PERFORMANCE OPTIMIZATION OF INDUSTRIAL MUNICIPAL SOLID WASTE COMBUSTORS – A NEED OF THE DAY TO CONVERT WASTE TO WEALTH

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ABSTRACT: The average amount of municipal solid waste (MSW) generated in Malaysia is 0.5–0.8 kg/person/day and has increased to 1.7 kg/person/day in major cities. Due to rapid development and lack of space for new landfills, big cities in Malaysia are now switching to incineration. However, a major public concern over this technology also is the perception of the emission of pollutants of any form. Design requirements of high-performance incinerators are sometimes summarized as the achievement of 3Ts (time, temperature, and turbulence). An adequate retention time in hot environment is crucial to destroy the products of incomplete combustion and organic pollutants. Also turbulent mixing enhances uniform distributions of temperature and oxygen availability. CFD modeling is now in the development phase of becoming a useful tool for 3D modeling of the complex geometry and flow conditions in incinerators. However, CFD flow simulations can enable detailed parametric variations of design variables. CFD modeling of an industrial scale MSW incinerator was done using software FLUENT Ver. 6.1. The 3D modeling was based conversation equations for mass, momentum and energy. The differential equations were discretized by the Finite Volume Method and were solved by the SIMPLE algorithm. The k- turbulence model was employed. The meshing was done using Gambit 2.0. The cold flow simulations were performed initially to develop the flow and velocity field. Using FLIC and FLUENT, it was possible to simulate all the three main phases of combustion i.e., the drying zone, devolatilization zone and the char burnout zone. Numerical simulations of the flow field inside the primary and secondary combustion chambers provided the temperature profiles and the concentration data at the nodal points of computational grids. The maximum temperature in the primary combustors for MSW and Mix fuel combustion were around 1600 K and 1900 K respectively. Parametric study was also done to minimize the NOx emissions. Nevertheless, the reactive flow modeling inside a MSW combustor has been done successfully using the FLIC and FLUENT programs. The results are useful in optimizing the design and operation of industrial waste combustors.

Keywords: CFD, combustion, flow simulations, MSW, turbulent mixing, temperatures profile

INTRODUCTION

The amount of waste generated by mankind and its disposal in landfills has already created growing concern over health and environmental problems. The situation has now risen to a point where incineration is perceived to be the best disposal option for waste that cannot be economically reused or recycled. The major advantage of this process is the dramatic reduction of the waste volume, typically by 90%, as well as the recovery of energy from burnable waste. However, a major public concern over this technology also is the perception of the emission of pollutants of any form (Jenny *et. al.,* 2004).

Municipal solid waste is a complex and very variable solid waste. Neither its physical nor chemical properties can be determined with the same certainty and reliability as for other fossil fuels. This is one of the major reasons why the operation of incinerators is rather difficult and as a consequence, many different types of grates and combustion chamber designs have been developed. The evolution of better and more efficient incinerators worldwide is currently hindered by the lack of reliable data and fundamentally based design procedures that are required to assist the design, operation and control of incinerators (Eriksson *et al.,* 2002).

STATUS OF MSW COMBUSTION TECHNOLOGY IN MALAYSIA : The growing scarcity of dumping sites for municipal solid waste and the increasing environmental problems with landfill have led to more stringent regulations and increasing cost of waste disposal in many countries. A lot of alternative methods have been proposed, and among them, waste incineration has been gaining more and more popularity by significantly reducing the volume of collected material into an inert residue and at the same time producing a combination of heat and electricity.

The average amount of municipal solid waste (MSW) generated in Malaysia is 0.5–0.8 kg/person/day and has increased to 1.7 kg/person/day in major cities. Currently, the waste management approach being employed is landfill, but due to rapid development and lack of space for new landfills, big cities in Malaysia are switching to incineration. The main components of the Malaysian MSW were found to be food, paper and plastic, which made up almost 80% of the waste by weight. The average moisture content of the MSW was about 55%, making incineration a challenging task *(Kathiravale et al.* 2003).

INSIGHT INTO MSW COMBUSTION PROCESS: The recent focus on incineration has been on environmental consequences, not on performance. In particular, the limitations, as well as the advantages, of incineration are being increasingly recognized *(Yang et al. 2002).* Incineration is not a waste disposal method but rather a waste processing technology. Modern incinerators, though simple in concept, are highly complex machines. The heart of any incinerator is the combustion chamber where waste is burned. However, the overall unit consists usually from various types of systems and equipment. Many types of wastes like municipal, industrial, medical, hazardous, radioactive have to be burned. Therefore, design and operation of incinerators is obviously a difficult task and effective supporting tools are very useful.

The combustion process in municipal waste incinerators can be looked upon as a two-step process taking place in two separate zones: the waste layer on the grate and the gas phase in the freeboard. Design requirements of high-performance incinerators are sometimes summarized as the achievement of 3Ts (time, temperature, and turbulence). An adequate retention time in hot environment is crucial to destroy the products of incomplete combustion and organic pollutants. Also turbulent mixing enhances uniform distributions of temperature and oxygen availability. In this context, the design of a combustion chamber, in which air and combustion gases pass through while participating in strong radiative heat transfer, must be carefully analyzed and evaluated (Stehlik *et al.* 2000).

CFD MODELING IN MSW COMBUSTION: The rising popularity of incineration of municipal solid waste (MSW) calls for detailed mathematical modelling and understanding of the incineration process. In this paper, governing equations for mass, momentum and heat transfer for both solid and gaseous phases in a MSW solid-waste incineration furnace are being described and relevant sub-models are presented. The burning rates of volatile hydrocarbons in a MSW combustor of solids are limited not only by the reaction kinetics but also by the mixing of the volatile fuels with air. The mixing rate is also being taken care of.

Over the years, various chamber designs and air/gas flow arrangements have been proposed and tested in actual field applications. Comparative evaluation of furnace chamber designs often relied on cold flow experiments using two-dimensional water tables and/or three-dimensional cold airflow models. However, even these scale model experiments are expensive and are limited in their applicability. On the other hand, numerical computation has rapidly become available by adequately accommodating the complex geometry and flow conditions in incinerators. CFD flow simulations now enable detailed parametric variations of design variables. Many researchers have performed numerical simulation of mixing inside the combustion chamber. The maximum destruction of pollutants inside the furnace is the main objective; therefore mixing of the cold air and hot gases and subsequent pyrolysis reaction of hypothetical organic pollutants are needed to be investigated. Numerical simulations of the flow field inside the combustion chamber provide velocity, temperature and concentration data at the nodal points of computational grids (Yang *et al.* 2004).

However, due to a very heterogeneous waste and initial research in this area, only a limited knowledge about the process has been accumulated. The combustion process, itself with its strong interaction between gas and solid phase, is difficult to understand and subsequently pollutants can hardly be traced back to their formation. Therefore, there is a strong need for deeper investigation into different aspects of the processes that exist and especially to control pollution at its source of formation.

MSW COMBUSTOR DESIGN: The existing industrial MSW combustors consisted of a Primary and Secondary Combustor. A typical arrangement of the combustor is being shown in Figure 1.

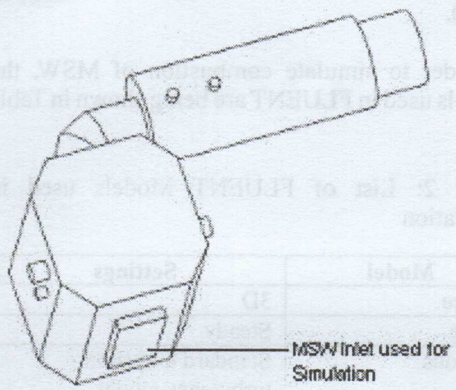


Figure 1: Basic design of combustor used for simulation

The specific features of the MSW combustor which have been used for modelling purpose are as follows:

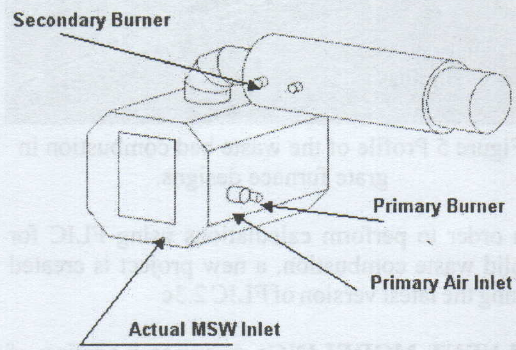
- The MSW inlet is made from the bottom of the primary combustor.
- The primary air supply is from the sides of the primary combustor as shown in Figure 2.
- The primary burners are introduced for heat supply.
- Similarly, the two secondary burners are placed for complete combustion of organic compound in secondary combustors.

The municipal solid waste characteristics are given in Table 1.

Table 1: Fuel Quality of MSW

Type	Quantity (tonne/day)			Calorific value (MJ/kg)			
Municipal	5.13			6.0			
Solid	Dry Basis (%)						Moisture
Waste	C	H	N	S	O	Ash	
(MSW)	46.2	6.9	1.3	0.2	28.2	17.2	55

The meshing was done using Gambit 2.0. In order to have a smooth meshing, fine meshing was done but care was again also given to computational time. Currently work is being done in simulating MSW flow in primary and secondary combustors. A typical grid is being shown in Figure 3.



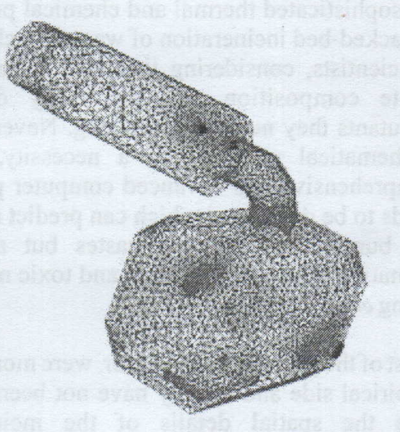


Figure 3: Meshing of combustor using Gambit 2.0

FLIC CODE: In FLIC which is a code written at the Sheffield University of Waste Incineration Centre (SUWIC) is used to simulate waste bed combustion. Figure 4 represents the philosophy of the waste bed combustion as done by FLIC code. Figure 5 shows the different stages in combustion which can be modeled using FLIC.

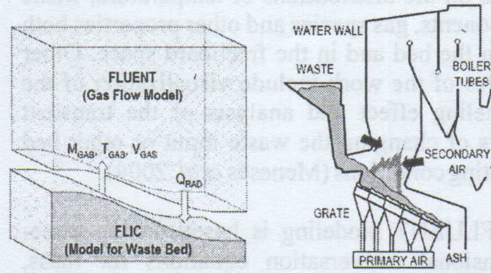


Figure 4 FLIC methodology for waste bed combustion and using FLUENT for gas flow modeling.

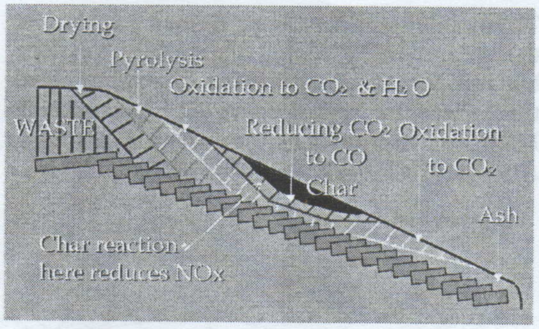


Figure 5 Profile of the waste bed combustion in grate furnace designs.

In order to perform calculations using FLIC for solid waste combustion, a new project is created using the latest version of FLIC 2.3c

FLUENT MODELING: Accurate modeling of the sophisticated thermal and chemical processes in packed-bed incineration of waste is a challenge to scientists, considering the wide variations in waste composition and the many different pollutants they may be generating. Nevertheless, mathematical modeling is a necessity, and a comprehensive and advanced computer program needs to be developed which can predict not only the burn-out of various wastes but also the formation of major pollutants and toxic materials (Yang *et al.,* 2003).

Most of the past works, however, were more on the empirical side and usually have not been able to give the spatial details of the incineration processes within the packed-beds. The current paper works on a much more detailed scale on modeling. The whole bed and the freeboard area above are divided into many small volumes, the transport equations concerning the flow, heat transfer and combustion of the solid and gas phases are then discretized over these volumes or cells, and solved iteratively over the whole computation domain. The computation gives the results on the distributions of temperature, waste components, gas species and other properties both within the bed and in the freeboard space. Other features of the work include visualization of the channeling effect and analysis of the transient effects of changing the waste input or other bed operating conditions (Meneses *et al.* 2004).

The FLUENT modeling is based on the three-dimensional conversation equations for mass, momentum and energy. The differential equations are discretized by the Finite Volume Method and are solved by the SIMPLE algorithm. As a turbulence model, the k- was employed; this consists of two transport equations for the turbulent kinetic energy and its dissipation rate. The FLUENT code utilizes an unstructured non-uniform mesh, on which the conservation equations for mass, momentum and energy are discretized. The k- model describes the turbulent kinetic energy and its dissipation rate and thus compromises between resolution of turbulent quantities and computational time (Ladislav *et al.* 2002).

In order to simulate combustion of MSW, the models used in FLUENT are being shown in Table 2.

Table 2: List of FLUENT Models used in simulation

Model	Settings
Space	3D
Time	Steady
Viscous	Standard k-epsilon turbulence model
Wall Treatment	Standard Wall Functions
Heat Transfer	Enabled
Radiation	P1 Model
Species Transport	PDF (species)
Combustion	Non Premixed Combustion

Due to heterogeneity of the MSW and little information about the physical properties of MSW, it is difficult to do combustion modeling. The simulations were done for both MSW and mixture of MSW and wood. It took very long time before a solution could be obtained. In order to have a converged solution the code had to run for 18000 iterations.

RESULTS AND DISCUSSION

A 3-D combustor was done using FLUENT Ver. 6.1, which incorporates the various sub-process models and solves the governing equations for both gases and solids. Thermal and chemical processes are mainly confined within burning bed.

The combustion simulation was done for both MSW only and the mixture of MSW and wood wastes. From the simulation results it was evident that for a large part of the burning process, the total mass loss rate was constant until the solid waste was totally dried out and a period of highly rising CO emission followed. The maximum temperature in the primary combustors for MSW and Mix fuel combustion were around 1600 K and

1900 K respectively.

Temperature profiles for the MSW combustor region is shown in Figure 6. According to simulations, the temperature near the inlet of primary air is low but the flow of MSW moves towards the primary combustor's exit the combustion process starts and temperature starts to increase. This gradual increase in temperature follow until it reaches the connector between primary and secondary combustor, where roughly it have a constant temperature of about 1300 K.

A significant temperature increase occurs as the flow enters the secondary combustor due to the presence of secondary burners. The temperature reaches to its highest value 1300K. Model prediction indicates that the combustion mode in this region is basically on carbon or char burning.

Turbulent flow in a packed bed of solids is quite different from flow inside a duct. Large-scale turbulence is possible within a packed bed due to the restriction imposed by the narrow and irregular channels through which fluid has to pass, and the spectrum of turbulence moves towards smaller scale, which means an increase in dissipation rate of turbulent kinetic energy. Particle resistance to the flow becomes much more important and the subsequent large pressure drop will dominate the flow field distribution (Kessel *et al.* 2004).

Transient phenomena such as the breaking of waste particles and the "catastrophic" creation of new burning channels occurring during waste incineration is a vital area requiring further investigation at the fundamental level. The underlying theory of bed behaviour must be extended to include these transient events. Most of the combustible material in waste is burned in the bed and its immediately adjacent freeboard region, producing CO_2 and H_2O (Ma *et al.* 2002).

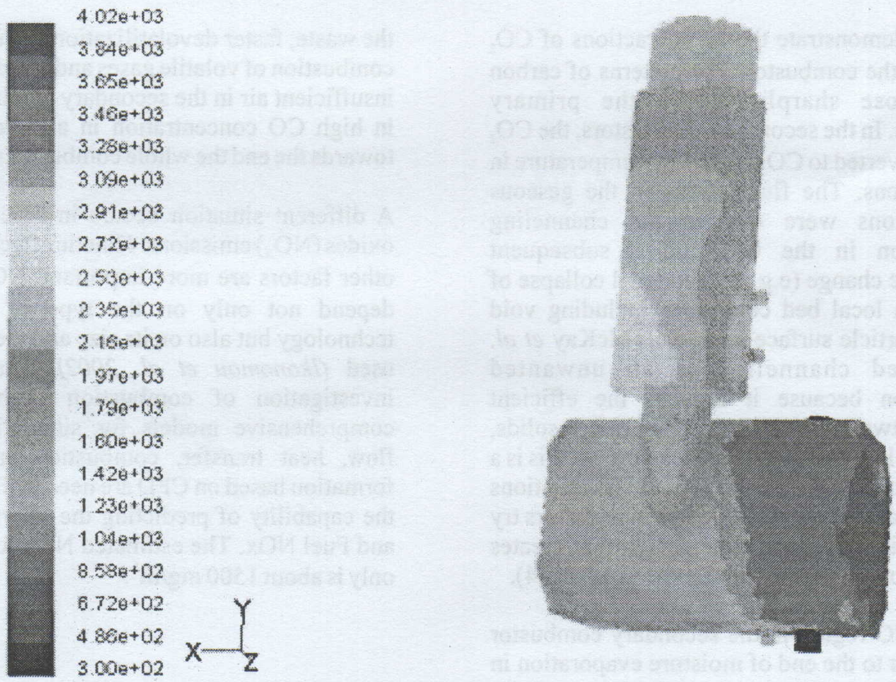
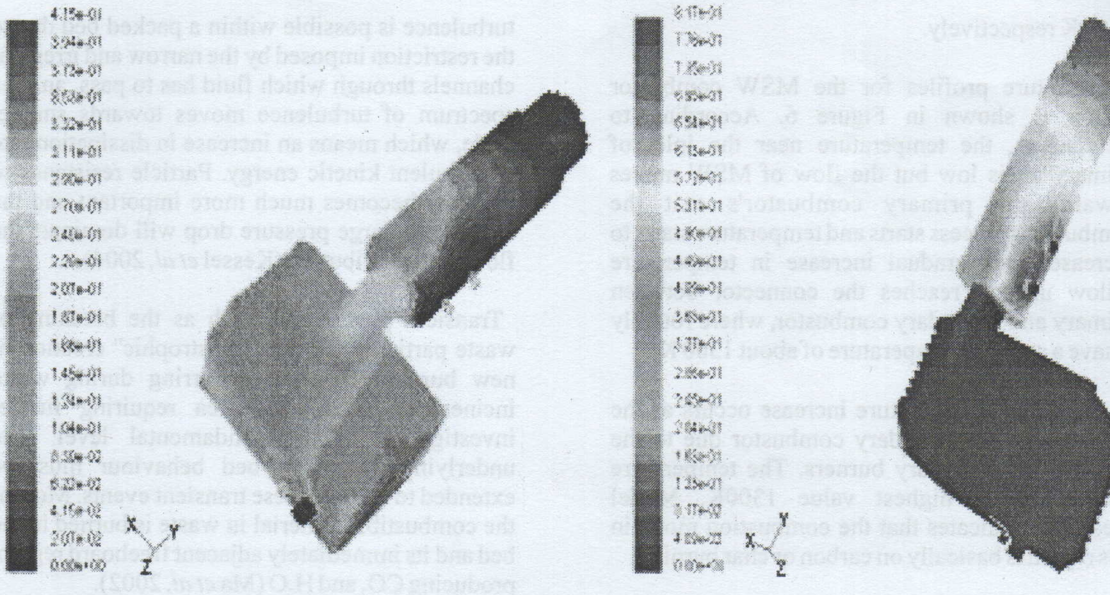


Figure 6: Contours of Static Temperature for MSW combustio



(a) CO_2 (b) CO

Figure 7: Contours of Mass fraction for MSW only mode.

Figures 7 demonstrate the mass fractions of CO_2 and CO in the combustor. The patterns of carbon dioxide rose sharply within the primary combustors. In the secondary combustors, the CO_2 has got converted to CO due to high temperature in those sections. The fluctuations in the gaseous concentrations were due to the channeling phenomenon in the bed and a subsequent catastrophic change (e.g. sudden local collapse of the bed) in local bed conditions including void fraction, particle surface area, etc. (McKay *et al.* 2002). Bed channeling is an unwanted phenomenon because it reduces the efficient contact between feed air and burning solids, resulting in low combustion efficiency. Yet this is a very important phenomenon in practical situations although many designers of MSW incinerators try to avoid this by proper grate design that creates right disturbances in the bed (Lavrici *et al.* 2004).

The high CO region in the secondary combustor corresponds to the end of moisture evaporation in the waste, faster devolatilization of the solids, and combustion of volatile gases and fixed carbon. The insufficient air in the secondary combustor results in high CO concentration in a region, which is towards the end the whole combustion process.

A different situation occurs in case of nitrogen oxides (NO_X) emissions. Kinetic effects along with other factors are more important. NO_X emissions depend not only on the type of combustion technology but also on its size and the type of fuel used *(Ikonomou et al. 2002)*. For a detailed investigation of combustion chambers some comprehensive models for simulation of fluid flow, heat transfer, combustion and pollutant formation based on CFD are needed. FLUENT has the capability of predicting the Thermal, Prompt and Fuel NOx. The estimated NOx for MSW fuel only is about 1500 mg/m^3.

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