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Research Development and Design of a Simple Solid Waste Incinerator,

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Technical Review

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Intermediate Technology Consultants Limited (ITC)
Schumacher Centre for Technology and Development,
Bourton Hall, Bourton-on-Dunsmore, Rugby CV23 9QZ UK
Tel: +44 - 1788 661103 FAX: +44 - 1788 661105

Integrated Skills Limited (ISL)
10 Broadbent Close,
20-22 Highgate High Street,
London, N6 5JW
Tel: +44 (0)181 341 2266 FAX: +44 (0) 181 292 7372

Technical Review

Low Cost Solid Waste Incinerator

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Acknowledgements

Adam Upjohn

Cambridge Technology Museum

Adrian Coad

Was very helpful in discussions on the subject of waste incineration in Middle to Low Income Countries

Executive Summary

Introduction

The objective of this initial technical review was to identify the current European state-of-the-art in waste incineration, to review current waste incineration practices in developing countries and to review historic incineration projects. The ultimate goal was to extract any lessons for this project (i.e. to build and operate a low cost incinerator).

The following deliverables were produced as part of this review:

- A questionnaire for the socio-economic review (concerning any important questions to ask prospective partner countries)
- The present report

A number of sources of information were used to derive this information, some of which are listed below:

- Internet (see useful sites in key web sites)
- UK IWM
- AEA Library
- WEDC Library and discussion with staff
- Institute of Chemical Engineers Library
- Coventry University Libretto
- SKAT – Solid Waste Management Directory of English Language Publications for low and middle income countries
- R'99 Conference (posting of call for information and individual discussions with delegates)
- Telephone and written discussions with informed individuals

A general paucity of data is noted which may be attributed to the low position incineration takes in the waste hierarchy and the assumed failure of a number of incineration projects.

However a change of attitude can be observed and guarded optimism was observed for low cost incineration with acceptable environmental standards fitting into an integrated waste management policy.

Questions for Socio-economic Study

The questions which were contributed to the socio-economic study were mainly concerned with industrial base, standards of technical education, rainfall statistics, waste statistics and calorific values, legislation and finally the perception of waste management by formal and informal stake-holders.

Technical Review

As a basis of investigation outline design specifications were drawn up.
Construction characteristics, emission standards and capital cost for an equivalent size incinerator (0.5 – 1 t/h) complying with EU emission legislation were presented (capital cost £1 – 1.7m).

It was concluded that the emissions from this EU standard incinerator should be used as guidance for the low cost incinerator and that any discrepancy between the two should be subjected to detailed scrutiny.

When looking at incineration in Middle and Lower Income Countries (MLICs) evidence showed that practices ranged from open burning and primitive combustion infrastructure to purpose built small scale combustion plants.

However there is a lack of research and reporting on this area of waste management and we had to rely mainly on anecdotal evidence.

Open burning and primitive combustion infrastructure are inefficient and are causes of air, land and water pollution.

Purpose built combustion plant was identified in South Africa and India. Although detailed information on the schemes is still outstanding we conclude that design and implementation of most of the schemes leaves room for improvement.

Evidence of large scale waste incineration in MLICs was uncovered in India (New Delhi), Indonesia, Thailand and Africa, but again reporting is patchy and we relied mainly on anecdotal evidence. (Further work in this area is planned however.)

The following problems with incineration in MLICs were identified:

- Low net Calorific Values (CVs) (3,400 – 7,500 kJ/kg)
- Use of inappropriate technology
- Pollution, fear of pollution and a general negative attitude as a consequence

Historic incinerators (or waste destructors as they were known) in the UK were studied to take advantage of experience gained with ‘low tech’ processes (cheap and common materials, low degree of automation etc.) early this century.

We conducted a site visit to the ‘Cambridge Destructor’ (a technology museum) and reviewed two books on the subject and concluded that some of the information gained could be useful in this project.

However before transferring any of this information to the project a number of test questions must be applied in order to exclude and polluting or otherwise inappropriate techniques.

Interface with the Bigger Picture

Incineration is only one building block of a waste management strategy and is situated towards the lower end of the waste management hierarchy. It is therefore important that the low cost incinerator interfaces with the existing and planned provisions for waste management. Account has to be taken of collection practices, existing potential for re-cycling and re-use, composting and disposal of residues.

The scheme should endeavour not to displace existing practices and cause the loss of livelihood or other benefits to existing stake-holders.

Other background considerations are with regard to existing and potential energy resources and background air quality.

Pre-concept for Phase 2

Based on the technical review and taking into account the bigger picture a pre-concept for the low cost incinerator is presented, to be carried over into Phase 2 (design) of this project.

No 'best option' was identified, therefore the pre-concept consists of a number of concepts and elements that make up an incineration process.

The following headings were included:
Front-end sorting and treatment, waste storage and feeding, combustion air pre-heat, forced or natural draft combustion air, stoking and de-ashing, combustion, flue gas cooling and cleaning, stack, instrumentation and monitoring, and residuals handling and disposal.

Conclusions and Recommendations

The following conclusions were made with respect to the low cost incinerator:

- There is a place in the waste management strategy of MLICs for a low cost incinerator scheme which is affordable, has a low pollution potential and fits into existing waste management provisions

- Areas of concern are:
  - Low calorific values
  - Appropriateness of low cost incineration
  - Displacement of existing stake-holders

- Environmental performance will probably be below the EU standards; this shortcoming must be addressed e.g. with an Environmental Impact Assessment (EIA) including a 'no action' scenario

- Lessons may be learned from historic UK incineration but excluding environmentally unsound concepts

- The pre-concept presents a number of solutions for each element of the low cost incinerator and the final choice of technology will be based mainly on environmental considerations and cost

The following key recommendations were made:

- Design and develop the incinerator in the context of waste management hierarchy and local waste management systems already in place
- Undertake detailed research into the composition of the waste in the potential project area
- Research the current waste management systems in the potential project area
- Identify current energy requirements within the vicinity of the project for possible waste to energy applications
- Assess environmental law and background pollution of the potential project area, and conduct an Environmental Impact Assessment (EIA)
- Pursue lines of research where useful information is still expected
- Assess the capital and running costs the market is willing to pay
- Make an evaluation of the environmental performance that can be expected at these costs

1. Introduction and Overview

Objectives

The aim of the technical review is to:

- Identify recent developments in waste management with respect to waste incineration
- Review current incinerator technology
- Identify historic technologies and extract useful lessons for this project
- Review and evaluate incinerator technology currently used and developed in or for developing countries

The underlying aim for this technical review is to establish the present state of the art for ‘high-tech’ and ‘low-tech’ incineration and retrieve any useful information for the following phases of the project. That is to design, build and operate a low cost incinerator.

Deliverables

Accordingly the following outputs are defined:

- **Produce questions for socio-economic review** to assist with the choice of host country. (This output has been forwarded to Nick Crick at the end of January 99 and is contained in Appendix 4, Country Questionnaire.) Background and methodology are described in Section 2 of this report.

- **Review present ‘low’ and ‘high’ technology** and historic incineration with a view to identifying any design and operational characteristics which may be used in Phase 2, design and build the low cost incinerator.
  These findings are presented in Section 3 of this report. (Concrete design considerations are presented in Section 5, Pre-concept for Phase 2)

- **Interface with the bigger picture**
  Low cost incineration is just one component of an integrated waste management system. It has to harmonise with the upstream (collection, pre-treatment, sorting) and downstream (residuals disposal) processes as well as related matters like energy and resources recovery and local employment.
  These findings are presented in Section 4 of this report.

- **Pre-concept for Phase 2**, design of test rig. In the course of data review from reports and existing schemes information gathered may result in concrete design information for Phase 2. This information together with the outlined specifications is the concrete input from the review into the design phase. The outlined specifications were drawn up in order to collect some of the information (for example to explain interviewees what kind of scheme we were interested in and for contractors as a benchmark). These outlined specifications are not prescriptive and are presented in Appendix 3. Elements of the design concept for Phase 2 are presented in Section 5.

Sources of Information and General Attitudes

The following sources of information were consulted:

- Internet (see useful sites in key web sites)
- UK IWM
- AEA Library
- WEDC Library and discussion with staff
- Institute of Chemical Engineers Library
- Coventry University Libretto
- SKAT – Solid Waste Management Directory of English Language Publications for low and middle income countries
- R'99 Conference (posting of call for information and individual discussions with delegates)
- Telephone and written discussions with informed individuals

A list of information sources and key issues is contained in Appendix 2.

Not much hard information is available on the subject of low cost incineration even in specialised publications.

There may be a number of reasons for this:

On the one hand incineration is regarded as a polluting process at the bottom of the generally accepted waste management hierarchy (minimise – re-use – re-cycle – treat – dispose), especially if no energy or secondary resources are recovered.

On the other hand we assume much of the hostility to incineration is due to the history of failures in the field of MSW incineration in lower income countries. We have also found indications that environmental pressure groups have fuelled some of the hostility against incineration following similar campaigns in Europe and the USA.

However we have detected a change of attitude and a number of our interviewees would welcome low cost incineration, provided acceptable minimum emission and operational standard could be guaranteed and if it fitted into an integrated waste management policy, taking account of waste minimisation and re-cycling. Other sensitive issues concern local employment and energy recovery.

2. Output for Socio-economic Review

Compared to most waste management options incineration can be expensive, requires high degree of skill to build and manage effectively, and can be seen to have high environmental impact. To ensure that the most appropriate design for an incinerator is developed and that it can operated efficiently and effectively under local conditions a range of information will be required covering technical, institutional, social, and environmental criteria.

In an attempt to address some of the issues raised during the technical review concerning the above criteria a questionnaire was developed and passed on to Nick Crick. He is undertaking the Socio-economic review for use during his visit to a number of countries considered to have potential for simple low-cost incinerators.

The questionnaire (see Appendix 4) was developed during the early stages of this technical review before much of the, albeit limited, information had been obtained. Therefore it should not be viewed as exhaustive but as a first attempt to obtain useful and 'real' information from the field.

2.1 Technical criteria

If low-cost incinerators are to be successful in the long term then it is important that any country installing them have the capacity to build and operate them efficiently and effectively to minimise environmental impact and to ensure operator safety.

The industrial base of the country is important as it is from this sector that the skills needed to build an incinerator will be obtained. The level of skills already available will be determined by whether the sector is formal or informal and the range of industries established (e.g. fabrication, casting, steel manufacturing). For example if a country has a active Chemical or Food and Drink industry then skills associated with operating and maintaining a furnace may be available. If not, are these skills available elsewhere or will the project need to train people from basic principles?

The high temperatures and the harsh environment that may be generated during incineration mean that specialised materials such as refractories (bricks, castables, clay etc.) and stainless steel may be required. These can be expensive especially if they need to be specially imported. Therefore information on the types, availability and cost of these and other more standard materials (bricks, sheet steel, etc.) needs to be obtained to enable the design to be as appropriate as possible.

Information on the local manufacture of incinerators and furnaces, current or historic, will also be useful in assessing a country's ability to manufacture and maintain the incinerator. This information will help the project to identify potential local manufacturers and assess any training needs they may have in the design and construction of incinerators.

In addition to the above the final design of the incinerator will be also be affected by a number of factors which will be, in the most part, specific to particular locations reflecting both national and local circumstances and requirements. These include environmental legislation, the nature and composition of the waste, the moisture content of the waste, current waste collection and disposal practice, and the existence of technical support.

2.2 Institutional considerations

If incineration is to become a real option for waste management then there must be an ability and willingness from the host country to implement and manage the technology. To help assess whether the local and national institutional framework is capable or willing to support incineration and, if necessary, training it will be necessary to obtain information on:

- national and local waste management policy,
- the legislative and regulatory framework and its enforcement,
- who is responsible for waste management at national and local levels,
- the potential to replicate the technology.

2.3 Social context

The introduction of an incinerator has to bring benefits to those who be most affected by it, both environmental and social, and avoid adverse impacts. Many developing countries will already have a waste management system which may be formal (provided by or on behalf of local government), informal or a mix of both. Introducing incineration may raise issues for people deriving a living from the existing waste management system especially in the informal sector, which may be the main or only source of income for many people.

Waste is often subjected to a comprehensive waste management activity at the primary collection stage providing a living for many people. This takes the form of picking or scavenging waste for materials that have value either for reuse or for recycling into other products. Typical scavenged materials include, glass, paper and cardboard, plastic, rags, gunny bags and scrap metals. In India the ‘pickers’ sell these waste materials to middlemen who then sell them on to the industrial sector for reuse or recycling. In 1992 it was estimated that pickers in Bombay sell plastic at between Rs 0.5 and Rs 12.00 per kilogram, paper and cardboard at between Rs 0.6 and Rs 2.00 per kilogram, glass at Rs 0.7 per kilogram, and scrap metal between Rs 0.5 and Rs 3.00 per kilogram (Scheu and Caud, 1992).

In Indonesia it has been estimated 300,000 Pemulungs (informal waste collectors) comb the streets of Jakarta in an attempt to convert rubbish into cash (Forbes, 1995). The Pemulungs are so successful that they save Jakarta’s administration an estimated $3millon a year in clean up costs. In 1992 they were able to get the national government to ban recycled paper and plastics imported from Europe because they had driven down the market price for locally recycled goods.

A similar situation is reported from Cairo where a 27,000 strong community of Zabeleen (garbage collectors) collect and sort an estimated 2,000 tonnes of household waste per day, nearly half of the total generated in city (Dunford, 1998). Valuable materials such as plastic, metals, glass, textiles and paper are removed and sold on for recycling or reuse, rotting food is often fed to pigs, and the remaining rubbish thrown on the bonfires and burnt.

The remaining waste after scavenging is usually of little or no economic value, often consisting of high levels of organic matter and inert materials (e.g. silt and dust from street sweepings) which have low calorific values. This is important, as the incineration potential of waste depends on its calorific value, which depends on the composition of the waste.

Therefore information on how waste is managed at the local level and how incineration is viewed is of great importance. This will enable the project to assess how incineration can complement existing waste management structures and not simply displace them with the knock-on effect of removing people’s livelihoods.

2.4 Environmental factors

Simple low-cost incinerators will have an impact on the environment and this will need to be assessed against the impact of both the existing disposal options and any other possible options.

Information on the existing air and water quality should be available in order to estimate the environmental impact of a new development on the background situation.

Just as important will be the perception of incineration by those who will be directly affected and by others such as environmental pressure groups.

Therefore the project needs to gauge local and national opinion before attempting to implement an incineration project.

Moreover the availability of environmental background information and environmental consultancy skills needs investigating.

2.5 Financial limits

The ability of the national or local government and/or communities to afford, operate and maintain an incinerator is very important. There will be little point in designing an incinerator that the intended users cannot afford. Although the initial capital cost should be the largest single cost of installing an incinerator, costs associated with its operation and maintenance will be ongoing and will need to be paid for.

This might be by the local or national government through taxation/rates or directly by individuals to the incinerator operator or refuse collectors. Either way the design and performance of an incinerator will by affected by financial constraints and some idea of the maximum capital and operating costs are required before design starts.

3. Results of Technical Review

3.1 Introduction

This project is concerned with designing and building a low cost incinerator with an outlined capacity of 10 tonnes/day. Exact thermal and mass throughput characteristics are not available at this stage.

As a starting point of this section we have looked at an incinerator of comparable size which complies with European Standards to set the scene. Then we look at evidence from waste incineration in Middle and Lower Income Countries and also look at historical waste incineration in the UK.

For this reason we proposed the Outline Specifications reproduced in Appendix 3.

3.2 European Standards

An MSW incinerator with a throughput of 0.5 to 1 t/h and an MSW CV of around 9,000 kJ/kg can be offered by a number of manufacturers at a cost of £1 – 1.7m.

Typically this plant would incorporate the following components:

- Hydraulic waste handling
- Hydraulic waste loading ram
- Incinerator with:
  - Burners to ensure 850 °C/2 sec.
  - Hydraulic grate system
  - Combustion air fans
  - Ash handling system
- Waste heat boiler
- Flue gas cleaning system (dry sorbent system, for example $Ca(OH)_2$ and activated coal) and with ceramic filters and ash handling/storage
- Exhaust gas ID fan
- All ancillary systems like compressed air, water, raw material and waste storage, control systems including exhaust gas monitoring

Typical emissions would not exceed the provisions of the European Directive 89/369 EEC for plants between 1 and 3 tonnes hourly throughput (refer to Table 3.1 below).

A Draft Directive on waste incineration has recently (October 7th 1998) been adopted by the European Commission, which aims at a ‘tightening’ of emissions to air, and an emission limit for Dioxins to air (0.1 ng/Nm3) and for NO_x. More importantly it is more specific than its predecessor Directives on releases to water and land, the definition of waste and operating and monitoring provisions.

Table 3.1 – Municipal Waste Directive Limits (reproduced from IPC Guidance Note S2 5.01)

mg/m^3 unless stated	**> 1 t/h < 3 t/h**	**Monitoring**	**Compliance Conditions**	
Total dust	100	Continuous	These are 7 day rolling averages, and daily averages may not exceed 130% of these values	
HCl	100	Continuous		
CO *	100	Continuous	These are hourly averages, and 90% of the measurements taken in any 24 hours must be < 150 mg/m^3	
HF	4	Periodically		These are spot measurements, all of which must be below these limits
SO_2	300	Periodically		
Heavy metals: • Pb + Cr + Cu + Mn • Ni + As • Cd + Hg	 5 1 0.2	Periodically	Applies to metals and their compounds expressed as metal	
VOCs *	20	Periodically	As total carbon	
* It should be noted that CO and VOC limits apply to the combustion gases prior to gas cleaning, as a measure of combustion performance				

One specific provision with some relevance is the Total Organic Carbon (TOC) in the bottom ash, which is restricted to 3% of dry weight in the Draft Directive.

This section on the modern European Standard of small-scale incineration has been included in order to provide a yardstick by which we should measure the project's performance.

– **With regard to the air emissions** from a low cost incinerator the emission levels in Table 3.1 should serve as guidance. If these standards can not be respected for our design we should ask the following questions:

  – Why not?
  – What would be the cost of achieving these standards?
  – What are the consequences (of not achieving them)?
  – Can we live with the consequences?

  For a given location the impacts of releases of different substances to air are site specific and depend on the proximity of sensitive receptors, background concentrations and weather patterns. For a given site scenario, it may therefore be possible to rank the releases to air in order of potential harm. It may also be possible to significantly reduce the potential for generation of certain releases by the pre-sorting of the waste. This may be possible for SO_2 (reduction of rubber content of feedstock), HCl (reduction of PVC content) and heavy metals (reduction of battery and electronic components, and special household waste content).

– **With regard to releases to land** and water the 3% TOC limit in bottom ash and the provisions of releases to water should be used as a guide.

– With regard to the requirement of **850 °C/2 sec. residence time** specified in the EU Directives, provisions should be made in our design that the underlying aim of achieving complete gas-phase burnout is pursued.

– On the one hand the **high capital cost of European standard incinerators** reflects the high degree of automation and instrumentation as well as high EU labour costs. On the other hand the high emissions and operational standards specified can only be achieved with sophisticated technology.

Operating costs in Europe are dominated by labour and residuals disposal costs (if capital servicing costs are ignored).

As a rule waste incineration in Europe is conducted on a larger scale and incorporates energy recovery. This leads to reduced capital cost (per installed unit capacity) and operating costs per tonne of MSW treatment.

3.3 Waste Incineration in Middle and Lower Income Countries

Background and Introduction

The subject of waste incineration must be considered within the context of the overall waste management picture in Middle and Lower Income Countries (MLICs).

Fast growing urban sprawls have outgrown traditional ways of dealing with waste. In contrast to most European cities, where waste collection is at the household door, in MLICs municipalities (or their contractors) collect from the streets. As a direct consequence MSW collected in European cities is a well defined stream delivered to a particular site according to a collection rota.

The waste stream in MLICs is not so well defined and may never arrive at the gates of a treatment or disposal site. Due to the informal collection and sorting provisions prevalent in many MLICs it is therefore important to focus on these issues before making any firm decisions on waste treatment methods (see also Section 2 and 4).

Questions that need to be clarified:

– Waste ownership and collection provisions
– Waste composition and changes to waste composition as a consequence of upstream informal scavenging (this may critically change the waste CV)

- How can the existing formal and informal structures be integrated into a new scheme (and avoid threatening the livelihood of existing stakeholders)
- An indication of the percentage of the total disposed waste (not recycled or re-used) that arrives at a disposal site is also important

Evidence of Small Scale Waste Incineration

Obtaining reliable information on the use of incinerators for solid waste disposal in developing countries has proved difficult. Although there have been a number of studies on waste management in MLICs covering municipal, medical, industrial and special waste, little work has been carried out on incineration.

Although incineration may not be widely used as a waste management tool, some form of incineration takes place in many countries either as straight waste disposal or as a volume reduction technique, controlled or uncontrolled. These practices range from open burning to relatively high tech waste combustion plants with energy recovery. The lack of reliable information is most likely due to lack of reporting rather than lack of activity in the area. (See also comments in Section 1 sub-section, Sources of Information and General Attitudes.)

Open Burning

Open burning in bonfires is a common practice in many countries (Dunford, 1998; Coad, 1999) either to dispose of the waste in the streets or to reduce the waste volumes at dump sites. In some countries householders will burn their rubbish at sundown as a means of disposal and to generate smoke to drive away mosquitoes (UNEP, 1996).

In parts of Asia it is common practice for people in the informal sector, who derive a living by recycling materials from waste, to burn rubbish piles making it easier to locate and recycle metals. Open burning also takes place at landfill sites to reduce the volume of the waste before landfilling, especially where bulldozers are not available to compact the deposits (UNEP, 1996).

This form of incineration is very inefficient and causes sever localised air and water pollution as a consequence of the poor controls and infrastructure (Gibriel, 1999).

Basic Infrastructure

Primitive infrastructure may consist of a 3-wall enclosure and a controlled system of feedstock input and ash management, and may, at the upper end of the scale, consist of primitive furnace technology.

Simple low-cost locally made incinerators have been used successfully by rural and peri-urban communities where the refuse is mainly combustible (Oluwande, 1984). Details of the design were not given other than that they are made from laterite, cement blocks and metal. Refuse is deposited on the ground close the incinerator and sun dried to some extent. Towards evening the waste is place in the incinerator and burnt. Oluwande suggests that these simple incinerators, strategically located at one per 200 to 300 people, has been found to be adequate for semi-urban communities with populations of up to 50,000 assuming a rate of refuse generation of between 0.1 and 0.25kg per person per day.

Other examples of such schemes are reported by Coad (Coad, 1999) and others especially if health care waste is included.

Pollution to air and water from such simple structures may already be reduced when compared with open burning as a result of higher combustion temperatures and improved management.

Purpose-built MSW Combustion Plant

The next step up the incineration evolutionary ladder is purpose made furnaces designed and built to burn MSW. We have identified three South African companies manufacturing these units and have asked for a quotation based on the Outline Specifications (see Appendix 3). We have also asked for references for existing plants which have not been sent (as of February 1999). From the quotations, telephone conversations and discussions with South African delegates at the R'99 Conference the following conclusions can be drawn:

– Three South African companies, SA Incinerators, Macroburn and Littergone offer small-scale incinerators for MLICs. For the Outline Specifications two price quotes of £42,500 and £48,300 were received (ex-works both excluding erection and commissioning)

– It is assumed that most of the designs offered originated from clinical waste type incineration

– All designs incorporate burners and conform to the South Africa Air Pollution Prevention Act 1965
– Anecdotal evidence from discussions with SA consultants, voluntary sector workers and government employees suggests that these designs could be further improved with respect to smoke emissions, gas residence time, etc.

Further evidence is required from operational schemes on performance (bottom ash burnout, emissions to air etc.), waste composition and general integration of the incineration process into waste management strategies.

Actual projects exist in Kokstad (Eastern Cape) and Underberg (Jewaskiewitz, McLean, 1999). Possible feedback on these projects and going back to the SA suppliers may be required. (Especially Dr. Mars from Littergone as they specially emphasised their efforts in pre-treatment and sorting of collected wastes, as well as training and awareness of operators.)

We are presently expecting (February 1999) an email from Mr. Jewaskiewitz giving details on one of the above quoted projects.

Another concrete example of waste incineration in practice was the Bombay pelletisation project (Sikka, 1999). Although Dr. Sikka's presentation at R99 did not include any reference to waste incineration this experience is relevant to the present project in several ways:

- Reference to waste sorting, pre-treatment, solar drying and secondary drying
- Pellets from waste are sold and used as fuel (waste to energy combustion)
- Selected waste is used in an on-site furnace to produce hot air for secondary drying of MSW

During discussion of the process with Dr. Sikka it became evident that the secondary drying process is powered from a waste incineration process. Also operational details on waste reception, selection, solar drying and the mechanical treatment to produce the pellets may be relevant to this project. I have given Dr. Sikka a questionnaire seeking information on these areas to which a response is still outstanding (questions given 5.2.99).

Medium to Large scale incineration in MLICs

The following evidence of large scale projects has been discovered and is reported here to complete the picture.

In East Africa the UNEP (1996) has reported that a waste to energy plant has been built in Tanzania and indicates that if successful 'this experience would show how safe operations at such a facility can be sustained with local resources'. This document also suggests that the local capacity to sustain safe and efficient operations of incinerators is a 'key consideration in weighing the appropriateness of this technology for African cities'. However, they caution that high costs, limited infrastructure and the composition of the waste stream itself suggests that incineration may be an inappropriate technology for some large African cities. The current status of the incinerator has not been ascertained.

In India an incinerator plant based in Delhi was installed but not used due to the composition of the waste which was high in moisture (70%) and low in combustibles such as paper, plastic and textiles (20%) with a total net calorific content of 5436 kJ/kg (RWSG, 1993). Although the caloric value is near or just within acceptable limits of incineration the high moisture content means that it would be difficult to incinerate without the use of a support fuel.

In Surabaya, Indonesia an imported incinerator is reported (UNEP, 1996) to operate at only two thirds of its design capacity as the waste needs to be dried on site for five days to make them incinerable.

Problems with Waste Incineration in MLICs

Net Calorific Value

The most important parameter when determining if a waste can be incinerated auto-thermically is its net Calorific Value (CV_{net}).

In countries like the UK, Germany and France typical CV_{net} of 'rest wastes' are between 7,500 and 12,000 kJ/kg, a range where combustion and gas residence conditions of 850 °C/2 sec can be sustained without auxiliary fuel (auto-thermically).

It is noted that the CV_{net} in European MSW is on an upward trend partly due to the increased effort to treat all waste fractions according to their characteristics. It can be concluded that in the European context the removal of organic and inert waste (kitchen and garden waste; ferrous and non-ferrous metals; glass) outweighs the effects of removal of combustible recyclables (plastic, paper, card and textiles) with respect to CV_{net}.

The underlying CV_{net} in some MLICs is as low as 3,400 to 5,000 kJ/kg (Sikka, 1999; Macfarlane, 1996).

This range is confirmed by other sources:

- Brazilian waste, town of Guaratinguetã 1992 - 5,780 kJ/kg (Frey, 1995)
- North African waste, Melilla 1996 – 4,200 to 7,450 kJ/kg (Döbeli, 1999)
- India waste, after extensive sampling - 3,350kJ/kg to 4,600kJ/kg (Bhide & Sundaresan, 1984).

As a rule MSW with a CV_{net} below 6,720 kJ/kg cannot be combusted without the use of auxiliary fuel with satisfactory combustion conditions (Döbeli, 1999).

The problem with low CV_{net} in waste is supported by the experience collected with large scale incineration projects in MLICs.

References to projects in India, Thailand, Nigeria (Lagos), Brazil (Sao Paolo), Lebanon (Beirut), Tanzania and Indonesia have been discovered and in most cases we assume that these projects have failed partly due to the problem of CV_{net} (UNEP, 1998; general discussions at R'99 and other).

It is possible that the problem of low CV_{net} can be overcome by the following measures:

- There is a trend towards increasing CV_{net} in MLICs in any event
- Careful selection of target countries and regions
- Careful study of waste arisings with respect to composition and CV
- Care can be taken to cover incoming waste from rain (throughout the collection chain)
- Evaluation and implementation of front-end sorting (e.g. separation of kitchen waste and subsequent composting or anaerobic digestion)
- The design can include drying of incoming waste

By being aware of the problem of low CVnet there are reasonable grounds to assume that it can be overcome. Other reasons include the use of inappropriate technology.

Appropriateness of Technology

Another reason for the failure of large scale projects is the transfer of technology into a context where the social and technological infrastructure (spares stocks, a repair and service industry, training and cultural background) for the technology does not exist.

We have appended a paper by Dr. David Wilson where he warns of the effects of importing high technology (see Appendix 5).

Again, careful study of the target countries and regions, and careful selection of the choice of technology, should help to overcome these historic problems.

Pollution or Fear of Pollution

Open burning has been long established as a means of reducing/disposing of MSW in MLICs and has rightly gained a reputation for atmospheric, water and land pollution.

This reputation may initially adhere to any new project incorporating incineration and has to be overcome by demonstrating that, done properly, incineration has its rightful place in the waste management strategy.

3.4 Historic Incineration in the UK

Introduction

Late last century and in the early 1900s Waste Incineration, or 'Refuse Destruction' as it was known then was a common waste treatment option and was also used to raise steam for sewage pumping and electricity generation.

These 'refuse destructors' were constructed from relatively cheap and common materials and automatic operation played a smaller role than in modern European technology.

We have therefore, as part of this technical review, looked at this historic technology in general and have also visited the Cambridge Museum of Technology where an historic installation can still be inspected. The aim was to extract any useful lessons from the literature review and the site visit.

The Cambridge Destructor

The site visit to Cambridge (Roberto Vogel and Andy Russell) took place on the 20.1.99. Adam Upjohn, acting curator of this museum, gave us all the help we required with information collection. This includes the following:

- Photographs of the storage, combustion and de-ashing processes
- A number of historic documents describing the operations at the pumping station and more general documents on waste destruction
- Sketches of the actual plant layout

The summary conclusions of the visit are the following:

– Six Marlowe, Alliott & Co destructor cells, each pair of adjacent cells sharing a Babcock & Wilcox water tube boiler (three boilers in total), were installed in 1894-95

– In combination with conventional coal grates these destructors raised the steam to pump Cambridge sewage through a two mile rising main to the sewage farm

– The throughput per day and cell is reported as 5.5 tons. However according to other records a total throughput of 40-50 tons/day was achieved with the six cells having a throughput capacity nearer 7-8 tons per day per cell

– ***Technical and Operational Details:***

- Feeding and stoking was carried out manually, allowing cold air to enter via the top charging inlet or the clinkering door at the lower end of the furnace
- The drying hearth dimensions were 1.33 x 1.85 m (2.46 m^2) and the combustion grate 1.55 x 1.85 m (2.87 m^2)
- Pre-heated combustion air was introduced via a steam driven fan under the grate
- The operation (pumping and destructor) was operated by a 3 man shift (2 x 12 hours shifts)
- In order to avoid charred paper leaving via the stack fine screens were installed at the stack entry
- Boiler specifications:
  Feed water temperature – 160 °F (71 °C)
  80 horsepower per boiler
  Working pressure 80 psi, no superheat
  Steam consumers: 2 Hathorn Davey Tandem Compound Steam Engines for sewage pumping; forced draft fan; electrical generator for site supply
- The clinker was removed from the lower furnace door with hand held stokers (for which a water trough for cooling/quenching is provided) directly into narrow-gauge railway based carts
- The destructor cells were constructed in a 9-inch lining of firebrick, held together with steel frames and tie bars. From the evidence of fused ash on the lining, temperatures of up to 1,000 °C were probably achieved at the lower (grate) end of the destructor cell
- An explosion door of dimensions approximately 30 x 40 cm was provided at the higher end of the furnace
- A sorting shed was part of the arrangement. However no details on its operations were available. Mr. Upjohn revealed that glass was carefully removed from the waste stream to avoid clogging of the grate

Some aspects of the Cambridge Destructor may assist us in the design phase of the present project. For this reason all sketches, copies of text documents, photographs and notes are filed in readiness for any further information being required.

Literature Review

1. Neal's book 'Refuse Destructors and Separation' (Neal, 1938) gives a useful overview of combustion and pre-sorting technology available in the early part of the century.

Information covered includes the following:

- A history of waste incineration
- Information on calorific values of historic waste
- Details of low-tech furnace construction; materials and dimensioning
- Dimensioning data for low-tech incineration (combustion air ratios, degree of preheat, heat exchanger design, etc.)
- Primitive dust interception and separation
- Heat recovery in low-tech boilers
- Methods of charging and clinkering
- Refuse Separation (low-tech, high work input) and clinker treatment, bailing of recovered material
- Treatment of organic and vegetable refuse
- Performance reports on some existing plants
- Tests of existing plants (historic)

2. Stirrup, FL. Public Cleansing Refuse Disposal - Ch. 8 Incineration, 1965 (Stirrup, 1965)

This book gives a useful overview of the waste management practice for UK local councils from the early 1930s up to the mid 1960s. The chapter on incineration provides information on:

- Physical and combustible characteristics of waste
- Site selection
- The basic incineration unit
- Segregation of waste
- Types of incinerator plant
- Incinerator construction and materials
- Waste to energy plant

These and similar works of reference may be used to derive low-tech/high labour solutions to design problems. However they must be used with caution, because of their age, changing waste compositions and, above all, the low priority that releases to air, land and water had in those times. After all it is successor plants of the ones described in Neal (Neal, 1938) which gave waste incineration such a bad name.

Conclusions to Survey of Historic Incineration

The notes from the Cambridge Destructor and information from historic textbooks may be helpful in finding low-tech appropriate solutions for the design of a low cost incinerator for MLICs.
However when taking over information from historic sources we have to be aware of the low regard that was given to releases to air, land and water in these times. Moreover, waste compositions early in this century may have avoided many problems that, were we to use similar treatment methods today, would result in gross contamination (low heavy metals contents, no PVC or other plastics etc.).

It is therefore proposed to conduct a test on each transfer (of design features, materials etc.) from historic sources for use in the present project. Test questions may include the following:

- Does the transfer influence releases to air, land or water?
- If ‘yes’, is there a ‘modern’ way of fulfilling the same function or can the polluting effect be abated?
- Has modern waste composition (as anticipated in this project) a bearing on the releases caused if transfer is used?
- Is there a better material or method to replace part or all of the transferred material or method?

Careful consideration must be given to the answers to the test questions in order to transfer ‘old’ knowledge to our times and only extract the ‘good’ information and leave behind potentially damaging or inefficient methods.

The following can usefully be learned from old designs and incorporated into the Low Cost Incinerator:

- The basic combustion chamber layout of the Cambridge destructor and as described in Neal’s book is sound and can be used
- The use of manual labour for pre-sorting, charging, stoking and de-ashing is perfectly acceptable and avoids a lot of complex machinery and automation
- A lesson from the Cambridge destructor is that glass stuck to the grate and is best removed by pre-sorting (and may have some recycling value)
- Materials and technologies used for heat bearing components; e.g. refractory bricks and tie-rods for the combustion chamber; bricks for the stack; iron grates
- Miscellaneous design features and dimensioning rules presented in Neal’s book can still be used

4. Interface with the Bigger Picture

Incineration cannot be introduced as a solution to a waste management problem without consideration of broader issues, which may affect the successful outcome of using this technology. As well as assessing incineration in terms of the criteria discussed briefly in section 2 it must also be viewed in context of its place within the waste management hierarchy and, more importantly, how it fits in with existing waste management practices.

4.1 Waste Management Hierarchy

Incineration is one option for the disposal of solid waste and is part of a hierarchy of waste management options that can be used. Although the exact definition, terminology and form of the waste hierarchy may vary according to individual commentators it can be assumed that it be broadly defined in the following sequence:

- Minimise or reduce the amount of waste by using less material in products, producing less waste in manufacture and producing longer lasting products with lower potential to impact on the environment.

- Reuse by segregating items that can be easily be used again (e.g. milk bottles)

- Recycle by finding beneficial uses for wastes such as glass and aluminium cans melted down and reformed or reused in other products.

- Treatment by composting organic waste and incineration of combustible waste preferably with energy recovery.

- Disposal by depositing into dedicated landfill sites preferably under controlled conditions.

This hierarchy places alternative waste treatment options in order of preference with waste minimisation at source the option with the least environmental impact and landfill having the greatest environmental impact. However, in many countries a sixth option can be added: uncontrolled dumping and burning.

Whilst the solid waste management hierarchy serves a useful purpose it should not be viewed as fixed and a degree of caution should be exercised before coming to any conclusion as to the environmentally preferred option for any given situation.

4.2 Local waste management practice

Most countries have some form of waste management system, formal or informal, which is financed by government expenditure with or without cost recovery from waste producers. There are a number of possible stages in the waste management process, some or all of which may be present in different countries. These are described below.

- **Generation of waste** at the household or industrial level.

- **Primary storage**. This may be at the household level **-** in traditional dustbins or other containers such as oil drums, baskets or just heaps, stored on or close to the point of waste generation – or may be in larger communal containers serving groups of households.

- **Primary collection** by labourers using a range of methods from simple handcarts, donkey carts, or tractor/trailers or by dedicated refuse trucks or container lifting vehicles. In some cases the waste is then transported directly to the final disposal point.

- **Separation of recoverable materials.** In many countries 'pickers' remove useful products such as metal, plastic, paper and textiles from the primary storage point. The remainder of the waste may be left in primary storage, dumped in the street or taken to the next stage in the process. The picker will sell on the useful products for recycling or reuse usually to middlemen. The pickers may also charge those responsible for the generation of the waste to remove it from their premises. A considerable number of people throughout many MLICs derive a living from such recovery (see Section 2).

- **Secondary storage** at a transfer station where waste is stored before being transferred to a dedicated disposal site. Some larger cities in MLICs make use of a number of transfer stations to collect the non-recyclable waste from the 'pickers' and then transport it to a suitable site. This service is usually undertaken by the local authority although it might be contracted out to private companies.

- **Final disposal,** where the waste is dumped, landfilled or could be treated by composting and/or incineration. Further segregation of waste can be undertaken at this point to facilitate treatment. Picking may also occur at this stage especially in situations where the waste is transported directly from the households to the disposal site bypassing the secondary storage stage.

4.3 Conclusion

Just where and how the incinerator fits in to the waste management strategy must be considered very early in the project to ensure that it is appropriate, delivers benefits and is not detrimental to any given situation. In particular, incineration should not be introduced into the system in such a way that recovery and recycling, which are higher in the waste management hierarchy and, more importantly, provide a livelihood for many people, are interfered with in any way. This will mean that incineration is not suitable for those countries where informal sector activity results in a waste stream with a CV too low for economic incineration.

Finally consideration should be given to whether the potential incinerator may be used as part of a waste to energy system. This may be a practical option if there is industry close to a potential site for an incinerator which could use the heat generated for raising steam or other heating.

The use of positive displacement steam engines is worth further research and consideration.

5. Pre-concept for Phase 2

During this technical review we have not been able to identify a "best option" or concrete existing design to take into Phase 2.

Therefore the pre-concept cannot be specific with regard to concrete features of the design. We will present a number of features and concepts which contribute to the incinerator design and discuss different options for implementation, thus opening the discussions on the design choices to be made in Phase 2.

(For purposes of brevity, some technical shorthand is used in the following.)

5.1 Front-end Sorting and Treatment

– **Remove PVC:** the removal of PVC (if contained in the incoming waste) if successful will drastically reduce the need for a "chemical scrubber" to remove HCl. Similar pre-sorting may be considered for rubber (SO_2 reduction).

– **Separation of other fractions** to reduce pollution potential, e.g. batteries and other heavy metal bearing waste components. A separate re-cycle or disposal route for this waste stream needs to be determined.

– **Removal of glass** may be necessary to avoid clogging of the grate.

– **Separation of some organic fractions** may be implemented to feed into a composting process (or anaerobic digestor) for soil improver. Alternatively some fraction may be used to feed animals.

– **Separate collection and sorting** by householders is an alternative to on-site sorting. This requires good communication with and participation by the householder.

– **Separation of other fractions** for separate disposal or as secondary raw materials on a case by case basis may be used to raise revenue, increase CV_{net} etc. Front end sorting may be carried out by the traditional scavengers, who can be integrated into the project.

– The **drying of waste** may be necessary to raise the CV_{net} of incoming or "rest waste" after removal of value fractions. Air drying or forced draft drying can be considered (use heat from the incinerator).

5.2 Waste Storage, Handling and Feeding

– The **storage of waste** should be carried out at the same place as the delivery and as near as possible to the feeding position in order to reduce internal transport. If the delivery is carried out at a raised point advantage can be taken of gravity in bringing it to the point of feeding. Storage could be combined with drying if the storage surface could be moderately heated. Handling should be carried out manually.

– **Top feeding** normally involves storage of the waste on a platform which also forms the furnace roof. I.E. feeding through a refractory lined charging door in the furnace roof by gravity (like Cambridge).
500 – 1,000 kg/h (8 – 16 kg per minute) is a big volume of waste to shift. Top loading involves the lowest amount of labour to achieve this. However top loading may cause lighter waste fractions to volatilise and be carried away with the combustion gases. Moreover the introduction of cold air when opening the sliding door is detrimental to good combustion.

– **Side, back or front feeding** involves more labour than top feeding. There is a case for developing (or copying) a low-tech mechanical feed system, where waste can be fed from the side without large amounts of cold air entering the combustion chamber.

5.3 Combustion Air Pre-heat

– Combustion air should be pre-heated due to the expected low CV_{net} of the waste. Heat exchangers with the exhaust gases are required, estimated degree of pre-heat: 100 – 250 °C. This may be done in combination with forced draught waste pre-drying (see above).

5.4 Forced or Natural Draft Combustion Air

– Very probably natural draft is not an option for the following reasons:

- Pre-heating in heat exchangers cause high pressure drops not normally sustainable with natural draft.

- High quality burnout on the grate (primary air) and in post combustion (secondary air) is greatly enhanced by air velocity, which cannot be sustained by natural draft.

Therefore an electrical drive will probably be required for forced draft combustion fan.

5.5 Stoking and De-ashing

– **Hydraulically driven grates** are probably out of the question as this would involve some costly high-tech equipment.

– **Manual stoking and de-ashing** should be done in a way which avoids excessive ingress air and without compromising the operators' health and safety and comfort. It is also recommended to arrange the de-ashing in such a way that clinker and ashes fall by gravity into wheeled containers.

5.6 Combustion

– The **main combustion chamber** may be modelled on the Cambridge destructor, incorporating a drying grate and a bar grate with under grate air injection (primary air). Combustion and post combustion chamber geometry need to determined with good mixing and turbulence in mind.

– A (costly) alternative to grate combustion is the **fluidised bed technology**.

– A **post-combustion chamber** with secondary air injection is strongly recommended to avoid problems with black smoke.

– The inclusion of **burners** to achieve satisfactory temperatures in post-combustion must be considered.

5.7 Flue Gas Cooling and Cleaning

– Flue gases must be cooled before gas cleaning can take place; from 850 °C down to a temperature consistent with gas cleaning. The cheapest way to do this is gas to air heat exchangers (see above Section 5.3). Attention must be paid in tube heat exchangers to high temperature corrosion. Other options are boilers and water injection. Temperatures should be below 300 °C to allow for condensation and agglomeration of some volatilised aerosols (PCDD/PCDF danger due to temperature window!).

– Gas cleaning options considered at this stage are limited to de-dusting (removal of particulates). Two techniques are proposed:

- **Cyclonic gas cleaning** systems have a lower cost and recent developments in hot cyclone designs may ensure a sufficient gas cleaning efficiency. With a high stack the natural draft may be sufficient to overcome the pressure drop across a cyclone.

- **Baghouse filters** (fabric filters) are the high-tech solution to particulate abatement. However recent developments may indicate lower than expected prices and simple solutions. The great advantage of these filters is the high efficiency in removing particulates to levels below 1 mg/Nm^3. Visible smoke plumes will be virtually eliminated, leaving only the gaseous species as a major concern. (Temperatures above 250 °C are a problem.) The filters require cleaning (compressed air) on a daily basis.

– One further element, which may need inclusion, is the Induced Draft (ID) fan. In combination with the bag house filter it is probably unavoidable.

5.8 Stack

The following consideration apply to the stack:

Height:

Increased dispersion and natural draft from high stacks (30 m to 40 m may be considered high in this context). Visual impact needs to be considered.

Material:

Steel stacks (two concentric tubes with lagging in between) can be manufactured off-site and assembled on a foundation.

Masonry may be a more appropriate material where local skills and materials are available.

5.9 Instrumentation

The following instrumentation is considered for inclusion in the project:

– Temperature sensors for combustion air, main chamber, post-combustion chamber, after gas cooling, after gas cleaning (before stack)

– O_2 sensor after gas cooling (expensive)

– CO sensor after gas cooling (expensive)

– Supervision of primary and secondary air (flow or pressure instrumentation)

5.10 Monitoring Ports/Facilities

Monitoring ports in the clean gas duct must be installed according to the envisaged monitoring protocols (i.e. British Standard, ISO, DIN or EPA)

5.11 Residuals Handling and Disposal Concept

Bottom ash handling may take advantage of gravity and fall directly into a wheeled container (see above, Stoking and De-ashing) which is then either driven directly to the point of disposal or to a point of further treatment. Alternatively the bottom ash may be directly conveyed to the point of further treatment by gravity. Scope for re-use of the bottom ash or some of its constituents may be explored (e.g. Fe metals recovery or as building material.

Other waste streams like fly-ash or separated heavy metal bearing fractions need to be land filled. As this is part of the overall process it is part of this project to establish environmentally appropriate guidelines for this activity.

6. Conclusions and Recommendations

It is clear that little is known about incineration of solid municipal waste in MLICs although there is a reasonable amount of formal and anecdotal information available on waste management in general. What is clear is that the effective management and treatment of waste is a major issue in many MLICs and that efficient low-cost incineration may be an appropriate solution if it is part of an integrated waste management concept having regard for environmental, social and economic circumstances.

Areas of concern are the low calorific value of the waste generated in many MLICs which is often compounded after materials such as plastic, paper and textiles are removed for reuse or recycling. Also the levels of moisture content are an issue especially when the calorific value of the waste is low. Therefore it will be necessary to ensure that the waste is reasonably dry before incineration and it contains sufficient combustible material to enable it to be incinerated effectively.

In most MLICs there is an active informal waste management sector providing a livelihood for many people ‘picking’ valuable materials from the waste. This is then sold on for recycling or reuse. Introducing new waste management technology could be seen by those in the informal sector as competition and a potential threat to their livelihoods. This may be especially true when introducing incineration technology which requires waste to have a reasonably high content of the materials currently picked (e.g. paper, textile and plastic) to ensure adequate combustibility of the waste.

Therefore the final design of incinerator should be appropriate to the needs of those who are responsible for operating the waste management system whether it is the formal or informal sector. The design needs to be seen as part of the local system and be capable of being operated and maintained effectively by those who have a direct stake in waste management in any given situation.

Another area for concern is the environmental performance of the incinerator. If it falls below the European standards (which it probably will, in view of the lower investment available) these shortcomings must be supported by sound argument, e.g. an Environmental Impact Assessment (EIA) of the base situation and the implementation (before and after study).

Lessons may be learned from historic incineration in the UK especially with respect to the use of appropriate technology.

However care must be taken not to integrate environmentally unsound concepts from this source.

Having considered social, environmental and technical issues the information gathered was collected to give a picture of the actual project and its components as presented in Section 5, Pre-concept.

The choice of technology will be mainly based on environmental considerations and the capital cost that the targeted market is willing to pay. Other considerations are health and safety, ease of operation and operating costs.

The cut-off date for the collection of information was set at mid-February and a few lines of research are not yet concluded. It may be necessary to re-launch some of these in the next project phase.

The following recommendations are made for consideration by the project team:

- **Design and develop the incinerator in the context of waste management hierarchy and local waste management systems already in place in potential target countries.**

- **Undertake detailed research into the composition of the waste in potential project areas.**

  Initiate research investigating the composition of the waste materials, the quantity generated and its average moisture content. Details of general climate pattern in the area would also be useful.

- **Research the current waste management system works in the potential project area.**

  Initiate a research project to investigate how the local waste management system works to assess:

  - who and how many people are involved in the current waste management system,
  - how those affected by introducing an incinerator can be brought into the project and what incentives may be needed, and
  - how an incinerator can be integrated into the existing system.

- **Assess the potential of using the incinerator as part of a waste to energy plant for the potential project area.**

- **Identify current energy requirements within the vicinity of the project.**

  Can some of this energy be replaced by a waste to energy scheme?

- **Assess environmental law and background pollution of the potential project area, and conduct an Environmental Impact Study (EIS).**

  - Are there environmental consultants active in the area?
  - Is background data available?
  - Assess national and local waste management and environmental law

- **Pursue lines of research where useful information is still expected.**

I.E. Dr. Mars from Macroburn and other information from South Africa or the questionnaire to Dr. Sikka on the pellet plant.

- **Come to an understanding of the capital and running costs the market is willing to pay.**

- **Make an evaluation of the environmental performance that can be expected at these costs.**

References

Ali, Mansoor et al, Chapter 13 - Education in Municipal and Informal Systems in Solid Waste Management, Educating for Real - The training of professionals for development practice, Editor - Nabeel Hamdi, IT Publications, ISBN 1 85339 333 9

Bhide A.D & Sundaresan B.B, 1984, 'Street Cleaning and Waste Storage and Collection in India', Managing Solid Waste in Developing Countries, Ed. John Holmes, J Wiley and Sons, UK

Brunner, Calvin R, 1991, Handbook of Incineration Systems, McGraw Hill, USA, 1991

Coad, Adrian, (Ed.), 1997, Lessons from India in Solid Waste Management, the Water, Engineering and Development Centre (WEDC), Loughborough University, UK 1997

Coad, Adrian, 1999, Emails and telephone conversation

Cotton, A, Mansoor Ali & Westlake, K (undated), Appropriate Landfilling of Solid Waste, DFID, UK

Döbeli, Juan Carlos, 1999, Communication and Report

Dunford, Jane, 1998, Finders Keepers, 70/third quarter, VSO Publications

Forbes, 1995

Frey, R, 1999, Communication and Laboratory Report

Gibriel A. Y., 1999, Discussion R'99

Jewaskiewitz, Stan, 1999, Discussions at R'99

Macfarlane, Colin J. & Rushbrook, Philip, 1996, Municipal Solid Waste Management in Middle-and-Lower-Income Countries, WHO

McLean, Michelle, 1999, Discussion R'99

Neal, A. W., 1938, Refuse Destructors and Separation, London, The Technical Press Ltd.

Oluwande, PA, 1984, 'Assessment of Solid Waste Management Problems in China and Africa', Managing Solid Waste in Developing Countries, Ed. John Holmes, J Wiley and Sons, UK

Sikka, Dr. Pavan, 1999, Pelletisation of Indian MSW etc.; presented at R'99

Strirrup, FL, 1965, Public Cleansing Refuse Disposal, Ch. 8 Incineration, Pergamon Press, UK 1965

Swithenbank J, Nassezadeh V, Goh R, & Siddall RG, (undated), Fundamental Principles of Incinerator Design, First International Symposium on Incineration and Flue Gas Technologies

UNEP, 1996, International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management

UNEP, 1998, Web site Newsletter and Technical Publications Municipal Solid Waste Management

Appendix 1

Terms of Reference and Itinerary

TOR for Roberto Vogal and Andy Russell: Proposed Plan for Technical Review 1.1.4

1. Aims and objectives:

- Identify recent developments in waste management w.r.t waste incineration.
- Review current incinerator technology.
- Identify historic technologies and extract useful lessons for the project.
- Review and evaluate incinerator technology currently used and developed in or for developing countries.

2. Output

The consultants will produce a technical report presenting the findings of the review and recommendations for the technical development phase of the project including:

- relevant information for socio-economic review (e.g. has country got industrial base?, other technical requirements identified during inception meeting etc.),
- pre-concepts for Phase 2 (including European technology), and
- waste management concepts (from core studies) to define how this project interfaces with the bigger picture.

3. Proposed work plan

1. Research and review studies on waste management in developing countries (RV & AR)
2. Review and evaluated existing incinerator technology including visit to AEA library (RV)
3. Review and evaluate incinerator technology currently use and developed for or in developing countries (AR)
4. Visit to Cambridge (RV & AR)
5. Report findings (RV & AR)

Information sources

- British library
- SCAT
- Internet
- IWM library
- AEA library
- Warwick University (discussion with Terry Thomas)
- ENDS report, IChemE, IMechE, Coventry University, ETSU.

4. Time use

RV - 10 days	AR - 10 days
5 days research	5 days research
2 days draft findings	2 days draft findings
1 day meeting	1 day meeting
1 day final report	1 day final report
1 day reserve	1 day reserve

5. Timescale

Work started early January 1999.
Final report to be delivered to ITC by end of February 1999.

Appendix 2

Table Information Sources

This information is available on request.

Appendix 3

Outline Design Specifications for Purposes of Literature Search/Manufacturers Questions

1. Waste Properties/Throughput (Draft)

- Waste composition (Municipal Solid Waste): Garden/Food waste 40 – 60 %; Paper 2 – 15%; Fines 10 – 30%; Inert 2 – 15%
- Waste CV_{net} 4000 – 9000 kJ/kg
- Waste throughput 750 – 1000 kg/h

1. Loading, Ash Handling

- Top loading: through a circular opening in furnace roof
- De-ashing: manually through ash door

1. Combustion

- Refractory: brick, castable; specify
- 1 x FD fan for all combustion air
- Pre-heating of primary air by heat exchanger from flue gases (or viable alternative)
- Secondary combustion: 1 sec. at 800 °C and secondary air injection (with CV net of 7000 kJ/kg)
- Auxiliary fuel: preferred option by way of top-loading solid auxiliary fuel; low cost burners for fuel oil considered

1. Gas Cooling and Gas Cleaning

- Cyclonic gas cleaning only (specify)
- Gas cooling (please propose)
- Flue gas transport; thermo syphon (updraft from stack) or ID fan (please specify)

1. Assembly, Operational Maintenance

- Keep Assembly, Operation and Maintenance simple
- No special tools
- Operators & Maintainers to be trained on-site
- Manual controls
- Monitoring instrumentation to be kept as simple as possible

– Lubricants and spares to be locally available

1. Options for Retrofit to be Considered

– Heat recovery
– Further gas cleaning

Note to Outline Specifications

These specifications are not intended to be restrictive in the sense that practicable and cost efficient alternatives are encouraged. The specifications are intended to focus the manufacturer's/bidder's mind and narrow down the number of alternative designs. In particular it is noted that the aim of achieving the daily throughput may be realised with more than one unit.

The aim is to design, build and operate a simple and reliable Municipal Solid Waste combustion device for the use of lesser developed countries at a moderate cost and causing a minimum of hazardous emissions and nuisance. Residuals should be of low hazard and biologically inert (i.e. good burnout).

The waste quality/quantity compositions are an approximation of the wastes that can be expected in an as yet unidentified lesser developed country. The operations are intended to be 2-shift, with a daily throughput of 10 t/day, so heat conservation during daily downtime should be considered.

If the manufacturer/bidder has concepts regarding front-end sorting/treatment and back end ash handling, these concepts are not excluded from the specification. However, the scope of the proposed scheme must be clearly stated.

Appendix 4

Country Questionnaire

Notes for Socio-economic Review

1. Has the country got an industrial base?
   - Formal and informal engineering sector (fabrication, casting, steel manufacture etc.)
   - Brick manufacture
   - Refractories industry (refractory bricks and castables)
   - Chemical, food and drink.

2. Materials availability
   - Mild steel (angle, channel, tube, sheet, plate etc.)
   - Stainless steel (as for mild steel)
   - Electrical (motors, switch gear).
   - Refractory materials (fire bricks, clays, cements etc)

3. Education facilities.
   - How is the engineering sector supported by education.
   - Are there university/technical colleges with test/laboratory facilities for testing emissions to air/water/land etc.
   - Apprenticeship schemes

4. Rainfall statistic
   - What is the average yearly rain fall
   - Is it seasonal or year round?

5. Availability of waste statistics
   - Type (municipal, industrial, medical)
   - Quantity
   - Composition
   - Moisture
   - Calorific value
   - Copies of reports of studies undertaken on any of the above

6. Local manufacture of incinerators or furnaces
   - Is there any local industry engaged in the manufacture of incinerators of any type (solid waste, medical waste etc.) or solid fuel combustion systems.

7. Employment
   - Current levels of unemployment, urban and rural.
   - Average local pay levels for consultants, managerial, skilled and general

labour.

8. Current waste management practice.
   - Who is responsible? and do local communities become involved?
   - Who pays?

9. Incineration
   - Is incineration currently practised as part of waste management schemes
   - Historic data on incineration projects (when and where, successful or unsuccessful - why, any reports etc.

10. Legislation/regulatory
    - Planning regulations (summary).
    - Releases to air/water/land (summary of regulations).
    - Are consents required for releases to air/water/land (summary of consent regulations and information on how to obtain consents).

11. Is there a general perception of a waste management problem by:
    - Government both National and Local (any reports, documents, proposals etc.) documentation
    - Local community
    - Local environmental organisations and other NGO (reports, documents etc.).

12. How is incineration viewed by:
    - Government policies.
    - Local communities.
    - Local environmental pressure groups and other NGOs.
    - Any reports documents to support views.

13. Are communities and Government environmentally aware
    - How much are peopling willing to pay for improvements to waste management
    - Is there a willingness support for local incineration initiative.

Appendix 5

The Challenge of Waste Management in low-income Countries
Dr. David Wilson 1998

Appendix 6

Results of Further Research

DFID Further Work

Appendix 6

Results of Further Research

1. Introduction

The cut-off date for the main body of the technical review report was the 15th February 1999 but many replies from our enquiries were still outstanding.

Moreover we found that evidence from large scale incineration and data from small scale schemes in South Africa were difficult to obtain. Other additional information was hoped for from the R'99 Conference follow-up.

Therefore an extension to the preliminary technical review was granted (Reference Number 1.1.4.1). In order to be able to finish and present the report as it stood it was decided to place any additional findings in this, Appendix 6.

Details of all enquiries made are confirmed in the Tables of Information Sources (1) and (2) below at the end of this Appendix.

2. Large Scale Incineration in Middle to Lower Income Countries (MLICs)

Danida

After contacting the Danish Ministry for Foreign Affairs we were referred to the Danish Embassy in New Delhi. Two emails were sent several weeks apart requesting information on this project and offering confidential treatment of information received. No response has been received to date (May 1999).

Dar Es Salaam

The project manager (Kieron Crawley) is attempting to collect information through diplomatic channels.

Surabaya, Indonesia

I have been able to obtain some reports from this scheme. This information can be summarised as follows:

- Population of Surabaya (1995) 758,000
- Waste arisings 1,925 t/day
- Plant site area 3.5 hectare
- Plant contractors: Cadoux Incorporated, France

–	Waste storage capacity	625 t in 2 pits
–	Combustion plant	6 x 33.6 t/d (1.4 t/h)
–	Gas cleaning & stacks: no gas cooling or cleaning	6 x 21 m stacks
–	Date commissioned	1993/94 (?)
–	Oil consumption 1995/96 (Distillation residue from refinery)	1,518,000 litres

– **Combustion conditions** and releases to air:

Primary combustion	800/900 °C
Secondary combustion	500/600 °C
(However a visitor reports not having seen temperatures in excess of 500 °C)	
Release to air at temperature set point of 800 °C (April 96)	
SO_x	41.800 mg/m^3
NO_x	1.518 mg/m^3
Particulates	26.920 mg/m^3
CO	0.000 % vol.

(Note: units and values are not clear from the reports at our disposal.)

– **Dispersion modelling** based on emission data dispersion modelling was carried out and demonstrated that the highest ground level concentrations for pollutant were at around 1000 m from the stack and in the region of:

28 μg/m^3	(SO_x)
0.6 pg/m^3	(NO_x)
7 μg/m^3	(Particulates)
1800 μg/m^3	(CO)

(Note: dispersion modelling was carried out in 1992; it is not clear what emission data it was based on.)

Surabaya – Operating Problems

– Some rain water ingress in bunkers makes waste even wetter. Big problems with waste wetness during the rainy season.

– Combustion process:

- Problems with high plastic content in waste
- Probably very low combustion temperature with wet waste (especially in the rainy season)
- A breakdown statistic mentions burners (45%) and the fire grate (26%) as the major problem areas followed by the push ram, ash grate and fuel pump (9%) and forced draft from (7%).
- One report mentions that if the secondary combustion burners are switched on the gases out of the stack turn from black to white.

Surabaya – Conclusions

The main problems can be summarised as:

- Low CV (3910 – 6604 kJ/kg); operators would now like to retrofit some kind of waste drying.
- The operators are not 100% familiar with the imported equipment.
  - The Environmental Impact Study does not seem to be carried out using actual emission data; emission data is not well documented, doubts about its validity arise.
  - Plastic in waste sometimes causes major breakdowns and off-line repair work.
  - To our knowledge this plant was purchased by the Surabaya Local Authority with no mention of donor money and is still operating at the present data.

Through Dr. Seier we have become aware of a number of incineration plants in Seoul, Korea of > 100,000 t/a built by Steinmüller. Problems reported are operational problems due to management, high water content in waste and high fuel oil consumption.

3. The South African Experience

We have been able to identify one waste management strategy in Ixopo in South Africa which included small scale waste incineration as an important element. We have spoken to the contractors (Johnson Thermal Engineering) and the consultants involved (Ray Lombard Associates).

It is noted that we asked all the other three contacts to submit reference plant information but have not yet received any such information from them. (See Table of Information Sources and Summary Findings (1) and (2) in this Appendix.)

Ixopo Municipal Waste Recycling and Incinerator Facility

This operation deals with waste from the Ixopo Transitional Council (Ixopo TLC) and medical waste from various hospitals and clinics in Kwazulu, Natal.

The following summarised information is derived from an Environmental and Operational Audit (Ref. 6.1) and several emails from Ray Lombard Associates and Johnson Thermal Engineering.

- Total waste delivered to the facility is approximately 145 tonnes per month - 31 tonnes medical waste, 114 tonnes general waste
- The quantities of cardboard removed for recycling are unknown. A program for the recovery of PVC, tins and non-combustibles is currently being implemented. No figures are as yet available.
- The incinerator has a total of 5 staff; (1 Manager, 1 Assistant Manager and 3 Operators.) and operates on one shift per day, 6 days a week -normal working hours.

- The volume of ash is approximately 1 - 3 cubic metres per week but is expected to be substantially reduced when the recycling and recovery program is fully implemented.
- The results of emission and other tests carried out in April 1998 are as follows:

  - Temp: 779 – 842 degrees C
  - Velocity: 11.6 – 16.4 metres per second
  - Flow: 4.1 – 5.8 cubic metres per second
  - O_2: 11%
  - CO: 39 ppm
  - SO_2: 28 mg per normal cubic metre
  - Cl as HCl: 267 mg per normal cubic metre
  - Particulates: 163 mg per normal cubic metre
  - Phenolic substances as phenol: 3.8 mg per cubic metre
  - Nitriles as CN: 3.1 mg per cubic metre
  - NO as NO_2: 118 mg per cubic metre

The plant is operated by a private contractor, Compass Waste Services, on behalf of Ixopo TLC.

I am not aware of any detailed EIA from the releases to air. No visible emissions from the stack are reported. According to Ref. 6.1 HCl, SO_2 and Particulates exceeded their provisional permit to operate (these limits are not known to us at present).

Ixopo Plant Details

Type:
TOXIC 400 from Johnson Thermal Engineering.

Combustion Principle:
Sub-stoichiometric primary chamber (static hearth) followed by a secondary chamber above exiting directly into a 21 m stack.

Feeding:
Hydraulic ram through guillotine door.

De-ashing:
De-ashing door at opposite end (manual?)

Combustion air:

Primary:	By natural draft, damper controlled
Secondary:	By variable speed FD fan

Burners:

Primary combustion:	1 burner (oil or gas)
Secondary combustion:	2 burners (oil or gas)

Controls & Monitoring:

- Dampers, FD fan speed, burner controls with plc (20 inputs and 12 outputs)
- Temperature monitoring primary & secondary combustion and chart recording
- Start-up/Shutdown sequence in auto-mode

Electrical Supply:
380 V/3-phase/50 Hz 4 wire, 20 kVA is installed power rating.

Cost Ex-Works:
£85 k

Fuel Cost:
£5 / tonne of waste treated

Civil Engineering:

- Shed covering incinerator and giving protection from driving rain and concrete slab surface.
- Sheltered adjacent concrete area for waste storage and separation.

4. R'99 Conference Contacts

Cards left at the poster session were processed and further information sent to the card owners. This led to contacting Dr. Seier who is developing a medium sized waste incineration facility for Korea at the Research Institute Karlsruhe (Forschungszentrum Karlsruhe).

This combustion system is based on a series of fluidising nozzle grates, gas cooling (no heat recovery) and a dry gas cleaning system. Design throughput is 30,000 t/a of low CV waste, the emission standard is based on the German 17. BImSch and the investment cost is DM 12m. Although the scale of this project is much greater and the technical standard high we will keep in contact with Dr. Seier and exchange information on selected subjects of our respective projects (e.g. low cost fabric filters).

Out of the other people contacted (see Tables of Information Sources) only Stan Jewaskiewitz led to further information, i.e. Ray Lombard and the Ixopo TLC project.

5. Techtrol Proposal

After missing the cut-off date of 15.02.99 their proposal was received on 08.03.99. Their detailed costing proposal for the Pyrotec 6750 is summarised below:

Throughput:	750 kg of MSW
CV:	6,500 kJ/kg
Combustion:	Primary and secondary combustion chambers
Burners:	2 in primary and 2 in secondary
Fuel:	Oil

Feed:	Hydraulic ram
Secondary chamber:	850 °C & 1 sec. residence
Stack height:	16 m
Controls and monitoring:	plc and temperature monitoring on primary/secondary combustion
Electrical supply:	415 V, 3-phase, 4 wire, 50 Hz, 80 A, anticipated usage 8 kW (without heat recovery)
Oil consumption:	70 l/hour operation (anticipated)
Price ex-works:	£130,000

6. Others

Discussion with Dr. Luis F. Diaz – 29th April 1999 at the WHO Seminar, Almaty, Kazakhstan

Q: Gut reaction to Low Cost Incineration (LCI) in Middle to Lower Income Countries (MLICs)?

A: Concern for releases to atmosphere:
With landfill substances are at least confined and concentrated; with incineration they become dispersed albeit diluted.

Q: Do you know the Enerwaste company?

A: No. RV to send contact details and web address, LD will look into.

Q: Do you know of publications on the subject of low cost incineration?

A: LD will look into and email if useful.

Q: How could Waste Incineration (LCI) fit into an overall strategy in the MLICs context?

A: Individually, case by case.

Q: Any references (for further study) of past successes or failures?
For plants in MLICs (Dheli, Dar Es Salaam, Thailand etc.)

A: Go to Dheli! Believe that the report on Dheli has been suppressed. Dar Es Salaam report is somewhere, try the World Bank. LD will look for report.

General thoughts on incineration:

Small scale facilities in MLICs: naturally looking for low cost, low technology. Incineration is not low cost or low technology – may be a mismatch between what is required and what incineration stands for.

There may be room for combustion as a waste treatment process but it needs to be thought out and robust.

7. Conclusions (Tentative as of 17:00 Friday 7th May 1999, to be reviewed)

Our conclusions relate to the experience of large scale waste incineration projects and to the feasibility of low cost incineration in MLICs.

Large scale incineration projects have been suffering problems with low calorific value waste, poor environmental performance and reporting and also problems associated with poor management and inappropriate technology.

It can be assumed that often technology was transferred from a 'Western' context with insufficient regard to adapting 'hard' aspects (waste characteristics) and 'soft' aspects (training, operational routines) of this technology to the MLIC's individual set of circumstances.

This has resulted in a poor performance record (low availability), high operating cost (oil) and such a poor environmental performance record that in many MLICs this waste treatment option is regarded with great suspicion.

Low cost incineration is presently used in at least one case (Ixopo, South Africa) as part of an integrated waste management strategy and with due regard to its environmental impact. This project demonstrates that even in a low cost situation a certain price has to be paid for achieving a modest but acceptable environmental performance.

We believe that the Ixopo operations and lessons from there have a high relevance for the Low Cost Incinerator project.

References for Appendix 6

Environmental and Operational Audit of the Ixopo Municipal Waste Recycling and Incinerator Facility, January 1999 *(18 February 1999; Ref.: Ixincaudit 199; Ixopo Transitional Council, P O Box 132, Ixopo 3276)*