.13
% of MSW		23	0	23	Under Grate	9.79
					Overall	3.13

Important Notes Log Book, Other Pages 17, 18

Time	Note
Note	This is first run with agitator on grate 2 and new radlle on grate 3
09:30	Start fire
10:10	Furthest elbow agitator gets red hot
11:20	Elbow agitator is 530 deg at hottest point
11:36	Average air vel across agitator inlet=2.3m/s corresponding to (2.3x8.66x10-3) 72m3/h with a negative pressure of -4.6mm water column
12:00	Problem with conveyor lifting system, need to stall MSW feed
12:40	Start feeding bin 1.4 (110kg)
12:55	Finishe bin 1.4, start feed bin 1.12 (178kg), dripping wet (estimate of 50% water content)
13:30	Problems with MSW wetness Tprim down to 600-700deg interrupt MSW feed back to BM
13:45	Rigged agitator on PA fan, reduced flow to ~6m/s (~180m3/h)
13:59	Resume MSW feed after BM only
14:10	Mixed feeding MSW and BM (3x6shovels BM in 9 minutes)
14:20	Finish bin 1.12 with 18 shovels BM
14:23	Start bin 1.3, moderatly wet (estimate CV at 7000kj/kg)
14:32	Start on BM again as T goes>600 deg
14:40	T prim still low --> rig up PA fan again and use FD PA under grate
15:10	Finish bin 1.3, considering problems we end this test run
15:25	Stopped PA fan
15:30	Re start PA fan on under grate, comb chamber under +ve pressure smoke leaks out agitator
15:50	Finish BM feed, stoking down
16:25	Last full stoke with problems (ash fusion?)
16:30	Stop SA fan: agitator is useless as it sits on top of bed of ash pointing upwards

Important Conclusions

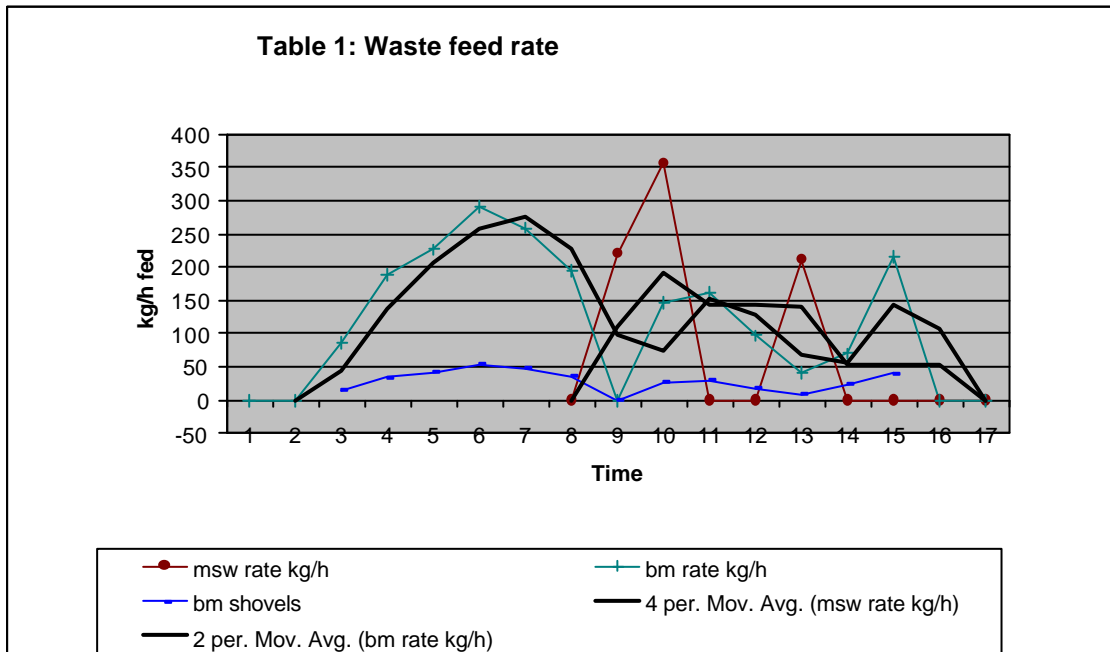
1	Agitating is still highly problematic, as we cannot break up bed especially with very wet MSW
2	
3	

TEST MSW4 Date 30/05/02 Waste Feed Rate

time	msw kg	bm kg	bin ID	Dt min	msw rate kg/h	bm rate kg/h	bm shovels	Power o/p (theoretical) kW
08:30		0		30.00		0		0
09:00		0		30.00		0		0
09:30		43		30.00		86	16	312
10:00		95		30.00		189	35	683
10:30		113		30.00		227	42	819
11:00		146		30.00		292	54	1053
11:30		130		30.00		259	48	936
12:00		97		30.00	0	194	36	702
12:30	110	0	1.4	30.00	220	0	0	428
13:00	178	73	1.12	30.00	356	146	27	1219
13:30		81		30.00	0	162	30	585
14:00		49		30.00	0	97	18	351
14:30	123	24	1.3	35.00	211	42	9	560
15:05		65		55.00	0	71	24	255
16:00		108		30.00	0	216	40	780
16:30		0		60.00	0	0		0
17:30		0			0	0		0

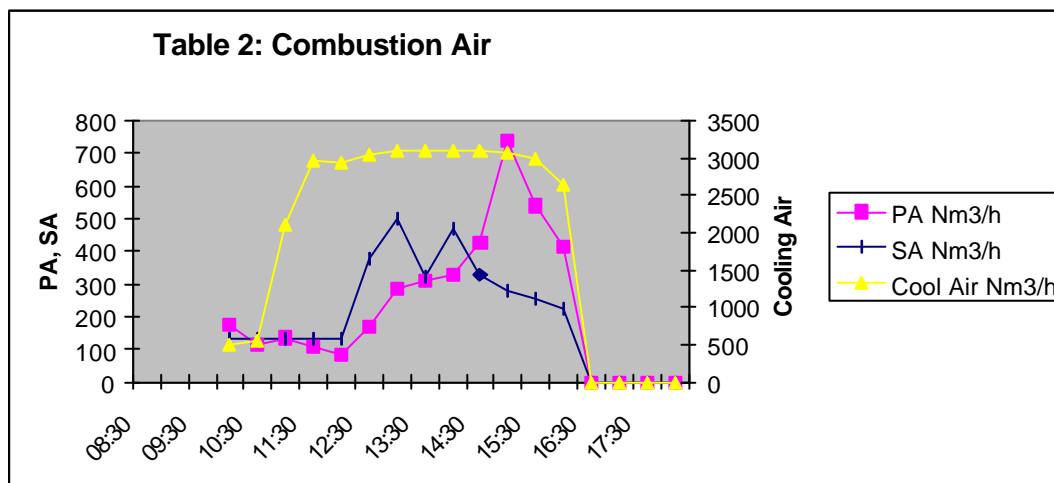
totals	411	1023.3		0	540	786.8571	1980.748	379
total bm	411 kg		weight/shovel		2.70			
Total MSW	411 kg		in min	120	Average	206 kg/h	BM	13000
Total bm	1023.3 kg		in min	390.00	Average	157 kg/h	MSW	7000
Total MSW + 1h			in min	180	Average	137 kg/h		

BM Moist	A	B	C	Average
%	28.2	36.7		32.45



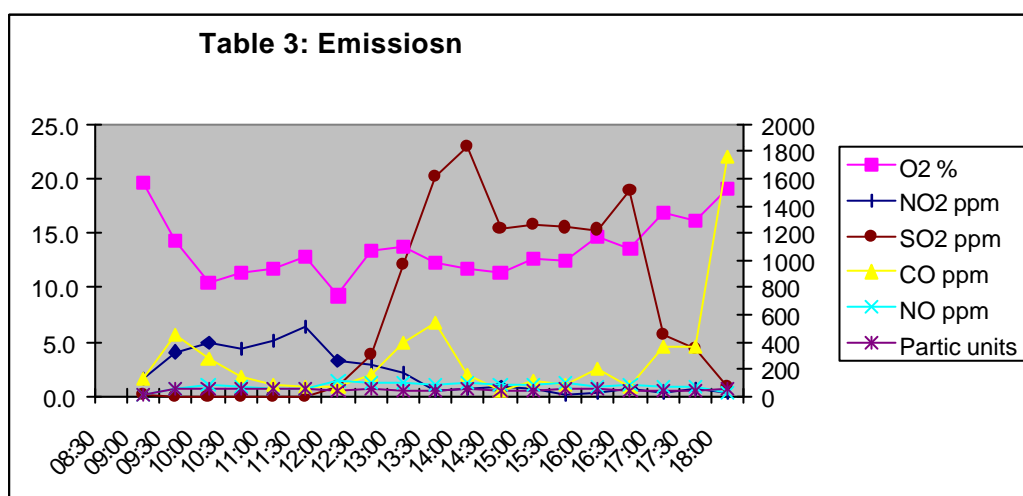
TEST MSW4 Date 30/05/02 Combustion Air

Average air flow in next 30 min			
time	PA Nm3/h	SA Nm3/h	Cool Air Nm3/h
08:30			
09:00			
09:30			
10:00	174	134	501
10:30	117	134	551
11:00	136	134	2113
11:30	109	134	2953
12:00	83	134	2941
12:30	168	377	3042
13:00	284	498	3085
13:30	312	324	3097
14:00	330	467	3099
14:30	424	326	3104
15:00	735	280	3063
15:30	539	257	2989
16:00	412	227	2630
16:30	n/a	n/a	n/a
17:00	n/a	n/a	n/a
17:30	n/a	n/a	n/a
18:00	n/a	n/a	n/a
Average	294	263	2552
MSW	360	333	3053
Average MSW +1h	365	321	3006
Last hour MSW	637	268	3026



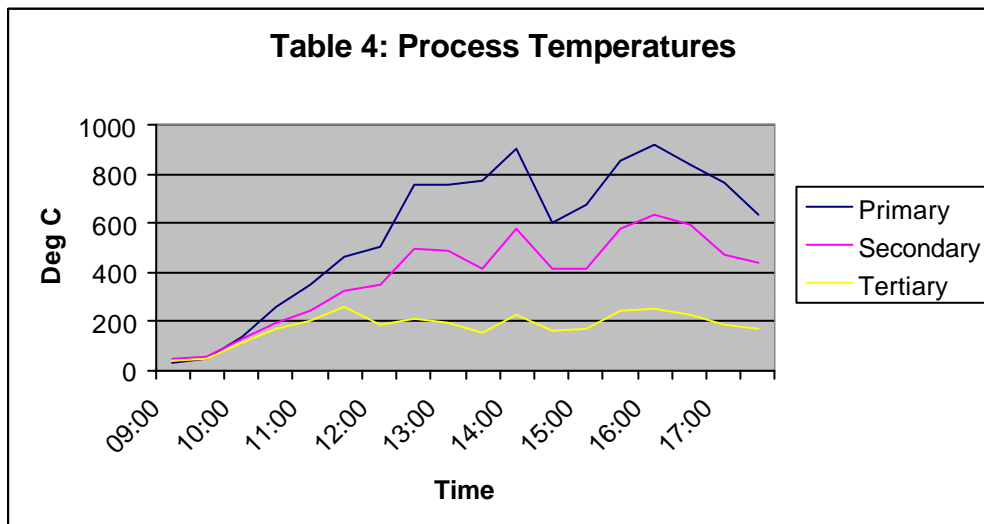
TEST MSW4 Date 30/05/02 Emissions

Average releases to air next 30 min						
time	O2 %	NO2 ppm	SO2 ppm	CO ppm	NO ppm	Partic units
08:30						
09:00	19.7	1.5	0.1	124.7	7.7	14.2
09:30	14.3	4.1	0.0	449.2	52.7	52.3
10:00	10.5	4.9	0.0	280.7	78.0	54.2
10:30	11.4	4.3	0.0	143.6	65.1	55.4
11:00	11.8	5.0	0.0	90.9	61.7	55.7
11:30	12.8	6.4	0.0	67.5	48.0	55.0
12:00	9.2	3.3	0.8	65.5	115.7	40.5
12:30	13.4	2.9	3.9	160.1	95.3	51.0
13:00	13.7	2.2	12.0	397.8	99.2	36.6
13:30	12.2	0.5	20.2	546.1	90.8	42.7
14:00	11.6	0.8	23.0	161.6	106.2	50.4
14:30	11.3	0.9	15.5	38.4	84.2	38.4
15:00	12.6	0.7	15.8	120.4	86.8	46.4
15:30	12.4	0.1	15.5	78.7	93.2	50.7
16:00	14.7	0.3	15.3	203.5	62.7	57.5
16:30	13.5	0.7	18.9	63.2	89.8	45.6
17:00	16.8	0.3	5.7	370.8	63.1	44.0
17:30	16.2	0.7	4.4	369.4	68.8	47.6
18:00	19.1	0.3	0.9	1762.0	22.5	61.5
Average	12.8	2.1	9.4	197.4	81.8	48.2
MSW	12.5	1.1	15.1	214.7	93.6	45.2
MSW +1h	12.8	1.0	15.6	196.6	89.8	46.6



TEST MSW4 Date 30/05/02 Temperature Process

Average temperature in next 30 min			
time	Primary	Secondary	Tertiary
09:00	31	43	40
09:30	49	55	48
10:00	133	129	109
10:30	258	197	173
11:00	350	241	203
11:30	468	321	261
12:00	507	353	183
12:30	754	499	209
13:00	757	486	194
13:30	776	413	149
14:00	907	581	229
14:30	602	411	163
15:00	675	415	170
15:30	856	576	245
16:00	923	635	254
16:30	838	597	222
17:00	766	474	183
17:30	637	439	168
18:00	n/a	n/a	n/a
Average day	572	423	195
Average MSW	761	483	194
Average MSW + 1H	792	514	203
Last hour MSW	766	495	208

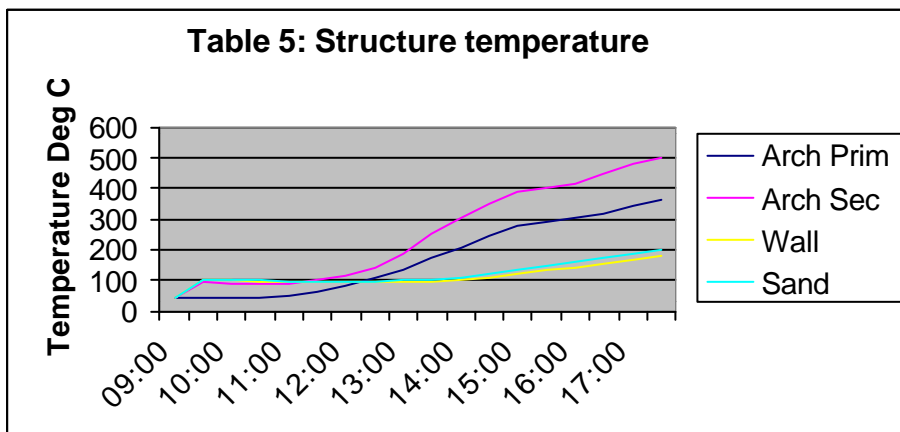


**Temperature
Structure**

TEST MSW4 Date 30/05/02

Average temperature in next 30 min				
time	Arch Prim	Arch Sec	Wall	Sand
09:00	44	44	44	44
09:30	43	93	100	103
10:00	42	89	98	101
10:30	44	87	97	100
11:00	51	90	95	98
11:30	65	100	94	97
12:00	84	114	94	96
12:30	106	139	94	97
13:00	136	186	95	99
13:30	173	250	98	103
14:00	208	304	103	110
14:30	248	354	111	120
15:00	279	388	121	133
15:30	291	401	132	146
16:00	302	416	144	160
16:30	320	447	155	172
17:00	345	482	167	185
17:30	361	499	179	199
18:00	n/a	n/a	n/a	n/a
Average day	175	249	112	120
Average MSW	206	289	108	115
Average MSW + 1H	215	300	115	123
Last hour MS	285	395	127	139

Temp at Start of burn(9:30)	43	91	99	102
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Discussion

Monitoring data, taken every 30 seconds, was downloaded at the end of each test operation, collated, and presented as half hourly averages in this report. The complete monitoring data set for the test is available separately from ITC.

Gas emissions (O_2 , CO , NO , NO_2 & SO_2) monitoring was carried out using a portable combustion gas analyser (Testo 33) with heated probe located at the exit from the secondary combustion chamber. Combustion and structure temperatures were monitored using K type thermocouples connected to a Grant Squirrel data logger and electronic readout. Particulate monitoring was carried out using an opacity meter (PCME DV400) fitted into the stack. Primary airflow was measured using a hot wire anemometer (Testo 445) while secondary and tertiary combustion air was measured using pitot tubes connected to electronic manometers.

Total burn time was 6.33 hours including the initial warm up and final burnout using biomass (wood-chip). A total of 1023.3 kg of biomass and 411kg of pre-sorted MSW was used during the test giving average feed rates of 157kg/h for biomass and 206kg/h for MSW. This represents a MSW throughput of 48.5% of the design maximum continuous rating (mcr) of 425kg/hour. It proved very difficult to maintain good combustion conditions within the primary chamber during operation on MSW especially MSW loads 2 and 3. This was due primarily to very wet MSW (~ 50% m.c.) in the second load used (bin 1.12) combined with over feeding and poor stoking technique (using the new agitator) which at times almost caused combustion to stop.

To try and improve air/fuel mixing the PA fan was rigged to the agitator air inlet duct. This resulted in very intense, though localised, combustion leading to high levels of clinker forming on grate 2. The third, and final, load of MSW (bin 1.3) was also fairly wet which made it difficult maintain good combustion conditions. Throughout the MSW tests on loads 2 and 3 biomass had to be used to support combustion and on a couple of occasions used exclusively until good combustion conditions were re-established.

Average power output on MSW was 319.6kW, which is well below the theoretical design mcr of 826kW. This output is based on the estimated c.v. for the MSW and the average hourly feed rate. However, biomass was used as a support fuel when incinerating MSW loads 2 and 3 and so increasing the c.v. of the feedstock resulting in higher actual power outputs than would be the case if only MSW had been used (see Table 1 page 3).

Under stable operating conditions the primary, secondary and tertiary (cooling) air were all below the theoretical flow rates for the LCI. The measured flow rate for primary air was $360Nm^3/h$, which is approximately 55% of the theoretical flow rate. At $333Nm^3/h$ secondary air is just over 32% of the estimated theoretical flow rate. The average tertiary airflow rate was $3053Nm^3/h$, just over 76% of the theoretical flow rate. This confirms the results of the three previous tests that suggest that calculated airflow rates were far higher than those measured. However, these results for air flow need to be viewed with some caution as a large amount of biomass was needed to support MSW combustion (biomass requires less air than MSW) and, as with the previous tests, ingress air through the feed chute, cracks and gaps in the

structure would also contribute to reducing the amount of (measured) ducted air required. Also as reported for the previous three tests the instrument readings for the secondary air may be inaccurate. Occasional readings taken manually, using a Testo 455 and hand held hot-wire probe, indicated that the flow rate through the secondary duct was at least twice that being measured by the insitue Pitot tube.

Emission levels reported have not been corrected for reference conditions (STP in dry gas containing 11% by volume, dry oxygen). Average emissions of O₂ were 12.5% with a peak of 13.7% and a low of 11.3%. Average CO emission was 215ppm with a peak of 546ppm and a low of 38.4ppm (see table 3 page 5). In the main levels of CO were well above those required from the LCI and are mainly due to the poor combustion conditions experienced and poor operation of the LCI throughout this test. Other gas emissions measured give average NO of 94ppm, NO₂ of 1ppm and SO₂ of 15ppm. which, within the sensitivity of the monitoring equipment, are within acceptable limits. The average opacity was 45 units 51 and a low of 38.4 units. Visual inspection of the stack emission showed no visible plume at these levels of opacity.

Both the primary and secondary combustion temperatures were low compared with previous tests. The primary combustion temperature stayed below 850⁰C (minimum required operating temperature) throughout most of the test when using MSW although a peak of 907⁰C was achieved (see data on page 6). Low combustion temperatures are to be expected considering the problems encountered with wet MSW and inadequate operation of the LCI.

At 94kg the residual ash represents 23% of the mass of MSW incinerated. A visual inspection of the ash showed good burnout had occurred which was not expected due to the poor combustion conditions that occurred. Therefore it is assumed that the burnout grate works well even if full primary and secondary combustions conditions are not achieved. Ash analysis from the over grate residuals (3 samples taken) indicate a loss on ignition of 3.13% confirming that good burn out had occurred. Analysis of under gate ash (1 sample taken) shows a higher degree of loss on ignition of 9.79% which would be expected as any un-burnt material falling through the grate would cool quickly and would tend not to burn out adequately. Over all loss on ignition of all the ash is low at 3.13 by mass.

The poor combustion conditions of low temperature, relatively high O₂ and very high CO emission are probably due to poor quality MSW (i.e. wet) and inadequate operation of the LCI. Improvements to MSW pre-sorting and storage are required to reduce the amount of non-combustibles materials present and ensure drier feedstock. Operation of the agitator proved problematical but it was the first time it had been used and further experimentation, during future tests should bring improvements in operating technique.

Appendix 5 – Test results MSW 5

Test Report Summary

Test: **MSW5** Date: **13/06/02**

Duration	From	To	Duration	Duration in minutes
Total	09:30	16:50	07:20	440.00
MSW	11:40	15:15	03:35	215.00
MSW + 1h	11:40	16:15	04:35	275.00

Feed	Total kg	per hour kg/h	moisture %	LCV (estimated) kJ/kg
BM	723.6	193	32.15	13000
MSW	917	256		7500
MSW + 1h	411	200		

Power (average)	BM	BM + MSW	MSW	MSW +1h
kW	356	617	533	417

Combustion Air Input (MSW)	Nm3/h	PA	SA	Tert.Air
MSW		270	257	3413
MSW + 1h		252	241	3411
Last hour MSW		151	176	3403

Emissions	O2 %	NO2 ppm	SO2 ppm	CO ppm	NO ppm	Partic units
MSW	13.5	0	2	289	109	56
MSW +1h	13.5	0	3	245	104	57

Temperature Process	Deg C	Prim Ch	Sec Outl	Tert.Outl
MSW		842	498	204
MSW + 1h		844	489	199
Last hour M		713	447	181

Temperature Structure	Deg C	Arch Prim	Arch Sec	Wall	Sand
Start Burn		60	78.5	104	109.5
MSW		307	290	118	134
MSW + 1h		336	311	127	145
Last hour M		421	372	142	164

Residuals	Mass	Ash Total	Under Grate	Over Grate	Quality	Loss on Ign %
	kg	148.9	21.3	127.6	Over grate	3.37
	% of MSW	16	2	14	Under Grate	5.78
					Overall	3.71

Important Notes Log Book, Other Pages 20-22

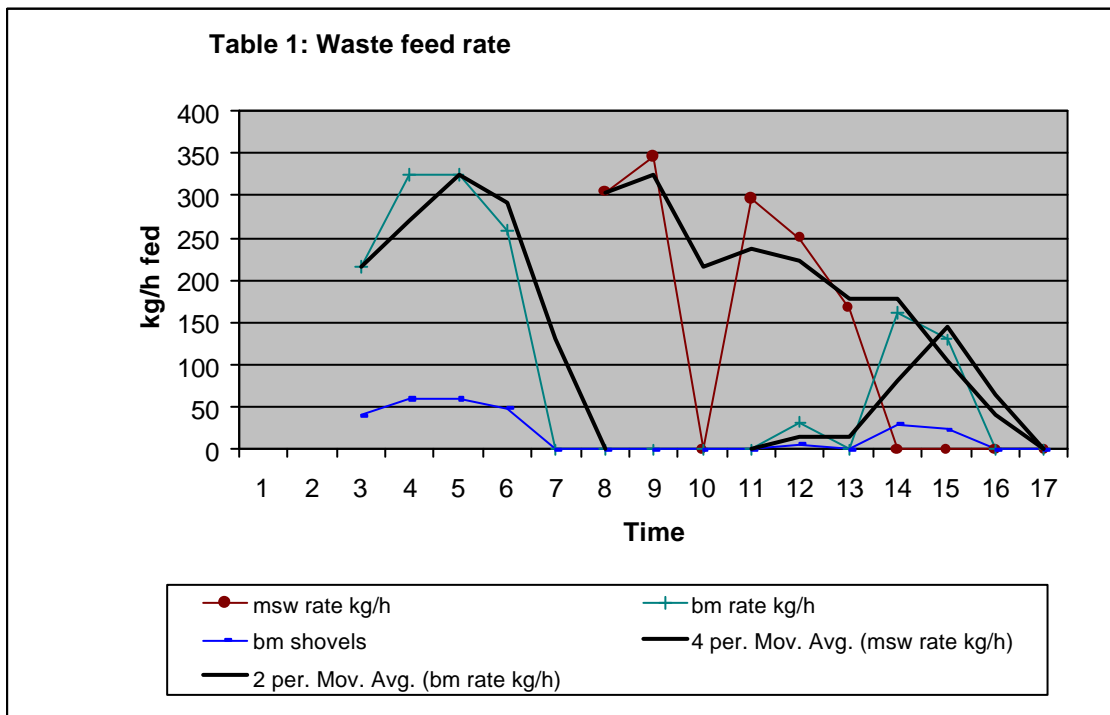
Time	Note
09:30	Ignition with cracle with diesel
10:30	After problems with transformer Testo445 (PA) finally working
10:35	SA fan on and tertiary air opening
10:59	Elbow temperature agitator=480 dg C
10:55	Cooling air damper -->35deg (3300m3/h)
11:30	SA damper -->20deg (280m3/h)
11:40	Start feeding bin 1.1 (152kg), feeding consistantly with MSW stopper is difficult
12:10	Start feeding bin 1.11 (152kg)
12:47	Agitate 1x/min 10-20 short jerks, rattle less often. This gives well dosed fire
12:48	Start bin 1.2 (173kg)
12:58	Reduced SA 20 deg (240m3/h) after it was increased at 12:28 to ~400m3/h
13:16	PA configuration: 90/90/50/5 deg (AA01/02/03/04) (350m3/h), fire on grate 3, SA 230m3/h
13:30	Start bin 1.5 (148kg)
13:45	PA configuration: 90/90/55/5 deg (AA01/02/03/04) (260m3/h), fire on grate 3, SA 20 deg 230m3/h, agitate 20 jerks/min (in 10sec), rattle 2x/min. The process is in a steady state condition
13:55	Start bin 1.15: an increase in SA is immediately reversed as CO goes up (quenching)
14:05	Comparative measurement SA: Pitot:231m3/h, Hot Bulb Anemometer (HBA) 362m3/h, damper position=17 deg
14:19	Reduce SA to ~200m3/h (pitot)
14:23	Start bin 1.14 (167kg). Very wet, containing large quantities of garden waste (from sort 2). All
14:39	PA configuration: 90/90/50/50 deg (AA01/02/03/04); the fire is low now. This shows clearly, that if the waste is not sufficiently dried on grate 1, combustion on grate 1 is poor as the waste does not brake up into smaller particles. Find also that precise lower feeding rates are difficult to control.
14:43	Fire starts to recover
15:10	Overfilled oven. Waste overhanging grate 2in solid lump-slowly breaking up thanks to mad agitation

TEST MSW5 Date 13/06/02 Waste Feed Rate

time	msw kg	bm kg	bin ID	Dt min	msw rate kg/h	bm rate kg/h	bm shovels	Power o/p (theoretical) kW
08:30		0		30.00				0
09:00		0		30.00				0
09:30		108		30.00		216	40	780
10:00		162		30.00		324	60	1170
10:30		162		30.00		324	60	1170
11:00		130		30.00		259	48	936
11:30	152	0	1.1	30.00		0	0	0
12:00	152	0	1.11	30.00	304	0	0	633
12:30	173	0	1.2	30.00	346	0	0	721
13:00		0		30.00	0	0	0	0
13:30	148	0	1.5	30.00	296	0	0	617
14:00	125	16	1.15	30.00	250	32	6	638
14:30	167	0	1.14	60.00	167	0	0	348
15:30		81		30.00	0	162	30	585
16:00		65		30.00	0	130	24	468
16:30		0		60.00	0	0	0	0
17:30		0			0	0	0	0

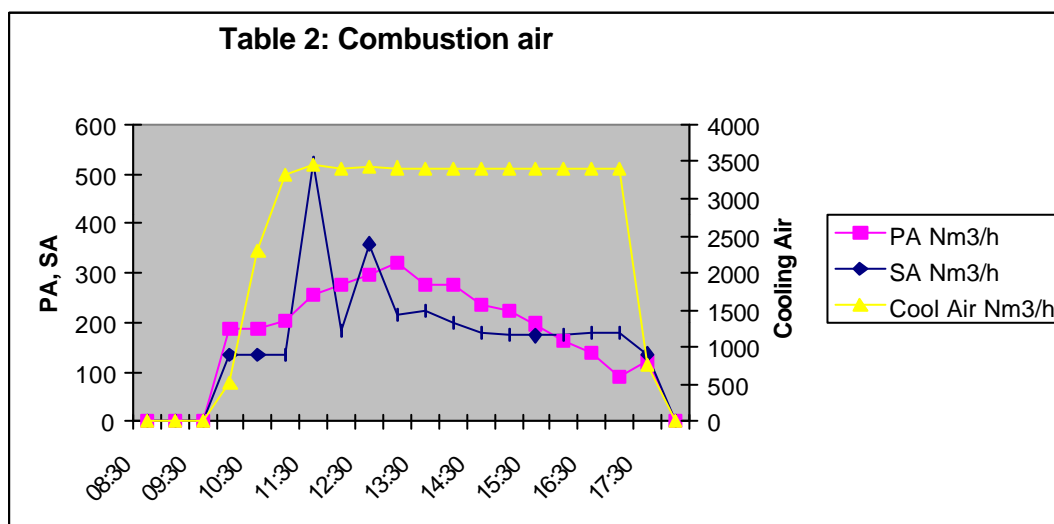
totals	917	723.6		0	540	1363	1447.2	268
total bm	411 kg		weight/shovel		2.70			
Assumed CV kJ/kg								
Total MSW	917 kg		in min	215	Average	256 kg/h	BM	13000
Total bm	723.6 kg		in min	225.00	Average	193 kg/h	MSW	7500
Total MSW	917		in min	275	Average	200 kg/h		

BM Moist	A	B	C	Average
%	21.4	42.9		32.15



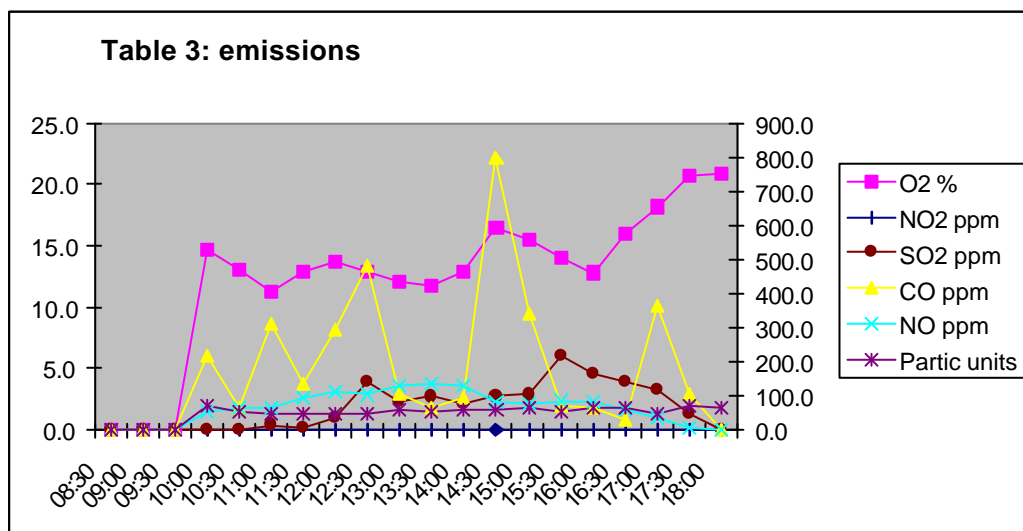
TEST MSW5 Date 13/06/02 Combustion Air

Average air flow in next 30 min			
time	PA Nm3/h	SA Nm3/h	Cool Air Nm3/h
08:30	n/m	n/m	n/m
09:00	n/m	n/m	n/m
09:30	n/m	n/m	n/m
10:00	189	134	511
10:30	186	134	2289
11:00	204	134	3332
11:30	255	523	3448
12:00	275	183	3399
12:30	296	359	3425
13:00	320	215	3416
13:30	277	223	3412
14:00	277	199	3402
14:30	235	179	3398
15:00	225	177	3406
15:30	197	173	3401
16:00	164	175	3403
16:30	139	177	3404
17:00	91	178	3405
17:30	121	137	753
18:00	0	0	0
Average	216	206	2988
MSW	270	257	3413
Average MSW +1h	252	241	3411
Last hour MSW	151	176	3403



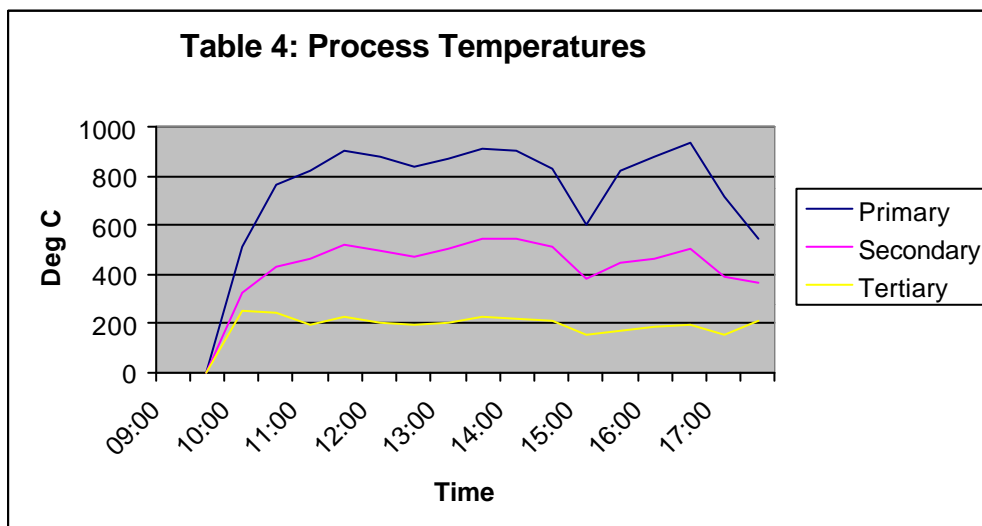
TEST MSW5 Date 13/06/02 Emissions

Average releases to air next 30 min						
time	O2 %	NO2 ppm	SO2 ppm	CO ppm	NO ppm	Partic units
08:30	n/m	n/m	n/m	n/m	n/m	n/m
09:00	n/m	n/m	n/m	n/m	n/m	n/m
09:30	n/m	n/m	n/m	n/m	n/m	n/m
10:00	14.7	0.0	0.1	215.8	55.2	69.3
10:30	13.0	0.0	0.1	64.9	65.5	53.7
11:00	11.2	0.0	0.4	311.5	68.1	46.3
11:30	12.8	0.0	0.1	134.1	95.1	49.0
12:00	13.7	0.0	1.0	294.0	110.9	50.1
12:30	12.9	0.0	3.9	483.8	103.2	50.5
13:00	12.0	0.0	2.3	107.0	129.2	60.7
13:30	11.8	0.0	2.7	65.3	136.9	55.9
14:00	12.9	0.0	2.1	92.7	131.5	57.2
14:30	16.5	0.0	2.7	798.4	83.0	60.5
15:00	15.4	0.0	2.9	339.4	78.7	64.9
15:30	14.0	0.0	6.0	71.5	85.7	55.2
16:00	12.8	0.0	4.6	62.6	84.5	64.3
16:30	16.0	0.0	3.9	30.1	62.0	64.5
17:00	18.2	0.0	3.3	364.7	37.1	47.7
17:30	20.7	0.0	1.3	108.3	4.9	71.7
18:00	20.9	0.0	0.0	0.0	1.0	65.7
Average	14.7	0.0	2.2	208.5	78.4	58.1
MSW	13.5	0.0	2.2	289.3	108.6	56.1
MSW +1h	13.5	0.0	2.8	244.9	103.9	56.8



TEST MSW5 Date 13/06/02 Temperature Process

Average temperature in next 30 min			
time	Primary	Secondary	Tertiary
09:00	n/m	n/m	n/m
09:30	n/m	n/m	n/m
10:00	515	329	248
10:30	766	435	245
11:00	826	466	198
11:30	906	524	226
12:00	878	493	199
12:30	840	474	194
13:00	873	503	203
13:30	910	549	229
14:00	902	543	221
14:30	828	512	211
15:00	599	382	151
15:30	821	444	174
16:00	884	466	182
16:30	938	501	198
17:00	717	386	153
17:30	548	366	211
18:00	440	338	210
Average day	776	454	203
Average MSW	842	498	204
Average MSW + 1H	844	489	199
Last hour MSW	713	447	181

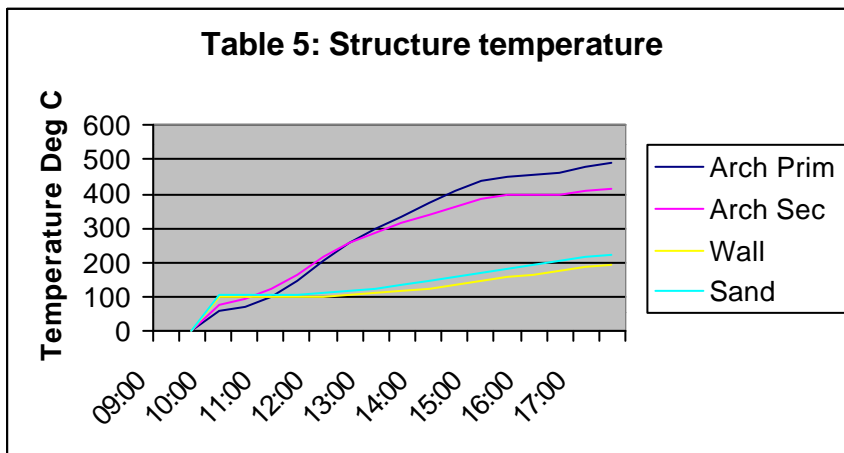


**Temperature
Structure**

TEST MSW5 Date 13/06/02

Average temperature in next 30 min				
time	Arch Prim	Arch Sec	Wall	Sand
09:00	n/m	n/m	n/m	n/m
09:30	n/m	n/m	n/m	n/m
10:00	60	79	102	108
10:30	72	94	101	106
11:00	104	124	99	105
11:30	150	166	100	106
12:00	204	214	102	110
12:30	256	256	105	116
13:00	298	288	111	125
13:30	335	314	119	136
14:00	371	338	127	147
14:30	407	362	137	158
15:00	435	383	147	171
15:30	449	396	157	183
16:00	455	396	168	195
16:30	464	400	178	206
17:00	478	410	187	216
17:30	490	418	196	223
18:00	491	414	155	43
Average day	325	297	135	144
Average MSW	307	290	118	134
Average MSW + 1H	336	311	127	145
Last hour MS	421	372	142	164

Temp at Start of burn(9:42)	60	79	104	110
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Discussion

Monitoring data, taken automatically every 30 seconds, was down loaded at the end of each test operation, collated, and presented as half hourly averages in this report. The complete monitoring data set for the test is available separately from ITC.

Gas emissions (O_2 , CO, NO, NO_2 & SO_2) monitoring was carried out using a portable combustion gas analyser (Testo 33) with heated probe located at the exit from the secondary combustion chamber. Combustion and structure temperatures were monitored using K type thermocouples connected to a Grant Squirrel data logger and electronic readout. Particulate monitoring was carried out using an opacity meter (PCME DV400) fitted into the stack. Primary air flow was measured using a hot wire anemometer (Testo 445) while secondary and tertiary combustion air was measured using pitot tubes connected to electronic manometers.

Total burn time was 7.33 hours including the initial warm up and final burn-out using biomass. A total of 723.6kg of biomass and 917kg of pre-sorted MSW was used during the test giving average feed rates of 193kg/h for biomass and 256kg/h for MSW. This represents a MSW throughput of approximately 60% of the design maximum continuous rating (mcr) of 425kg/hour. Initial feeding went well with a throughput high of 346kg/hour being reached but this gradually trailed off to around 125kg/hour before rising slightly to 167kg/hour during the final hour of operation. The very wet nature and large amount of garden waste present in the final load (bin 1.14) was probably the main contributing factors for the reduction in throughput towards the end of the test on MSW.

Average power output on MSW was just under 533kW with a peak of 721kW and a low 348kW all of which is below the theoretical design mcr of 826kW. While MSW was used exclusively for most of the test 16kg of biomass was used as support fuel to help maintain good combustion conditions towards the end of the test.

Under stable operating conditions the primary, secondary and tertiary (cooling) air were all below the theoretical flow rates for the LCI. The measured flow rate for primary air was $270\text{Nm}^3/\text{h}$, which is approximately 41% of the theoretical flow rate. At $257\text{Nm}^3/\text{h}$ secondary air is just under 25% of the estimated theoretical flow rate. The average tertiary airflow rate was $3341\text{Nm}^3/\text{h}$, which is just over 83.5% of the theoretical flow rate. This confirms the results of the four previous tests that suggest that calculated air flow rates were far higher than the actual required in practice although to some extent ingress air through the feed chute, cracks and gaps in the structure will contribute to a reduction in the amount of (measured) ducted air required. Also as reported for the previous tests the instrument readings for the secondary air may be inaccurate. A comparative measurement carried out using a hand-held hot wire anemometer indicated a flow rate of $363\text{m}^3/\text{h}$ while the (permanent) Pitot tube reading was $231\text{m}^3/\text{hour}$, a difference of $132\text{m}^3/\text{hour}$ between the two readings.

Emission levels reported have not been corrected for reference conditions (STP in dry gas containing 11% by volume, dry oxygen). Average emissions of O_2 were 13.5 % with a peak of 16.5% and a low of 11.8%. Average CO emission was 289ppm with a peak of 798ppm and a low of 65.3ppm (see table 3 page 5). In the main levels of CO

were well above those required from the LCI and are mainly due to inadequate stoking and agitation of fuel to obtain good fuel/air mixing.

Other gas emissions measured give average NO of 109ppm, NO₂ of 0ppm and SO₂ of 2ppm which, within the sensitivity of the monitoring equipment, are within acceptable limits. The average opacity was 56 units with a peak of 64.9 and a low of 49 units. Visual inspections of the stack emission showed no visible plume at these levels of opacity.

The average primary combustion temperature was 842°C which is slightly below the minimum temperature (850°C) required. Table 4 (page 6) shows that the average half hourly primary combustion temperature was above 850°C for most of the test and on a number of occasions above 900°C. A low of 599°C which occurred towards the end of the test when very wet MSW was used is the main reasons for the average dipping below 850°C. Secondary combustion temperatures were reasonable averaging 344°C less than the corresponding primary temperature. Tertiary temperatures were kept below 250°C throughout the test on MSW.

At 148.9 the residual ash represents 16% of the mass of MSW incinerated. A visual inspection of the ash showed good burnout had occurred although it did contain a large amount of ferrous materials and glass. Ash analysis from the bottom or over grate ash (3 samples taken) indicate a loss on ignition of 3.37% confirming that good burn out had occurred. Analysis of under gate ash (1 sample taken) shows a higher degree of loss on ignition at 5.78%. which is reasonable as any un-burnt material falling through the grate into the combustion air plenum and would tend to cool quickly and not to burn out adequately. Under grate ash represents only a small proportion of the ash produced and has little effect on the overall loss on ignition of 3.71%.

Appendix 6 – Test results MSW 6

Test Report Summary

Test: **MSW6** Date: **20/06/02**

Duration	From	To	Duration	Duration in minutes
Total	08:50	16:20	07:30	450.00
MSW	11:37	15:10	03:33	213.00
MSW + 1h	11:37	16:10	04:33	273.00

Feed	Total kg	per hour kg/h	moisture %	LCV (estimated) kJ/kg
BM	866.7	248	25.7	14000
MSW	1007	284		7500
MSW + 1h	1007	221		

Power	BM	BM + MSW	MSW	MSW + 1h
kW	449	729	590.96244	461

Combustion Air Input (MSW)	Nm ³ /h	PA	SA	Tert. Air
MSW		235	346	3666
MSW + 1h		293	324	3572
Last hour MSW		246	227	3189

Emissions	O ₂ %	NO ₂ ppm	SO ₂ ppm	CO ppm	NO ppm	Partic units
MSW	13.2	0	22	117	92	43
MSW + 1h	13.7	0	20	128	89	46

Temperature Process	Deg C	Prim Ch	Sec Outl	Tert. Outl
MSW		935	511	197
MSW + 1h		915	498	195
Last hour MSW		944	504	206

Temperature Structure	Deg C	Arch Prim	Arch Sec	Wall	Sand
Start Burn		71	107.5	140	71.5
MSW		424	403	172	72
MSW + 1h		451	422	184	74
Last hour MSW		529	481	207	76

Residuals	Mass kg	Ash Total	Under Grate	Over Grate	Quality	Loss on Ign %	
		136	16.2	119.8	Over grate	97.5	
	% of MSW	14	2	12	Under Grate	94.39	
	Loss on ignition of fly ash accumulated on sec. floor				98.38	Overall	97.13

Important Notes Log Book, Other Pages 25,26

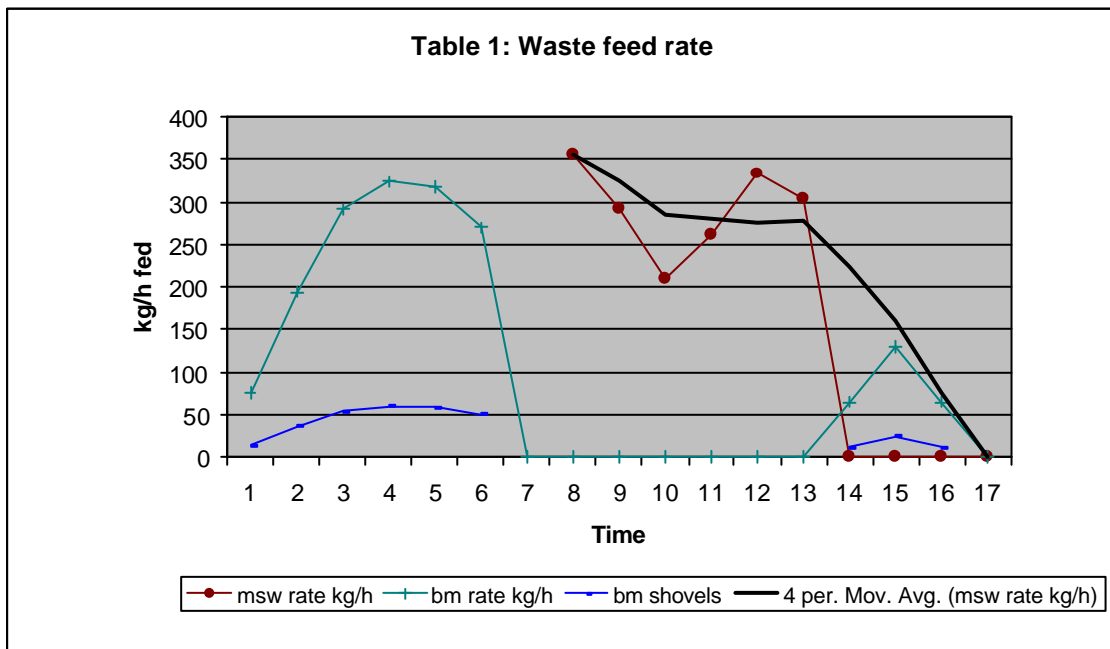
Time	Note
General	This is the last test held at EMC and coincides with CRE's monitoring of gaseous emissions
08:50	Fire lit with cradle
09:27	Start SA fan for cooling to keep T in Tertiary below 200degC
10:15	SA damper 20 deg (240m ³ /h) after O ₂ down and CO up: situation normalises straight away.
10:22	Increase SA to 25deg (~600m ³ /h)
10:51	Cooling air to 35deg (>4000m ³ /h)
11:23	SA to 730m ³ /h (O ₂ down to 6% with BM)
11:37	Start feeding MSW Bin 1.6 (128kg)
11:48	SA increase to 1060m ³ /h; PA distribution: 90/90/90/5 deg (dampers AA01/02/03/04)
11:54	SA to 1207 m ³ /h, slight reduction in PA but reduce SA straight away to ~800m ³ /h
12:00	Start feeding Bin 2.6 (178kg): CO>300ppm
12:05	Reduce SA to 620m ³ /h and re-encreased to 1110m ³ /h immediately
12:10	Optimisation SA results in settling at 430m ³ /h
12:21	CO problems are controlled by SA adjustment and frequent agitation
12:25	Start Bin 2.2 (146kg). This is wettest load today
12:55	In order to keep O ₂ and CO down very vigorous agitation is required
13:02	Start Bin 1.7 (105kg); need to ignore PA monitoring as we experiment with PA pre-heating with 2x 2kW heating elements.
13:18	Pre-heat reaches 99.6deg C and a positiv impact on combustion stability is noted
13:22	Pre-heat at 117deg C
13:31	Start Bin 'No Name' (131kg) very wet from sort 3
13:54	Inspite of 132deg C pre-heat and vigorous agitation O ₂ values persist high (14%); this again is an indication that the haet release cannot be controlled adequately. We are aiming at an O ₂ of 8-11%. We need more pre-heat more combustion surface and better agitation
14:06	Start Bin 1.16 (152kg)
14:20	Reduce cooling air to 30deg (3150m ³ /h); PA pre-heating has tripped
14:40	Start Bin 1.9 (152kg) again very wet
14:45	One PA pre-heater operating

TEST MSW6 Date 20/06/02 Waste Feed Rate

time	msw kg	bm kg	bin ID	Sorting No	Dt min	msw rate kg/h	bm rate kg/h	bm shovels	Power o/p (theoretical) kW
08:30		37.8			30.00		76	14	294
09:00		97			30.00		194	36	756
09:30		146			30.00		292	54	1134
10:00		162			30.00		324	60	1260
10:30		159			30.00		319	59	1239
11:00		135			30.00		270	50	1050
11:30	128	0	1.6	4	30.00		0		0
12:00	178	0	2.6	4	30.00	356	0		742
12:30	146	0	2.2	4	30.00	292	0		608
13:00	105	0	1.7	4	30.00	210	0		437
13:30	131	0	no name	3	30.00	262	0		546
14:00	167	0	1.16	3	30.00	334	0		696
14:30	152	0	1.9	3	30.00	304	0		633
15:00		32			30.00	0	65	12	252
15:30		65			30.00	0	130	24	504
16:00		32			30.00	0	65	12	252
16:30		0				0	0		0

totals	1007	866.7		25	480	1758	1733.4	321
total bm	867 kg		weight/shovel		2.70			
Total MSW	1007 kg		in min	213	Average	284 kg/h	BM	14000
Total bm	866.7 kg		in min	210.00	Average	248 kg/h	MSW	7500
Total MSW	1007		in min	273	Average	221 kg/h		

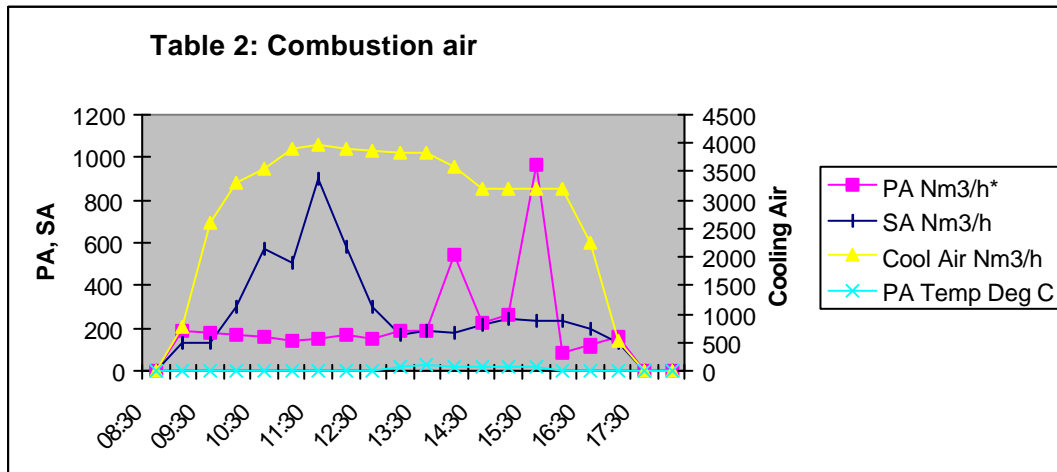
BM Moist	A	B	C	Average
%	25.7			25.7



TEST MSW6 Date 20/06/02 Combustion Air

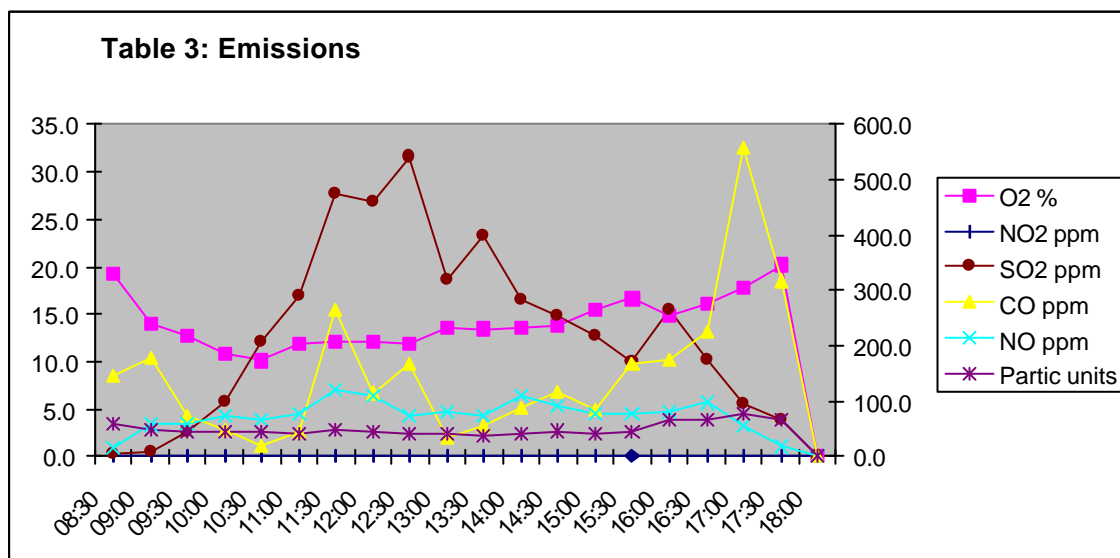
Average air flow in next 30 min				
time	PA Nm3/h*	SA Nm3/h	Cool Air Nm3/h	PA Temp Deg C
08:30	n/m	n/m	n/m	n/m
09:00	188	134	768	16
09:30	175	134	2590	17
10:00	173	304	3292	18
10:30	163	574	3556	18
11:00	144	502	3895	19
11:30	149	895	3967	19
12:00	168	577	3902	19
12:30	151	303	3856	19
13:00	187	172	3830	90
13:30	187	187	3819	130
14:00	546	183	3581	75
14:30	225	215	3197	69
15:00	266	240	3180	88
15:30	967	237	3191	90
16:00	87	238	3193	22
16:30	119	198	2246	20
17:00	163	134	541	20
17:30	n/m	n/m	n/m	n/m
18:00	n/m	n/m	n/m	n/m
Average	239	307	3094	44
MSW	235	346	3666	64
Average MSW +1h	293	324	3572	62
Last hour MSW	246	227	3189	79

Notes: 1. PA flows not accurate during PA preheating (see log notes)



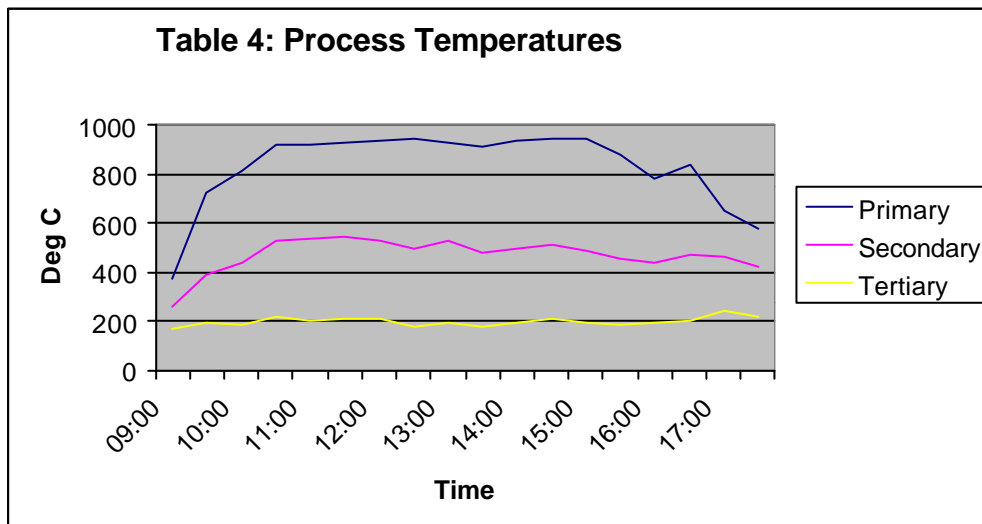
TEST MSW6 Date 20/06/02 Emissions

Average releases to air next 30 min						
time	O2 %	NO2 ppm	SO2 ppm	CO ppm	NO ppm	Partic units
08:30	19.3	0.0	0.3	147.7	15.3	58.2
09:00	14.0	0.0	0.5	179.7	57.7	48.4
09:30	12.8	0.0	2.7	73.7	60.5	45.2
10:00	10.7	0.0	5.8	47.2	74.5	43.3
10:30	10.1	0.0	12.1	19.0	66.1	44.0
11:00	11.9	0.0	16.9	44.2	75.9	42.3
11:30	12.0	0.0	27.7	265.8	119.6	48.8
12:00	12.0	0.0	26.9	115.3	108.9	45.8
12:30	11.8	0.0	31.6	169.3	74.9	42.1
13:00	13.6	0.0	18.7	35.3	79.6	39.8
13:30	13.5	0.0	23.4	56.4	72.3	38.9
14:00	13.6	0.0	16.6	89.2	110.5	42.7
14:30	13.8	0.0	14.8	118.5	91.0	46.8
15:00	15.5	0.0	12.8	83.2	78.7	42.5
15:30	16.6	0.0	9.9	168.7	76.5	43.8
16:00	14.9	0.0	15.5	173.9	81.0	65.4
16:30	16.1	0.0	10.2	224.5	97.2	66.3
17:00	17.9	0.0	5.6	559.6	56.9	76.2
17:30	20.2	0.0	3.8	317.7	18.0	66.5
18:00	n/m	n/m	n/m	n/m	n/m	n/m
Average	14.2	0.0	13.5	152.0	74.5	49.8
MSW	13.2	0.0	21.5	116.6	91.9	43.4
MSW +1h	13.7	0.0	19.8	127.6	89.3	45.7



TEST MSW6 Date 20/06/02 Temperature Process

Average temperature in next 30 min			
time	Primary	Secondary	Tertiary
09:00	372	260	168
09:30	724	390	189
10:00	811	435	185
10:30	924	532	221
11:00	922	535	201
11:30	932	543	213
12:00	935	532	207
12:30	943	500	181
13:00	931	526	193
13:30	916	479	177
14:00	940	500	193
14:30	943	516	214
15:00	945	492	197
15:30	884	454	183
16:00	785	441	192
16:30	839	470	204
17:00	655	460	243
17:30	575	427	219
18:00	n/m	n/m	n/m
Average day	832	472	199
Average MSW	935	511	197
Average MSW + 1H	915	498	195
Last hour MSW	944	504	206

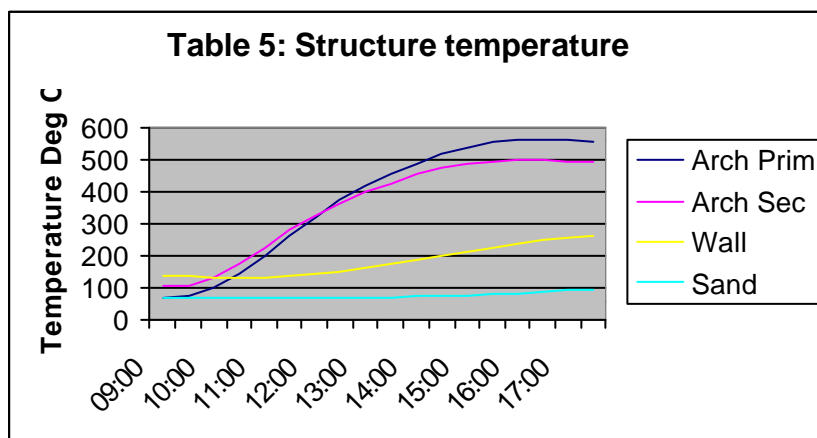


**Temperature
Structure**

TEST MSW6 Date 20/06/02

Average temperature in next 30 min				
time	Arch Prim	Arch Sec	Wall	Sand
09:00	69	104	138	70
09:30	74	108	136	69
10:00	100	132	134	70
10:30	143	175	134	70
11:00	198	226	134	70
11:30	261	280	137	70
12:00	322	329	144	70
12:30	376	366	152	70
13:00	421	399	163	70
13:30	459	430	175	72
14:00	491	455	188	73
14:30	518	474	200	75
15:00	541	488	213	78
15:30	558	497	226	81
16:00	566	502	238	85
16:30	565	500	249	88
17:00	562	497	258	91
17:30	560	493	266	94
18:00	n/m	n/m	n/m	n/m
Average day	377	359	182	76
Average MSW	424	403	172	72
Average MSW + 1H	451	422	184	74
Last hour MS	529	481	207	76

Temp at Start of burn(8:46)	71	108	140	72
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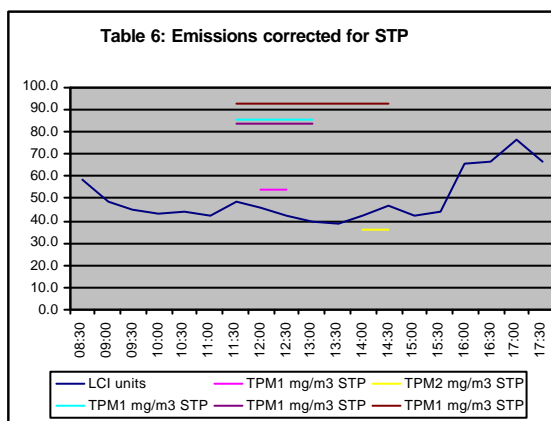
LCI construction and operation

TEST MSW6 Date 20/06/02 Emissions Corrected

Average releases to air next 30 min (LCI instruments in ppm/% at actual conditions)								Dry at 11% O2 STP		
time	O2 %	NO2 ppm	SO2 ppm	CO ppm	NO ppm	Partic units		SO2 mg/Nm3	CO mg/Nm3	NO mg/Nm3
08:30	19.3	0.0	0.3	147.7	15.3	58.2		5.90	1295.68	220.45
09:00	14.0	0.0	0.5	179.7	57.7	48.4		2.32	377.43	198.73
09:30	12.8	0.0	2.7	73.7	60.5	45.2		10.84	130.95	176.34
10:00	10.7	0.0	5.8	47.2	74.5	43.3		18.74	67.25	173.97
10:30	10.1	0.0	12.1	19.0	66.1	44.0		37.22	25.55	145.43
11:00	11.9	0.0	16.9	44.2	75.9	42.3		62.05	70.94	199.97
11:30	12.0	0.0	27.7	265.8	119.6	48.8		103.10	432.07	318.77
12:00	12.0	0.0	26.9	115.3	108.9	45.8		100.05	187.83	290.77
12:30	11.8	0.0	31.6	169.3	74.9	42.1		114.97	269.18	195.37
13:00	13.6	0.0	18.7	35.3	79.6	39.8		83.94	69.37	256.80
13:30	13.5	0.0	23.4	56.4	72.3	38.9		103.66	109.25	229.89
14:00	13.6	0.0	16.6	89.2	110.5	42.7		75.38	177.25	360.15
14:30	13.8	0.0	14.8	118.5	91.0	46.8		68.64	239.67	301.96
15:00	15.5	0.0	12.8	83.2	78.7	42.5		78.03	222.16	344.85
15:30	16.6	0.0	9.9	168.7	76.5	43.8		76.09	564.81	420.04
16:00	14.9	0.0	15.5	173.9	81.0	65.4		84.05	413.55	315.72
16:30	16.1	0.0	10.2	224.5	97.2	66.3		70.45	675.33	479.79
17:00	17.9	0.0	5.6	559.6	56.9	76.2		59.90	2616.35	436.16
17:30	20.2	0.0	3.8	317.7	18.0	66.5		160.07	5821.69	541.80
18:00	n/m	n/m	n/m	n/m	n/m	n/m				
Average	14.2	0.0	13.5	152.0	74.5	49.8		69.2	724.5	295.1
MSW	13.2	0.0	21.5	116.6	91.9	43.4		91.0	213.3	287.3
MSW +1h	13.7	0.0	19.8	127.6	89.3	45.7		88.8	268.5	303.4
Comparison CRE Monitoring							Particulates	SO2 mg/Nm3	CO mg/Nm3	NO mg/Nm3
Which	from	to	Code	Units						
LCI	12:00	13:00		units		44.0				
CRE	11:54	12:55	TPM1	mg/m3 str		54				
LCI	14:00	15:00		units		44.7				
CRF	13:54	14:55	TPM2	mg/m3 str		36				
LCI	11:30	15:00		mg/m3 Ref			91.0	213.35	287.3	
CRE	11:39	15:15		mg/m3 Ref			158	145	186	

Particulates Comparing LCI results with CRE

time	LCI units	TPM1 mg/m3 STP	TPM2 mg/m3 STP	TPM1 mg/m3 STP	TPM1 mg/m3 STP	TPM1 mg/m3 STP
08:30	58.2					
09:00	48.4					
09:30	45.2					
10:00	43.3					
10:30	44.0					
11:00	42.3					
11:30	48.8			85	83	92
12:00	45.8	54		85	83	92
12:30	42.1	54		85	83	92
13:00	39.8			85	83	92
13:30	38.9					92
14:00	42.7		36			92
14:30	46.8		36			92
15:00	42.5					
15:30	43.8					
16:00	65.4					
16:30	66.3					
17:00	76.2					
17:30	66.5					



Appendix 7: Waste Sorting

Index

- 1 Methods and location
- 2 Training, incentives, problems
- 3 Dates of sorting

1 Methods and location (Extract from H&S plan)

Project Description

The Waste Sorting Operations will comprise the following Steps:

Step 1: the delivery and drop-off once per week on six occasions of nominal 3-4 tonne compacted & unsorted household waste loads from a pre-weighed waste collection vehicle into Bay 3 at the materials recycling facility (MRF) (Bay 3 is located closest to the ready-mixed concrete batching plant). These will be known as Load 1, 2 and so forth to Load 6.

The collection vehicle will have appropriate Transfer Note paperwork raised by the MRF site manager in advance to enable the load to be legally deposited in Bay 3 of the MRF. The collection vehicle will attend the main HQ weigh-bridge before and after delivering the load into Bay 3. Records of weights will be taken from the weigh-bridge and entered onto the Waste Sorting Record Form.

Before drop off of Load 1 the Bay will be divided into two sections with a 300mm high 'kick-board' wall: one section to receive the waste load and the second section for the parking of 6 lidded and uniquely numbered 1,100-litre capacity wheelie bins. Appropriate signage will be in use in Bay 3. Four clearly marked bins will receive sorted waste materials: paper, glass, metal and PVC or unknown plastic respectively: the remaining two bins will be used for all other waste and, for the purposes of the LCI Test rig project, will be labelled as 'Products';

Step 2: 6 lidded wheelie bins will be selected from the store at the main Grundon HQ, uniquely numbered and identified with one of the following 6 signs: 'Non-PVC/Reject Plastics'; 'Metals'; 'Paper and Cardboard'; 'Glass'; or (2 No. of) 'Products'. The bins will be lifted by the MRF fork-lift truck by MRF site personnel onto the back of the MRF/No.2 landfill low loader vehicle. The low loader will be driven by MRF site personnel to the site load-cell weigh-bridge. The fork-lift truck driven by MRF site personnel will then unload the 6 empty wheelie bins and place each in turn on the load cell weigh-bridge for weighing. Weights will be recorded on the Waste Sorting Record Form. The bins will then be reloaded onto the low loader and driven to the Bay forecourt in the MRF. The bins will be unloaded by the fork-lift truck onto the forecourt and pushed in turn into the wheelie bin section of Bay 3 to await use.

Step 3: waste bags in the dropped-off load will be split where necessary using suitable tools such as shovels and the contents sorted by a team of three trained non-permanent personnel using tools such as litter pliers and brushes. The personnel will select, identify and lift individual waste objects in turn using litter pliers or other appropriate tools, such as shovels, and place each object into the appropriate open wheelie bin. This process will continue until the entire load has been sorted into the bins;

Step 4: each of the 6 wheelie bin will be closed and then pushed in turn out of the bay into the Bay forecourt area where they will be lifted by the MRF fork-lift truck by MRF site personnel onto the back of the MRF/No.2 landfill low loader site vehicle. The low loader will be driven by MRF site personnel into the main Grndon HQ site parking nearby to the site load-cell weigh-bridge. The fork-lift truck driven by MRF site personnel will then unload the 6 wheelie bins and place each in turn on the load cell weigh-bridge for weighing. Weights will be recorded on the Waste Sorting Record Form.

Step 5: the bins will be separated. The two bins marked 'Products' will be loaded onto the curtain-sided road vehicle using the fork-lift truck and the road vehicle's tail lift as appropriate. The bins will be secured and the appropriate Transfer Note paperwork will be raised and checked. The road vehicle will then drive to EMC at Stoke Orchard to deliver the bins marked 'Products'. The 4 remaining bins will be reloaded onto the low loader site vehicle and the appropriate Transfer Note paperwork will be raised and checked prior to the contents being taken for disposal at the Ewelme No.2 landfill. Where the tonnage within the 4 remaining bins is less than 2 tonnes, arrangements will be made for the bins to be temporarily stored in the Bay forecourt area until the minimum quantity of 2-tonnes has been amassed for landfill disposal.

2 Training Incentives, Problems

The actual sorting was carried out by a highly unmotivated, unskilled work force with only a limited grasp of English. As the work demands attention to detail and reliability, but is also disagreeable by the nature of the material treated, it is not astonishing that we had major problems with the sorting aspect of the tests. Even while a person from the project team was on site, we could not constantly supervise the 3-4 sorters. This meant that as soon as backs were turned sorting became very poor. Unfortunately the quality of sorting could only be determined when feeding the product in the tests, days later and 60 mile removed from the site of sorting.

As there was not enough money to provide for a permanent supervisor (after sort 1 & 2, Rob Holmes had that function) during sorting the incentive money scheme was devised. £20.00 was promised to each sorter if the product turned out to be to specifications (i.e. no metal, glass, PVC, electronics and bulky material). However problems with checking the material on the day more than 30 cm deep proved difficult and sorting results became only marginally better (see emission reports).

Training to the sorters (which were virtually always different individuals) was provided on three occasions. A big problem was the correct filling in of records, after sort 2. The number of the sort should have provided the first digit in the bin code; this resulted in some confusion.

3 Dates of Sorting and Result

22.04.02: Preparations and Tara of bins RV and RH

23.04.01: Sort 1 supervised all day by RH; all 10 bins used for MSW 1 and 2 tests; good quality for most bins

LCI construction and operation

- 30.04.02 Sort 2 supervised all day by RH; very rainy all day; produced 6 very poor quality (wet, contamination) bins. Two of which burnt in MSW 3 and one in MSW5. The rest was discarded.
- 22.05.02 Sort 3 supervised 2 h by RV; rest of day by Rob Harris, incentive paid after checking; 6 bins of poor wet (dripping) quality with contamination. 3 bins burnt in MSW 4.
- 4.06.02 Sort 4 supervised 2-3 h by AR; produced 9 bins of better quality; incentive paid later; 4 burnt in MSW5 and 4 in MSW6

Appendix 8 – Construction photographs

Photographs removed to reduce file size.
Available on request from ITC

Appendix 9: List of design modifications for pilot plant (from DG meeting 6)

Design Modifications

- 1 Secondary air pre-heating. Test results indicate the need to pre-heat secondary air and so a simple cross flow (single or double pass) heat exchanger to be fitted into the stack just after the tertiary air inlet. Secondary air to be supplied using existing FD fan.
- 2 Secondary air flow measurement. A Venturi to be fitted in the secondary air duct using a simple U tube and scale to provide readout
- 3 Pre-heat primary combustion air. Use heat in wall between primary changer and downward section of secondary to pre-heat primary combustion air and provide hot/cold air mixing at entrance to primary air inlet duct
- 4 Simple design for primary air flow meter.
- 5 Feed chute redesign to make vertical hopper. Manually operated ram to be used to load a fixed volume of MSW into the LCI. Ensure that new design does not allow MSW to fall behind chute on to hot components where it may constitute a fire risk.
- 6 Locate all controls, monitoring displays and actuators in a single control room.
- 7 Provide primary side air from both sides if possible.
- 8 Modification to grate plenum. Plenum redesign to provide separate under grate air duct and ash removal facility. Also redesign plenum box so that ash falling through grate flows freely into the ash box
- 9 Modify grate 1 (drying grate) to enable combustion gases from grate 2 and 3 to dry MSW. Increase step size between grates 1 and 2.
- 10 Grate 2 rattle/agitator review. New design using sliding blade that can also be rotated in wall sleeve. Grate 3 rattle to be made from cast iron.
- 11 Ash chamber deeper and shorter.
- 12 Avoid direct connection between all joints and interfaces between the inner (refractory) and outer walls of the LCI/inter. A thick layer of mineral wool to be placed at joints and interfaces.
- 13 Viewing port to be repositioned to give better view of grates. Preferred location in corbelled wall at ash end. More air purge ports to be added (all around the tube) and sight glass to be easily removed for cleaning. Also additional viewing port required for the secondary chamber in upward section of 2nd chamber.
- 14 Buckstay to be added to arches & corbelled wall at ash end.
- 15 Redesign shuttering to enable sand to be backfilled easily. Silver sand not to be used.

Improvements to Sorting Process

1. In depth study required to assess the types of materials likely to be present in Gambian MSW.
2. Develop waste sorting methodology.
3. Large sorting floor (under roof) with bund and a wall in one corner, or along one side, against which waste can be tipped and shovelled. Minimum floor area 8 x 5m (similar to used for sorting at Grundon's site)
4. Screen required to remove sand with a pit to keep sand away from sorting area.
5. Bring existing waste pickers in the Gambia into the project to become waste sorters for the LCI. Discussion with the pickers, LCI team, NEA and Gambian

LA's required to establish how pickers can be brought on board, how they will receive payments for work and a system of bonuses for good sorting.

6. Develop sorting handbook including information on how to identify PVC and other plastics.

Appendix 10 – LCI Inspection Reports

Inspection Form LCI After Test Burn: MSW1

Date: 02/05/02

1. Combustion Chamber

General Comments

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Grates

Grate 1	Clear
Grate 2	Bed of residues ~1/2 step in depth. Some metal and glass in with ash
Grate 3	Covered to full height of step. Mix of fines & large pieces that break when handled.

Walls

Cracks in both halves of prim. chamber & along arch

Arch

Crack joins crack in walls. Cement shrinkage in many joints

Comments on Ash (Volume/Position)

Ash on grate 3 + 1/2 of burn out grate covered. 1/2 grate 2 covered. ~ 150kg of residue containing metal and ceramic

2. Secondary Chamber

Crack about half way along down ward section of chamber. Crack across arch joining with crack in vertical wall

3. Other

Sand ingress into primary chamber from join between inner and access tunnel at ash end.

Done by: AJBR

Date: 07/05/02

Inspection Form LCI After Test Burn: MSW2

Date: 09/05/02

1. Combustion Chamber

General Comments

Two new cracks identified. Sand ingress. Otherwise structure in good condition

Grates

Grate 1	Clear of ash
Grate 2	Grate covered with shallow layer of ash
Grate 3	Covered with ash and other residue up to height of step. Ash also in burnout pit.

Walls

Major crack appears in LH wall opposite cross chamber. All other cracks as before (see Inspection Report MSW1).

Arch

No new cracks (see Inspection Report MSW1).

Comments on Ash (Volume/Position)

Large amount of tin cans, glass & ceramic with ash. Due to poor sorting of MSW. Ash burnout good.

2. Secondary Chamber

Vertical crack in wall separating downward and upward section of 'S' chamber

3. Other

Some sand ingress at joint between primary access arch and primary access tunnel.

Done by: AJBR

Date: 13/05/02

Inspection Form LCI After Test Burn: MSW3

Date: 22/05/02

1. Combustion Chamber

General Comments

Mineral rope coming out of joint between primary access arch and access tunnel.
Build up of sand where rope has come out.

Grates

Grate 1	Clear of ash
Grate 2	Ash over all grate. Little clinker found
Grate 3	Ash over all grate and into burnout pit. Little clinker. Ash also in burnout pit.

Walls

No new cracks found (see Inspection Report MSW1). As build up around ash door

Arch

No new cracks (see Inspection Report MSW1).

Comments on Ash (Volume/Position)

A little clinker found. 20 aerosols, 100 tin cans, 20 bottles, other broken glass, battery, umbrella frame found. Other wise ash burnout good. Better sorting required

2. Secondary Chamber

No new cracks (see Inspection Report MSW1 & MSW2)

3. Other

U'grate 2 – some non-Fe, good burnout, little char. Ash = 13.9kg.
U'grate 1 – some non Fe, poor burnout, some char. Ash = 8.5kg
Total U'grate = 22.4kg

Done by: AJBR

Date: 27/05/02

Inspection Form LCI After Test Burn: MSW4

Date: 30/05/02

1. Combustion Chamber

General Comments

Some sand ingress around ash door. Crack in corbelled wall above ash door becoming larger.

Grates

Grate 1	Clear of ash
Grate 2	Mainly fused ash (clinker) up to 50mm deep in places. Clinker covers all of grate except for some loose ash trapped behind agitator. Clinker had to be chipped off.
Grate 3	Some clinker but mainly loose ash. Some metal and glass present..

Walls

No new cracks but all old cracks becoming enlarged. Main concern is crack in corbelled end (ash end) which is much wider than last inspection (MSW3)

Arch

No new cracks

Comments on Ash (Volume/Position)

A lot of clinker on grate 2. Loose ash on grate 3 and in burnout pit. Metal, some glass, and a battery found. Burn out good

2. Secondary Chamber

No new cracks but existing cracks larger. Small build up of sand in at foot of secondary (upward) 'S' chamber.

3. Other

U'grate 2 – some non-Fe, good burnout, little char. Ash = 13.9kg.
U'grate 1 – some non Fe, poor burnout, some char. Ash = 8.5kg
Total U'grate = 22.4kg

Done by: AJBR

Date: 05/06/02

Inspection Form LCI After Test Burn: MSW5

Date: 13/06/02

1. Combustion Chamber

General Comments

Sand ingress between ash arch & access tunnel. Large amount of tin cans & glass present (mainly from last MSW load). Cans well oxidised & starting to degrade

Grates

Grate 1 Clear of ash. No burnt out areas or deposits

Grate 2 All grate covered with ash – mainly loose with some small amounts of clinker. Some oxidation (flaking) to elbow and forks of agitator. Mineral deposits on wall and around grate holes

Grate 3 Covered in ash up to 150mm in places. Little clinker present. Some mineral deposits around grate air holes.

Walls

No new cracks. Existing cracks enlarged. Mineral deposits around side air holes on grate 2 & on opposite wall to about 2 brick courses above grate.

Arch

No new cracks. Existing crack enlarged. Main problem is crack in corbelled area above primary chamber access arch. Now up to 8mm wide in places.

Comments on Ash (Volume/Position)

Glass & tin cans (> 50) found. 6 aerosols found. Ash has good burnout very little un-burned material found.

2. Secondary Chamber

No new cracks. Build up of sand and ash in arch between upward and downward section of secondary 'S' chamber.

3. Other

U'grate ash 21.5 kg. Good burnout small amounts of char present

Done by: AJBR

Date: 17/06/02

Inspection Form LCI After Test Burn: MSW6

Date: 20/06/02

1. Combustion Chamber

General Comments

Large amount of Fe (tin cans) present (from last 3 bins of MSW). Cans well oxidised & starting to degrade. Some glass found

Grates

Grate 1	Clear of ash. No burnt out areas or deposits
Grate 2	All grate covered with ash – mainly loose with some small amounts of clinker. Clinker fused to air holes reducing air hole size by up to 30%. Some oxidation (flaking) to elbow and forks of agitator. Mineral deposits on wall and around side air holes
Grate 3	Covered in ash up to top of step. Little clinker present. Some mineral deposits around grate air holes.

Walls

No new cracks. Existing cracks enlarged. Mineral deposits around side air holes on grate 2 & on opposite wall to about 2 brick courses above grate.

Arch

No new cracks. Existing crack enlarged. Main problem is crack in corbelled area above primary chamber access arch. Now up to 8mm wide in places.

Comments on Ash (Volume/Position)

Tin cans (> 50) found. Ash burnout not as good as previous tests with some un-burned materials present.

2. Secondary Chamber

No new cracks. Build up of sand and ash in arch between upward and downward section of secondary 'S' chamber. Build up of sand between arch joining upward and downward section of 'S' section due to shrinkage of refractory cement. Some very fine hairline cracks in upward section but not very extensive

3. Other

Generally good burnout small amounts of char present

Done by: AJBR

Date: 26/06/02