Developments in the Application of Zone modelling for Furnace Efficiency Improvements.

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Recent developments in the applications of the ZONE method for computing radiation exchange in furnaces will be described including:

- The use of isothermal CFD simulations to provide heat release patterns and inter-zone flow data in a three-dimensional zone model.
- The coupling of a zone model with a model of heat transfer in a porous medium to predict the transient performance of a furnace incorporating permeable panels in the refractory lining.
- The development of a "spectral" zone model, which allows for the discrete absorption and emission spectra of combustion products, and its application to investigate the effects of using high emissivity coatings for furnace linings.

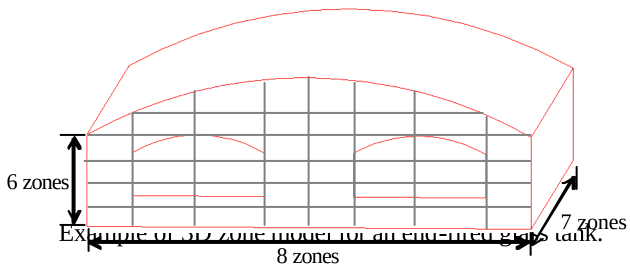
The ZONE method provides a powerful tool for modeling complex systems where the boundary conditions are complex functions of the combustion side conditions and where they may also be transient in nature.

Introduction

Prediction of the thermal performance and efficiency of a furnace requires accurate calculation of the complex radiative heat exchange in the system. This can be achieved by use of the ZONE method of radiation analysis, which has been applied to a wide range of furnaces and boilers. The zone method has modest computational requirements so that it is suitable for quickly analysing a wide range of operating scenarios and can also be used to simulate transient furnace operation.

Theory

In the zone method the furnace enclosure is split into a number of volume and corresponding surface zones each of which are considered to be isothermal and have constant radiation properties. An overall energy balance is then formulated for each zone taking into account the interzone radiative exchanges and, if appropriate, convection from gas zones to adjacent load or refractory surface zones. For each volume zone the enthalpy transport into or out of each zone as a result of the flows of the hot combustion products is also included as is any heat release due to combustion. The resultant set of non-linear equations (one per zone) can then be solved iteratively to yield the temperature of each of the gas zones and either the unknown temperature or heat flux for each surface zone and hence the thermal behaviour of the whole furnace system. A full description of the ZONE method is given by Rhine and Tucker [1].



Example of 3D zone model for an end-fired glass tank.

Examples of recent applications

3-D model of glass melting furnaces

Objective is to predict NOx emissions for different firing configurations, whilst maintaining heat flux profile to the glass.

Zone model developed using 7x6x8 zones = 336 volume zones; 285 surface zones (see figure above). It applies either:

i) A simple plug flow assumption for flow with variable combustion and heat release assumptions,

ii) Or flow and combustion data is derived from isothermal CFD simulation.

Incorporates a thermal NOx model. Some results to be presented in presentation by Quinqueneau and Fricker.

Modelling porous wall furnace[2,3]

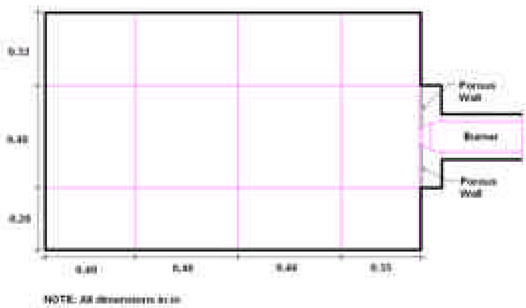
ZONE Modelling of a Porous Wall Furnace using 12 gas zones, and 4 load and 34 wall surface zones.

Applies flow data from an isothermal CFD simulation using Thring-Newby criterion to allow for non-isothermal conditions in actual furnace.

Links ZONE model to a model of heat transfer in porous wall to predict heat flux enhancement and energy recovery in flue gases

Simulates the transient performance by linking with a 1-D conduction model for the walls and load.

Results compare well to experimental data.



Development of spectral ZONE model

Applies exponential wide band model to simulate individual emission/absorption bands for CO_2 and H_2O and their variation with T.

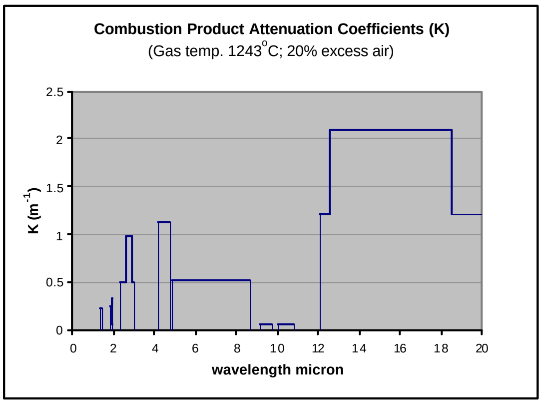
- Requires recalculation of geometric exchange areas at each iteration (temperature change) since band absorption properties are a function of T
- Applied to predict effects of high emissivity coatings in furnaces
- Refractory walls are non-grey and emissivity can be < 0.5 at temperatures above 1000^{o}C

Grey gas models predict no effect when wall emissivity is increased.

Simple ZONE models using the weighted-sum-of-grey -gas approach predict savings - due to the 'clear' gas component – spectral window.

More advanced EWBM being applied to give more accurate prediction in real furnace applications.

EWBM show higher savings compared to w.s.g.g. model.



Conclusions

1) The Zone model is adaptable to a wide range of thermal problems.

2) It can be used to model transient and steady-state problems.

3) Large 2 and 3-dimensional zoning can now be handled.

4) Flow and combustion data can be mapped from fast CFD simulations.

5) Detailed spectral radiation effects can be modeled.

6) Computational time is not an issue.

References

1. *Modelling of gas-fired furnaces and boilers*, Rhine J.M. & Tucker R.J. Mcgraw-Hill, 1990.
2. *Development and experimental testing of a porous ceramic wall to improve the thermal performance of steel billet reheating furnaces*, Tucker R.J., Ward J. et al., J. Energy Institute, 2008, vol. 81, no. 3, pp 135-142.
3. *The effect of installing porous refractory panels on the transient start up performance of a gas-fired reheating furnace*, Ward J. *et al*. Proc.ASME Conference, Boston, MA, 2008.