Reducing Pollution from Urban Waste in Africa

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1 Introduction

Open dumping and burning of domestic and commercial waste is a common phenomenon in many developing countries. Burning often takes place at waste disposal sites and can be the result of spontaneous combustion or deliberate attempts to reduce waste volume. As well as the health hazards posed by vermin and scavenging undertaken without protective clothing, the open burning of waste leads to toxic releases to both groundwater and air. These contribute to lasting damage to the environment, with serious implications for the health of local people and livestock.

To tackle waste disposal problems successfully, it is important that the authorities concerned have at their disposal appropriate waste management strategies and technologies together with guidelines on how and when to use them. This project sets out to establish whether low-cost small-scale incineration, up to 10 tonnes per day, can and should be added to a 'tool box' for use by local authorities in developing countries who face a growing problem of waste in their towns and cities.

A Department for International Development (DFID) funded project was established to research, design, build and test an appropriate incinerator that can be constructed at low cost, using locally available materials to promote cleaner and more complete combustion. A major aspect of the project was to investigate how the incinerator could be integrated into a waste management system – waste sorting and handling, recycling, income generation, and bringing on board those who, usually in the informal sector, derive a living by scavenging from waste dump sites.

A full scale prototype was built and tested in the UK to assess whether it would meet the design criteria in terms of waste pre-sorting and materials recovery, operating temperature, waste throughput, emission levels and structural integrity. Throughout the test period flue gas emissions were monitored, including O_2, CO, NOx, and particulates. Other emissions such as HCl, HM, and PCDD/F were also monitored on one test operation only.

The paper will present the findings of the research (technical and socio-economic), undertaken in the UK and a number of developing countries, that informed and underpinned the design of the prototype incinerator, followed by details of the results and lessons learnt during the design, construction and testing of the prototype.

2 Technical review

The main aim of the technical review was to develop the technical criteria on which a design for a low cost incinerator could be developed. To achieve this a number of desk top investigations and field trips were undertaken:

- Review of current European practice in waste incineration
- Review of incineration in the UK
- Review of current waste incineration practice in developing countries

- Field visit to South Africa.

As the project is concerned with small-scale incineration the technical review focused on incinerators in the range 0.5 to 1 t/h.

The review of current European practice indicated that the majority of municipal solid waste (MSW) incinerators are large scale although there are some companies offering small-scale incinerators in the range of 0.5 to 1 t/h. Typically incinerators of this size requires dry waste (i.e. moisture content of 40% or less) with a calorific value of 9,000 kJ/kg, have high levels of automation (waste handling, waste feeding, combustion air, flue-gas clean up, etc) and have capital costs of £1 to 1.7 million.

Early 20th century incinerators (or refuse destructors as they were known) in the UK were studied to take advantage of experience gained with ‘low tech’ processes early last century. These types of incinerators have a high thermal mass, are constructed from relatively cheap and common materials (bricks, steel frames and tie bars, cast iron grates, etc), and tended to be manually operated. In some cases pre-heated combustion air was introduced via a steam-driven fan under the grate.

In developing countries the open burning in bonfires is common practice 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, both as a means of disposal and to generate smoke to drive away mosquitoes (UNEP, 1996).

Also in many Asian and African countries it is common practice for people in the informal sector, who derive a living by recycling materials from waste, to burn rubbish piles, so 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).

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 found other than that of an incinerator made from cement blocks with steel frames and stacks. Refuse is deposited on the ground close to the incinerator and sun-dried to some extent. These simple incinerators, each strategically located to serve 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 0.25 kg per person per day.

More advanced purpose made small-scale incineration plant was identified in South Africa and India. A study tour of South Africa identified a number of small-scale incinerators ranging from relatively cheap, simple, manually-operated plant to more expensive (£80,000 plus) plant using modern refractory materials, oil burners and some degree of automation (MSW feed and combustion control).

The main issues with incineration in medium and low income countries (MLICs) were identified:

- Low net calorific values (CVs) for MSW of between 3400 and 7500 kJ/kg
- Use of inappropriate technology (too large and sophisticated).
- Pollution, or fear of pollution, and a generally negative attitude as a consequence.
- Incineration should fit in with the existing waste management structure (formal and/or informal).

3 Socio-economic review

The main aims were to identify whether small-scale low-cost incineration (LCI) has a valid role to play in waste management in MLICs, and to select a partner country in which a pilot plant could be built and tested under 'real' conditions.

The process was undertaken in two phases: the first to assess the need and demand for a LCI and the second to identify a suitable partner country.

A number of assumptions were made in order to carry out the evaluation:

- The small-scale incinerator will have a throughput of 10 tonnes per day
- The cost to build the incinerator will be around £20,000 (including materials and labour)
- The incinerator will not create significant adverse environmental impact and will offer improvements over a situation where open burning takes place.
- The waste to be incinerated will consist of MSW only.
- The plant will require a waste mix with a calorific value of at least 7000 kJ/kg in order for combustion in the incinerator to be self sustaining.

3.1 Need and demand

In the context of this project need was defined as the existence of problems which may be alleviated by use of the low-cost incinerator. Need then develops into demand when the problem is perceived to be significant and the country in question has an ability and willingness to finance the cost of providing the technology.

A desk top review of countries was carried out to establish the existence of need and demand against the following criteria:

The criteria used for establishing a need for an incinerator were:

1. Does open burning and uncontrolled dumping presents a major health hazard through degradation of water and air quality?
2. Do enough communities exist, producing waste at a rate of at least 10 tonnes per hour, to justify the development of the incinerator?
3. Is the waste collected and delivered to a central point?
4. Is the cost of engineering controlled landfill, especially for smaller communities, prohibitively expensive?
5. Does the MSW have a reasonably high calorific value or else is there available a suitable co-firing fuel to improve the overall CV of the waste?

Demand:

6. Is there an awareness of health and environment issues in government and the general population?
7. Is the concept of the incinerator acceptable?
8. Is the incinerator affordable?

A representative sample of MLICs in three geographical regions were investigated: the Caribbean, Asia and Africa/Middle East. South America was not included largely because of language difficulties. The findings of the survey indicated that Caribbean and Asian countries did not demonstrate a valid need for a low-cost incinerator. In Africa, however, a need could be shown to exist in several countries and therefore a demand assessment was undertaken for these countries.

Table 1 Review of need and demand in African countries

Country	NEED CRITERIA						DEMAND CRITERIA			
	1	2	3	4	5	Need	6	7	8	Demand
Botswana	✓	✓	✓	×	✓	×	✓	?	✓	✓?
Egypt	✓	✓	✓	✓?	✓?	✓?	✓	✓	?	✓?
Eritrea	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ghana	✓	✓	✓	✓	✓?	✓?	✓	✓	✓	✓
Kenya	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Malawi	✓	✓	✓	✓	✓?	✓?	✓	?	✓	✓?
Morocco	✓	✓	✓	✓?	✓?	✓?	✓	?	✓?	✓?
Palestine	✓	✓	✓	✓?	✓?	✓?	✓	✓	✓	✓
Tanzania	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
The Gambia	✓	✓	✓	✓	✓?	✓?	✓	✓	✓	✓
Zimbabwe	✓	?	✓	×	?	×	✓	?	✓	✓?

Although it is more difficult to establish the existence of demand from a desk study it was possible to make some assessment against the criteria based on information that was available and previous experience of members of the project team.

From this survey four countries were selected for more detailed study, including a field trip, to evaluate demand. The main criteria for selecting the short list was that the central government of the country showed a positive interest in participating in the project. However, other criteria such as political stability, DFID's local strategy and English language capability were also important.

The four countries chosen were Kenya, Malawi, The Gambia and Zimbabwe. On completion of the studies, the countries were ranked and The Gambia was chosen as the partner country.

4 Prototype design

Based on the findings of the socio-economic and technical review (including in-country visits) the following technical criteria were developed for a prototype incinerator:

Front-end operation

- Pre-sorting to remove non-combustibles (glass, metal etc), PVC, batteries and other fractions which could cause pollution when incinerated, and some organic fractions.
- Sorting area and storage of pre-sorted waste to be as close as possible to feeding position to minimise internal transport.
- Manual feeding

Combustion

- Combustion must be self-sustaining without using fossil fuel burners.
- Achieve combustion temperatures of at least 850°C for 2 seconds.
- High thermal mass combustion chamber.

- Sub-stoichiometric combustion in the primary chamber under natural draught conditions.
- Operate with MSW of calorific value 5000 – 9800 kJ/kg (MCR 7000kJ/kg).
- Manual stoking and de-ashing to be undertaken in a manner that minimises air ingress and without compromising the operators' health and safety.
- Forced draught secondary combustion to promote complete combustion.
- Locally available biomass derived support fuels can be mixed with the MSW as required and also be used for start-up and close down.

Construction

- The LCI should be built using appropriate materials and building techniques that match the materials and building skills available in the majority of developing countries.
- The LCI should be capable of being operated and maintained using locally available skills and materials.

The design consists of an inner refractory-brick built incinerator surrounded by an outer protective wall made from standard cement blocks (to keep people away from hot surfaces). There is a gap of approximately 300 mm 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 vertical, without a roof, and follows the contour of the incinerator. Figure 1 shows the basic layout.

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 (one drying and two combustion grates) inclined at 20^{o} 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. Combustion takes place under sub-stoichiometric conditions and using natural draught.

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, forcing hot gases to pass first vertically downwards, then vertically upwards. After the secondary chamber the hot gases pass into the tertiary chamber, where they are cooled by mixing with cool air. From the tertiary chamber a connector joins the system to the existing smoke gas stack of the 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, so helping to reduce the likelihood of air ingress into the combustion chamber and also acting as a low-cost insulation material.

MSW is fed from the drying grate end of the primary chamber and residuals removed from the other. Stoking is manual, using a combination of agitators and raddles on the grates and forcing the MSW onto the drying grate from the feed chute.

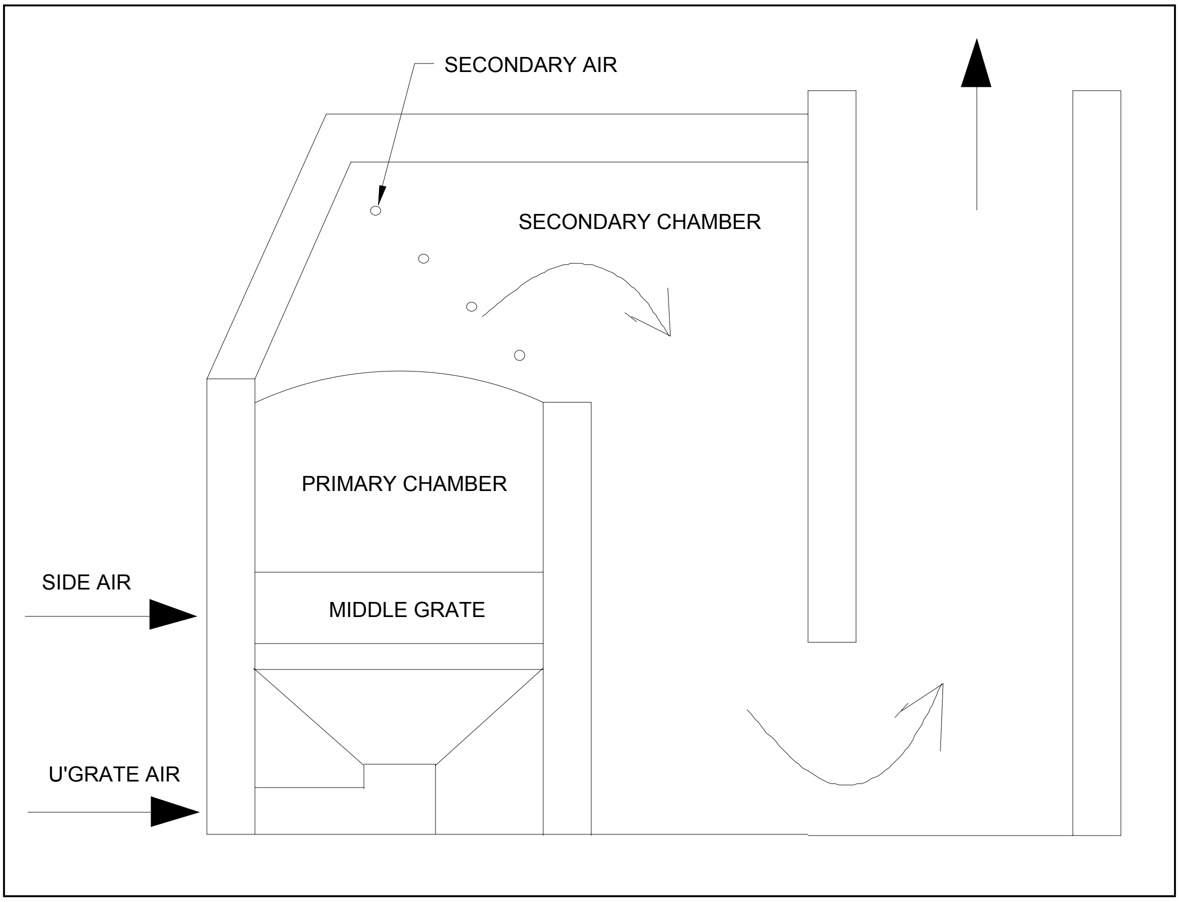

Figure 1: Incinerator layout

5 Test results

Construction and testing were undertaken in the UK at a site owned and operated by EMC Ltd (formerly the Coal Research Establishment, CRE) 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 incinerator.

The only technical issue associated with the test site was the distance between the incinerator, located under an existing covered area, and the nearest suitable stack. The stack was approximately 12 metres from the incinerator and necessitated the use of horizontal ducting to connect the stack to the incinerator.

The LCI was tested on both biomass (wood chip) and municipal solid waste (MSW). Altogether eight tests were carried out using wood chip and six 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 the scheduled test using municipal solid waste (MSW) to simulate real conditions. In addition wood chip was used to fire up the incinerator to achieve nominal operating conditions (i.e. temperature, O_2 and CO emissions) 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 grant the sorting tests an exemption from Waste Management Licensing at EMC's site. Grundon Waste Ltd organised the waste sorting team and provided general site supervision. The LCI project team provided a short training session at the beginning of each day's sorting and provided a limited amount of supervision. All bins were numbered and the empty weight noted. Full bins were then weighed before delivery to the incinerator 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.

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 and glass content should have been controlled by the sorting operations. Due to the remoteness of the sorting, poor motivation of the temporary staff employed to sort the waste, and inadequate supervision (by the LCI team) this part of the test operations was disappointing.

After each MSW test the primary chamber was opened up and the ash removed, weighed and analysed for loss on ignition. 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.

As would be expected from a prototype a number of problems were encountered during the testing, including:

- Internal stoking system burnt out.
- Poor sorting of MSW resulted in large quantities of glass and metals entering the incinerator.
- Some MSW was very wet, resulting in poor combustion conditions.
- Build up of ash in corners of 'S' chamber and the long horizontal sections of the stack connection duct.

Continuous monitoring for temperature, air flow, 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 air flow using a Testo 445 fitted with a hot bulb anemometer. Forced air flow was measured using pitot tubes in secondary air duct and tertiary air duct. Air flow monitoring calibration was carried out during commissioning, ensuring an accurate reading by use of correction factors (pitot tube grid measurement and mass balance).

Emissions: O_2, CO, NO, NO_2, and SO_2 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 a PCME meter fitted across the main exhaust stack. This gave continuous readings through all the tests. (This unit was only calibrated against the gravimetric monitoring results during MSW6 run).

The results of the tests are summarised in Table 2.

In addition EMC were contracted to undertake an assessment of emissions to atmosphere in accordance with the relevant British Standards and UKAS accreditation. Table 3 summarises the test average results measured by EMC during MSW test 6.

The 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 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 similar components in the waste will be less than in the UK.

Table 2: 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 (out)	^{o}C	922	860	763	761	842	935
Secondary (out)	^{o}C	564	587	470	483	498	511
Tertiary	^{o}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

The full inspection of both the primary and secondary chambers (after the last test operation) showed some cracking of the refractory bricks and shrinkage of the fire cement joints. These can be minimised through the addition of expansion joints and applying a thinner layer of refractory cement to the joints.

Significant build up of ash had occurred on the floor, especially the corners, of the secondary chamber between the downward and upward section. Also ash was deposited along the length of the horizontal ducting that connects the LCI to the stack. This build up could have contributed towards the formation of dioxins through the de novo synthesis reaction.

6 Conclusions

The initial performance of the prototype incinerator, although some way short of meeting all its design criteria, was encouraging and it is felt that with some modifications it should be possible to meet most of the design specification..

Lessons learnt from the test work have led to a number of small modifications being incorporated into the design of second prototype to improve performance and reduce emissions. These include:

Table 3 Summary of CRE measurements of gaseous and particulate releases on 20/06/02[1]

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_xm^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 EMC, Stoke Orchard, Cheltenham.

- Improved stoking and feeding systems
- Pre-heated primary and secondary air
- Addition of expansion joints
- Improved internal geometry to prevent build-up of ash in the secondary chamber and tertiary chamber.

- Recirculating some of the combustion gases through the drying grate to promote better drying of the MSW
- Improved QA for the pre-sorting of MSW.

These modifications have now been incorporated into the design of the second prototype that is due to by built in The Gambia. The incinerators performance will then be operated and monitored under real conditions over a protracted period. If, and only if, the LCI proves to be acceptable will the construction drawings, the construction manual and operation manual be made available to third parties.

In parallel with the pilot project, an environmental monitoring programme using appropriate monitoring technology will be undertaken which will include training of staff working for The Gambian National Environment Agency.

References

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

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