46th IEA-FBC Meeting
May 18th, 2003, Jacksonville, USA

Simulation of BFBCs fired with biofuel mixtures – A CFD based modelling concept

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Since new biofuels are being used all the time there is a growing demand of information from industry concerning biofuel co-fired BFBCs. Improvement of boiler availability in terms of ash deposition control, emission control, boiler design, additives among others are of great interest. Within the Åbo Akademi Process Chemistry Group improvement of some of these details has been done [1] using Computational Fluid Dynamics (Fluent 6.1). In order to do that accurate simulation of combustion in BFBCs is required. Therefore further development of the already existing BFBC modelling concept [2] is made focusing especially on a new simplified bubbling fluidised bed model. The goal is to get an easily controlled model with a closed mass and energy balance which produces accurate enough input for CFD simulation of combustion in BFBC freeboards.

The simplified bubbling fluidised bed model includes two regions, the splashing region and the bed region, in which conditions are considered to be uniform in all directions and in time. Energy and mass balances have been calculated across both regions to predict the general conditions regarding temperature and composition of the gases released from the bed. The energy balance has been calculated on an absolute enthalpy basis relative to standard temperature and pressure. The streams coming into the bed region have been considered constant while the stream of exiting gases has been considered variable. The computer code has been organised into a bed class with methods that calculate the mass and energy balances on the upper and lower regions of the bed based on input parameters.

The conversion of fuel to products in the bed has been based on the availability of oxygen assuming complete combustion given sufficient oxygen and incomplete when lacking. In the bed region, char is converted to CO_2 and CO, first converting all char to CO and then as much as possible to CO_2 given availability of O_2. Under fuel lean conditions all char is converted to CO_2 and the oxygen continues upward into the splashing region. Volatiles are assumed to be methane, and are converted solely to CO_2. The product gas stream is then passed out of the splashing region, where it will be used as a boundary for Fluent.

The energy balance is based on absolute enthalpies and energy fluxes due to heat transfer, as shown in the equations below.

$$n_{react} \cdot H_{react_{IN}} + E_{in} = n_{prod} \cdot H_{prod_{OUT}} + E_{out} \rightarrow \sum_{i=0}^{m} (n_i \cdot (\int_{298}^{T} Cp_i \cdot dT + \Delta H_{f_i})) = E_{out} - E_{in}$$

Bed and splashing region walls are considered perfectly insulated. Radiation occurs between the bed and splashing regions and between the splashing region and the upper walls, based on the equation:

$$q_{rad} = \sigma \cdot A \cdot \varepsilon \cdot (T_1^4 - T_2^4)$$

The streams that enter and exit the bed and splashing regions are balanced to conserve mass such that there is no accumulation in the bed over time. With the input streams having a predetermined mass flow rate, the output gas streams, both from the bed to the splashing region and the splashing region to the freeboard, must be the sum of the incoming streams.

So far the simplified bubbling fluidised bed model can only be used as a stand alone model where input of fuel, primary air and recycled flue gas directly to the model is required. The model output in terms of composition, temperature and velocity of combustion gases can then separately be used as boundary conditions for Fluent calculations. In the future the bed model is also expected to be used as a Fluent submodel meaning that it would be connected to Fluent simulations involving reacting fuel particles. The information from the particles reaching the bed would then be used as bed model input whereas the model output would directly be given back into the Fluent freeboard simulation.

In order to show some results for this first version of the model a preliminary setup was made. In this setup 50% of the fuel was assumed to be converted in the bed and therefore be included in this bed model. This fuel contained 35 mass-% moisture and 72 mass-% volatiles while the ash content was neglected. An incoming mass flow of 32 kg/s primary air and 3 kg/s recycled flue gas was used. 40% of the incoming air was assumed to be uncombusted in the bed and moved further to the splashing region. Also an inert bed sand circulation to the splashing region of 40 kg/s was assumed. The following chemical reactions were used:

Bed reactions:

$C (s) + 0.5 O_2 \rightarrow CO$
$C (s) + O_2 \rightarrow CO_2$

Splashing region reactions:

$CO + 0.5 O_2 \rightarrow CO_2$
$CH_4 + 2 O_2 \rightarrow CO_2 + 2 H_2O$

The resulting temperatures for this setup were 1130 K for the bed and 1250 K for the splashing region.

In the following figures the influence of different parameters on the bed and splashing region temperatures are shown:

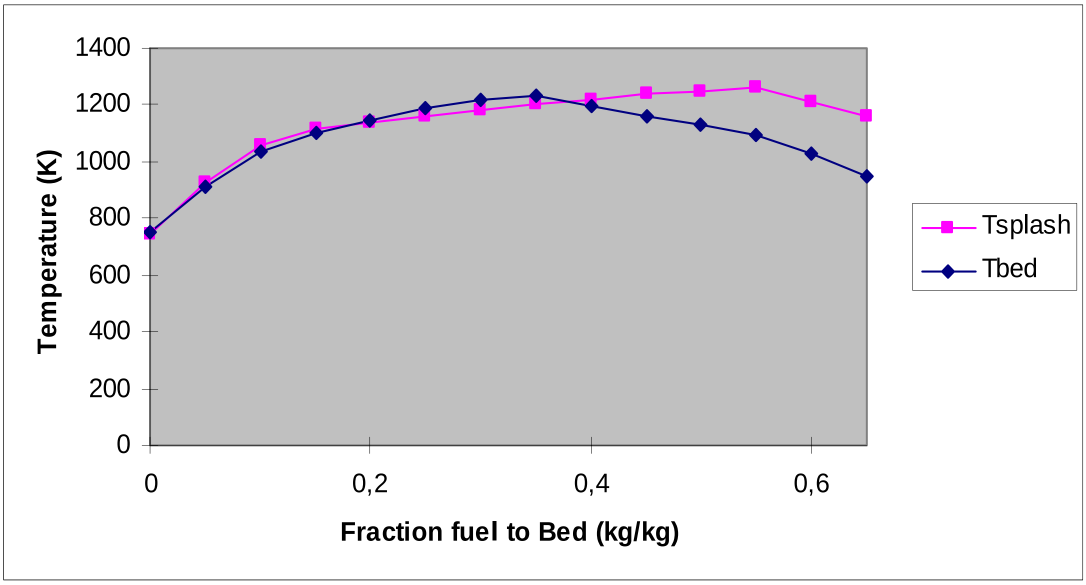

Figure 1. The fraction of fuel to bed as function of temperature. As the fraction to the bed increases, initially there is an increase in temperature as more fuel is available, until at 0.35 there is not enough oxygen for complete combustion and the bed temperature drops. At 0.65 there is not enough air to convert all of the char to CO.

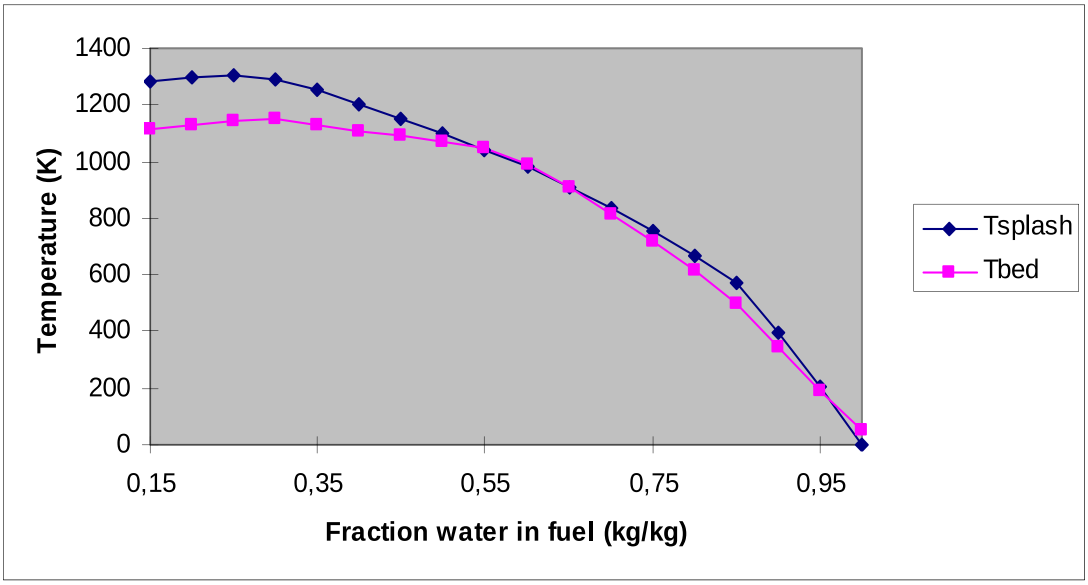

Figure 2. The fraction of water in fuel as function of temperature. As the water increases, the temperature decreases. Also as the water fraction increases, the combustibles fraction decreases. That is most likely why there is the initial slight increase due to moving closer to fuel-lean proportions.

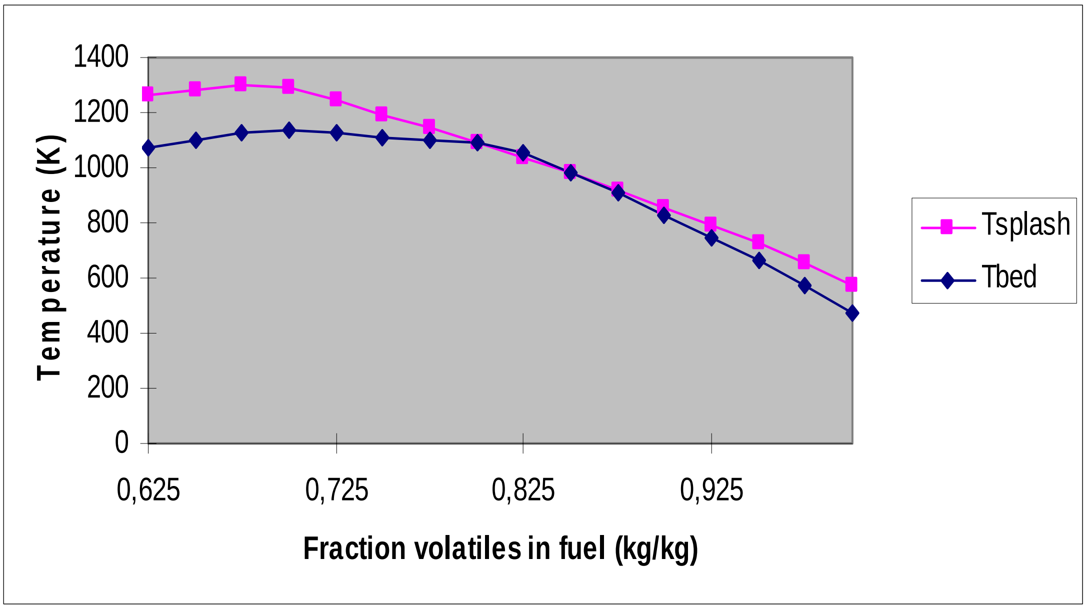

Figure 3. The fraction of volatiles in fuel as function of temperature. Char gives more heat than methane so initially the temperatures are higher. They rise a little at first probably due to the char converting to carbon dioxide, but then drops again due to the lower heating value of methane.

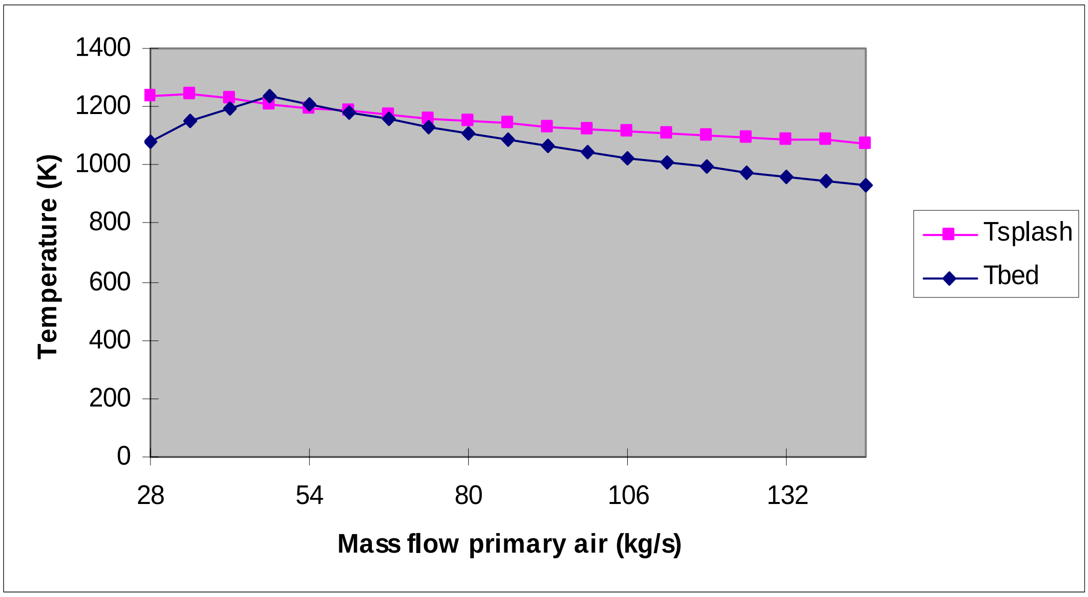

Figure 4. The mass flow of primary air as function of temperature. This is over a very broad range, showing up until there is excess oxygen in the splashing region. The peak in the bed temperature is caused by the char reaching the point where all of it is converted to carbon dioxide and extra air only drops the temperature instead of raising it.

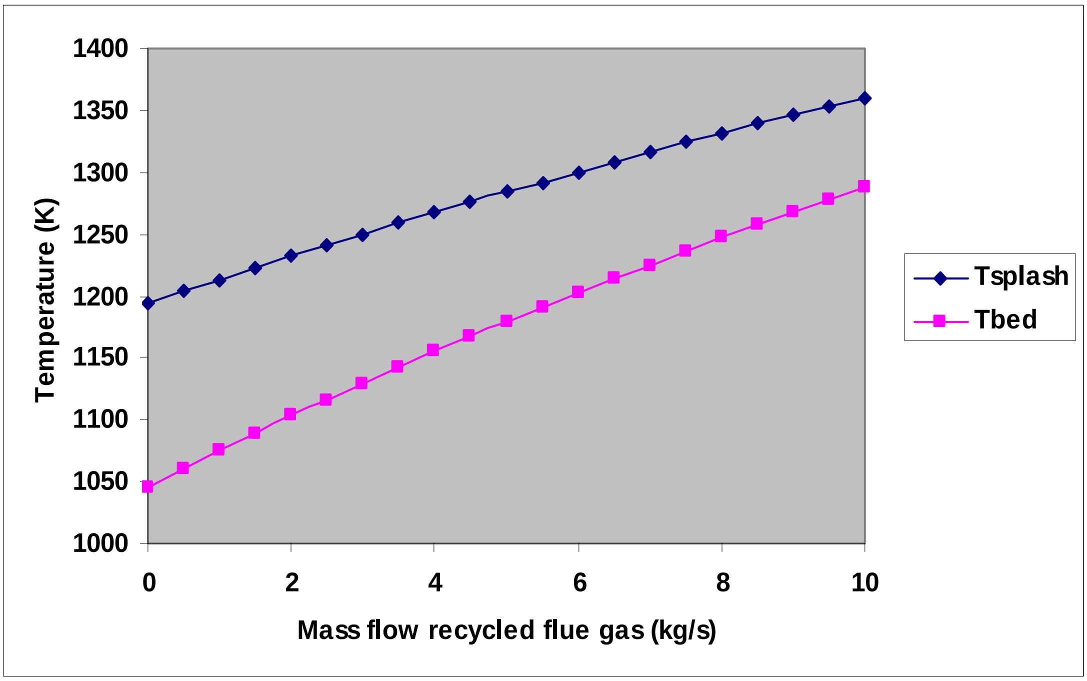

Figure 5. The mass flow of recycled flue gas as function of temperature. The more carbon monoxide and oxygen added, the higher temperatures.

REFERENCES

1 Mueller C., Skrifvars B.-J., Backman R., Hupa M.: Ash Deposition Prediction in Biomass Fired Fluidized Bed Boilers - Combination of Computational Fluid Dynamics and Advanced Fuel Analysis, Progress in Computational Fluid Dynamics, Vol. 3, Nos. 2-4, p. 1, 2003.

2 Lundmark D., Mueller C., Skrifvars B.-J., Hupa M.: CFD-Modeling of Combustion and Deposition in a Biofuel Co-fired Bubbling Fluidised Bed Combustor, Seventh International Conference on Energy for a Clean Environment, Lisbon, 2003.