Flow, reactions and production of syngas in the porous biomass layer

Kamil Kwiatkowski$^{12}$, Paweł Żuk$^1$, Karol Wędołowski$^{12}$, Konrad Bajer$^{12}$

$^1$Institute of Geophysics, Faculty of Physics, University of Warsaw
$^2$Interdisciplinary Centre for Mathematical and Computational Modelling, University of Warsaw
Outline

- Biomass gasification – first view
- Necessary functionalities of the solver
- Handle porosity - setPorosity
- Unsteady flows - porousPisoFoam
- Reacting flows – myPorousReactingFoam
- Results and brief comparison with Fluent
- In progress: myPorousReactingFeedFoam
- Biomass gasification – second view
- In progress: biomassGasificationFoam
- Short summary
- Two reasons to visit Warsaw this September
Biomass Gasification – first view

syngas

\((H2, CO, CH4, CO2, N2,...)\)
Inolved processes

- evaporation of water from wet biomass
- pyrolysis of dry biomass
- gasification of biomass – heterogeneous reactions which take place on the surfaces (mainly) within the porous layer
- heterogeneous combustion of char structures

Energy transfer between gas and solid
Involved processes

basic biomass properties
- porosity and its anisotropy
- heat conductivity
Require functionalities

- flexibility in defining and changing in time complex porous zones -> setPorosity
- handling unsteady flows in the porous bed -> porousPisoFoam
- solving the reactions, that may take place in air and the produced syngas itself -> myPorousReactingFoam
- extending the properties of the porous layer, so that it can transfer heat and react chemically -> myPorousReactingFeedFoam
- including reactions between air, syngas and various kind of biomasses -> biomassGasificationFoam
Handling porosity – setPorosity

6th OpenFoam Workshop, PennState, 13-16.06.2011
porousPisoFoam + reactingFoam
=> myPorousReactingFoam

• piso loop to handle unsteady flows in porous media
• gas-phase reactions only, based on reactingFoam approach
• works as reactingFoam if there is no porous media
• flow and reactions of gas within porous feed
• enable to change shape of porous zones
• involved chemistry (mainly syngas combustion) should not be too „heavy” => few-steps reaction mechanism, skeleton mechanism
First results -> myPorousReacingFoam

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First results -> myPorousReacingFoam

Temperature

H2O

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Comparisons with Fluent

OpenFOAM

ANSYS Fluent
Comparisons with Fluent

- Comparable calculation time
- “Comparable” coding time (OpenFOAM library and Fluent User Defined Function)
- takes time to get comparable results
In progress - myPorousReactingFeedFoam

- There is energy transfer between gas and solid
- Solid is the sink or source of species and energy

- how to deal with biomass reacting feed?
- how to transfer energy properly?
Table 1: Composition and properties of turkey feathers, for different water content, compared with properties of wood biomass. The data on feather properties and composition come from our measurements taken in the feather gasification installation in Olsztyn. Other data are derived from Lieuweg et al. (2010).

<table>
<thead>
<tr>
<th>quantity [% of mass]</th>
<th>wet turkey feathers</th>
<th>turkey feathers</th>
<th>dry turkey feathers</th>
<th>pine bark</th>
<th>oak bark</th>
<th>tan oak</th>
<th>bagasse</th>
<th>switchgrass</th>
<th>poplar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content</td>
<td>51.6</td>
<td>18.3</td>
<td>0.0</td>
<td>n/r</td>
<td>n/r</td>
<td>n/r</td>
<td>n/r</td>
<td>n/r</td>
<td>n/r</td>
</tr>
<tr>
<td>Volatiles</td>
<td>47.7</td>
<td>71.2</td>
<td>88.3</td>
<td>72.9</td>
<td>76</td>
<td>87.1</td>
<td>85.6</td>
<td>76.7</td>
<td>84.8</td>
</tr>
<tr>
<td>fixed carbon</td>
<td>5</td>
<td>8.5</td>
<td>10.3</td>
<td>24.2</td>
<td>18.7</td>
<td>12.4</td>
<td>12.0</td>
<td>14.4</td>
<td>12.5</td>
</tr>
<tr>
<td>Ash</td>
<td>0.7</td>
<td>1.1</td>
<td>1.4</td>
<td>2.9</td>
<td>5.3</td>
<td>0.5</td>
<td>2.44</td>
<td>9.0</td>
<td>2.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ultimate analysis</th>
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</thead>
<tbody>
<tr>
<td>carbon</td>
</tr>
<tr>
<td>hydrogen</td>
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<tr>
<td>oxygen</td>
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<tr>
<td>phosphorus</td>
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<tr>
<td>silica</td>
</tr>
<tr>
<td>calcium</td>
</tr>
</tbody>
</table>

| HHV [MJ/kg]       | 11.937              | 20.164           | 24.671             | 18.4      | 17.5     | 17.2   | 19.0    | 18.1         | 19.0  |
| LHV [MJ/kg]       | 10.076              | 18.711           | 23.442             |           |          |        |         |              |
Second view

ultimate analysis:
C, H, N, O, S + H2O + ash = 100%

proximate analysis:
moisture, volatiles (e.i. cellulose, hemicellulose and lignine for wood), fixed carbon, ash = 100%

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In progress - myPorousReactingFeedFoam

- First „dirty” attempt to allow biomass react:
  - treat porous biomass as non-moveable gas and use thermochemistry for gas
  - biomass composition:
    - FEED_H2O + energy => H2O (gas)
    - FEED_C, FEED_N, FEED_S, FEED_O
    - FEED_CELLULOSE + energy => FEED_C + gas …
  - new „equation of state” nessesery
  - other problems

- Alternative – completely new library
- Other ideas?
To cover real-life sizes of the biomass particle have to prepared our own measurements

\[
k_{Cel} = 3,9 \times 10^{11} \cdot \exp\left(-\frac{166400}{R \cdot T_{solid}}\right)
\]

\[
k_{Hem} = 1,45 \times 10^9 \cdot \exp\left(-\frac{123700}{R \cdot T_{solid}}\right)
\]

\[
k_{Lig} = 1,2 \times 10^8 \cdot \exp\left(-\frac{141300}{R \cdot T_{solid}}\right)
\]

\[
S_m = k_{Cel} \cdot m_{Cel} \cdot k_{Hem} \cdot m_{Hem} + k_{Lig} \cdot m_{Lig}
\]
energy transfer – Whitaker’s approach

\[ \text{Re} = \frac{V \cdot d}{\nu} \]

\[ \text{Pr} = \frac{c_p \cdot \mu}{k} \]

\[ Nu = 2 + \text{Re}^{0.6} \cdot \sqrt[3]{\text{Pr}} \]

\[ \alpha = Nu \cdot \frac{k}{d} \]

\[ \dot{Q} = -\alpha \cdot \Delta T \cdot S \]
In progress – biomassGasificationFoam plans, ideas, goals

- collects all functionalities mentioned above (~3 months) for wooden and animal biomass (turkey feathers)
- porous media will not be treated as continuous layer, it will be constructed of set of porous (or not), moveable (or not), reacting (surface and volume) balls or cylinders (4~6 months)
- more attention will be put into heat transfer and chemistry (4~6 months)
- fine-tunes to handle the municipal wastes (6~9 months)
- includes third (liquid) phase (for completeness) (?)
- compares with ANSYS Fluent, we are simulatanuously coding OpenFOAM solvers and Fluent UDF (all the time)
- compares with measurements (already scheduled)
Summary

• We handle the flow within porous media
• The gas phase can react chemically
• The process could be unsteady

Main issues:
• solid phase chemistry
• gas-solid energy transfer
• surface reactions
• model input and initialisation

Plans and Ideas:
• feed builds from balls or cylinders (porous or not, movable and reacting), coupled heat transfer and chemistry. Details comparisons with experiments!
• OF details simulations of the processes in one biomass particle to go deeper into chemistry and thermodynamics
Acknowlegments

- Dr Marek Dudyński
  Modern Technologies and Filtration Sp. z o.o.

- The strategic program of scientific research and experimental development of the National (Polish) Centre for Research and Development: Advanced Technologies for Energy Generation; Task 4. Elaboration of Integrated Technologies for the Production of Fuels and Energy from Biomass as well as from Agricultural and other Waste Materials; Subtask 4.4 Cogeneration plants.

- Numerical computations were partially performed in the Interdisciplinary Centre for Computational and Mathematical Modelling (ICM), University of Warsaw, grant number G34-8.

- This research is partially sponsored by Foundation for Polish Science, programme VENTURES (operated within the Innovative Economy Operational Programme 2007-2013).
Two reasons to visit Warsaw this September

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- more than 350 oral presentations cover all aspects of turbulence
- up to now 550 participants
- one of the most important event on turbulence science in Europe

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- 11 stories about the greatest minds and its discoveries in the history of turbulence research
- 1 book published by Cambridge University Press
Thank you for your attention and patience.

Feel welcome to visit our project’s homepage and contact us:

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