Two-Dimensional CFD Model of an Air-Blown Updraft Coal Gasifier

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Outlook

1 Air blown Updraft Coal Gasifier

2 Numerical models for updraft gasifier

3 Results

4 Conclusions and future developments
Coal gasification is a key technology for advanced, high efficiency low-emission power generation.

Gasification processes are currently employed in large-scale IGCC power plants.

In near future, gasification technologies could become very interesting for medium and small-scale industrial applications.

Air-blown coal updraft gasifier is an interesting technology for distributed generation.
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Updraft gasifiers are characterized by a complex multiphase, chemical reacting flow.

Advanced numerical models are required to simulate the complex multiphase flows.

Updraft coal gasification preliminary CFD model is developed.

MFIX (Multiphase Flow with Interphase eXchanges) code (Syamlal et al., 1993) is considered for updraft gasifier simulation.

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**Numerical model**

- Coal
- Drying & Devolatilization
- Gasification
- Combustion
- Ash
- Air+Steam
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Gas and solid phases are considered as interpenetrating continua: Eulerian-Eulerian approach.

The solid phase is accounted as continuous media, characterized by its constitutive equations solved in a Eulerian frame.

Solid stress is modelled considering kinetic and plastic theories of solid.
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Granular kinetic theory

- Conservation equations are solved for each phase for continuity, species mass fractions, momentum and energy.

- Solid phase momentum equation is expressed in the following way:

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\frac{\partial (\rho_s \varepsilon_s U_s)}{\partial t} + \nabla \cdot (\rho_s \varepsilon_s U_s U_s) = \nabla \cdot S_s + \varepsilon_s \rho_s g - I_{sg}
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  - Solid stress
  - Gravitational
  - Interphase

- Gas-solid momentum exchange \( I_{sg} \) is given by the drag force and by the mass transfer.

- Solid stress depends on particle collisions and friction described by granular theory.
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Numerical models for updraft gasifier

Viscous and plastic granular flows

- \( \varepsilon_g > \varepsilon^*_g \): solid stress is described by the kinetic theory of granular material.
- \( \varepsilon_g \leq \varepsilon^*_g \): solid stress is described by the plastic theory.
- Stress is related to the particle collisions.

\( a \varepsilon^*_g \): void fraction at packed condition.

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CFD Updraft Gasifier

CCT 2009
Numerical models for updraft gasifier
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Coal gasification is modelled according to the following reactions sequence:

- Drying
- Devolatilization
- Char heterogeneous reactions

In updraft gasifiers drying and devolatilization are considerably faster than heterogeneous reactions.

At this early state of model development, drying and devolatilization are not accounted.
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Heterogeneous reactions model

- The unreacted shrinking core model is considered (Wen, 1968)
- Three resistance mechanisms are considered:
  - External gas film
  - Ash layer
  - Reaction on unreacted core
- The following heterogeneous reactions are considered:

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\begin{align*}
2C(s) + O_2 & \rightarrow 2CO \\
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In gas phase the following kinetic mechanism of Jones and Lindstedt (1988) is considered:

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\text{CH}_4 + \frac{1}{2}\text{O}_2 & \rightarrow \text{CO} + 2\text{H}_2 \\
\text{CH}_4 + \text{H}_2\text{O} & \rightarrow \text{CO} + 3\text{H}_2 \\
\text{CO} + \text{H}_2\text{O} & \rightleftharpoons \text{CO}_2 + \text{H}_2 \\
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Geometry and simulation conditions

- The numerical simulation is performed considering a simple cylindrical geometry \((D = 30 \text{ cm}, H = 195 \text{ cm})\)
- A initial bed height of 40 cm is assumed, corresponding to 35 kg of coal
  - Only one fuel charge is considered
- Air flow rate: 66.5 kg/s
- Steam flow rate: 9.1 kg/s
- Gasifier time-dependent behaviour is investigated considering a period of 1000 s
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Syngas composition vs. time @exit

The figure shows the instantaneous mass fraction at the exit.

Steady condition is reached within about 600 s.
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The figure shows the syngas mass fraction along the reactor at 600 s. 

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Syngas composition vs. height @600 s

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Bed height variation

- The animation shows the variation of char mass fraction with time.
- The model accounts for the char consumption and the bed height variation.
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- Include **coal inlet and ash removal** in the model
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Thank for your attention!

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