Integrated FLIC/FLUENT Modelling of Large Scale MSW Incineration Plants

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Summary

The combined simulation of FLIC and FLUENT was carried out for the combustion chamber of the municipal waste incinerator to predict the waste bed combustion and the gas flow field simultaneously.

The combined simulation provided input conditions on both codes: the gas release from the waste bed for FLUENT and the radiative heat influx from the furnace for FLIC. After several updates of the two models, the heat and mass interaction reached a steady-state. The ignition point of the waste combustion in the final solution was advanced by around 0.5m, compared to the initial results using an assumed constant radiation heat flux.

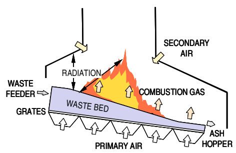
The predicted results of waste combustion from FLIC was compared to the measured data within the bed using the novel ball instrument. The maximum bed temperature measured was 1000°C - 1128°C. Big fluctuations of temperature and of oxygen were observed. The model predicts quite satisfactory the upper and lower boundaries of both the temperature and O_2 fluctuations.

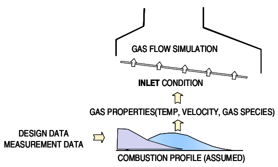
In the gas flow field, the jet arrays of the secondary air dominated the flow pattern throughout the secondary combustion chamber. A high temperature and high velocity gas stream was created following the jet trajectories. Improving the secondary air is necessary for more efficient use of the furnace volume.

Conventional Flow Simulations

➤ Major Phenomena in the Incinerator Combustion Chamber

- Waste combustion in the bed on the grates
- Gas flow region over the bed
- Close interaction of the two regions through heat and mass transfers
  - Release of combustion gas from the bed to the gas flow region
  - Radiative heat transfer between the furnace wall, the flame and the waste bed





➤ Usual gas flow simulations for waste incinerators

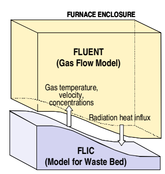
- are based on simplification of waste combustion
  - The waste bed becomes the inlet of the gas plenum
  - The input conditions(temperature, velocity and gas concentrations) of the inlet are calculated from an assumed combustion profile
- This method allows simple simulations of the incinerators, but limits the capability of usual gas flow simulation
- The gas flow simulations have provided useful information on the gas flow characteristics for various furnace shapes and on the effect of secondary air injections etc.

Combined Simulation Strategy

➤ The objective – simultaneous simulation of waste combustion and gas flow field considering their heat and mass interaction

➤ Calculation procedure: Iterative calculation of FLIC and FLUENT

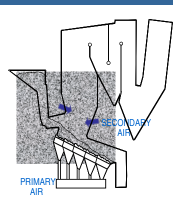
- FLIC→FLUENT: Gas properties leaving the bed as input conditions of the inlet
- FLUENT→FLIC: Radiation profile along the bed as boundary condition on the top of the bed
- Convergence criterion: changes in radiation or in the gas temperature

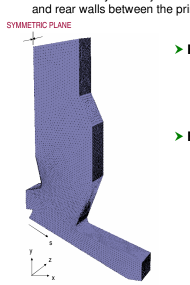


Simulation Method for Waste Incinerator

➤ MSW Incineration Plant

- Throughput of waste: 10 ton/h
- Total flow rate of combustion air : ~36,000Nm3/hr (80% excess air)
- Grate: Martin type, 3.76m x 8m
- Moisture : Volatile Matter : Fixed Carbon : Ash content in waste = 36: 32: 8.2: 23.8%
- Lower Calorific Value of waste = 7,655 kJ/kg
- The secondary air is injected from 28 nozzles located on the front and rear walls between the primary and secondary combustion chambers.





Unstructured mesh using 159,607 cells

➤ FLIC for simulation of waste combustion

- Number of cells=160 x 200
- Input conditions
  - Primary air flow rate=16:32:26:18:8%
  - Waste residence time=80 min, Particle size=ϕ45mm

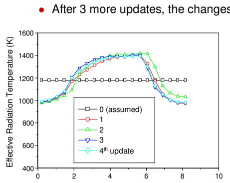
➤ FLUENT v6 for gas flow simulation

- Flow Models
  - Turbulence: Renormalized Group k-ε model,
  - Radiation: Discrete Ordinate Method with the Weighted Sum of Grey Gases Model for gaseous emission by CO_2 and H_2O
  - Reaction: Eddy break-up/kinetic rate
- Combined Simulation
  - 200 iterations for one input update from FLIC
  - The input update is repeated until the radiation profile from FLUENT becomes stable

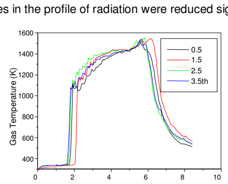
Intermediate Results of Combined Simulation

➤ Interaction between FLIC and FLUENT during the iterative calculation

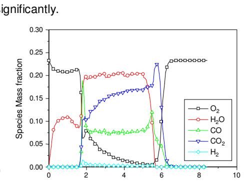
- The radiation temperature was initially assumed to be constant at 1173K.
- The first radiation profile became similar with the temperature distribution of the combustion gas leaving the bed shown in the right graph. since the temperature on the furnace wall and gaseous emission is determined by the properties of combustion gas and the flow pattern.
- After 3 more updates, the changes in the profile of radiation were reduced significantly.



Changes in the updates of profile of incident radiation on the bed predicted by FLUENT



Changes in the updates of gas temperature escaping the bed predicted by FLIC

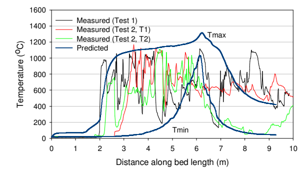


Gas concentration at the final update to be used as input conditions for the waste bed in FLUENT

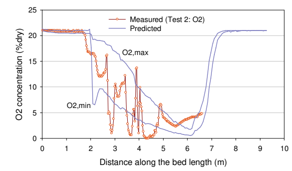
Results: Waste Combustion

➤ Comparison with measurements using the ball instrument

- Ball instrument : a unique instrument that can be introduced into the incinerator with the waste feed and tumbles along with the burning waste material while recording temperatures, gas composition and bed motion onto its thermally-insulated electronic chip. The size of the instrument was about 130mm in diameter and 220mm in length.
- The waste feed was ignited at a position of 1.8 m to 2.0 m from the waste entrance. The maximum bed temperature measured was 1000°C - 1128 °C. Big fluctuations of as high as 800 °C were observed. This is due to, among other reasons, a thin combustion layer as predicted by the mathematical model where the thermocouple tips moves out and then into its boundary constantly as the measuring device tumbles along the bed. Fluctuations of O_2 concentration in the moving bed were also observed.
- The model predicts quite satisfactory the upper and lower boundaries of both the temperature and O_2 fluctuations.



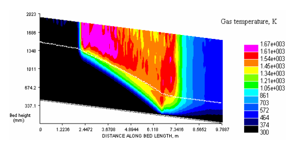
Gas temperature measured and predicted



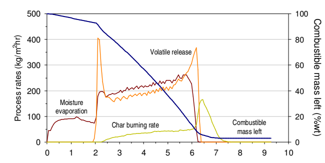
Oxygen concentration measured and predicted

➤ Progress of waste combustion

- Calculation shows that all the physical and chemical processes are confined to a narrow band of 250mm along the bed height, which is 6 times of the particles assumed.
- During the first 2m along the bed length, only moisture evaporation occurs in the bed.
- At a location near the 2m position, a very sharp rise in the devolatilisation rate occurs as the bed temperature is raised above the threshold (260°C) and volatile gases start to release from the solids. Char begins to be formed and starts to burn at a position of 2.3 m along the bed length.
- At a position of 6.3 m, all the moisture in the solids is evaporated The devolatilisation process is completed at a position of 6.3m, and the char burning rate rises to a peak level as all the O_2 is now available to its combustion.
- The whole combustion process is completed at 7.5 m.



Gas temperature within the bed

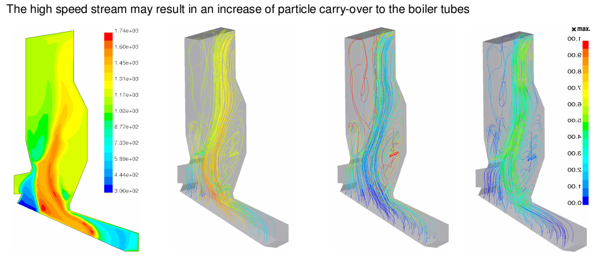


Rates of combustion process

Results: Gas Flow Field

➤ Main features of the flow field

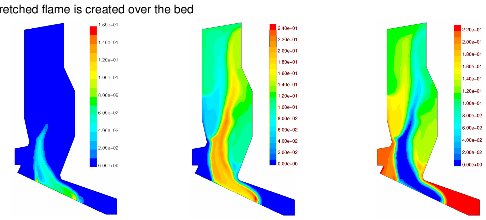
- The secondary air jets dominate the overall flow pattern
- A hot high-speed gas stream is formed following the jet trajectories
- The high speed stream may result in an increase of particle carry-over to the boiler tubes



Temperature contour on the symmetric plane | Streamlines colour encoded by gas temperature (0-1740K) | Residence time (0-10 sec) | Velocity magnitude (0-20m/s)

➤ Gaseous reaction

- The gaseous reactions occur by fresh oxygen from the secondary air in the main hot gas stream
- A long stretched flame is created over the bed



CO mass fraction | CO_2 mass fraction | O_2 mass fraction

Conclusions

➤ FLUENT/FLIC Combined Simulation

- Simultaneously predicts the waste combustion and the gas flow field
- Allows investigation of the effect of various design and operational parameters in incinerators

➤ Combustion and Flow Characteristics of the Waste to Energy Plant

- Waste combustion ignited at s=2m and completed at s=7m
- Active mixing and reaction by the secondary air in the gas flow field
- The high speed hot gas streams increase the particle carry-over to the boiler
  - Optimisation of the injection method of the secondary air is necessary to improve the flow pattern for better mixing and reaction efficiency

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