INCINERATOR EMISSIONS

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The De Montfort Medical Waste Incinerator has been described by Picken and Bennett(1) and has now progressed from an experimental unit to an essential tool for hospitals and clinics in developing countries. More than 700 have now been built in Africa alone, and probably more than 1000 in total, mostly by the major Aid Agencies in conjunction with mass immunization campaigns. The design has been continuously refined in response to the discovered needs of the users, and it is now cheaper to build and more robust than the original. This model is shown in Figure 1.

Figure 1: Incinerator completed in Nairobi

In the main, it has fulfilled its primary objective very satisfactorily, in that it has reduced large quantities of general hospital waste and large numbers (over30 million in Africa in the last 2 years) of used hypodermics to ash at very high temperatures, and its fuel consumption has proved to be almost zero. It is popular with users for three main reasons; it is cheap to build, it uses locally available materials and labour thus saving hard currency, and it is easy to use.

It has however been criticised for the production of harmful exhaust gases, and the occasional high levels of smoke. These criticisms are mainly from environmentalists who are not technically involved in the real problems of medical waste.

This paper is an attempt to explain the mechanics of combustion of solid wastes, and to give some hard information on results derived from a total of four monitored tests carried out over a period of four years, and the logistics of disposal needs in developing countries. Some of the legal requirements of various countries will also be considered.

Mechanics of Combustion

The De Montfort Incinerator is a two chamber, cross flow design, with intermittent top loading, and air induced entirely by the action of a 4m chimney. It is normally operated entirely by the heat released by the burning of the load materials, but this can be supplemented with solid, liquid or gaseous fuel. The rate of combustion is governed by the rate of airflow into the primary combustion chamber.

If there is to be a minimum of fuel used, the combustion must be maintained by the exothermal reaction of the material with oxygen.

The principal reactions are those of carbon and hydrogen with oxygen.

Since the waste material is static, sufficient oxygen for complete combustion can only be obtained by either enriching the air with pure oxygen, or by moving the air past the material (c.f. turbulence in an internal combustion engine).

In the absence of power-driven turbulence, the air in the immediate vicinity of the burning waste material will inevitably be depleted of its oxygen content.

This oxygen starvation will lead to partial combustion of the carbon to CO rather than CO_2. Hydrogen will normally burn to H_2O.

Secondary combustion will take place if the CO and other intermediate products meet with oxygen or non-depleted air at a sufficiently high temperature for gaseous combustion to CO_2 to take place.

In an open fire, this secondary combustion can be observed as “flames” immediately above the burning material, as fresh air is drawn in to the zone by convection.

My incinerator design is an attempt to achieve this primary and secondary combustion with the minimum of airflow (to maintain high combustion temperatures and long residence time) and no outside power source.

Since combustion effectiveness is also a function of gas residence time (defined as the ratio of total combustion chamber volume to gas volume flow), it is important that the air volume flow is not too great, otherwise the incinerator dimensions would need to be increased with consequent cost penalties.

Environmental Considerations

Whereas the incinerator has been enthusiastically adopted and used in many developing countries, there is a body of opinion, which believes that emissions from the chimney can do such damage that other means of disposal must be used. Some national authorities take an intermediate position and insist on either using a very tall chimney to disperse the gases (e.g. India), or that an incinerator conforms to a standard such as the Best Practical Environmental Option, developed in South Africa.

The De Montfort incinerator has been tested on several occasions to investigate the content of the flue gases in terms of CO, Smoke, dioxins and furans. This paper will try to summarise the results of these tests so that informed rational decisions can be made on the desirability of using this cheap and versatile incinerator in the field.

Performance and Emissions Tests carried out

The original (**Mark 1**) incinerator had been tested by CSIR, in South Africa, in December 1999, Brent and Rodgers (2). Representative samples of waste from a typical primary health care centre were prepared by the South African Department of Health at the CSIR testing facilities. Emissions and destruction efficiencies were measured, and the principal findings were that "*the medical waste tested in the trial was rendered non-infectious, the syringes were destroyed and the needles were rendered unsuitable for use.*
The emission of particulates, metals and chlorides comply with South African regulations for primary health care clinical waste used in the South African trials on small-scale incinerators and the fuel to waste feed conditions for the tests. The combustion efficiency does not comply and the organic emissions are higher by a factor of at least 20 times."

It was noted that the test had been carried out at temperatures below 600°C, and that an undue quantity of wood was burned during the tests, which contributed to the high organic emissions.

The next test was of a **Mark 2** incinerator (same size primary combustion chamber, larger secondary combustion chamber) at De Montfort University. The load consisted of mixed medical waste, supplied by ECHO Health Care Ltd, but containing very few hypodermics. The principal findings were:

- "*the combustion chamber temperature was above 800°C for most of the test;*
- *for most of the running time there was no visible smoke emission. Only rarely did the smoke level exceed that which is considered acceptable in a diesel engine road vehicle. Such smoke as was collected proved to contain only carbon. No metallic elements were present;*
- *the flue gas was found to contain virtually no dioxins or furans;*
- *oxygen level in the flue gas varied between 4% and 16%;*
- *carbon monoxide level was mostly in the region of 100 ppm, with levels above 400 ppm occurring only rarely.*"

A third test was carried out on the **Mark 3** incinerator (larger primary and secondary combustion chambers) in the presence of observers from *Médecins Sans Frontières* in December 2000. This test was carried out to test the efficacy of the incinerator to burn wet textiles as well as general clinical and household waste. Some diesel fuel was added to maintain temperatures. The principal results were: "*In all cases, at least one of the temperature zones through which the flue gas had to pass exceeded 800°C. This was true even when the load consisted entirely of wet garments, as might be the case during an epidemic such as Ebola fever*".

These tests were of insufficient precision to satisfy some of the critics, so in May 2003, WHO funded a new test designed to quantify dioxin emissions when the incinerator was burning exclusively hypodermics.

Hypodermic Incineration Test

A new incinerator, built as a **Mark 8a**, was constructed at a site in Leicestershire. 8000 hypodermic syringes of various sizes were sent to the site by WHO. Casella CRE Emissions of Cheltenham were engaged to sample and analyse the exhaust gases, and the incinerator was operated by the designer and a technician. Two 2-hour tests were carried out, one at maximum loading rate, and one at a loading rate designed to limit smoke production. Loading rates, temperatures and smoke levels were recorded as well as the gas samples.

The following results were reported by Casella CRE Emissions, Ford (3), and by Picken (4).

Emission of PCDDs & PCDFs

Because there are several hundred closely related compounds, not all of which are toxic, the results are quoted as concentrations having the same toxicity equivalent (TEQ) as polychlorinated dibenzo-p-dioxins (PCDDs) or polychlorinated dibenzofurans (PCDFs), which are considered to be the most toxic.

For the two determinations undertaken, the upper limit and lower limit waste gas PCDD and PCDF concentrations were measured to be as in Table 1.

Table 1

Condition	Concentration ng/m^3 (TEQ)	
	Test 1	Test 2
Upper limit	0.1413	1.605
Lower Limit	0.0287	1.582

These figures were measured from samples take within the chimney; the dilution after leaving the chimney would greatly reduce the concentration.

The corresponding PCDD and PCDF discharge rates on an upper limit basis are shown in Table 2.

Table 2

Condition	Discharge rate ng/h (TEQ)	
	Test 1	Test 2
Upper limit	5	173

These figures compare with the average dioxin release from a typical family barbeque, cooking meats on a charcoal bed, of between 12 and 22ng, and concentrations in the vicinity of 0.6 to 0.7ng/cu.m.

Emission of PCBs

For the two determinations undertaken, the upper limit and lower limit waste gas PCB (polychlorinated biphenyl) concentrations are shown in Table 3.

Table 3

Condition	Concentration ng/m^3 (TEQ)	
	Test 1	Test 2
Upper limit	19.9	11.5
Lower Limit	0	0

The corresponding PCB discharge rates on an upper limit basis are shown in Table 4.

Table 4

Condition	Discharge rate ng/h (TEQ)	
	Test 1	Test 2
Upper limit	717	1242

In both cases none of the 12 dioxin-like PCBs targeted were detected in the samples collected, although detection limits were substantially higher than usual.

In both tests, the temperature of the gas path reached 800°C for nearly the whole test.

Smoke levels were unacceptably high for test one where loading rate was at a maximum, but lower for test 2. Figure 2 shows a smoke level considered to be unacceptable for use near a hospital or residential area.

Figure 2: Smoke due to overloading

Practices of Medical Waste Disposal encountered in developing countries

Common practices of medical waste disposal include open fires, open pit with occasional burning, shallow burial, storage – but no treatment, dry drum, "incinerator", disposal with general waste, dumping in isolated areas, throwing into a river or re-cycling without sterilisation.

These means variously lead to atmospheric pollution (seen within a few yards of operating theatres, delivery wards and canteens), water pollution, soiled ground, the opportunity for animal scavengers to forage for body parts, for children to find needles and use them as tooth-picks or to stab one another for fun, used needles to be re-used for medical or other purposes.

Human and Resource Problems Encountered

1. Lack of awareness of any problem.
2. Lack of knowledge of what actually happens (as against what is believed to happen).
3. Problem of "ownership" of the need for effective medical waste disposal. Medical waste disposal is not a "nice" subject, so there is a reluctance to accept responsibility for it.
4. Medical "culture" i.e. medical staff feel that their responsibilities finish once an injection is given or a soiled dressing removed.
5. Lack of resources at many rural hospitals i.e. very little money and few skilled people available.
6. Allocation of resources. Where there is some money, it is more likely to be spent on additional drugs or syringes, a new ward or operating theatre or equipment for them.
7. Social structure. In some cultures an injection is expected (with the consequential problem of acquiring and then disposing of the syringe).

8. Poverty of individuals. Where patients have to supply their own syringes, the cost of a new one is high compared, say, to a basic meal. There is therefore a great temptation to re-use a syringe – with the consequential risk of infection. It has been estimated that 2000 people per week are infected with hepatitis B as a result of using used syringes. The long term cost of treatment must be compared with the cost of a new syringe.
9. Inappropriate legislation. In India, for example, legislation was passed in the summer of 1998 with support criteria to say that the chimneys on medical waste incinerators had to be at least 30 meters high. Whilst understandable for large incinerators in city centres, such legislation may be inappropriate for rural areas. This may result in waste being left untreated or the law disregarded.
10. Lack of provision of fuel by hospital authority. Little (if any) identification of the waste in waste bags. Very wet kitchen waste is sometimes included in the loads.
11. Operators are often not trained to use the incinerator properly.
12. Operators are often not allowed the time to operate the incinerator properly.
13. Incorrect sitting of the incinerator (too near to hospital wards or housing).

Conclusion

The sole purpose of this paper is to report facts on what has become an emotional issue. The test results reported are the only objective results available, and they represent only spot checks of limited duration with specific loads. However they do put into context the claims sometimes made that incineration is always the most dangerous option for disposing of medical waste. All human activity tends to have some ill effects on the environment. Travelling particularly by air, is a case in point, as is manufacture, cooking, heating and cooling of houses. The desirability of undertaking any of these activities is a matter of judgement, and this is so for the incineration of toxic and contagious waste.

It is also evident that social, legal, economic and environmental considerations are part of the design equation. More complete combustion could be achieved in a more sophisticated incinerator, but its price would then put it beyond the reach of the hospitals and clinics that now use it. Non-combustion methods may result in less air pollution, but may give rise to other forms of pollution.

It is the responsibility of those who would ban incineration to find a solution that would be acceptable and economically possible. The alternatives that have been proposed to date do not seem to be realistic, and would leave a residue of highly infectious waste after every immunization campaign. The results also question whether barbeques or open fires are ethically responsible.

Figure 3: Hospital waste in Kosovo before incinerators were built

References

1. Picken D.J and Bennett M.C., 2000
   (UK ISSN 0963-3308 - Reference No 2000/014)
2. Brent AC and Rodgers Dec. 1999. CSIR Contract Report 86DD/HT200
3. Ford N., 2003. Report to WHO
4. Picken DJ, 2003. Report to WHO