Bed Combustion in a Furnace Enclosure
- a Model for the MSW Incinerator

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ABSTRACT

The bed combustion in an incinerator interacts with the gas flow region through heat and mass transfer. Combined bed combustion and gas flow simulations are performed to investigate this coupled interaction for various operating conditions and furnace configurations. Radiation onto the bed from the furnace is interrelated with the combustion characteristics in the bed, and is also affected by the flow pattern in the gas flow region. Since the contribution of gaseous emission to the total radiation is significant, an adequate flow pattern in a well-designed furnace shape would lead to an increased heat influx on the bed, especially in the early stage of the waste combustion. Advancing the initiation point of the waste combustion can also reduce the size of the lower gas temperature region above the bed, which can be achieved by controlling operating conditions such as the waste feeding rate, the bed height and the primary air flow distribution.

Keywords : bed combustion, CFD, combined simulation method, incinerator

INTRODUCTION

Combustion of a fuel bed in a furnace enclosure is commonly applied in various types of solid fuel combustion chamber, such as the grate-type incinerator of the municipal solid waste(MSW). To maintain the continuous operation, the fuel bed is exposed to radiation transferred from the hot gas flow region, by which the drying and combustion of the fuel are initiated. Combustion gas released from the fuel bed flows through the furnace, undergoing the thermal destruction of the products of incomplete combustion(PICs) after mixing with the additional combustion air. Such interaction of heat and mass transfer between the fuel bed and the gas flow field is one of basic phenomena in the furnace enclosure.

While the gas flow region and the bed combustion are inter-related with each other, previous studies have been performed separately for the bed combustion or for the gas flow field. The bed combustion related studies have been carried out usually using the fixed bed combustor under controlled furnace conditions [1-3]. Progress of combustion in the homogeneous fuel bed and corresponding properties of the released gas have been studied according to the fuel characteristics and the primary air injection. Numerical modelings of the fuel bed combustion are recently reported, which simplify the bed as an unsteady 1-dimensional system[3,4].

Computational fluid dynamics(CFD) simulation has become one of the favorite methods applied in incinerators[5-6]. Usual simulations, however, often neglects the interactive heat and mass transfer between the fuel bed and gas flow region. Rather than being solved directly, the waste bed has been treated as an inlet condition for the gas flow region, of which combustion gas conditions are calculated from an arbitrarily assumed combustion profile. Even with these limitations, these results have been found useful to improve the overall flow pattern by optimizing the design and operation parameters such as the furnace configuration and the modes of secondary air injection.

Recently, Ryu[7] have proposed the combined simulation of the gas flow and the fuel bed combustion. In this combined simulation method(CSM), release of combustion gas from the fuel bed, i.e. the inlet condition of the gas flow field, is predicted from a specific bed model, which also receives the heat transferred to the bed from the gas flow simulation model.

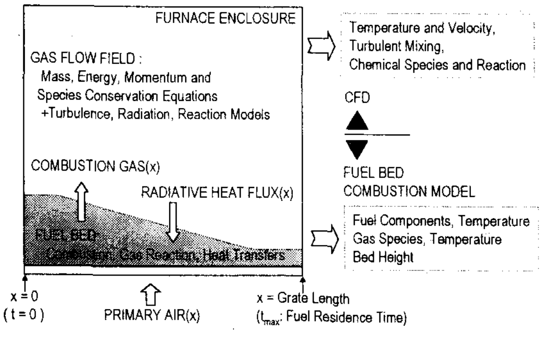


Figure 1. Strategy of the CSM of the fuel bed combustion and the gas flow field

This study is to investigate the interaction of the bed combustion phenomena with the gas flow region in the waste incinerators using the CSM. Patterns of heat and mass transfer between the two regions including the bed combustion characteristics are analyzed, according to selected parameters such as the fuel bed height and furnace configuration.

COMBINED SIMULATION METHOD (CSM)

Shown in Figure 1 is the strategy of the CSM for a furnace enclosure having the fuel bed combustion and gas flow field[7]. The bed combustion of solid fuel is solved using fuel bed combustion model. Generation of combustion gas from the fuel bed is introduced into the gas flow simulation as an inlet condition. Computational fluid dynamic simulation provides numerous data set for the flow field and heat transfer. Radiative heat flux from the gas flow field to the fuel bed is exported into the bed model as a boundary condition for the top surface of the bed. By iterative calculations of the two models, converged solutions on both regions are acquired which are also in equilibrium of their interaction.

Concept of the model for the waste bed combustion is shown in Figure 2. By assum-

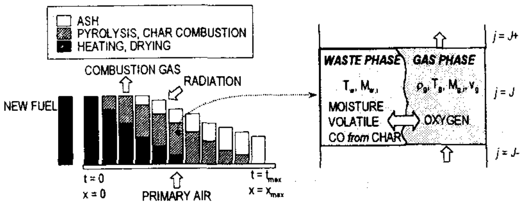


Figure 2. Concept of the waste bed combustion model

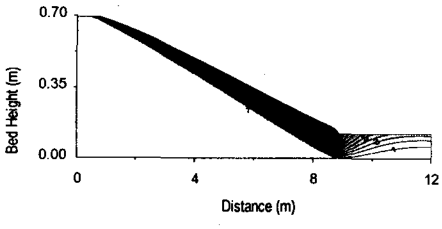
ing continuous and quiescent movement of the homogeneous waste particles on the grate and by neglecting the heat and mass transfer in the horizontal direction, the waste bed can be simplified into an unsteady 1-dimensional system, which has the waste and gas phases. Time elapsed after introduction onto the grate is transformed into its horizontal position for the given speed of the waste throughput. Heterogeneous combustion of the waste and gaseous reactions in the gas phase are incorporated in submodels. Detailed information can be found in authors' previous papers[3,7].

SIMULATION CASES

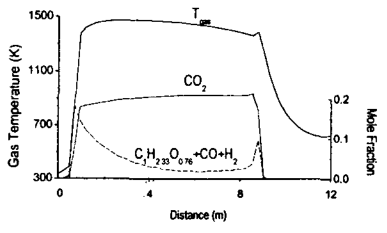
Test Incinerator and Selected Parameters

Typical incinerator combustion chamber of 150 ton/day was chosen. Its grate was 12m long and 3.2m wide. The waste contained 45% moisture, 10% ash and remainder in the combustible $C_1H_{1.76}O_{0.58}$(LHV=1800 kcal/kg). Excess air ratio for the combustion air was 1.8, of which 70% was supplied into the waste bed as a primary air. A parabolic distribution of the primary air was assumed(V/V_{ave}=1.3 at the center, V/V_{ave}=0.4 at both ends) to provide sufficient air during the active combustion.

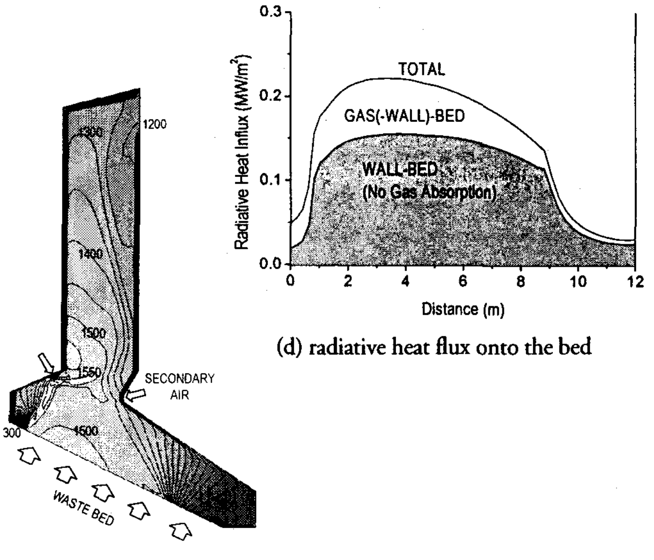
In this study, three of design and operating parameters were selected; waste residence time, bed height, and furnace shape, while keeping the fuel properties fixed. Case 1 was chosen as a reference case for the counter-current type furnace. The waste bed was assumed to progress uniformly on the grate for the given residence time, 100 minutes, corresponding to the bulk height of 68cm. In Case 2, the bed height was reduced by a half but the throughput speed of the waste was doubled, in order to maintain the identical waste feed rate. Thus, the waste bed of the height 34cm stayed for 50 minutes on the grate in this case. Case 3 was chosen for an alternate combus-



(a) gas temperature within the bed



(b) gas properties leaving the bed



(d) radiative heat flux onto the bed

(c) temperature on the center plane of the gas flow field

Figure 3. Results of the combined simulation for Case 1

tion chamber having the co-current flow type configuration, while keeping other conditions identical with those in Case 1.

Simulation Methods

The gas flow simulation was performed with typical computational modeling on the incinerator using a commercial code, FLUENT ver5.1. A structured grid was constructed with 60×61×23 cells on a half volume of the combustion chamber, using a symmetric plane condition at the center. The RNG k-ε model was adopted for turbulence. To predict radiation, the discrete ordinate method was employed, including the emission of CO_2 and H_2O. The total absorption coefficient was calculated by the weighted sum of gray gases model(WSGGM). Participation of soot and fly ash in radiation was not taken into account. In gaseous reaction, the irreversible oxidations of the PICs were calculated using the Magnussen-Hjertager model.

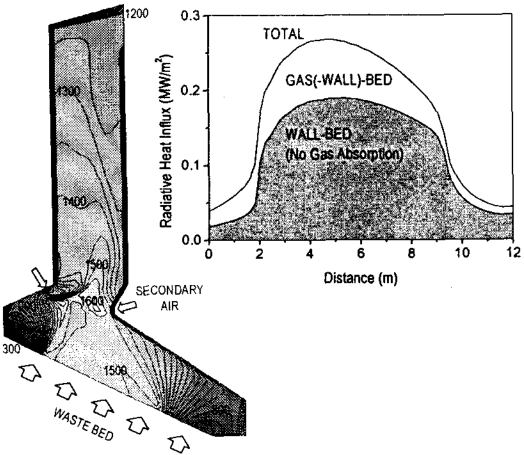
In the bed model, the fuel layer was divided into 150 cells, each of which marched along the bed with a time step of 1 second.

The update of its input condition from the bed model and the export of the incident radiation upon the bed were repeated through a batch process for every 200 iterations, until the change of the incident radiation decreased to below maximum 4% for all node points.

RESULTS AND DISCUSSION

Case 1 - Reference Case

Figure 3 shows typical results of the CSM for Case 1; gas temperature within the waste bed, gas properties leaving the bed(Figure 3(a)) and the temperature on the symmetric plane of the gas flow region(Figure 3(b)). While the waste bed is under heating and drying processes in the upstream part, a low gas temperature region is formed above the bed. Soon, the combustion of the waste is initiated in the bed with an increase of the PICs such as $C_1H_{2.33}O_{0.76}$, H_2 and CO, as shown in Figure 3(a). The combustion is continuously propagated into the bed and corresponding region of the high gas temperature is formed in the primary combustion chamber.



(a) (b)

Figure 4. Temperature on the center plane of the gas flow field(a) and radiative heat flux onto the bed(b) for Case 2

Shown in Figure 3(d) is the radiative heat flux onto the bed for Case 1. Contribution of gaseous radiation to the total heat flux is also plotted in the figure as a white area, which was calculated by disabling the WSGGM for the converged solution. Radiation is a main heat source for the drying and pyrolysis of the waste on the top of the bed. Thus, increasing the radiation heat influx in the upstream part of the bed is necessary to achieve the efficient waste combustion. Gaseous radiation is relatively important before the initiation of combustion in this case, since its portion in the total radiative heat flux is about a half at x<1m.

During the active combustion of the waste in x=1~9m, the bed is exposed to high heat flux from the hot combustion gas and furnace wall. The absolute value of gaseous radiation is larger in x=3~4m which is under the middle of the hot gas region. When the waste combustion is finished, the radiation also decreases continuously due to the temperature drop of the combustion gas.

Case 2. Changes in Combustion Condition

This case has a doubled throughput speed of the waste having a half bed height. Since the heating and drying of the waste is largely dependent on time, corresponding delay before the initiation of combustion becomes almost doubled initially in this case. Then, the low gas temperature region above the upstream part of the bed develops further as the calculation is repeated, which is unfavorable for the initiation of combustion. As a result, Figure 4(a) shows that 2.4 times larger low temperature region is formed above the upstream part of the bed where the combustion is not commenced.

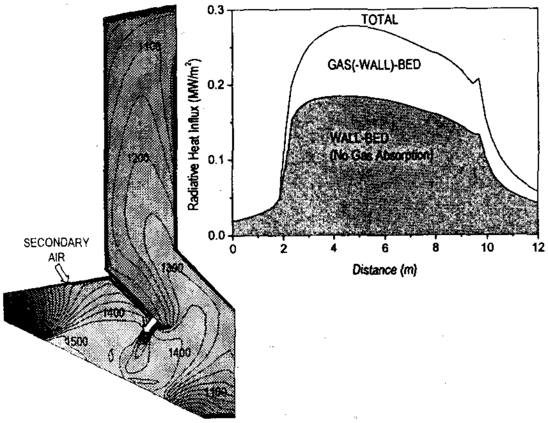
In Figure 4(b), the low radiation zone also increases to x<2m. The gaseous radiation in that zone still takes significant portion, which is caused by the hot gas region over 1600K formed in the center of the combustion chamber.

Controlling other operation parameters would help to contract the low temperature region above the bed. For example, preheating the primary air supply would speed up the moisture evaporation and heat-up of the bed fuel. Slowing down the throughput speed of the bed, i.e. the grate movement, in the upstream part of the bed also reduces the length before the combustion initiation, while providing the waste with more time for moisture evaporation.

Case 3. Co-current Furnace Configuration

Shown in Figure 5(a) is the gas temperature contour for Case 3. Since the hot gas stream from the bed flows to the right side, the low gas temperature region upon the upstream part of the bed becomes very large. Thus, the upstream part of the bed is almost isolated from the exposure to the upper hot gas stream, unlike as in Figure 4(b). Initiation of the combustion is also delayed significantly, which can be inferred from the temperature distribution on the waste bed.

In Figure 5(b), radiative heat flux in the upstream part of the bed(x<2m) decreases to 40% of that for Case 1. Contribution of the gaseous radiation in that part becomes negligible due to the change in the flow pattern of the hot gas stream, while it is about a half in Figure 4. On the contrary, gaseous radiation



(a) (b)

Figure 5. Temperature on the center plane of the gas flow field(a) and radiative heat flux onto the bed(b) for Case 3

increases significantly in the central and downstream parts of the bed(x>4m), which are exposed directly to the hot gas stream.

These results imply that a well-designed gas flow pattern determined by the furnace configuration or the secondary air enhances the waste bed combustion through the radiative heat transfer. Reduction of the furnace volume near the feeder along with a control of the waste throughput speed would improve the radiation distribution in the early stage of combustion.

Radiation during intermediate solutions

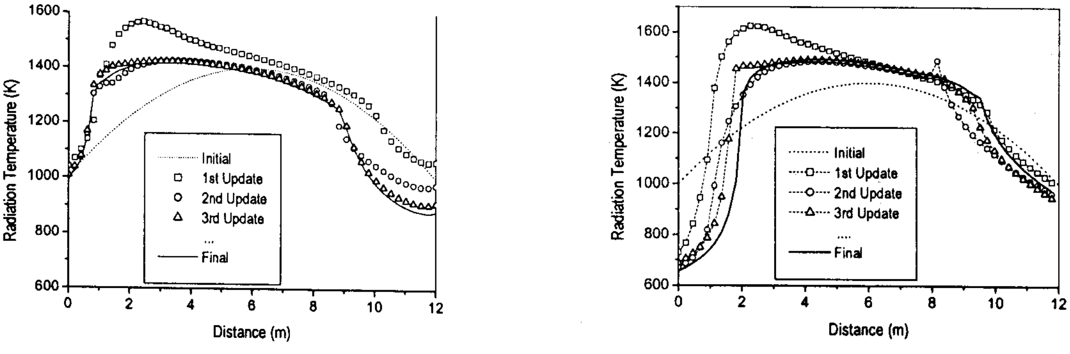
Investigating the intermediate solutions of the CSM provides additional insight on the bed-gas interaction. Figure 6 shows the profiles of the effective radiation temperature in the early iteration steps for Cases 1 and 3. For the initially assumed parabolic distribution of radiation, the waste combustion progresses slowly, consuming more oxygen within the bed. Thus, resultant gas temperature from the bed becomes relatively high. Then, the radiation temperature on the bed becomes very high at the first update in Figure 6(a), which is not fully converged yet. Changes in radiation profile become stable rapidly after the second update of the waste bed combustion and the gas flow field.

Case 3 in Figure 6(b) shows a different trend of intermediate radiation profiles. At the first update, the heat flux at x<1m decreases significantly, since the large low temperature region develops above the bed. It results in a delayed initiation of the combustion at the next update of the waste bed combustion. The size of the low radiation zone increases continuously up to x<2m, as the computation is repeated.

CONCLUSIONS

The coupled interaction between the fuel bed combustion and gas flow region was investigated for the grate-type waste incinerators. The combined simulation method was employed to simultaneously predict the bed combustion and the gas flow dynamics.

Since the effect of gaseous emission in radiation is significant, an adequate flow pattern in a well-designed furnace configuration can increase radiative heat flux onto the bed, especially in the early stage of the waste combus-



(a) (b)

Figure 6. Distribution of effective radiation temperature for intermediate solutions of Case 1 and Case 3.

tion. Combustion-related operating parameters can also contribute to the efficient radiation by minimizing the size of low temperature region above the upstream part of the bed. The combined consideration of the bed combustion and gas flow field including their interaction is essential to achieve the integrated control of design and operating parameters.

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