Solid fuels co-combustion modelling in a stoker furnace

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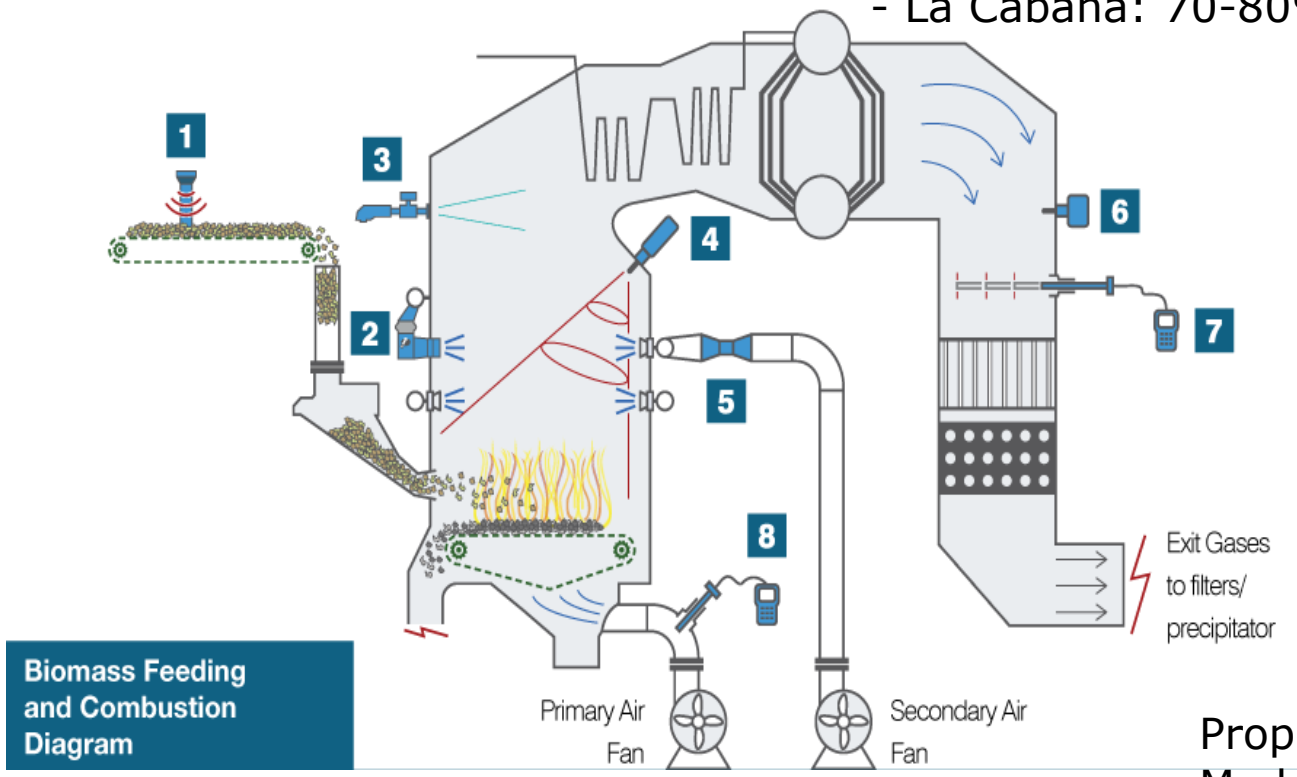
Outline

- Motivation and objectives
- Problem simplification
- Model outline
- Processes to model
- Results
- Experiments of coal pyrolysis for:
  - Coal pyrolysis (and swelling) analysis
- Conclusions and future plans

Motivation

Colombian power station:
- Mayaguez: 75-90% biomass + 10-25% coal
- La Cabaña: 70-80% coal + 20-30% biomass



Problems:
- low fuel (both!) conversion,
- lack of data from the boiler.

Stoker furnace with an over-grid feeding system

Source: ValveExport

Proposed approach:
Model of a stoker furnace for better insight into combustion performance

Objectives

Development of a stoker furnace model:

- To link process parameters with combustion performance.
- To link fuel characteristics with residence time required for full conversion (when will the given fuels convert completely).
- To simplify processes description for modelling.

Support from experiments:

- To determine which fuels - including coal, biomass and their mixes create problems with combustion.

Model outline (1)

Stoker furnace can be approximated with a **fixed-bed reactor model** (Hobbs 1993)

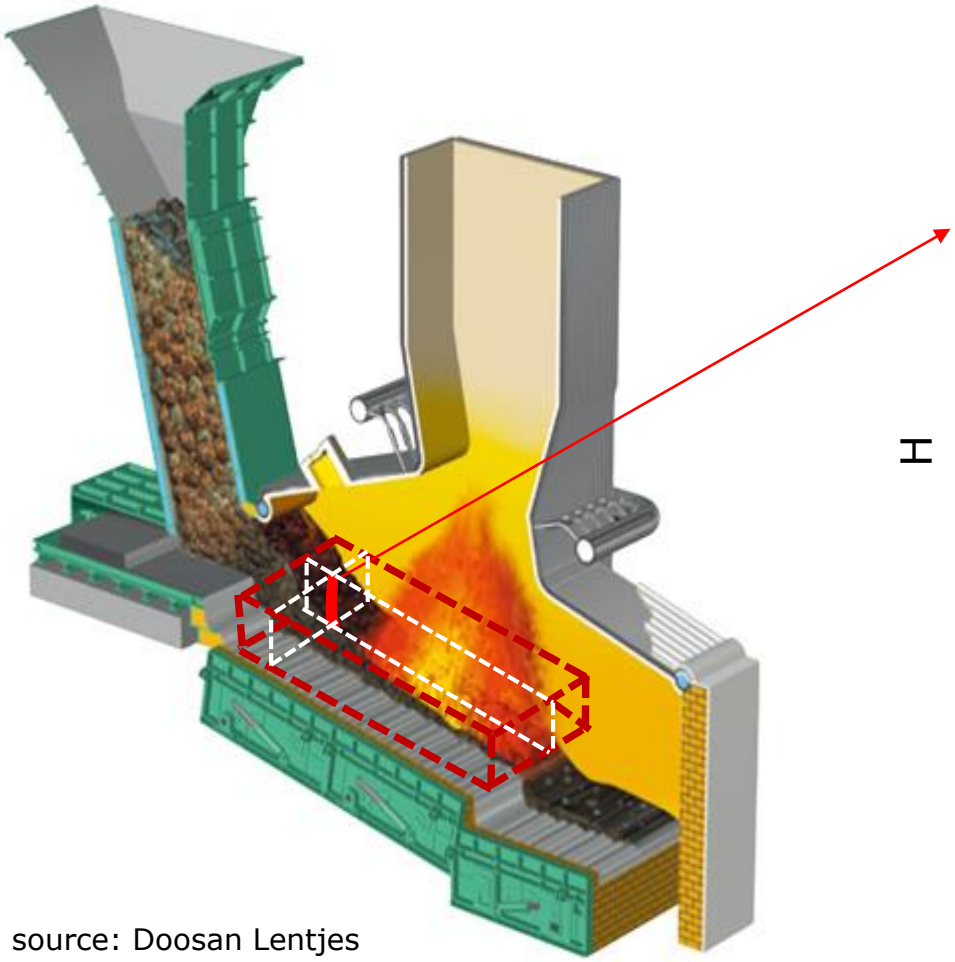
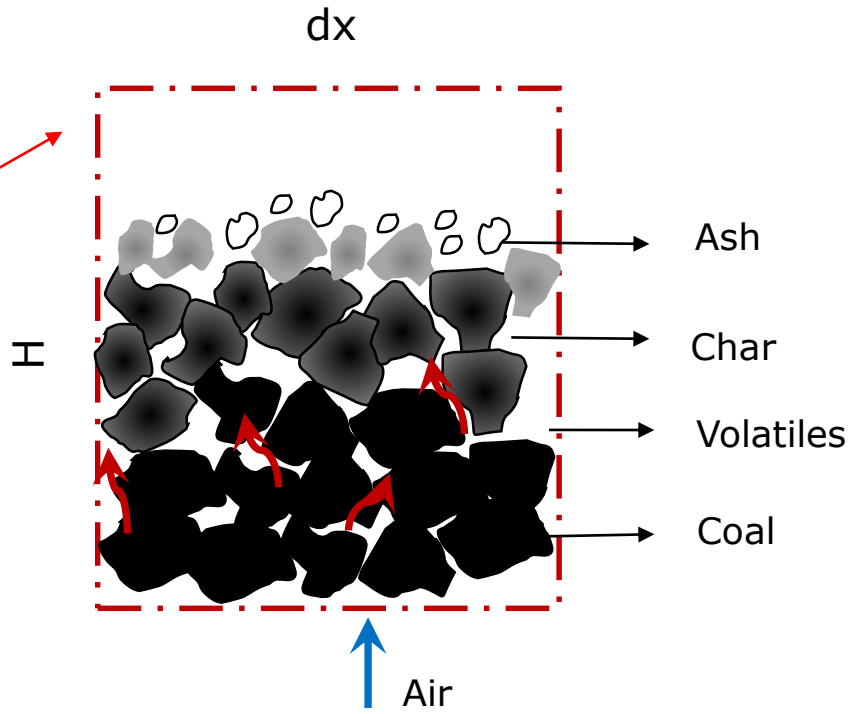
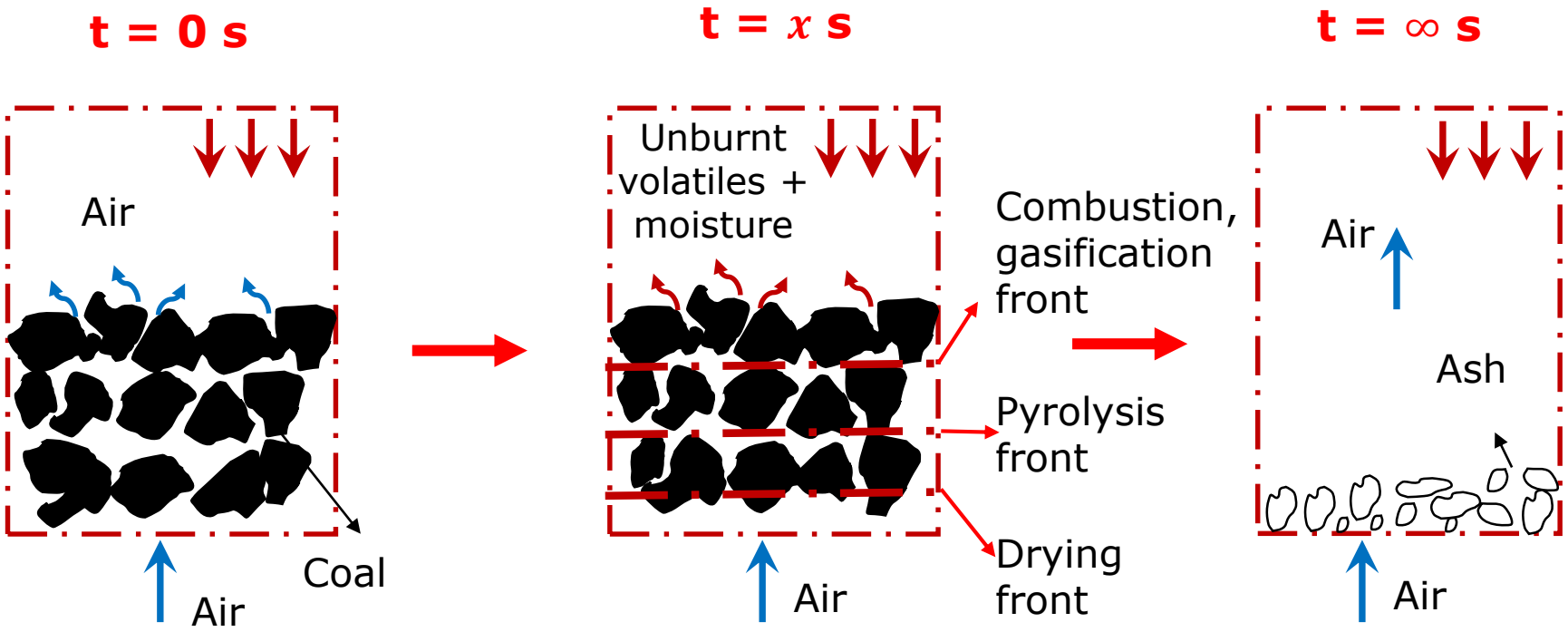


Fig. source: Doosan Lentjes



1D model

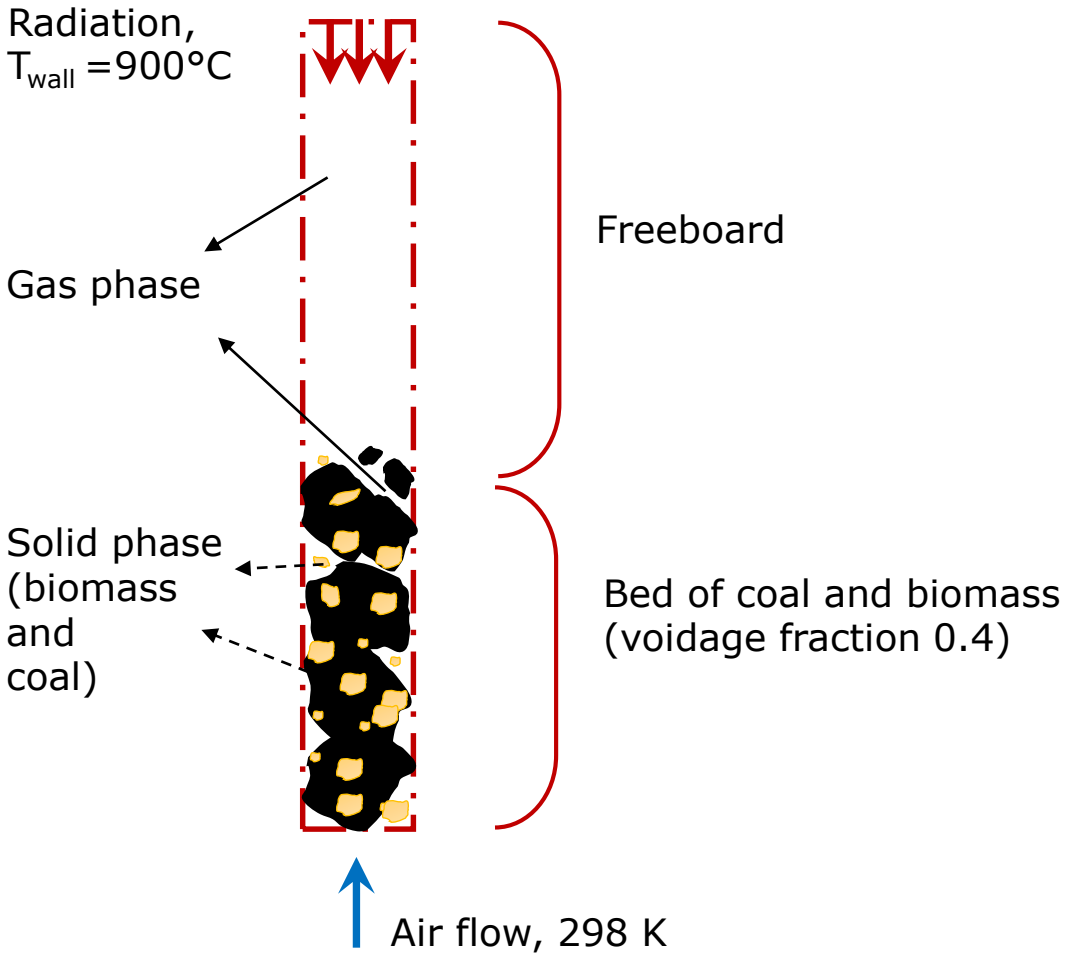
Model outline (2)



All zones within a fixed-bed furnace may overlap

Radiation

Model outline: fuel mix (1)



Initial conditions
(t=0 s)

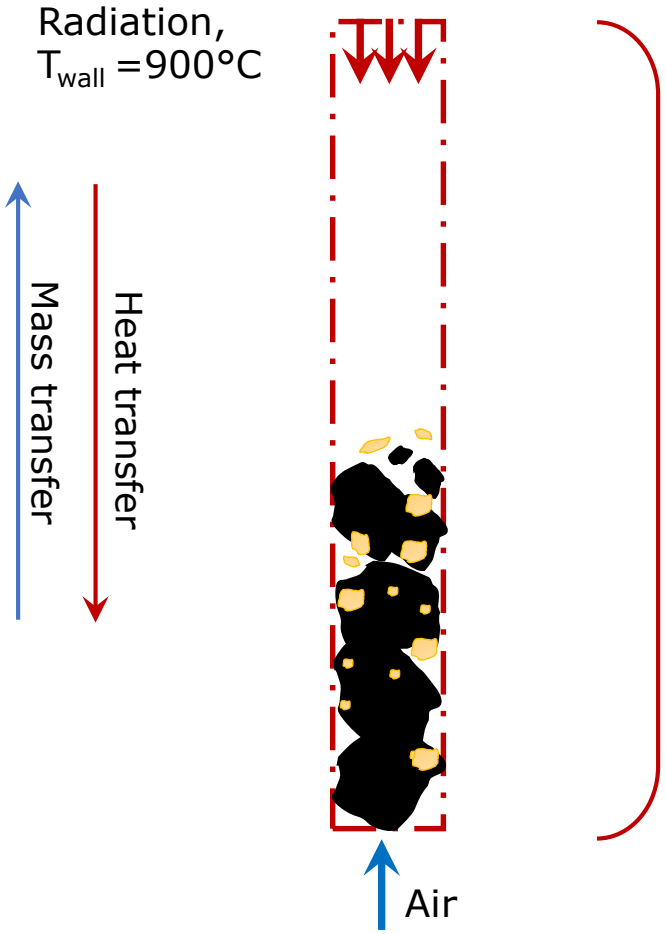
Gas phase: Air (p_{O2}=0.21)

Solid phase:
Coal and biomass
homogenous mixture:
bituminous
- M 8%
- VM 38%
- C 44%
- A 10%

Temperature at t_0:
Freeboard: 300 K
Bed: 300 K

BC, at H_0: T_{air}, p_{O2}=0.21; H_{max}: $q_{ceiling}$

Model outline: processes and reactions



Homogenous combustion: H_2, CO, CH_4

Gas mixing

Gasification with CO_2 and H_2O

Char combustion to CO and CO_2

Devolatilization, CH_4

Drying

- Exothermic and endothermic processes
- All processes depend on temperature

Model outline: processes and reactions

1. Drying

Moisture evaporation rate R_M based on saturation pressure

$R_M = k_M(c_{M,gas} - c_{M,saturation})$, with $k_M = A_M \exp(-\frac{E_{a,M}}{RT})$

2. Pyrolysis

One-step global reaction: Fuel → Char + Volatiles

$R_V = k_V c_{V,solid} = k_V(c_{V,\max} - c_{v,out})$, with $c_{V,\max} = \mathrm{Q}(1-\mathrm{D})\mathrm{c_{VM}}$

Q – real VM yield
D-swelling factor

3. Combustion and gasification

$$\mathrm{C} + \mathrm{n}O_2 \rightarrow 2(1-\mathrm{n})\mathrm{CO} + (2\mathrm{n}-1)\mathrm{CO}_2$$

$R_{C,comb} = k_{comb} S_{norm} p_{O2}$ $\quad R_{C,gas1} = k_{g1} p_{CO2}$, $R_{C,gas2} = k_{g2} p_{H2O}$

4. Volatiles: combustion and mixing with O_2

$R_{H_2} = k_{H_2} c_{H_2}^x c_{O_2}^y c_{H2O}^z$ $\quad R_{GF} = \min(\frac{c_{fuel}}{RC_{fuel}}, \frac{c_{O_2}}{R_{mix}})$

$R_{CO} = k_{CO} c_{CO} c_{H2O}^{0.5} c_{O2}^{0.5}$

$R_{CnHm} = k_{CO} c_{CnHm}^{0.5} c_{O_2}$ Rate orders + kinetic parameters from literature

To solve

Mass balance

Gas phase

$$\frac{\partial(\phi\rho_g Y_{ig})}{\partial t} + \frac{\partial(\phi\rho_g V_g Y_{ig})}{\partial y} = D_{e,g}\frac{\partial}{\partial y}\left(\frac{d\phi\rho_g Y_{ig}}{\partial y}\right) + \sum S_{Y_{i,g}}$$

Solid phase

$$\frac{\partial((1-\phi)\rho_s Y_{is})}{\partial t} + \frac{\partial(((1-\phi)\rho_s V_s Y_{is})}{\partial y} = S_{Y_{is}}$$

Energy balance

Gas phase

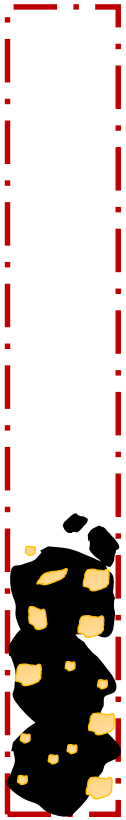
$$\frac{\partial(\phi\rho_g H_g)}{\partial t} + \frac{\partial(\phi\rho_g V_g H_g)}{\partial y} = \frac{\partial\lambda_g}{\partial y}\left(\frac{\partial T_g}{\partial y}\right) + S_a h_s\left(T_s - T_g\right) + \sum Q_h$$

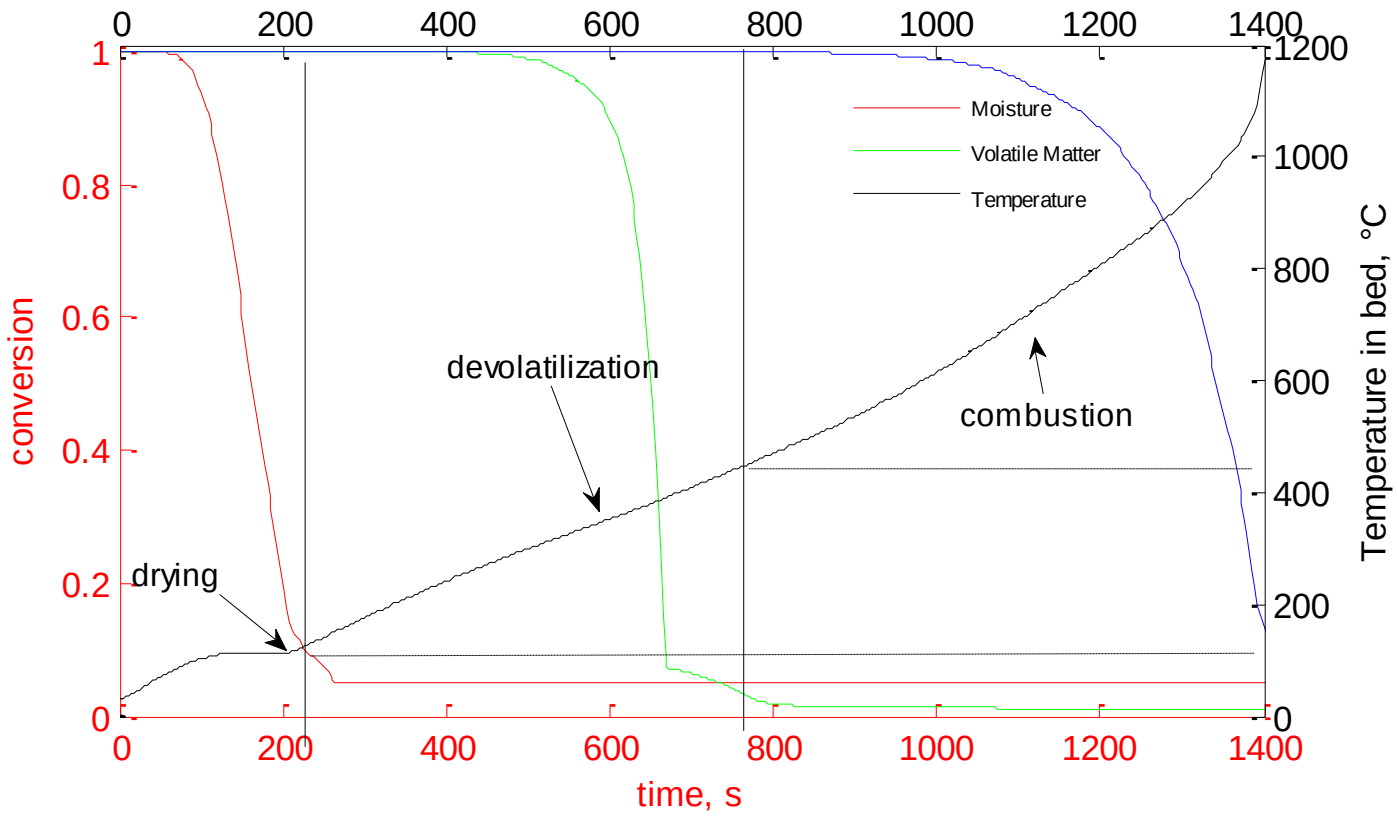
Solid phase

$$\frac{\partial((1-\phi)\rho_s H_s)}{\partial t} = \frac{\partial\lambda_s}{\partial y}\left(\frac{\partial T_s}{\partial y}\right) + S_a h_s\left(T_g - T_s\right) + \frac{\partial q_{rad}}{\partial y} + \sum Q_{sh}$$

Numerical approach: 1D domain discretization, grid points: 100, finite volume method, implicit steps, solved in Matlab (ODE15s solver)

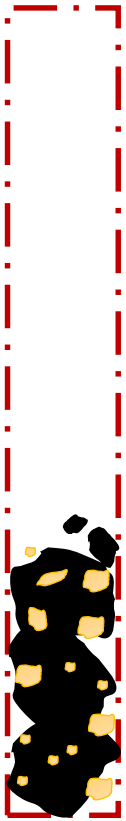
Results – fuel mix (1)

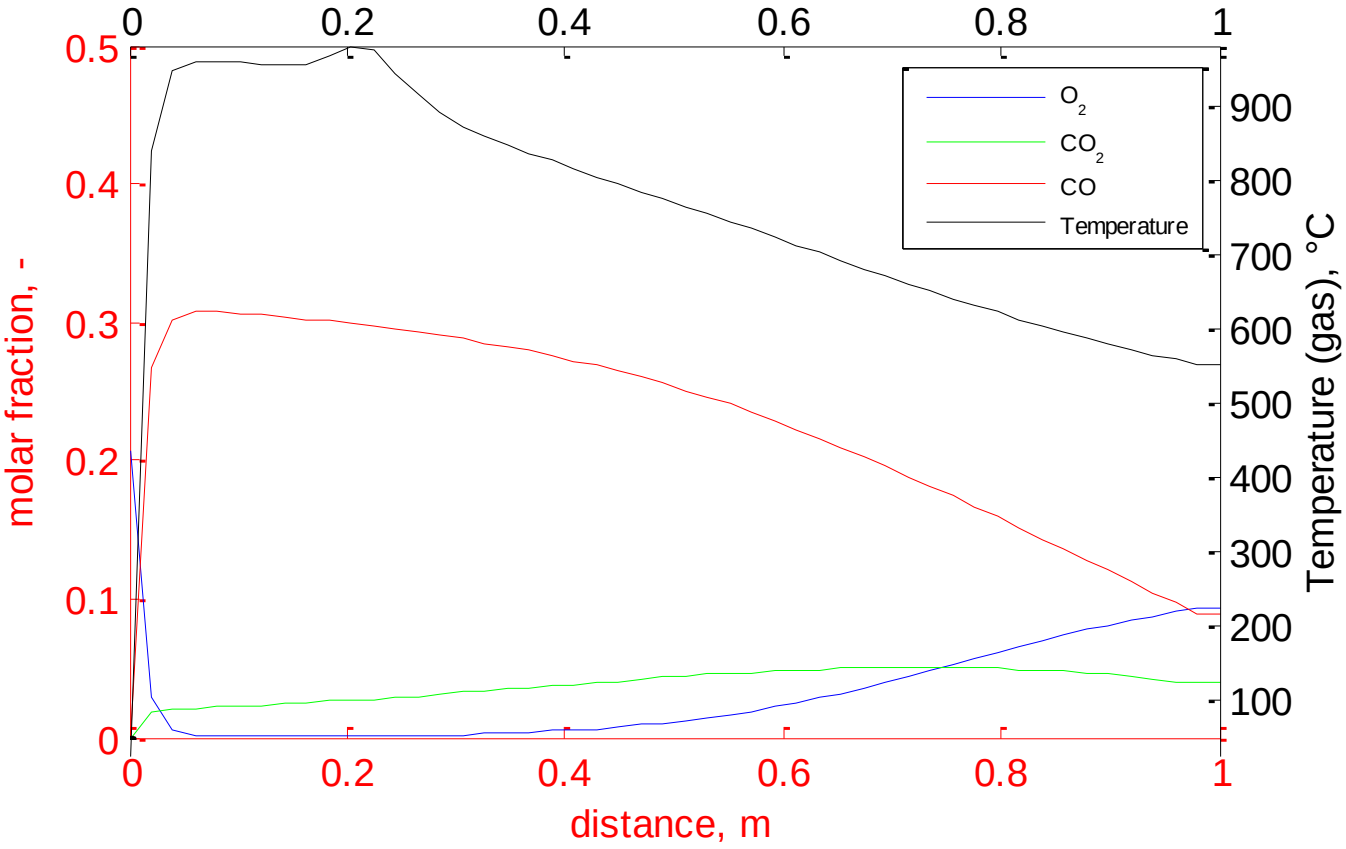




Conversion of moisture, volatiles and char in the bed of coal

Results – fuel mix (2)





Gas composition across the furnace at t= 1400 s

Experiments: pyrolysis (1)

Ash fusion test rig

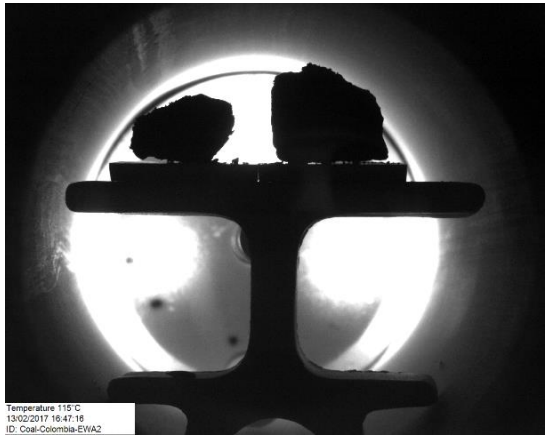
Pyrolysis(N_2) in a CAF furnace with camera

Ramp up to 900°C

7°C/min

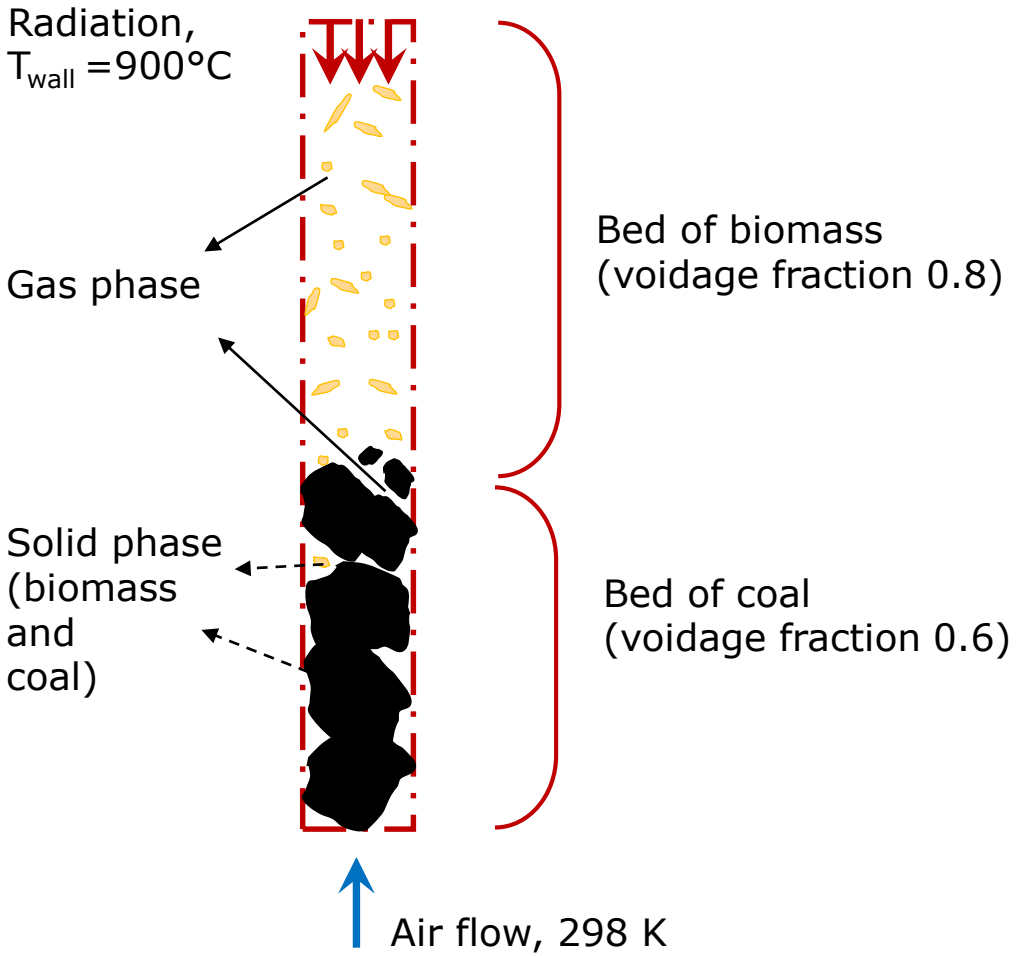
v_{N2} = 2 l/min

Heat up recorded with the camera



115°C

Under development: two separate fuels



BC, at H_0: T_{air}, p_{O2}=0.21; H_{max}: $q_{ceiling}$

Initial conditions
(t=0 s)

Gas phase: Air (p_{O2}=0.21)

Solid phase:
Coal: bituminous
- M 7%
- VM 30%
- C 50%
- A 13%

Biomass: bagasse residue
- M 10%
- VM 75%
- C 13%
- A 2%

(both: ECN Phyllis2 database)

Temperature at t_0:
Freeboard: 500 K
Bed: 300 K

Conclusions and future work

- Combustion in the stoker furnace can be approximated with 1D simplified model
- Full computations are long (in Matlab), a further simplification of the processes can be considered
- Full conversion of fuel mix can be achieved in 25 min
- Experiments showed that particle shape for coals used in the Colombian stoker changes drastically (need for $\phi = f(T)$)
- Next steps: Development of two-fuel model and validation against data from the Colombian stokers

Thank you

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Acknowledgement:

The study was funded by The Engineering and Physical Sciences Research Council (EPSRC, UK) through the Newton Fund in partnership with Colombia.