Jurnal Kejuruteraan 8 (1996) 3-10

Modelling of Solid Waste Incineration

Normah Abdullah, Rakmi Abdul Rahman
and Razali Deman

ABSTRACT

A model for incineration of municipal solid wastes was formulated based on material and energy balances and reaction kinetics. The model was tested for various air supply rates. The study has given a picture of variations in the incineration chambers. The simulations has also shown that the slowest stages in the incineration process is the initial feed heating and the water vapourisation.

ABSTRAK

Satu model untuk pembakaran sampah buangan pembandaran dirumuskan berdasarkan kepada imbangan bahan dan tenaga dan tindak balas kinetik. Model tersebut diuji untuk pelbagai kadar udara suapan. Kajian telah memberi satu gambaran tentang variasi yang berlaku di dalam ruang pembakar. Keputusan daripada simulasi menunjukkan tahap yang paling perlahan dalam proses pembakaran ialah pada proses mula pembakaran suapan dan proses pemeruapan air.

INTRODUCTION

In the incineration process solid waste is burnt in a controlled environment to yield energy and release, ideally, harmless mineralised products. In the high temperature environment of an incinerator, that is at about 800°C to 1500°C various reactions and processes could occur. Such activities are enhanced if the feed is a mixture of various compounds.

Municipal solid waste (MSW) is generated at a rate of 0.75 - 2.50 kg/head day. For Kuala Lumpur alone the MSW generation rate is expected to reach 4,000 tonnes/day by the year 2000 (Rakmi Abdul Rahman 1984). With critical shortage of land around large cities, incineration is expected to play a major role in MSW disposal for the bigger cities of Malaysia. A large incinerator handles about 1,500 tonnes/day of MSW. Therefore if the MSW from Kuala Lumpur is to be incinerated, at least three large incinerators are required for this city alone. Already two are being planned, one in Jinjang and another in Sri Petaling (NST 1990).

The presence of various components in MSW means that various reactions and processes could occur, such as formation of polychlorinated organics notably dioxins and furans, and volatilation of metals such as mercury, selenium and cadmium. If the incineration processes are not properly controlled, the release of such dangerous pollutants to the atmosphere could, in the long term, pose serious health and environmental problems. Controlling a complex process such as MSW incineration requires an in-depth understanding of the combustion processes and variations occurring within the reactor.

In the past years, a considerable amount of research has been carried out in incinerator technology. Recent findings indicate that carbon monoxide (CO), oxygen, moisture and furnace temperature are closely related to dioxins and furans emissions (Floyd Hasselriis 1987). By control of temperature and/or oxygen, and the use of CO as an indicator, Floyd Hasselriis (1987) has also discovered that it is possible to find and maintain optimum combustion conditions so as to minimize dioxins and furans. Further research is still needed to be done to determine the mechanism for the formation of these compounds before they can be adequately controlled.

The aim of this research work is to construct a simplified combustion model by integrating the theoretical knowledge of combustion with test data obtained to date. At this early stage of the research, a model has been developed to predict the temperature and final products formed where complete combustion has been assumed.

This paper reports the findings from an on-going study on the modelling of MSW incineration. The purpose of the study is also to enable incinerators to be fine tuned to Malaysian MSW so as to prevent release of dangerous pollutants to the air.

METHODOLOGY

MODELLING ASSUMPTIONS

As a start, a simplified model based on material and energy balances and reaction kinetics was formulated. The model is based on an incineration system as shown in Figure 1, where volatilised products are partially combusted in the primary chamber and completely combusted in the secondary chamber. To produce the simplified model, the following modelling assumptions have been made:

1. The MSW feed is assumed to be made up of cellulose and water. This assumption is fairly valid as MSW has an empirical formula very close to that of cellulose, that is $C_{30}H_{48}O_{19}N_{0.5}S_{0.5}$ (Rakmi Abdul Rahman 1984) where as that for cellulose is $C_{30}H_{50}O_{25}$.
2. MSW is fed by a fixed velocity moving grate in a bed as shown in Figure 2.
3. The system has no liquid phase. Any tar produced from pyrolysis is assumed to be immediately volatilised at the reaction temperature.
4. Gaseous equilibrium is achieved between primary chamber and secondary chamber.
5. The processes within the combustion chamber are adiabatic.
6. Heat transfer within the chamber occurs via radiation as well as mixing of hot gases.
7. The gas leaves the bed at the same temperature as the bed and air is well distributed along the bed.

COMBUSTION MECHANISM

Combustion occurs via several stages. These stages are given below:

1. The feed temperature is raised to the water vapourisation point, i.e., 100°C.

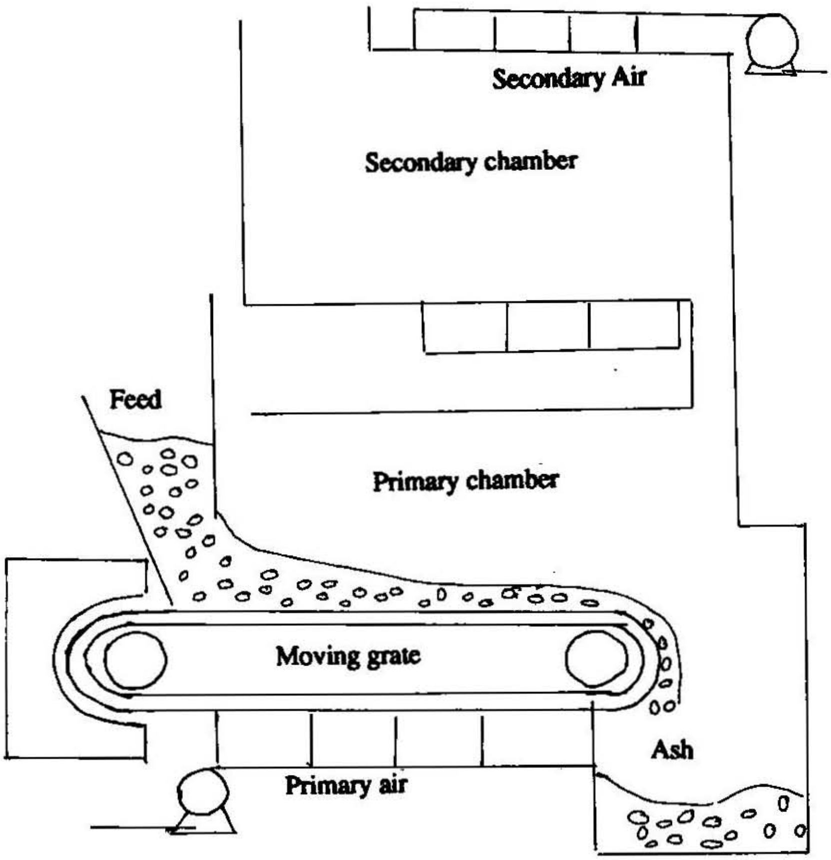

FIGURE 1. Incineration system

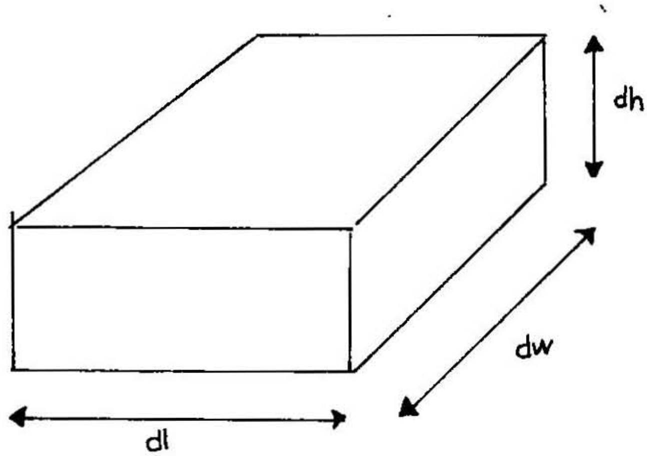

FIGURE 2. Shape of the bed to incinerator

2. As water is vapourising, the temperature remains constant at 100°C.
3. On completion of water vapourisation, the feed temperature rises to the pyrolysis temperature.
4. Pyrolysis takes place.
5. On completion of pyrolysis of organics, charcoal starts to burn.

The combustion can be represented as shown below (Kilzer and Broido 1965):

$$\text{cellulose} \begin{cases} \xrightarrow{220^{\circ}C\text{-}280^{\circ}C} \text{Dehydrated cellulose} + \text{Water} \rightarrow \text{Charcoal} + \text{Gas A} \\ \xrightarrow[\text{above } 280^{\circ}C]{} \text{tar} \rightarrow \text{Charcoal} + \text{Gas B} \end{cases}$$

In this study, the above mechanism is quantitatively represented as shown below:

$$\text{cellulose} \begin{cases} \xrightarrow{(a)} (Y_a) \text{ charcoal} + (1-Y_a) \text{ gas A} \\ \xrightarrow[(b)]{} (Y_b) \text{ charcoal} + (1-Y_b) \text{ gas B} \end{cases}$$

Y_a and Y_b are mass fractions of charcoal formed via path (a) and (b) respectively. Path (a) occurs at lower temperatures while path (b) occurs at higher temperatures. For simplicity, both reactions are assumed to be first order. Then, the rate of cellulose degradation can be represented as,

$$\frac{dW}{dt} = -KW$$

where W =. weight of cellulose
K = reaction constant (s^{-1})
= $K_o e^{-E/RT}$
K_o = 0.2×10^{-10} (s^{-1})
E = reaction activation energy
T = reaction temperature in Kelvin
R = 8.314 kJ/kmol k

Using this equation and parameters from (Van Gineken et al. 1979) the rate of formation of charcoal and gases was then balanced with the mass of converted cellulose. The mechanism for charcoal combustion as given by (Overend et al. 1985) was assumed; the mechanism is given below:

$$2C + O_2 \rightarrow 2C(O)$$

$$C + CO_2 \rightarrow CO + C(O)$$

$$C + H_2O \rightarrow H_{2(g)} + C(O)$$

$$4C(O) \rightarrow 4CO_{(g)}$$

the overall reaction can be given as:

$$4C + O_2 + CO_2 + H_2O \rightarrow 5CO + H_2$$

RESULTS AND DISCUSSION

The modelling results are shown in Figures 3 to 7. Figures 3 and 4 show the percentages of mass left and temperatures for the different sections of the feed bed. The length of bed with high temperature is shorter than that with lower temperature as the higher temperature hastens combustion.

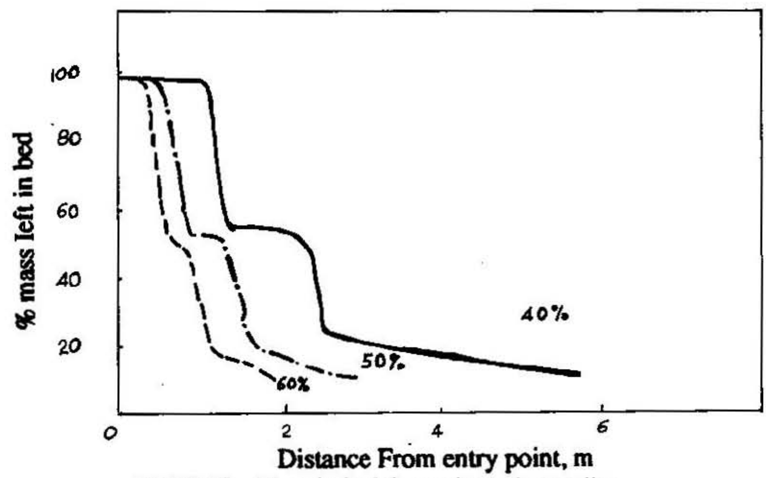

FIGURE 3. Mass in bed for various air supplies

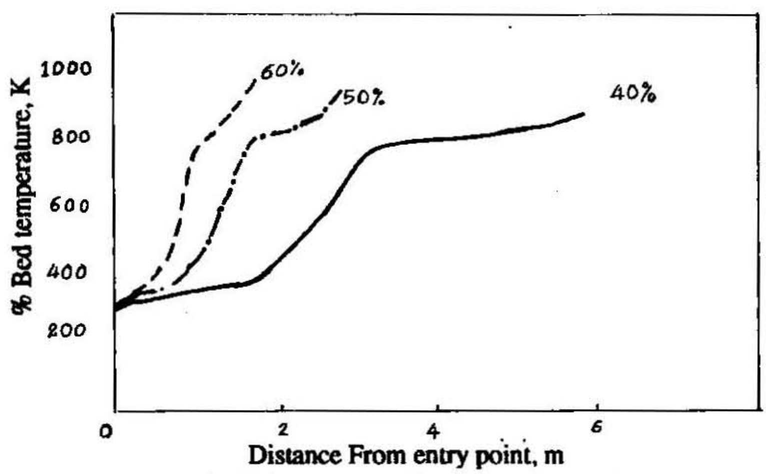

FIGURE 4. Bed temperature for various air supplies

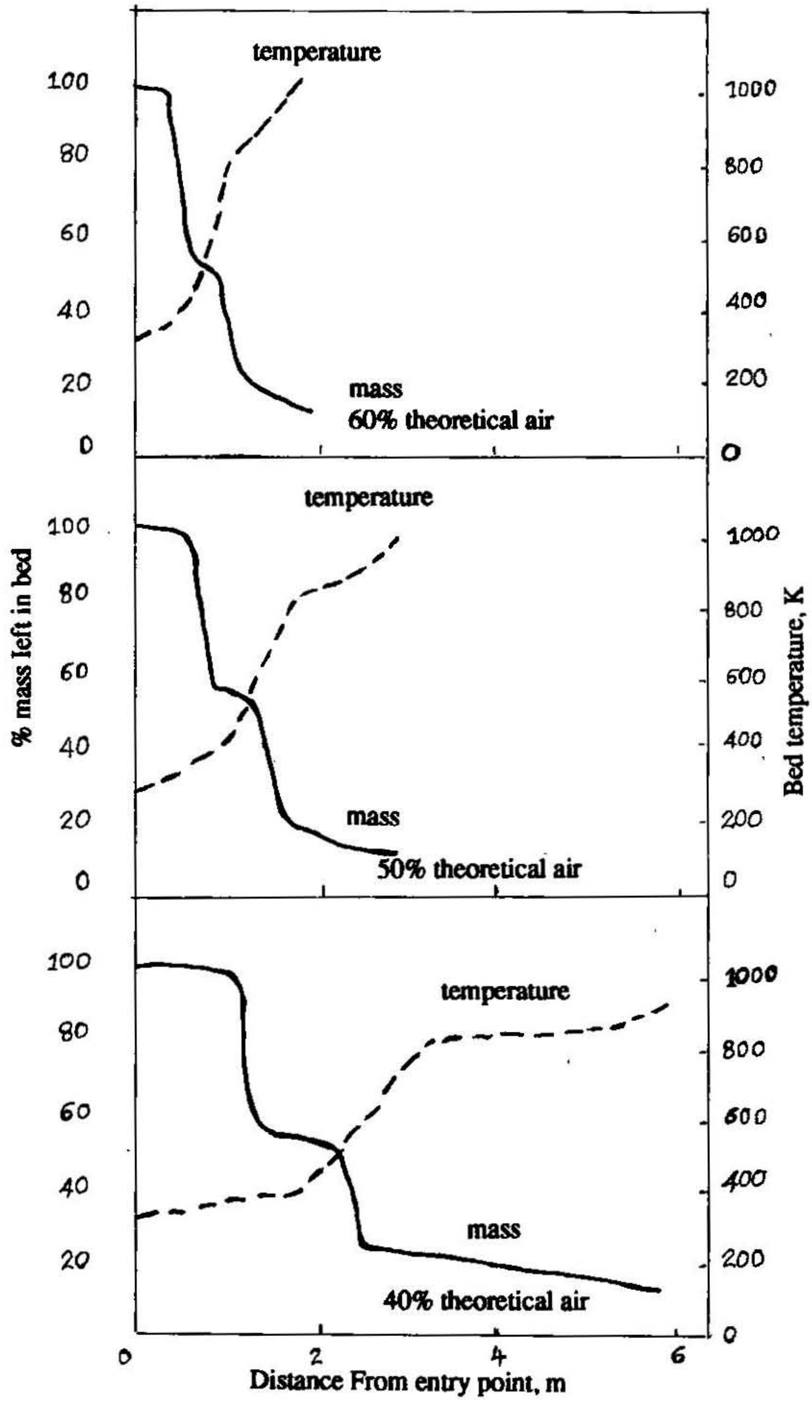

FIGURE 5. Mass in bed and temperature profiles for various air supplies

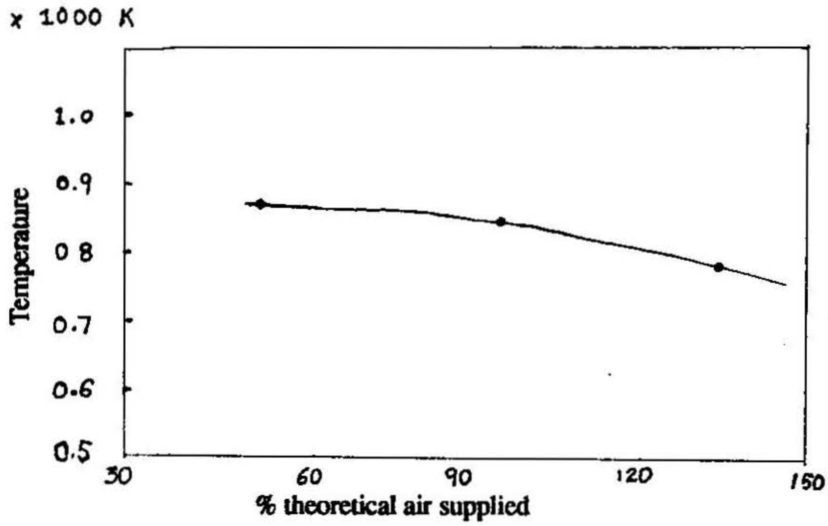

FIGURE 6. Primary chamber temperature versus air supply

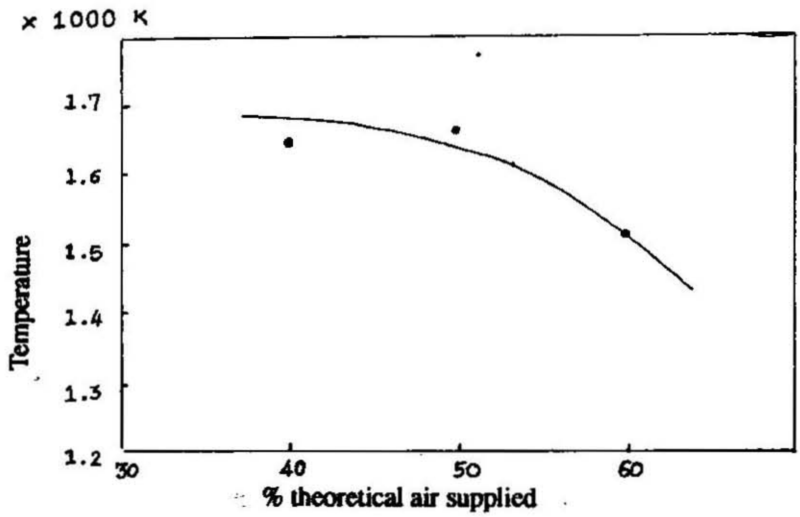

FIGURE 7. Secondary chamber temperature versus air supply

Figure 5 shows that pyrolysis occurs very rapidly and that the slow steps are feed heating, water vapourisation and charcoal conversion. Charcoal conversion is slow at low temperatures but speeds up at higher temperatures.

Figures 4 and 5 show that the temperature profile is influenced by the temperature of the primary chamber. Low chamber temperature slows down charcoal combustion.

The simulations also show that the primary chamber temperature, thus the bed temperature, decrease with increase in air supply (Figure 6), this is due to the supply of excess air to the chamber. As shown by Figure 7 the temperature of the secondary chamber also decreases with percentage air supply.

Simulation results show that the concentration of CO in the flue gas is about 0.002% which is much lower than the 0.06% given by (Calvin 1985). This lower value is probably due to the assumption of equilibrium achieved between gases. In actual processes, equilibrium is seldom achieved, Calvin showed that the equilibrium factor was only 0.032.

The differences with findings from other studies indicate the inadequacies of the simplified model. Nevertheless this study provides a picture, albeit a simplified one, of variations in the incinerator and has given a starting point for modelling of the complex process. Further adjustments to the model are necessary before a more accurate one is obtained.

CONCLUSION

The municipal solid waste incineration model which was formulated based on material and energy balances and reaction kinetics has managed to give a simplified picture of variations in the incineration chambers. The simulations has also shown that the initial feed heating and water vapourisation are the slowest steps in the incineration process.

NOTATION

dh	Height of bed
dl	Length of bed
dw	Width of bed

REFERENCES

Calvin R.B. 1985. *Hazardous Air Emission from Incineration.* London: Chapman and Hall.

Hasselriss, F. 1987. Optimization of combustion conditions to minimize dioxin emissions. Presented at ISWA-WHO-DAKOFA specialise seminar. Copenhagen, 20, 22 Januari 1987.

Kilzer F.L. & A. Broido. 1965. Speculations on the nature of cellulose pyrolysis. *Pyrodynamics* 2: 151.

Kumar R. & S. Ahmad. 1989. Computer simulation of a municipal solid waste combuster. *Pollution Control Association* 39: 1328-1333.

NST. 1990. City hall to turn garbage into power. *New Straits Times.* 28 June 1990, Kuala Lumpur.

Overed R.P., Milne T.A. & Mudge L.K. 1985. *Fundamentals of thermochemical biomass conversion.* Amsterdam: Elzevier.

Rakmi Abdul Rahman. 1984. Municipal solid waste as an energy source. *Proc. First Symp. Malaysian Chemical Engineers.* 265-280.

Van Gineken C.P.M., W.J.A.H. Shoeber & M. Tels. 1979. A mathematical model of cellulose pyrolysis. *Recycling* 1: 663-673.

Department of Chemical and Process Engineering
Faculty of Engineering
Universiti Kebangsaan Malaysia
43600 UKM Bangi
Selangor D. E., Malaysia