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IMPROVED COMBUSTION PROCESSES IN MEDICAL WASTES INCINERATORS FOR RURAL APPLICATIONS

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ABSTRACT:- *The emergence of sustainable development programmes and the problem associated with continued steady increase in population have increased public awareness and concern for the environment. In particular, the demand for health services has increased to an extent that the health sector produces large quantities of biomedical wastes that can have severe impact on the environment if not properly disposed. Although incineration is not a clean process of disposing these wastes, it is still a preferred method especially when operated at elevated temperatures. The problem in developing countries is that several incinerators either in rural or urban areas operate at low temperatures and are therefore sources of environmental pollution. This paper describes the use of cost effective and appropriate pollution control systems to achieve acceptable combustion conditions. A small rig was designed for conducting tests on the incineration of rural clinical wastes in Botswana. Experimental results showed that if proper combustion conditions are applied to low technology rural clinical waste incinerators, the operating temperatures could increase from around 400 to above 850^{o}C. It was concluded that by increasing the operating temperatures of the current disposal methods and using wet scrubber in rural clinical waste incinerators, the combustion conditions could be improved significantly.*

INTRODUCTION

Botswana is a semi-arid country with an approximate surface area of 576 000 square kilometres and an estimated population of 1.7 million that is growing at 2.4% per annum. Rural dwellers represent more than 70% of the country's population and these depend on traditional agriculture and pastoralism [1]. As part of the government's commitment to improve medical care, several health facilities have been built throughout the country. For example, in 1996 there were 30 general and primary hospitals, 209 clinics and 1001 health posts/mobile stops in Botswana. Hospitals are located in urban areas while clinics provide health services for both urban and rural communities. Health-posts and mobile-stops serve small settlements. It is estimated that currently the country produces 2.5Mt of clinical wastes per year [1, 2].

The expected increase in the volume of medical wastes in Botswana demands sound environmental and economic methods of disposal. Although disposal of biomedical wastes by incineration has been in practice over the years largely due to its hazardous nature, incineration is not a "total disposal" method because the materials contain non-combustibles, and have residual ash. Tillman [3] studied the combustion of solid wastes and found that medical waste has a calorific value, of over 387 kJ/kg. His work also showed that medical waste is highly reactive with a hydrogen-carbon and oxygen-carbon atomic ratio of 1.46 and 0.31 respectively. It was deduced that although these values were lower than the reactivity associated with mixed municipal solid waste based fuels, they were however, comparable to those for biomass fuels. Consequently, medical waste is a rich material from combustion perspectives.

From the environmental viewpoint, there is a strong concern about the level of air pollutants such as dioxins and furans from developed countries to minimise medical wastes and to encourage sterilisation by autoclaving to reduce the volume of disposable pharmaceutical and laboratory items [6, 7]. Recently, two medical facilities in Chicago, namely, Carle Foundation Hospital and Covenant Medical Center stopped medical waste incineration completely. They are determined to reduce waste, encourage the recycling option and use materials with less health effects if incinerated [8].

In many developing countries, including Botswana, it is essential that as a first step, disposal of clinical wastes should be carried out in an appropriate manner if sustainable health development is to be achieved.

METHODS OF CLINICAL WASTE DISPOSAL IN BOTSWANA

In Botswana, the disposal of clinical wastes is the responsibility of individual health facility but district or town councils may control the procedure. As expected, because of the lack of national guidelines and regulations waste disposal techniques vary from one centre to the other. The public awareness, in terms of human health hazards, damage to wildlife and the environment, as a result of inappropriate clinical waste disposal methods seems to be very low despite the implementation of the Canadian System of medical waste designation that provides information into the content of the waste stream [3]. For example, by the Canadian system, the infectious waste "red bag" normally contains materials contaminated with body fluids, blood, bandages exposed to wounds and other pathological materials. These hazardous wastes can either be buried in landfill or incinerated.

Many rural health providers have changed completely from landfill systems to incineration of one type or the other. Thus, current clinical waste disposal methods in Botswana may be grouped into three, namely, open pit combustion, low technology in-house incineration, and high technology in-house incineration. There are no commercial or central incinerators to handle biomedical wastes in Botswana.

Hincrichs [9] indicated that for complete combustion the incineration operating temperatures should usually be in the range of 850^{o}C to 1100^{o}C. It is important to note that the operating temperatures of low technology in-house incinerators were between 400^{o}C and 450^{o}C, while those of high technology in-house incinerators were found to be around 760^{o}C. Although it was not possible to establish the combustion temperatures of burning clinical waste in an open pit system, it may be assumed that the temperatures would be much lower than those in low technology in-house incinerators. Thus it can be expected that open pit incineration may not completely eliminate the pathogens.

It should be noted that, since more than 60% of the health facilities in Botswana are located in rural areas and remote settlements, the disposal of clinical wastes by incineration in these places either by open pit or low technology incineration may be injurious to human health. In these two clinical waste disposal methods, pollution controls are not usually employed. Since medical waste incinerators (MWI) have been identified as major contributors of dioxin to the environment, it can be inferred that medical waste disposal facilities in Botswana may be causing serious environmental damage.

Figure 1 shows a typical low technology in-house incineration plant used in village clinics. Most of these incinerators were found to be in very poor condition and as a result the flue gases did not discharge through the smokestack, but through cracks and other openings. It was also observed that the chimney height of between 2 to 3.5m was not adequate for proper dispersal of flue gases. It is certain that such chimney emissions will result in increased concentrations of pollutants in areas immediately downwind from the source. When interviewed, residents near sites at the low-technology incinerators perceived themselves as adversely affected by smoke pollutions. The investigation found that fossil fuels are frequently introduced into the combustion chamber of the incinerator as a measure to enhance combustion of wastes. The use of auxiliary fossil fuel to assist combustion is not currently encouraged in operating low technology in-house incinerators. However in this

Figure 1: Low technology in-house incinerator

study, a small quantity of paraffin was applied on top of the charge only to assist the initial ignition stage. In high technology in-house incineration plant, diesel fuel or coal was used to support combustion throughout the incineration process and the operating temperatures varied between 700°C to 900°C depending on the type of fossil fuel used.

EXPERIMENTAL PROCEDURE

The experimental rig is shown in figure 2. It is a cylindrical mild steel pot of 300 mm inside diameter and 440 mm height, internally lined with refractory bricks of thickness 60 mm. The primary air was fed to the windbox underneath the fuel grate by a forced draught fan, and a gate valve controlled the flow-rate. Thermocouples of the K-type were inserted through the wall to the centre of the pot to measure the fuel bed temperatures at distances of 25 mm and 410 mm from the grate. A wet flue gas scrubber was connected to the rigid flue duct fixed at a height of 0.8m above the pot combustor. Water was sprayed from three nozzles located uniformly around the circumference of the scrubbing drum. The cyclone performed a centrifugal deodorization by rotating the smoke and its particulate matters at high speed.

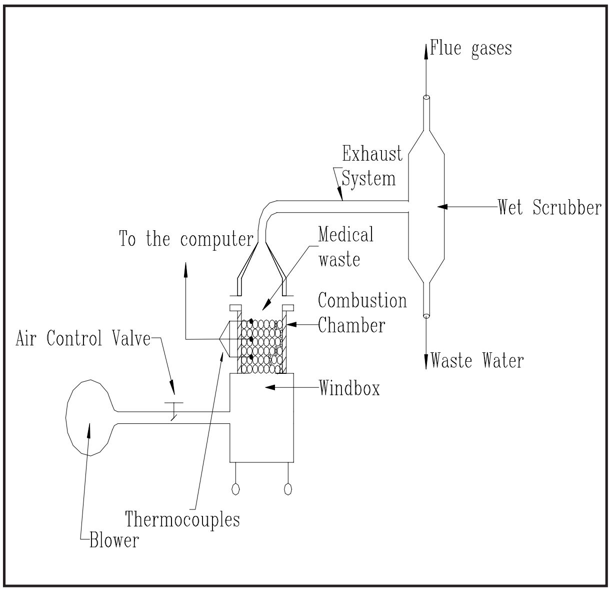

Figure 2: The combustion pot of the test rig

Prior to each test, the weight of the clinical waste was recorded and then charged into the pot combustor. The medical wastes of interest included soiled dressings, sponges, surgical gloves, disposable sheets, filters, plastic hypodermic tubings and syringes. To initiate combustion, a small (standardised 0.1 kg) mass of crushed charcoal soaked in methylated spirit was spread over the top surface of the fuel charge. The charge was then ignited manually by introducing a burning match. When combustion had commenced, the pot combustor was aligned with the fixed flue gas duct, and the primary air control valve was fully opened.

RESULTS AND DISCUSSION

Introduction

The authors performed combustion experiments using waste generated in a village health clinic. The main objective of this work was to determine the thermal characteristics and the emission levels from the combustion processes of typical village clinical waste at temperatures above the normal operating temperatures of between 400°C and 450°C. The results would then assist in providing a disposal system that would reduce the net environmental burden of biomedical incineration. For simplicity, only a sample of the results obtained from these experiments have been presented. This enables the main findings of the investigation to be identified and explained.

The stages of the combustion process

The combustion process for a solid fuel, unlike that for liquid and gaseous fuels usually takes place in two stages as shown in figure 3. These are known as the ignition, and the burnout stages [10, 11]. The ignition stage is assumed to start when the top of the fuel bed reaches its ignition temperature, while the burnout stage starts when the fuel at the base of the combustion chamber ignites. The burnout stage is assumed to finish when the fuel temperature begins to fall rapidly.

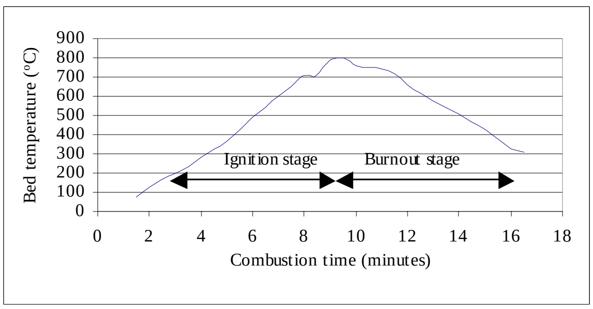

Figure 3: Two stages of combustion

RESULTS

Figure 4 depicts the typical temperature profile when the air pressure across the fuel bed was 250 mm H_20. It can be observed that the rate of reaction was relatively high which implies that the rate in which oxygen was absorbed by the reaction was low. It can therefore be inferred that relatively high level of volatile matter was present in clinical waste. In table 1 the highest recorded emission level of carbon monoxide occurred for the test conditions in figure 4 and this corroborates low rate of oxygen absorption. Figures 4 and 5 show the temperature profiles for the same bed weight but different airflow rates. From the two temperature profiles, it can be seen that the ignition and burnout stages were significantly extended as the airflow was reduced.

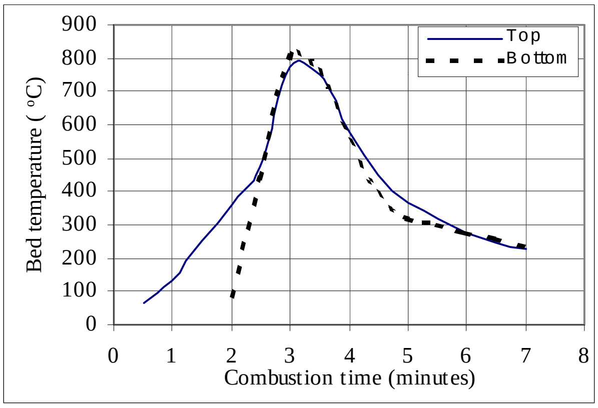

Figure 4: Temperature variation with combustion time (Δp across the fuel bed 250mm H_20)

Table 1: Variation of test conditions with pollutants

Test No.	Bed weight (kg) (Clinical waste)	Δh mmH2O across the fuel bed	Pollutants (ppm max)	
			C0	S02
1 (Fig 4)	1.10	250	4557	699
2 (Fig 5)	1.10	50	4191	394
3 (Fig 6)	1.33	7	41	3
4 (Fig 7)	1.22	Natural		

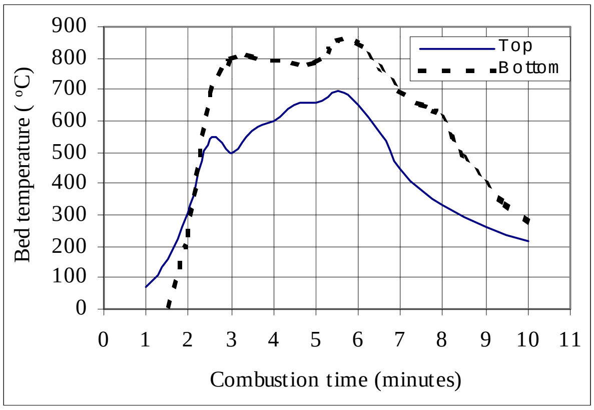

Figure 5: Temperature variation with combustion time (Δh across the fuel bed 50mm H_20)

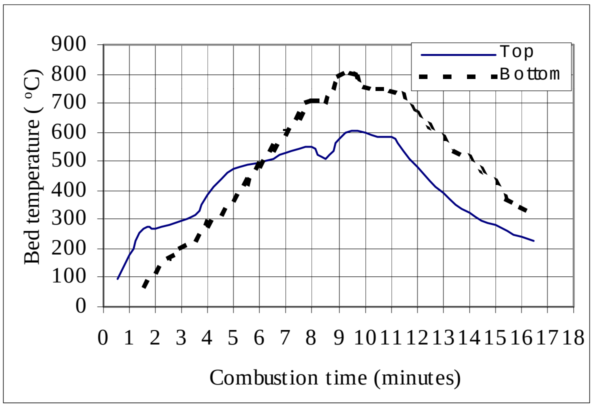

Fig. 6: Temperature variation with combustion time (Δh across the fuel bed 7mm H_20)

As the rate of reaction for the results in figure 4 was relatively high, it may be assumed that the oxygen concentration level in the flue gas for this data was well above 6% given in European Directive 2000/76/EU on the reduction of air pollution from waste incineration plants (12). It seems that although more airflow rate ensures complete combustion, excessive airflow rate may result in cooling effect and reduction of the combustion time. In fact, the data presented in figure 4 shows that between 3.5 and 5 minutes into the combustion process the fuel bed temperature dropped from 800°C to 300°C within 1.5 minutes. Such combustion behaviour is consistent with the observations made by Swithenbank et al [13]. These authors noted that oxygen concentrations between 8% and 10% in the flue gas represent wastage of sensible heat energy carried away in the flue gases, which will reduce the thermal efficiency.

Considering the normal operating temperatures of between 400°C and 450°C for the low technology in-house incinerator and comparing those with a maximum temperature of 800°C recorded in figure 4 it could be concluded that if the combustion conditions such as gas-residence time are reduced, facilities similar to the current test rig would achieve the range of operating temperatures reported by other researchers such as Hincrichs [9]. Such combustion conditions would ensure proper disposal of clinical waste in village communities in Botswana. With particular reference to gas-residence time, the EU Directives, 89/429/EEC and 2000/76/EU on the reduction of air pollution from waste incineration plants, require that the combustion gases in the combustion chamber must be kept at temperature of at least 850°C for two seconds or more in the presence of at least 6% oxygen (12,14).

At the present time, the gas-residence time is calculated according to BS 3316, Part 2, 1987 (15). According to this standard, the gas-residence time is given by the equation:

$$G_{RT} = V/V_1 \quad (1)$$

Where G_{RT} = gas residence time
V = volume of the reactor
V_1 = volumetric flow rate of the gas (dependent on airflow rate)

Using the above equation it was found that the gas-residence time in this study ranged from 0.3 to 2 seconds. However, equation 1 represents the ideal case of a plug flow reactor, where it can be assumed that every elemental volume of the gas will spend the same time in the combustor. However, real flows exhibit more complex flow patterns because of the presence of boundary layers and flow separation. Such real flow effects lead to channelling, internal re-circulation, and the presence of stagnant flow regions. Some studies have shown that calculating the gas-residence time according to BS 3316, Part 2, often over estimates the real residence time [16]. Consequently, the UK Environmental Agency now recommends the application of computational fluid dynamics (CFD) to assess gas-residence times in waste combustor [17].

The results in figure 5 show that fuel bed temperature above 850°C specified in the European Directive (12, 14) was reached at approximately 5.5 minutes into the combustion process. It can also be observed that there was a relatively improved burnout stage when compared to the results in figure 4. In fact the burnout stage took approximately 3 minutes during which the fuel bed temperatures at 25 mm above the grate, varied between approximately 800°C and 860°C. The high temperatures and improved burnout stage were due to relatively low airflow rate for data in figure 5. On the basis of the temperature profile achieved in figure 5, it could be concluded that if the current rig were to be used for the disposal of clinical waste in rural communities the combustion conditions as in figure 5 would reduce the net environmental burden of low technology in-house incinerators.

Considering the results in figures 4, 5, and 6, it can be seen that the peak temperatures reached were nearly similar, confirming that variation in combustion airflow rate did not influence peak bed temperature, but influenced the behaviour of the two stages of combustion.

Figure 7 shows the results when the blower was switched off to assess the thermal picture at conditions similar to the practical situation of rural clinical waste incineration in rural communities. It can be observed that the peak temperature of 727°C was reached at approximately 12 minutes into the combustion process. Comparing this peak temperature with the operating temperatures (400°C – 450°C) of low technology in-house incinerators, it is clear that the current test rig is better than the method, which is used in rural clinics in Botswana. However, Figure 7 also shows that there was some fluctuation in fuel bed temperature during the ignition stage. This phenomenon was due to the difficulty in achieving a uniform spread of flame on top of the bed confirming that the blower was not operating.

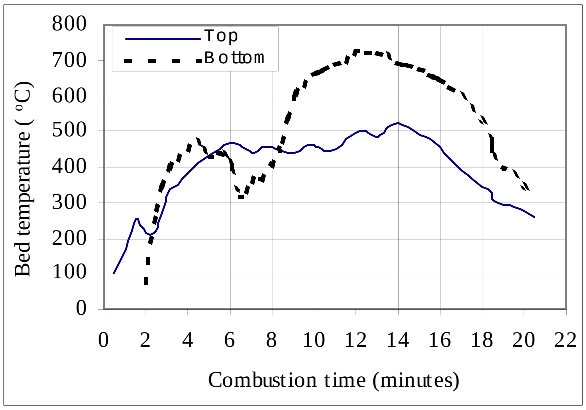

Fig 7: Temperature variation with combustion time (Forced draught fan not operating)

CONCLUSION

Measurements of the temperature variations and gaseous emission levels have been made for combustion of typical rural clinical waste.

- Observation of the thermal output of typical rural clinical waste based on the maximum temperature as shown in figure 5 confirm that the use of small incinerators similar to the experimental rig for incineration of village clinical waste in Botswana would raise the operating temperatures.

- When the combustion rates are appropriate the combustion stages appear to represent the optimum. These findings are confirmed by the results in figure 5. This would be an advantage for using design of this type for the disposal of clinical waste in village communities in Botswana.

REFERENCES

1. Statistical Bulletin, December 1996 and March 1997 Volume. 21 N0 4 and Volume 22 N0.1. Published by the Central Statistics Office. Printed by the Department of Printing and Publishing Services.

2. Study on the Management of medical Wastes by the National Conservation Strategy and GTZ German Technical Co-operation. Report N0: NCS/GTZ 7/96, 1996.

3. Tillman, D.A., 1991. The combustion of solid fuels and waste. Academic Press Limited. London .

4. US Environmental Protection Agency. Medical waste management and disposal, Noyes Data Corporation, New Jersey, 1991.

5. Littlewood, R.C., 1994. Biomedical waste minimisation. Medical safework video, Kew.

6. umr – http//www.med.uiuc.edu/studorg/psr/ waste.htm. October 1999.

7. Hincrichs, R.A., 1992. Energy. Saunders College Publishing. United States of America.

8. Rampling, T. W, and Gill, P.J.,1993. Fundamental research on the thermal treatment of waste and biomass. ETSU B/T1/00208/ REP/2. Warren Spring Laboratory (UK).

9. Gera, D. and Gautam, M. Emissions from RDF/coal blended fuel combustion. Chemosphere, volume 27, number 12, 1993, pp. 2353 – 2363.

10. Directive of the prevention of air pollution from new municipal waste incineration (2000/76/EU). Official Journal of the European Communities, December 2000.

11. Swithenbank, J., Nasserzadeh, V Goh, R. and Siddall, R.G., 1999. Fundamental principle of incinerator designs. Sheffield University Waste Incineration Centre. International FBC Conference, Savannah, Georgia, USA, pp 75-82.

12. Directive of the prevention of air pollution from existing municipal waste incineration (89/429/EEC). Official Journal of the European Communities December 1998.

13. British Standard, BS 3316, Part 2 1987, London

14. Nasserzadeh, V, Swithenbank, J, Lawrence, D, Garrod, N, and Jones B., 1995. Measuring gas-residence times in large municipal incinerators, by means of a pseudo-random binary signal tracer technique. Journal of the Institute of Energy, September, volume 68, pp. 106 – 120.

15. Environment Agency. Processes subject to integrated pollution control, waste incineration. Guidance Note S2 5.01, October 1996.