Developments in the Application of ZONE Modelling

for furnace efficiency improvements

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Outline

- Brief description of the ZONE method

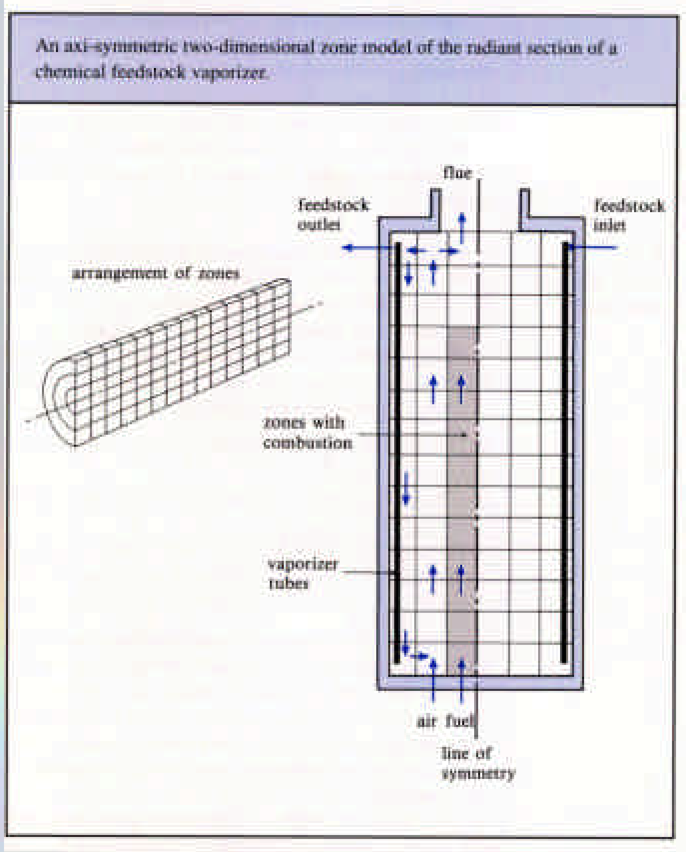
- Recent advances
  - Coupling to CFD
    - modelling of GdF simulated glass melter

- Novel applications
  - Coupling to permeable wall heat transfer model
  - Spectral ‘gas band’ modelling

ZONE model – Key features

- Radiation model
- Handles:
  - Geometry accurately
  - Non-grey combustion gases
  - Surface reflectivity

- Can be coupled to:
  - CFD for flow/combustion data
  - System/load models for variable boundary conditions
  - Transient simulation



An axi-symmetric two-dimensional zone model of the radiant section of a chemical feedstock vaporizer.

Furnace Geometry

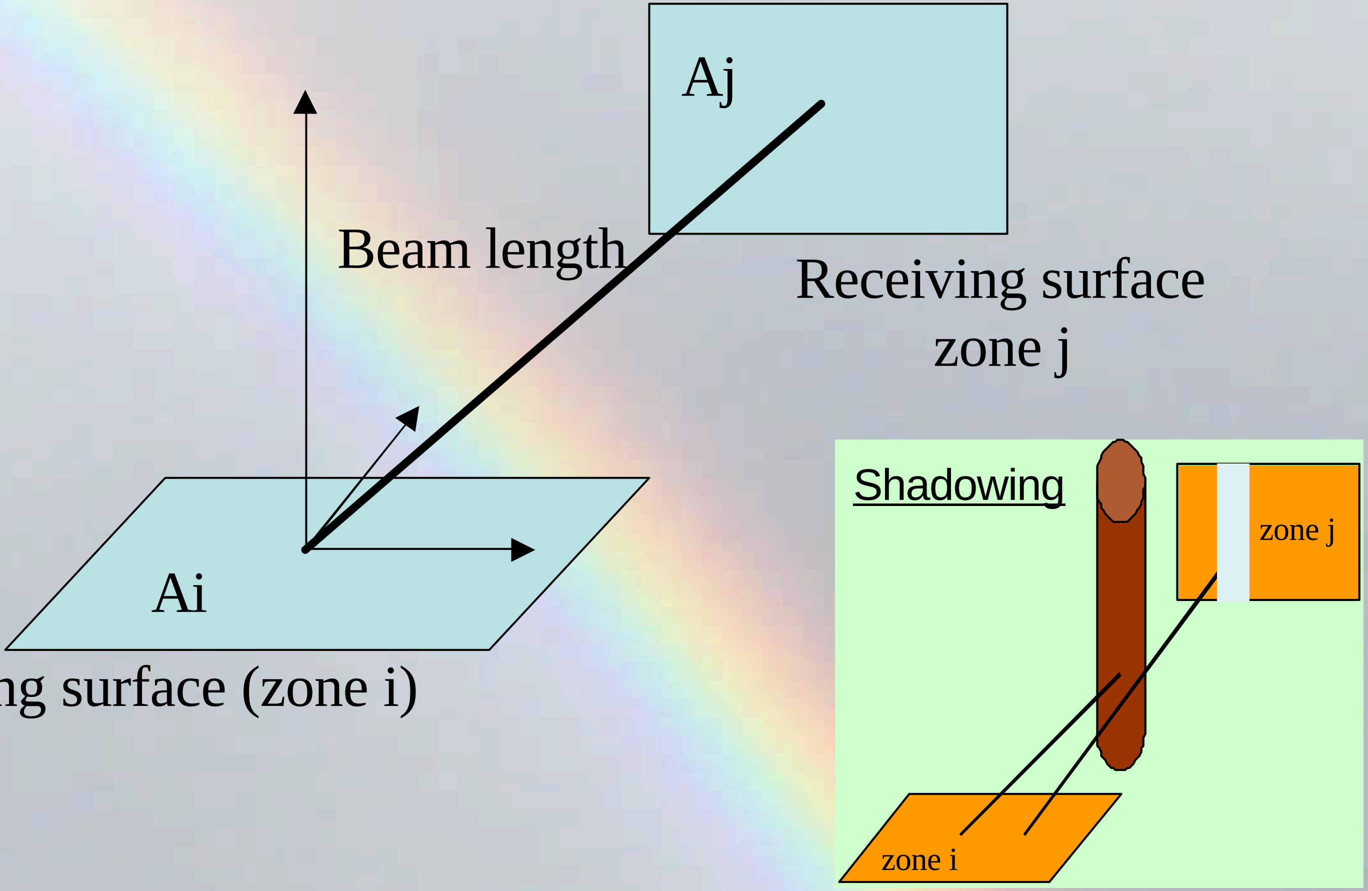
- Direct exchange areas define ‘view factors’ between gas and surface zones
  - Derived by Monte Carlo ‘ray-tracing’ method
- Total exchange areas
  - Allow for surface reflection
- Directed flux areas allow for gas non-grey properties
  - Weighted sum of grey gases model
  - 1 clear + 2 grey gases

$$\overline{gg}, \overline{gs}, \overline{ss}$$

$$\overline{GG}, \overline{GS}, \overline{SS}$$

$$\overrightarrow{GG}, \overrightarrow{GS}, \overrightarrow{SG}, \overrightarrow{SS}$$

Monte Carlo Method for Direct Exchange Areas



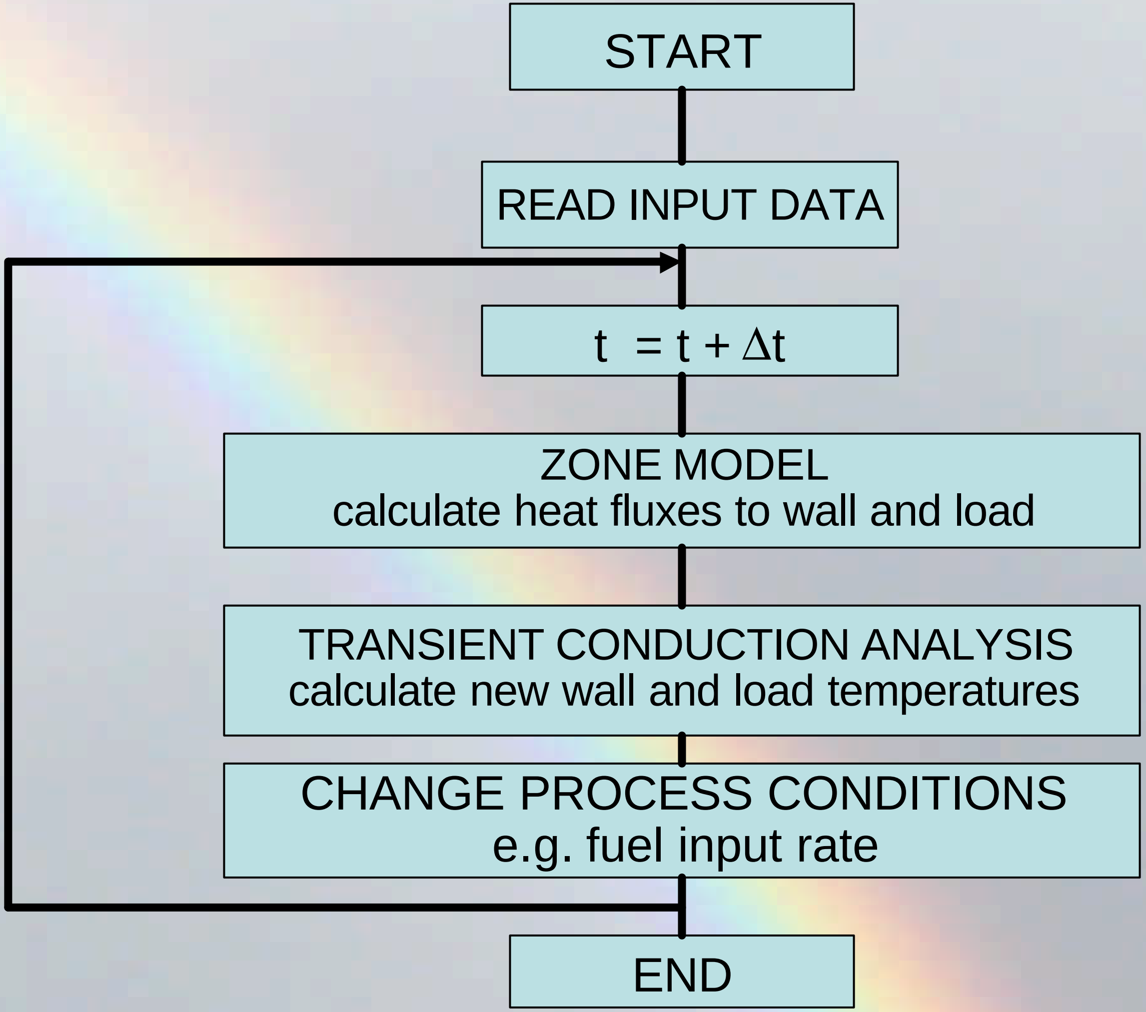
Beam length

Receiving surface
zone j

emitting surface (zone i)

Shadowing

Transient ZONE model



START

READ INPUT DATA

$t = t + \Delta t$

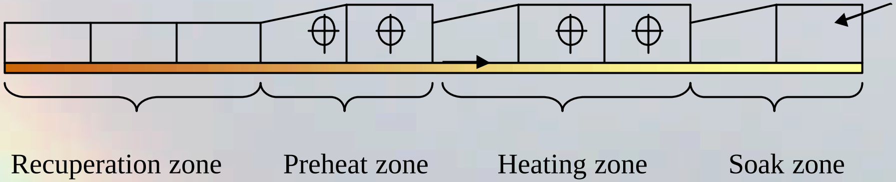
ZONE MODEL
calculate heat fluxes to wall and load

TRANSIENT CONDUCTION ANALYSIS
calculate new wall and load temperatures

CHANGE PROCESS CONDITIONS
e.g. fuel input rate

END

Transient simulation of steel temperatures in a reheating furnace

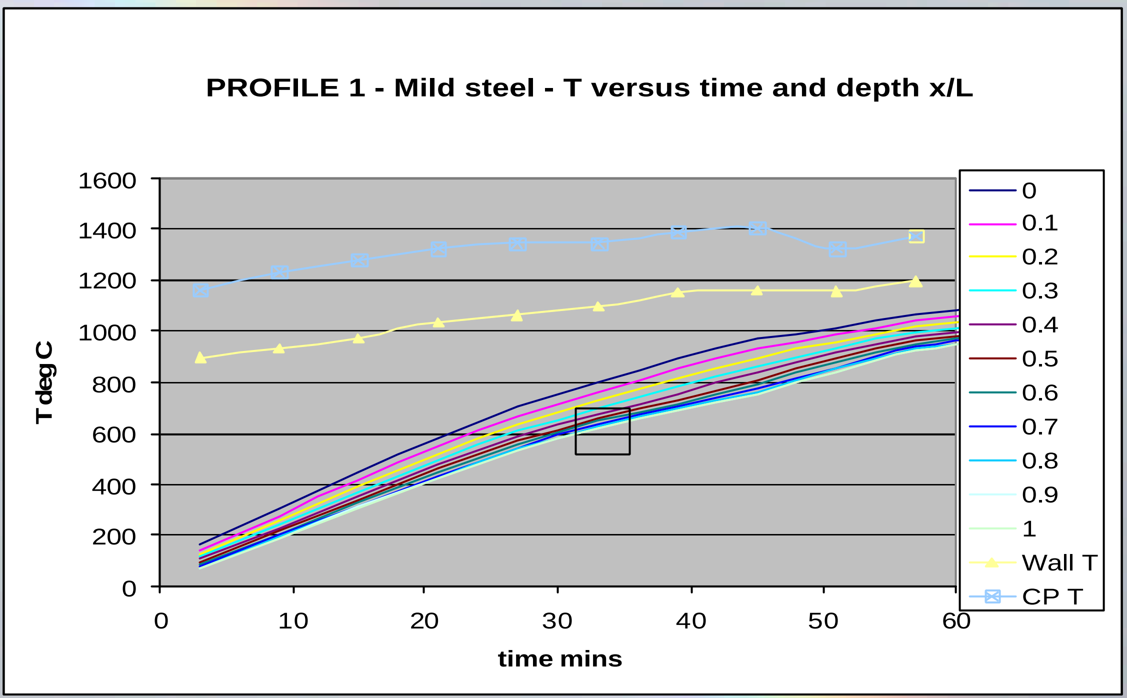


Recuperation zone

Preheat zone

Heating zone

Soak zone

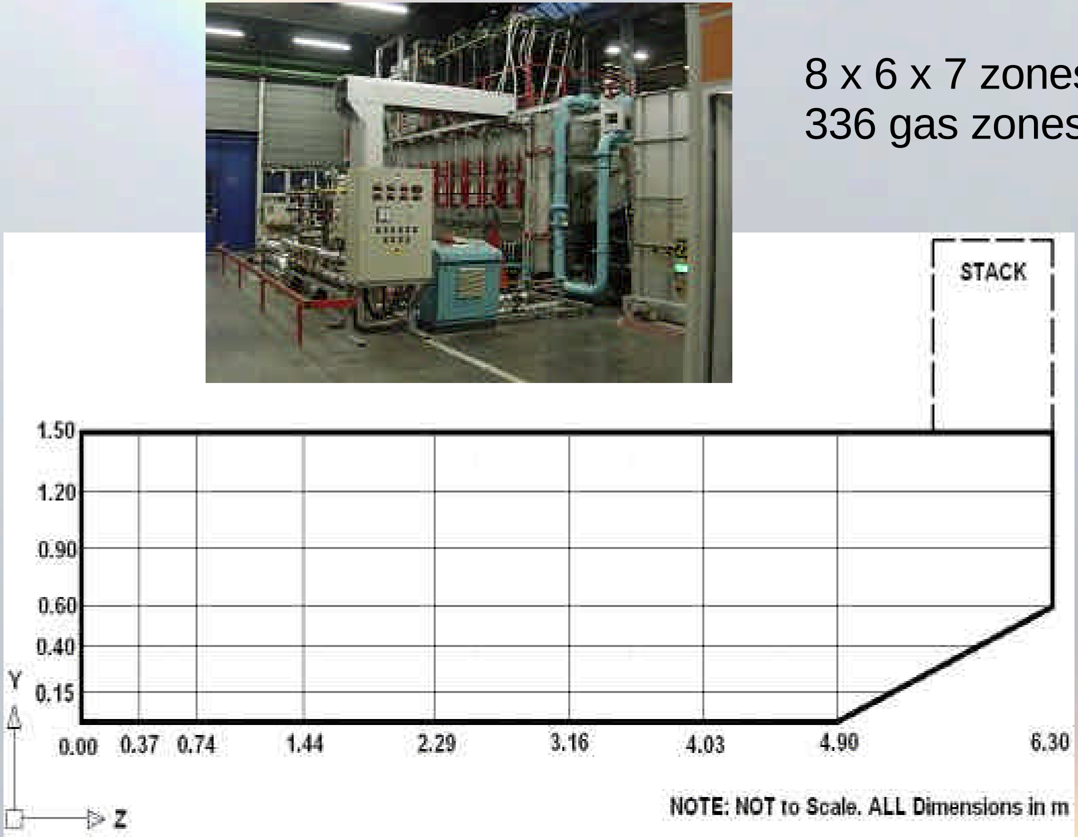


Coupled ZONE/CFD model

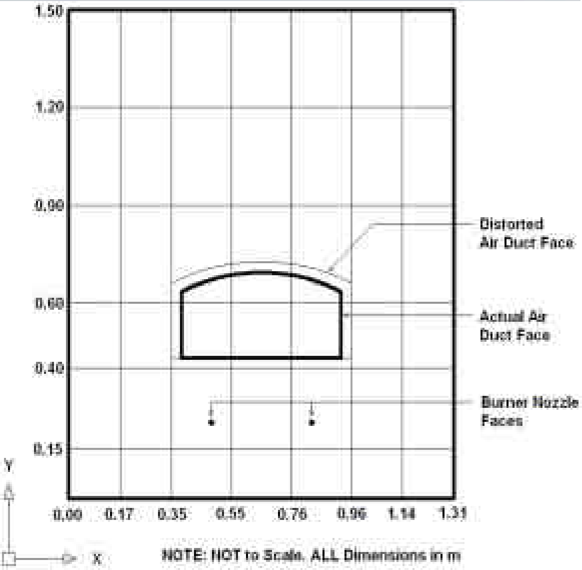
Modelling of simulated glass melting test furnace at GdF.

MULTI-ZONE MODEL OF A GLASS MELTING TEST FURNACE

8 x 6 x 7 zones:
336 gas zones; 285 surface zones



NOTE: NOT to Scale. ALL Dimensions in m



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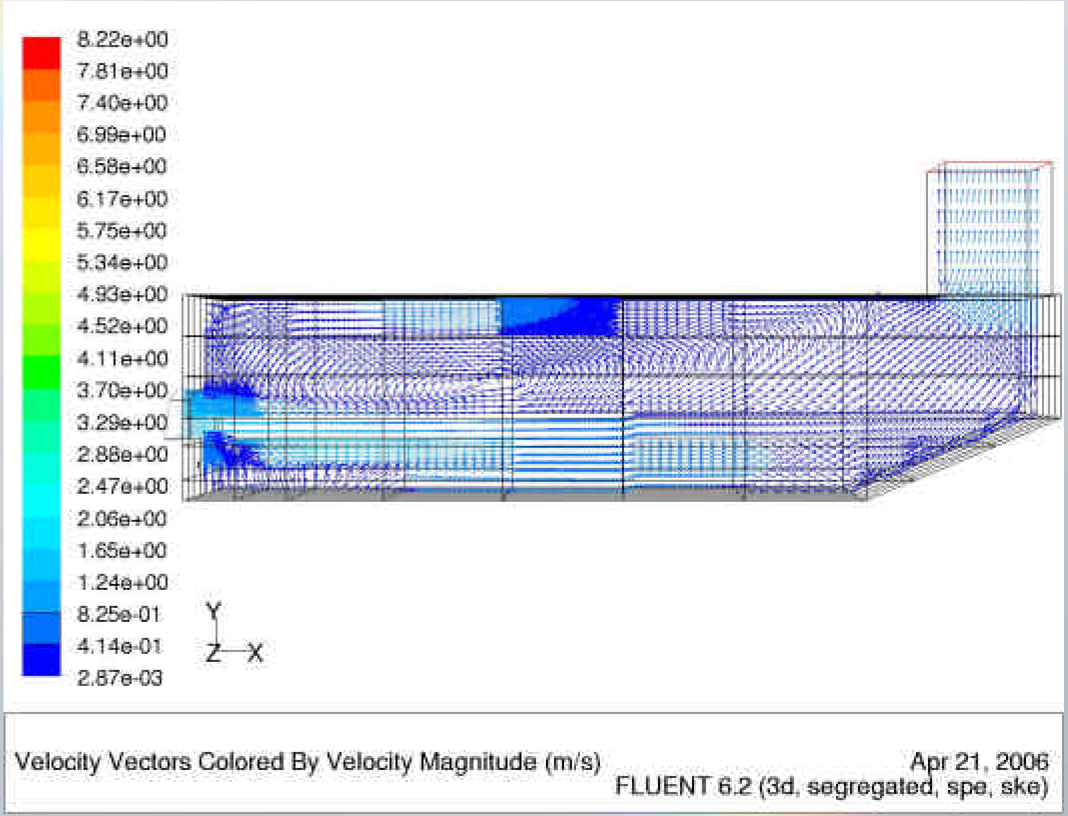
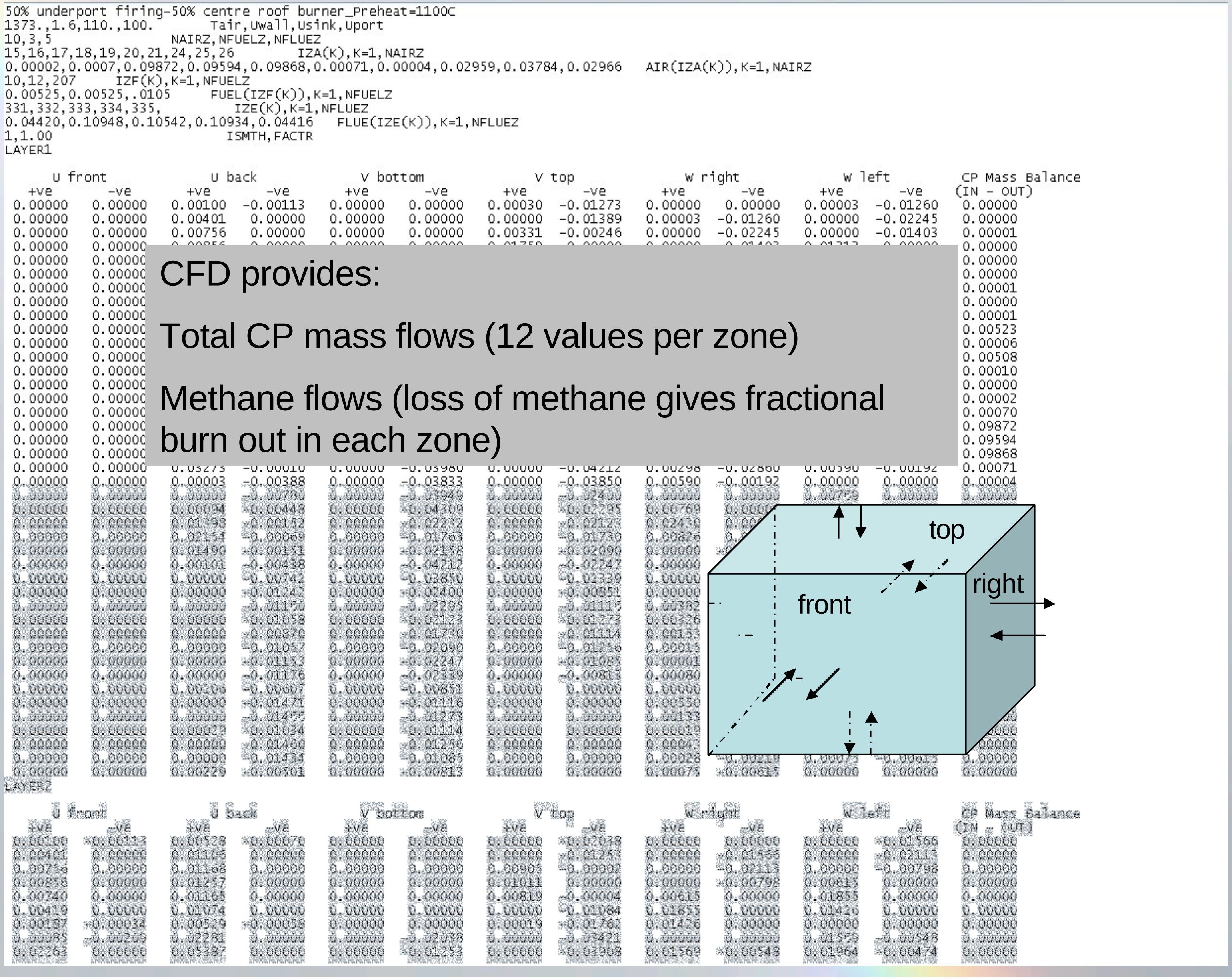
Isothermal CFD results

- Velocity mid plane along length



A UDF extracts data from FLUENT into a readable form for the zone model



```
50% underport firing-50% centre roof burner_Preheat=1100C
1373.,1.6,110.,100.       Tair,Uwall,Usink,Uport
10,3,5              NAIRZ,NFUELZ,NFLUEZ
15,16,17,18,19,20,21,24,25,26        IZA(K),K=1,NAIRZ
0.00002,0.0007,0.09872,0.09594,0.09868,0.00071,0.00004,0.02959,0.03784,0.02966   AIR(IZA(K)),K=1,NAIRZ
10,12,207     IZF(K),K=1,NFUELZ
0.00525,0.00525,.0105     FUEL(IZF(K)),K=1,NFUELZ
331,332,333,334,335,          IZE(K),K=1,NFLUEZ
0.04420,0.10948,0.10542,0.10934,0.04416   FLUE(IZE(K)),K=1,NFLUEZ
1,1.00                      ISMTH,FACTR
LAYER1

      U front             U back              V bottom             V top               W right              W left          CP Mass Balance
  +ve       -ve       +ve       -ve       +ve       -ve       +ve       -ve       +ve       -ve       +ve       -ve       (IN - OUT)
 0.00000   0.00000   0.00100  -0.00113   0.00000   0.00000   0.00030  -0.01273   0.00000   0.00000   0.00003  -0.01260   0.00000
 0.00000   0.00000   0.00401   0.00000   0.00000   0.00000   0.00000  -0.01389   0.00003  -0.01260   0.00000  -0.02245   0.00000
 0.00000   0.00000   0.00756   0.00000   0.00000   0.00000   0.00331  -0.00246   0.00000  -0.02245   0.00000  -0.01403   0.00001
 0.00000   0.0000                                                                                                        0.00000
 0.00000   0.0000                                                                                                        0.00000
 0.00000   0.0000                                                                                                        0.00000
 0.00000   0.0000                                                                                                        0.00001
 0.00000   0.0000                                                                                                        0.00000
 0.00000   0.0000                                                                                                        0.00001
 0.00000   0.0000                                                                                                        0.00523
 0.00000   0.0000                                                                                                        0.00006
 0.00000   0.0000                                                                                                        0.00508
 0.00000   0.0000                                                                                                        0.00010
 0.00000   0.0000                                                                                                        0.00000
 0.00000   0.0000                                                                                                        0.00002
 0.00000   0.0000                                                                                                        0.00070
 0.00000   0.0000                                                                                                        0.09872
 0.00000   0.0000                                                                                                        0.09594
 0.00000   0.0000                                                                                                        0.09868
 0.00000   0.00000                                                                                                       0.00071
 0.00000   0.00000   0.00003  -0.00388   0.00000  -0.03833   0.00000  -0.03850   0.00590  -0.00192   0.00000   0.00000   0.00004
```

CFD provides:

Total CP mass flows (12 values per zone)

Methane flows (loss of methane gives fractional burn out in each zone)

ZONE model – NOx modelling

- Kinetic model for thermal NOx
- ‘O’ radical overshoot
  - Partial equilibrium model for [O] increases [NO] by x 3.5 (approx.)
- Reburn mechanism
  - [NO] reduction in fuel rich zones
  - Function of local [CH_4]

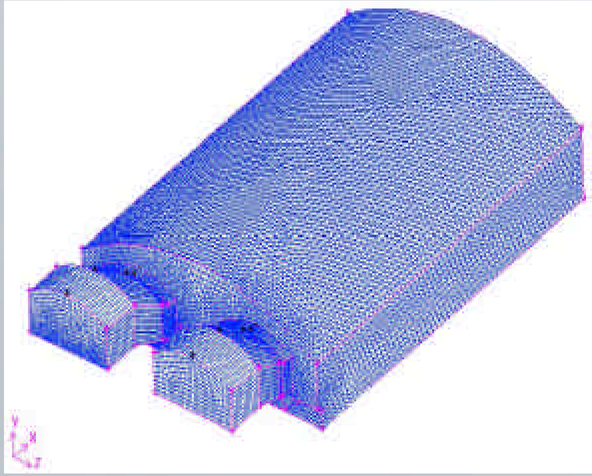
Convergence times

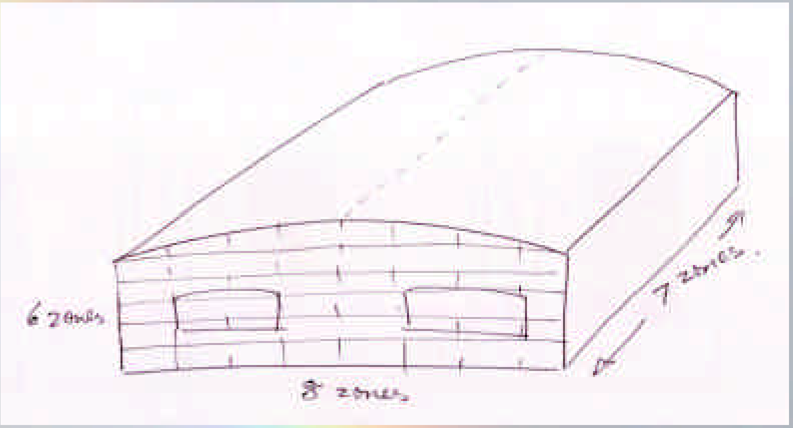
- CFD - 3 days (1.5 days if starting from initial flow field)
- ZONE model -1minute

- Results of this model are the subject of the next paper…………

ZONE model of end-fired glass tank

- 336 gas zones
- Includes coupled glass side and wall heat transfer equations to predict surface zone temperatures
- Enables rapid investigation of parameters
    - Excess air, Air preheat T; Surface properties; Load throughput and T
- Predicts NOx

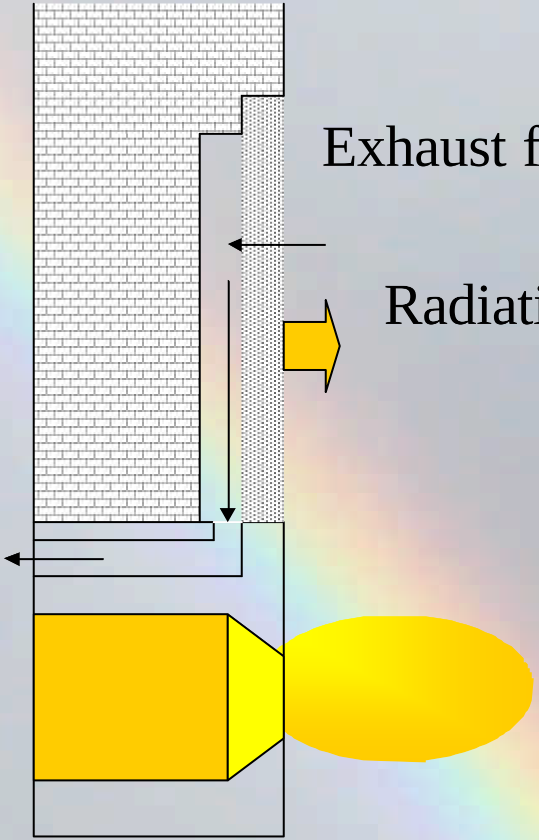




Example applications

- Permeable wall furnace model
  - Coupling to CFD model for flow data
  - Linking with 1-D permeable wall heat transfer model
- Spectral ‘gas band’ radiation model of fired heater

Recuperative-Radiant Burner



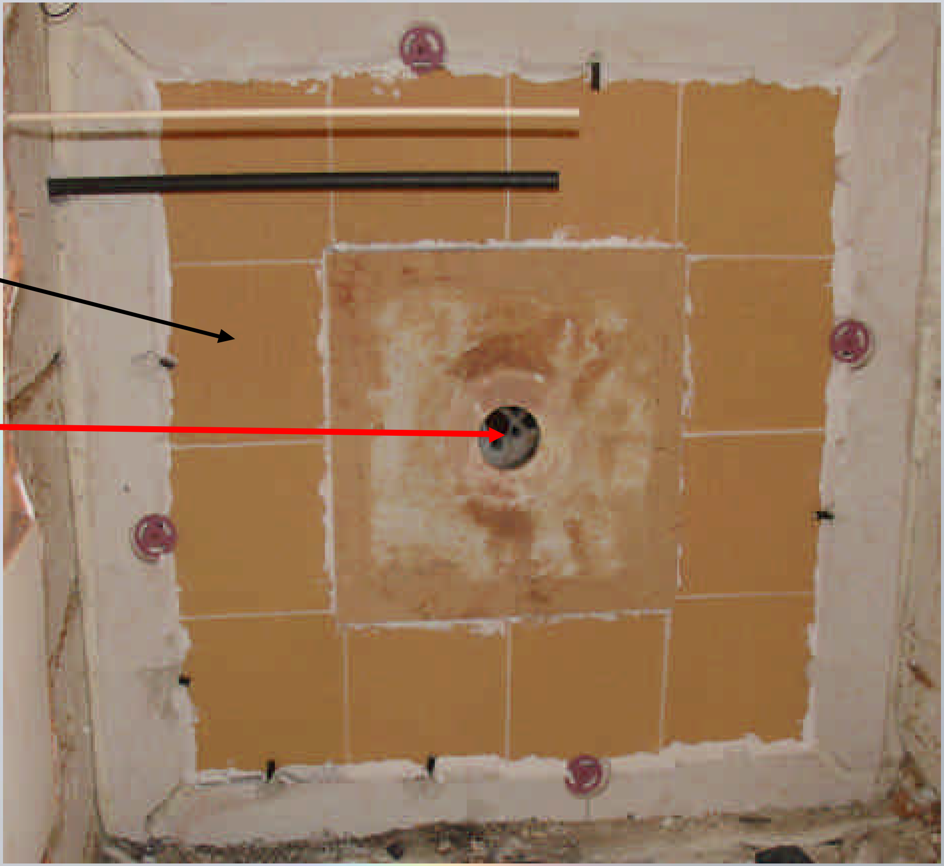
Exhaust flow

Radiation from tile

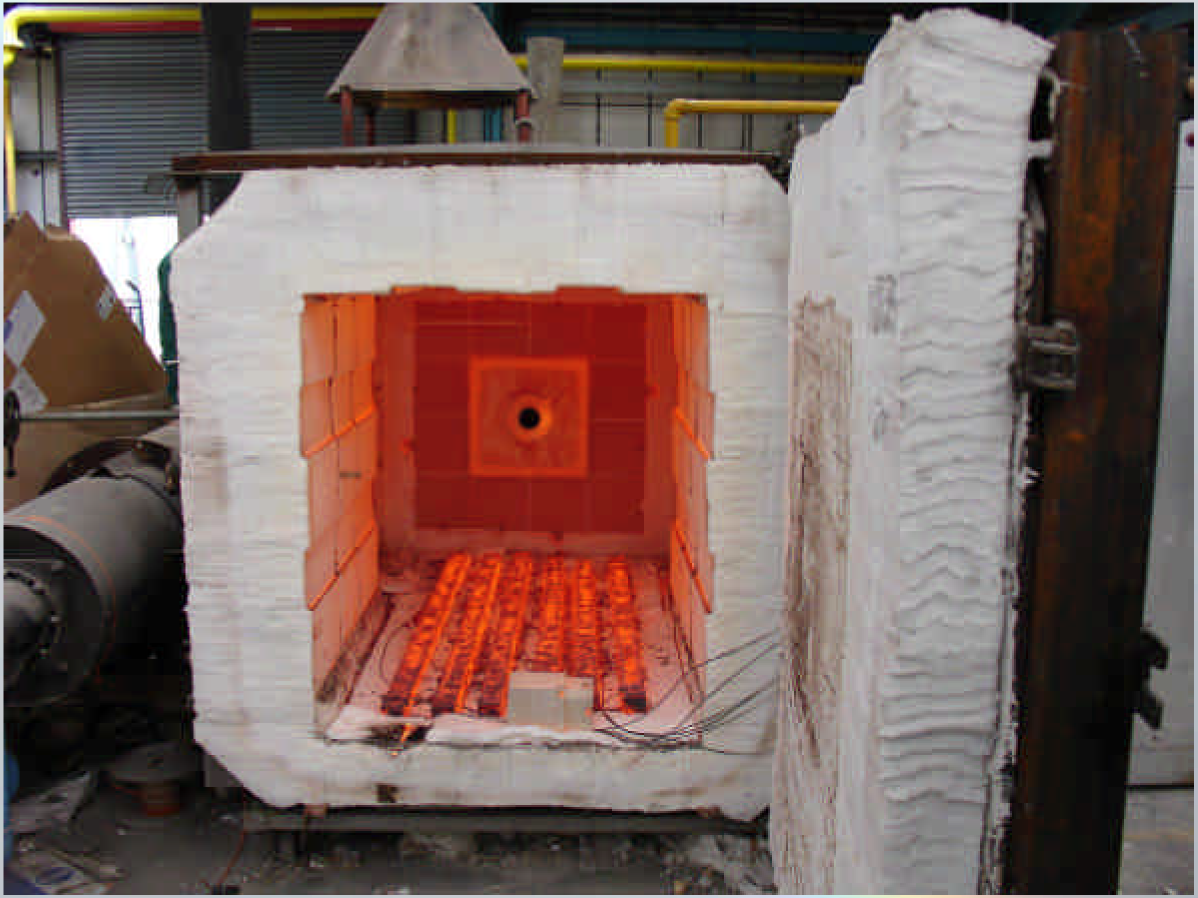
To recuperator

Construction of Permeable Wall

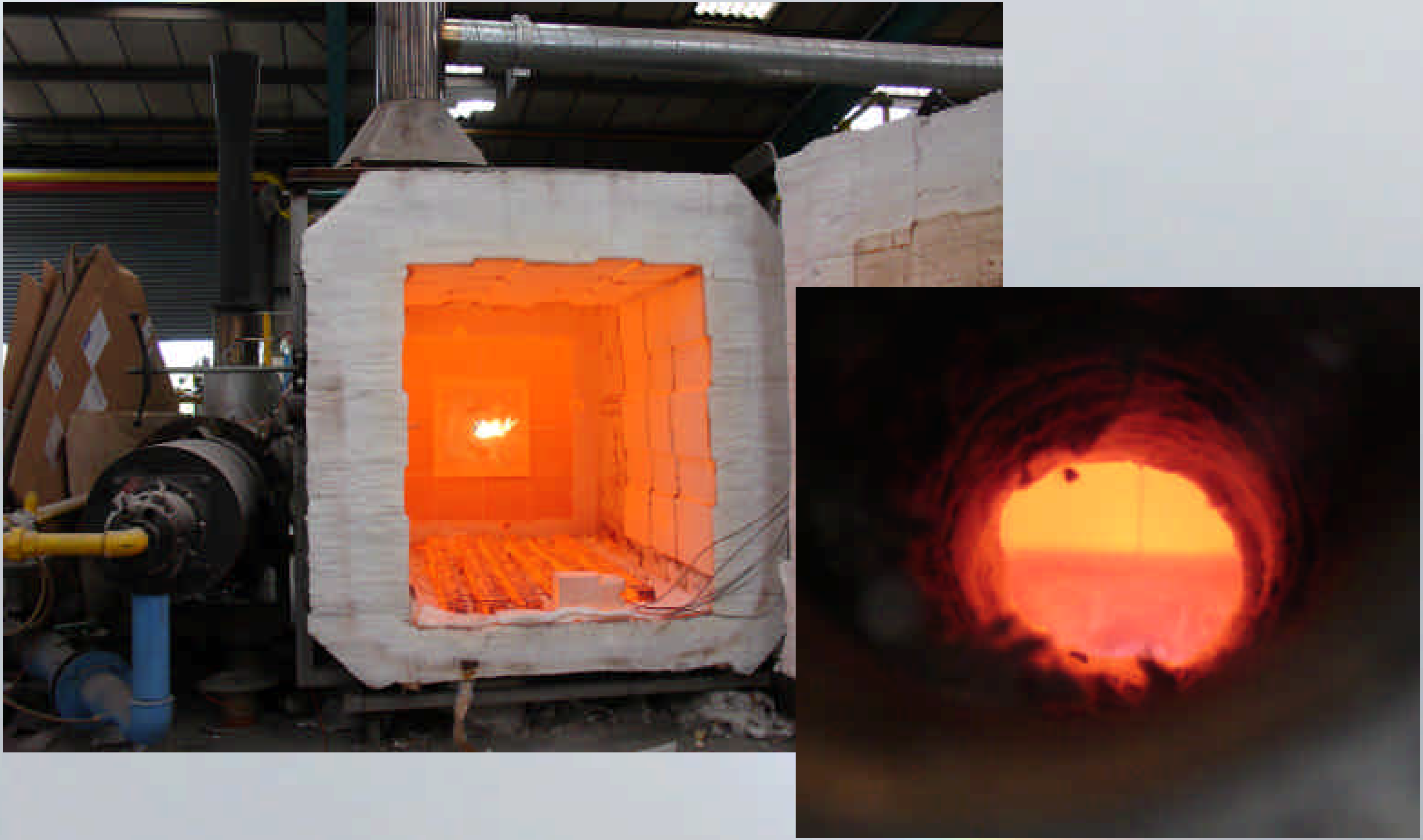
- Permeable wall area = 0.44m^2
- Recuperative burner input = 135 kW$_{net}$ (Natural Gas)
- Nominal air temperature = 400^{o}C



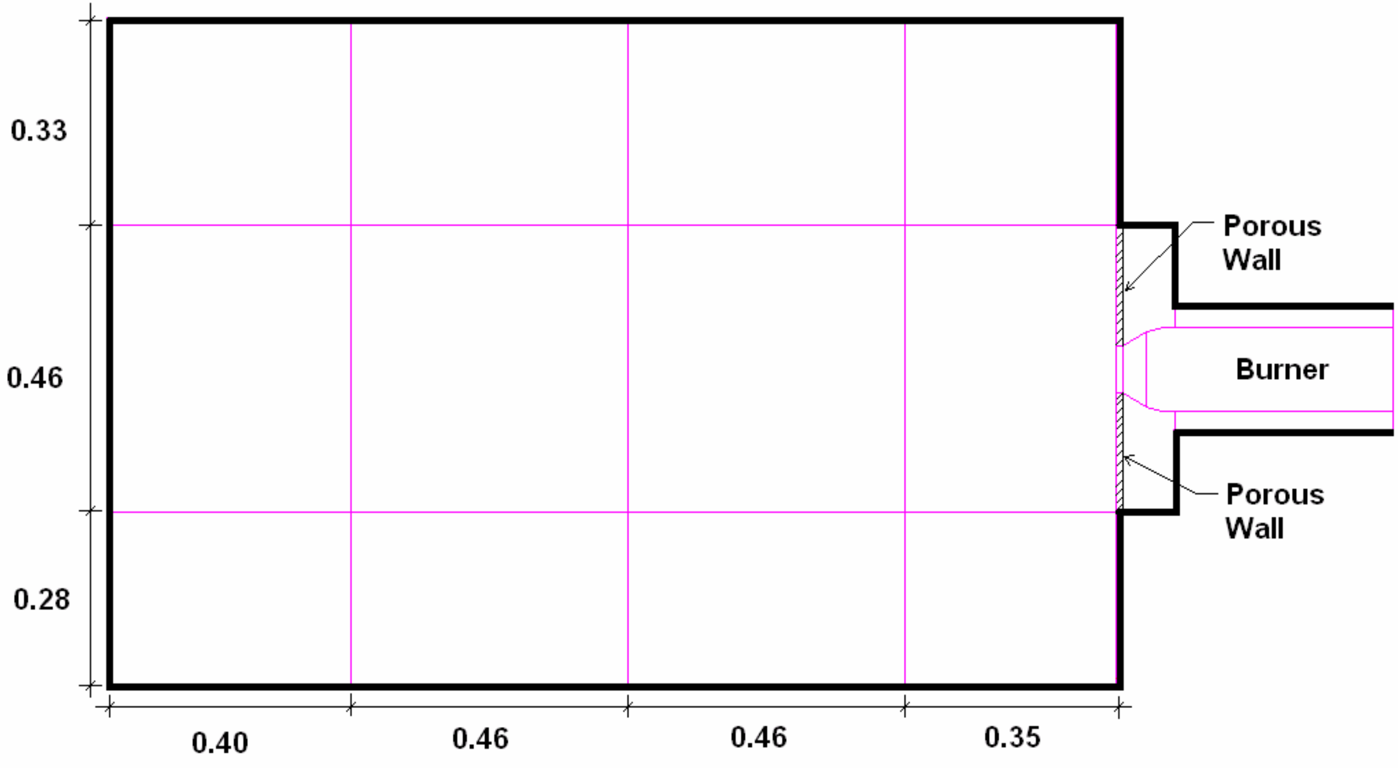
View of Permeable Wall



The Permeable Wall in Operation



THE ARRANGEMENT OF ZONES IN THE MODEL



NOTE: All dimensions in m

Coupled ZONE model and 1-D porous wall heat transfer model

- 12 Gas zones
- Surface zones:
  - 33 refractory; 4 load(steel); 1 porous wall
- **Monte Carlo** technique used to calculate the exchange areas
- Furnace atmosphere represented by a **3 term 'weighted sum of grey gases'** model
- "Once Off" Isothermal CFD Calculation of the Inter-Zone Flows
- Finite difference calculation of the transient temperature distributions for each "surface"and load
- Zone model coupled with a 1-D model of flow & heat transfer in the porous panel

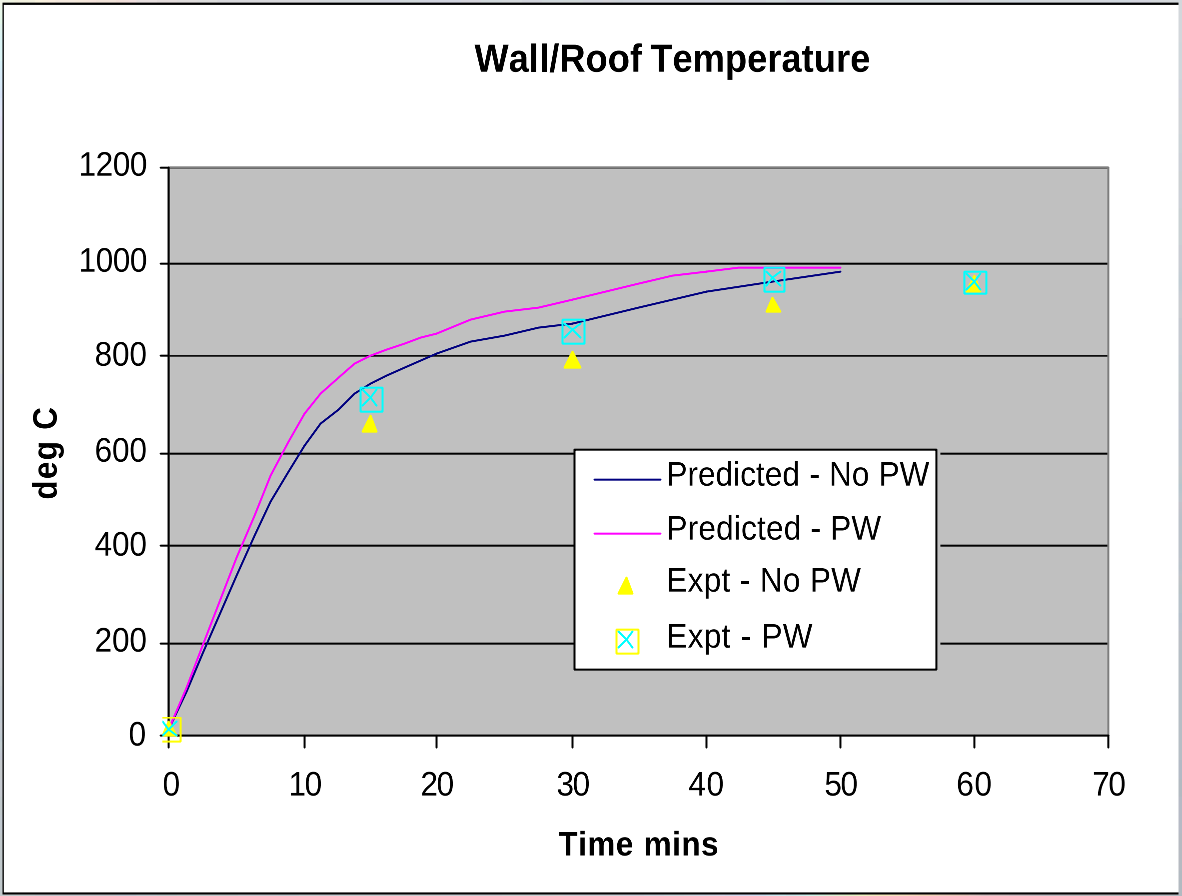
PREDICTED AND MEASURED ENERGY CONSUMPTIONS

Mean Billet Temperature = 1000ºC

Temperature Uniformity = ±10°C

Porous panel	Gross Energy Consumption (MJ)	
	Measured	Predicted
NO	849	806
YES	660	681

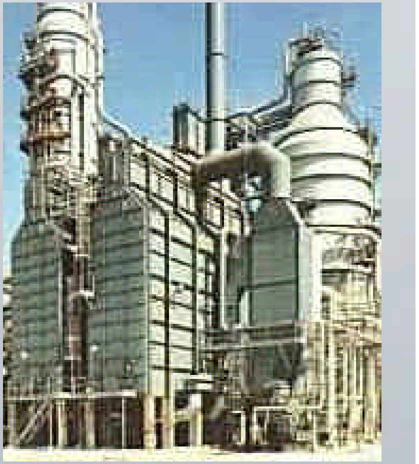
PREDICTED & MEASURED REFRACTORY TEMPERATURES



Example applications

- Permeable wall furnace model
- Spectral ‘gas band’ radiation model of fired heater
  - Automatic recalculation of exchange areas for each gas band
  - Link with non-grey surfaces

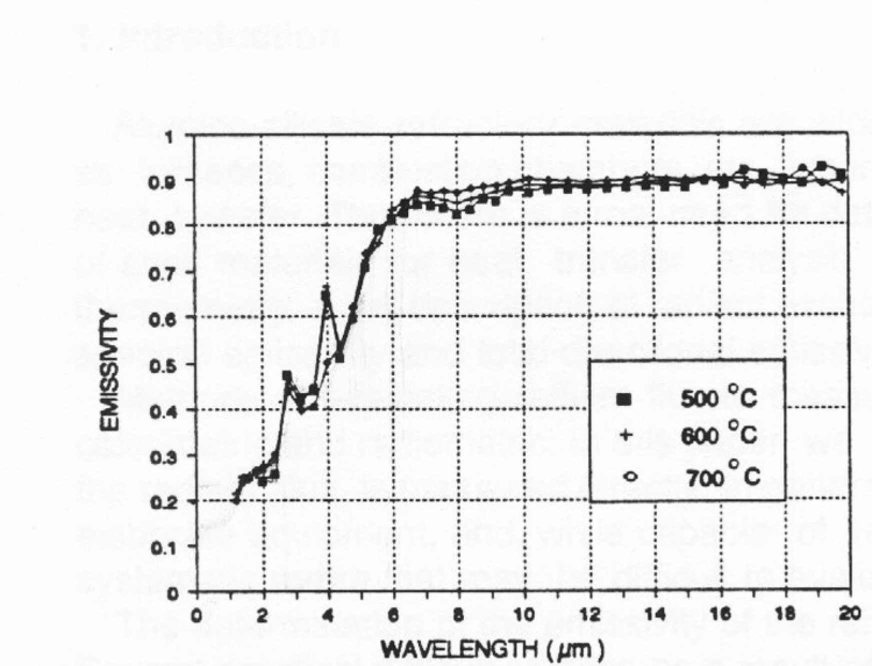
Radiant Section of a Reformer Furnace



- Parameters:
  - 10 x 11 x 1 metres
  - Heat sink surface 10 x 11 meters
  - Load throughputs 7.5 -12 MW
  - Temperature 950°C
  - Methane combustion 10-30% excess air
- WSGG model and EWBM are compared
- Exchange areas have to be recalculated for each band
  - Band widths and Attenuation coefficients are f(T)

Spectral ‘gas band’ modelling

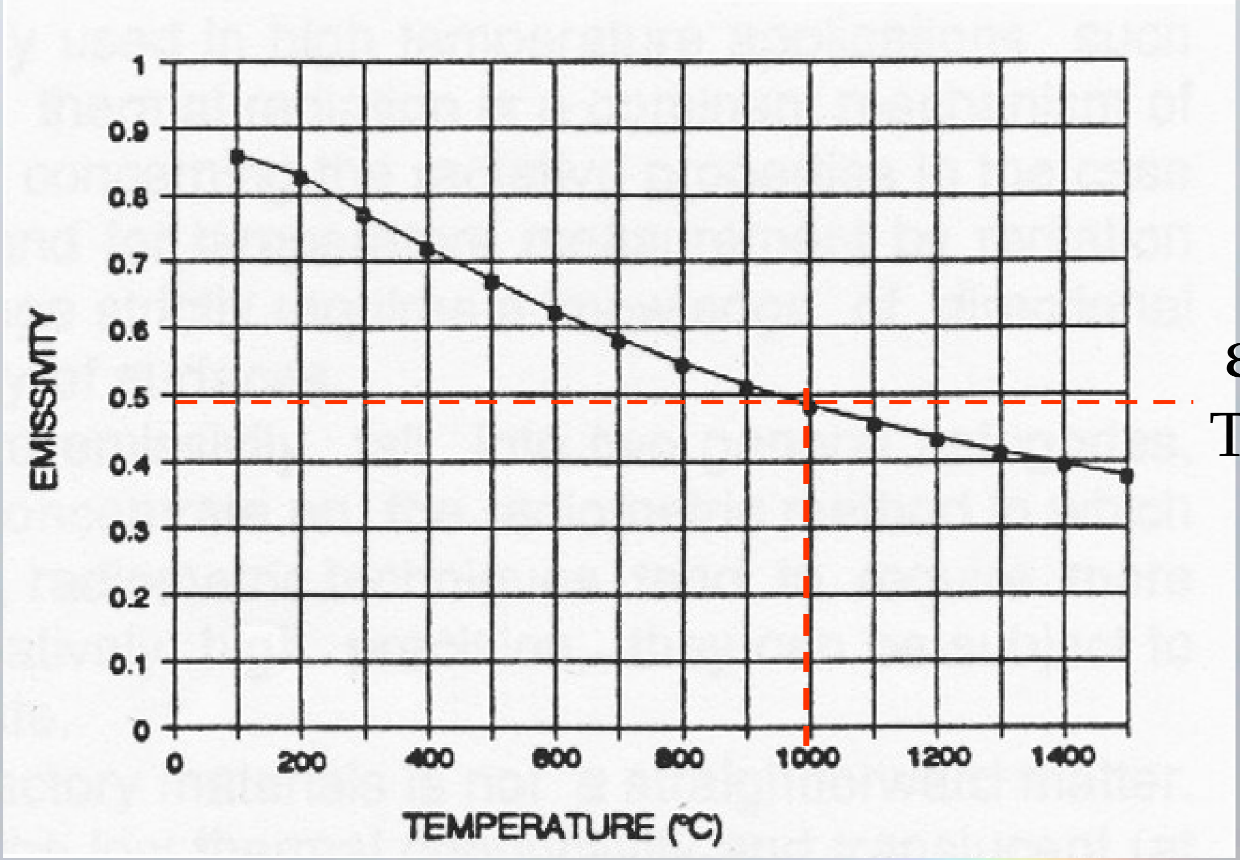
- Objective:
  - To extend ZONE model to non-grey surfaces



Spectral ε of alumina-silicate refractory (*Manchester University*)

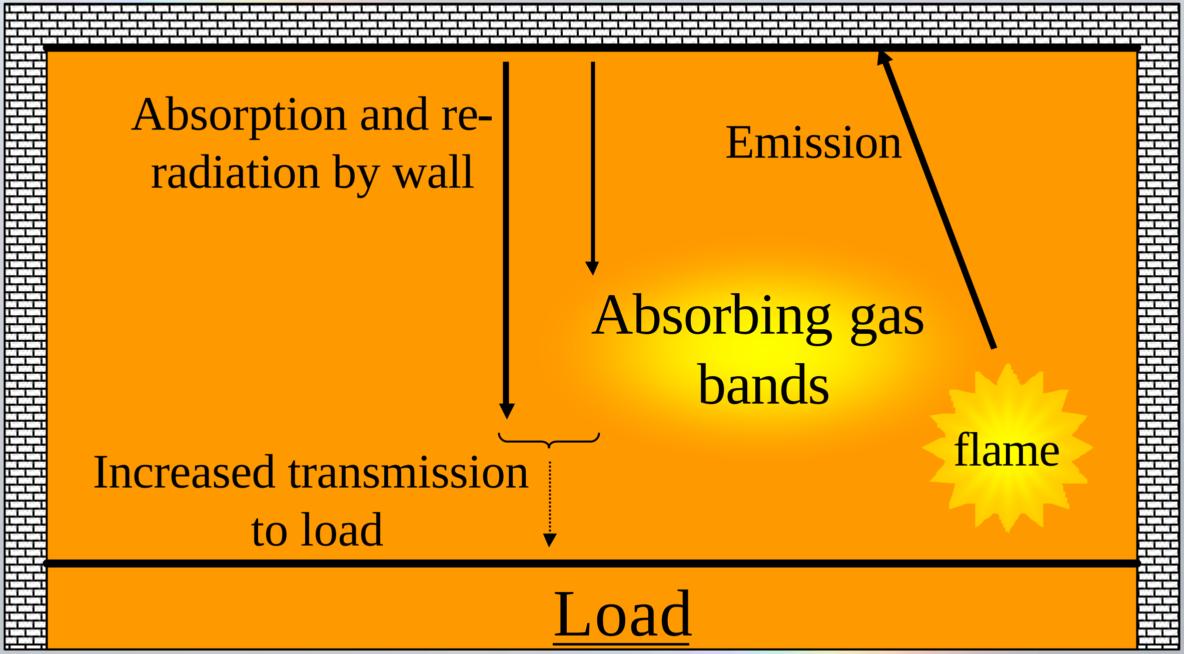
Total Emissivity of a Refractory

Source – Manchester University



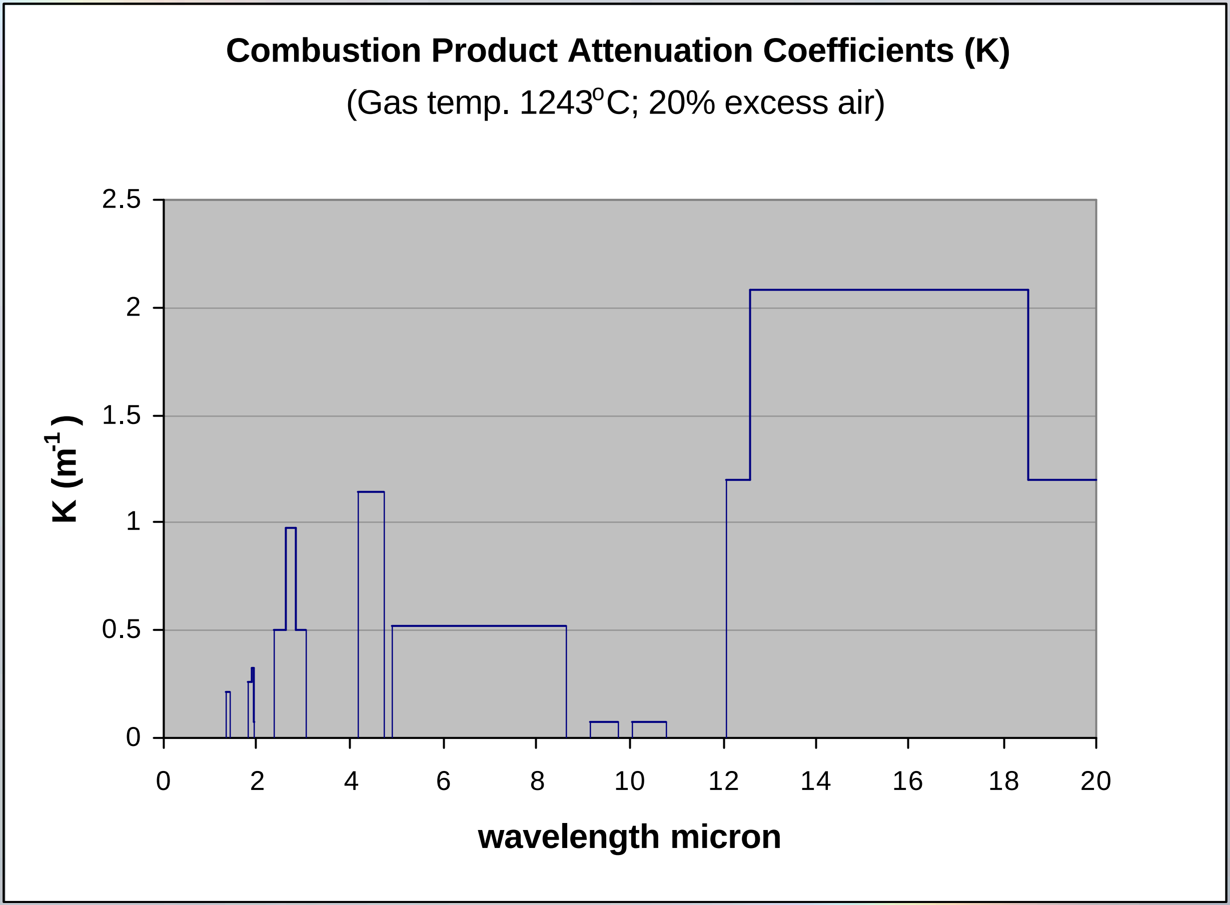
$\varepsilon < 0.5$ at $T > 1000^oC$

Refractory Wall Emissivity Effect



Needs a realistic representation of the spectral properties of the gases

Exponential wide band model
(EWBM)

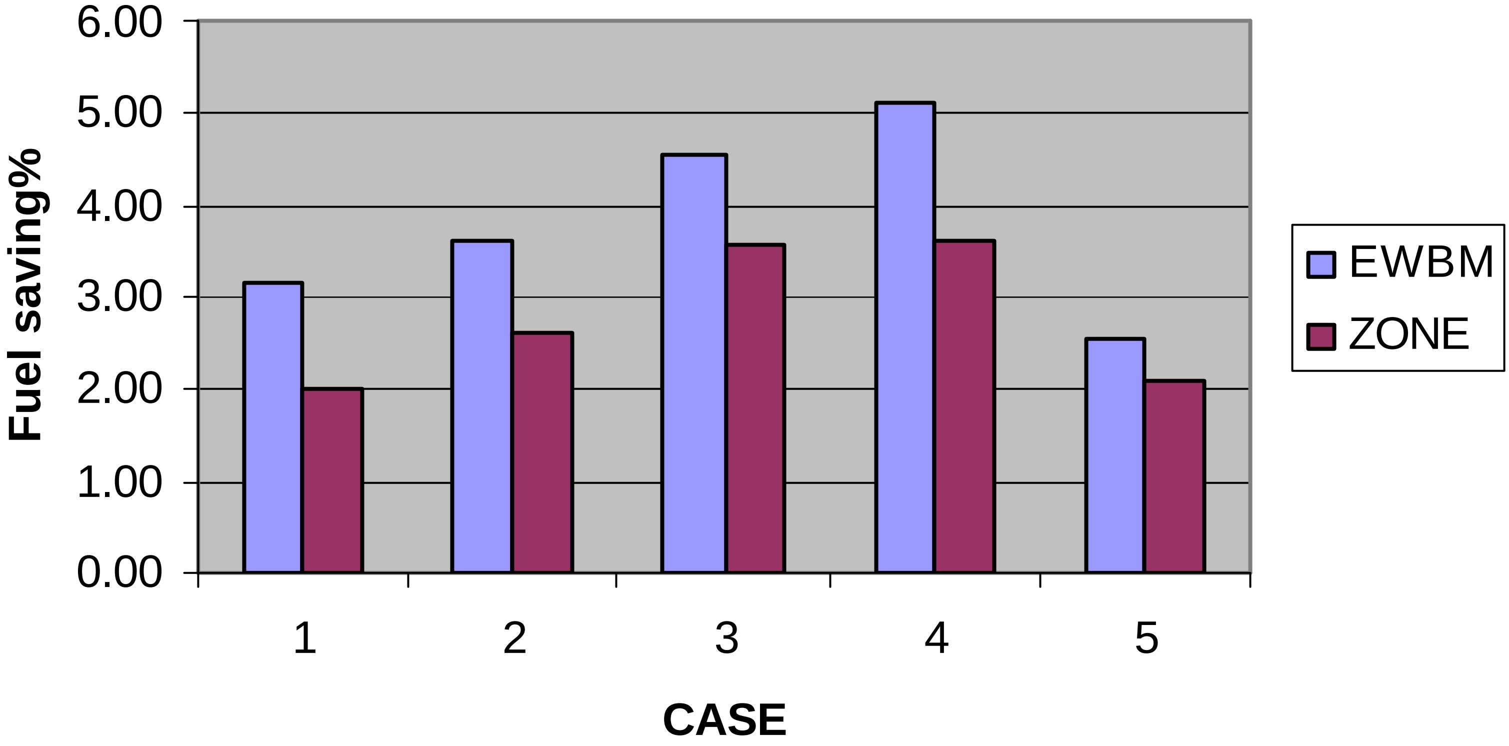


Combustion Product Attenuation Coefficients (K)

(Gas temp. 1243^{o}C; 20% excess air)

Predicted effect of high emissivity coatings

WSGGM compared to EWBM



High Emissivity Coatings

- High-ε coatings are commercially available
  - Emisshield
  - Enecoat
  - Emi-coat
- Exaggerated energy saving claims
- Need more accurate spectral models to predict savings

SUMMARY & CONCLUSIONS

- ZONE models provide powerful, accurate and fast solution of complex systems

  e.g. Combustion side model can be linked to models of process side, down/up stream components, transient models
- Fast multi-zone simulations possible
  - Memory and CPU speeds not an issue
  - 336 zones computes in <1 minute
  - Link with CFD models for flow and combustion data
- Capability to model spectral ‘gas-bands’ and non-grey surfaces

Thank you!