MODELING BIOMASS GASIFICATION IN LARGE SCALE CIRCULATING FLUIDIZED BEDS

W. Klose and J. Riesen
University of Kassel, Institute of Thermal Engineering
Kurt-Wolters-Strasse 3, D-34109 Kassel, Germany

Introduction

Successful implementation of fluidized bed biomass gasifiers in an industrial scale [1,2,3] and a socio-economic background which allows the profitable utilization of the technology for energy production purposes, promises an increasing number of applications. Computer models are useful to obtain a detailed knowledge about the process and to optimize the equipment. The thermochemical conversion of biomass in a fluidized bed involves different physical and chemical phenomena which have to be considered during the development of a mathematical model. It is therefore inevitable to simplify and to make sometimes drastic assumptions to be able to create a usable reactor model.

In the framework of a European research project a model for an industrial circulating fluidized bed (CFB) biomass gasifier is developed. While detailed measurements of large scale reactors are scarce or not available in the open literature, reactor models or submodels have to be validated against via measurements in smaller units. The grade of simplification during the model development therefore has to take into account a possible scale-down for this purpose. Here a model for the prediction of the axial temperature profile in the riser section of such a gasifier is presented.

Mathematical Model

The mathematical model is applied to a cylindrical CFB-gasifier. It is assumed that the bed operates at steady-state conditions. An internal circulation of the bed solids resulting in a dilute upflow of solids in the core of the riser and a dense annular zone is taken into account for the calculation of the different heat transfer processes. The bed is assumed to consist of a mixture of up to three solids (inert material (silica), char and a catalyst (dolomite)). For both, the gases and the solid phase thermochemical properties like thermal conductivity, heat capacity and emissivity are calcutated as a function of the local temperature and the local composition. The riser is divided into a discrete number of horizontal cells. In Figure 1 a cell consisting of a core and an annular part is shown. The different convective enthalpy flows entering the core and the annular zone from upper respectively lower cells and the interchange between core and annulus have been taken into account. The heat transfer to and through the reactor wall is calculated, to be able to determine the heat losses of the reactor. As the operation temperature of CFB gasifiers is in the range of 750 °C to 1000 °C the radiative heat fluxes are considered as well [4]. Heat generated or consumed due to chemical reactions is represented by the use of a source term for every horizontal cell. The fluid-dynamic pattern representing the distribution and the velocity of gases and solids in the riser section is taken as an input for the model. The geometry of the gasifier is adapted to the unit described in [3].

Simulation

Temperature profiles measured in industrial scale CFB gasifiers are scarce and often not published in the open literature. Only a few temperature profiles for pilot-scale CFB plants (0.1 to 0.5 MW thermal capacity) have been found (see Figure 2)[5,6,7,8]. Although one of the well known features of a fluidized bed reactor is it's homogeneous temperature distribution, the measured temperature profiles in CFB biomass gasifiers indicate an axial gradient. Different effects like heat losses through the reactor walls or endothermal gasification reactions might be responsible for the decrease in temperature with increasing reactor height. On the other hand an injection of secondary air can result in a temperature increase near the injection point. To be able to describe the above mentioned effects at least a one-dimensional model has to be used. Due to the lack of measurements in large scale CFB's a parameter study for the above mentioned effects has been carried out, taking a fluid-dynamic pattern of the riser section as an input of the model.

Results and Discussion

Effect of heat losses through the reactor walls
Heat losses of a CFB-gasifer are a consequence of the bed-to-wall heat transfer, the conduction through the reactor wall (refractory, steel, insulation) and the heat transfer to the surrounding. It is further a function of the volume to surface ratio of the cylindrical reactors and decreases with increasing bed diameter, respectivly capacity of the gasifier [9]. For a well insulated industrial gasifier the heat losses can be estimated to about 3% of the thermal capacity [10]. The bed-to-wall heat transfer in the riser section of a CFB-reactor is calculated as the sum of a particle convective, a gas convective and a radiative part [11].

$$\alpha_{bed-wall} = \alpha_{pc} + \alpha_{gc} + \frac{A_{w,proj.}}{A_w}\alpha_r \qquad (1)$$

Figure 3 shows the three parts of the bed-to-wall heat transfer coefficient for two reference cases. In the first case (black and blue lines) the bed is supposed to be a mixture of silica (85 %) and char (15 %). The red lines represent the effect of additional use of dolomite as a catalyst (55 % silica, 15 % char, 30 % dolomite). The heat transfer is dominated by particle convective mechanism and the addition of dolomite has a neglectable influence for the bed-to-wall heat transfer. This is mainly due to comparable thermophysical properties of silica and dolomite. The differences beween both cases can be much larger if the particle diameters of the solids differ significantly (blue lines). But even for low particle concentrations (≤ 0.03) the radiative component of the bed-to-wall heat transfer is high and the main factors influencing the magnitude of the heat losses will be the insulation thickness and heat conduction through flanges and other supports connected with the reactor.

Effect of secondary air injection and endothermal reactions

The injection of secondary air in fluidized bed gasifiers tends to increase the temperature. Due to this effect cracking reactions of higher hydrocarbons,which are formed during the pyrolysis of the biomass in the bottom zone of a CFB-gasifier, are increasing. Higher solid concentration in the riser section of a CFB-reactor compared to the freeboard of a bubbling fluidized bed-reactor (BFB) is supposed to be responsible for a temperature rise due to secondary air is not so significant as in a BFB-gasifier. Figure 4 compares the temperatures for the riser section of a CFB-unit with (Fig. 4a) and without secondary air (Fig. 4b).

Endothermal reactions of the char and gaseous hydrocarbons with steam and carbon dioxide lower the bed temperature. The consideration of the endothermal reactions results in a temperature profile in the riser as shown in Figure 4c. These calculations were done under the assumption of a constant mass fraction of char over the reactor height.

The calculated temperature gradients (Fig. 4) are small compared to the ones resulting from the measurements in Ref. 7 and 8 which is mainly a consequence of lower solids concentration in the riser section of the smaller units than chosen for the calculations.

Conclusions

The three main effects responsible for an axial temperature profile in a CFB biomass gasifier have been included in a model solving the energy balances for horizontal layers of the riser section taking into account the core-annular flow structure. The use of dolomite as a catalyst does not influence the bed-to-wall heat transfer mechanisms as long as the particle size does not differ significantly from the particle size of the inert material. Compared to measurements or calculations of intraparticle temperature profiles during the main stages of thermochemical biomass conversion (drying and pyrolysis) [12] the axial temperature profile in an industrial scale CFB biomass gasifier (without consideration of secondary air) is small and a more simplified model can be chosen for a complete reactor model to save computing time. Further research has to be carried out in coupling the energetic model with a fluid-dynamic model and a model describing the chemical reactions to maintain a complete reactor model for a large scale CFB biomass gasifier.

References

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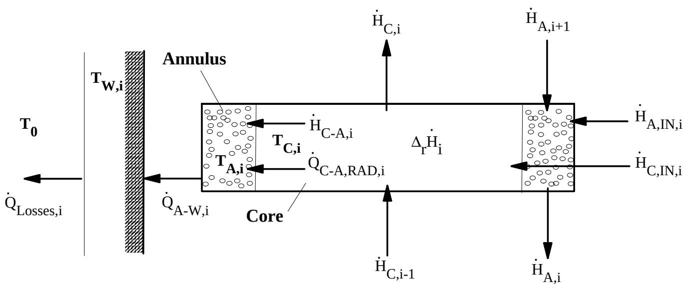

Figure 1: Enthalpy flows for a riser cell

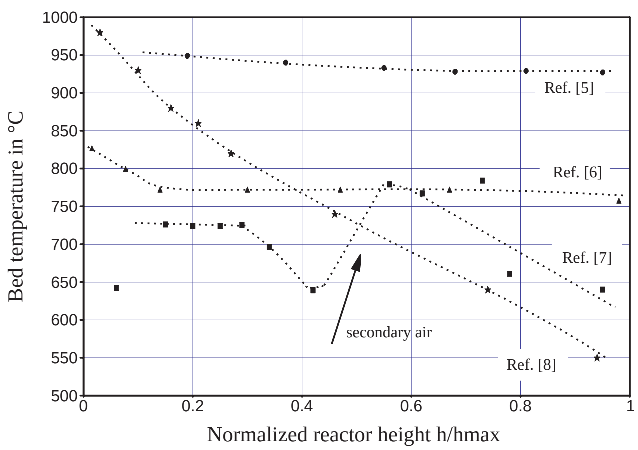

Figure 2: Temperature profiles in CFB-biomass gasifiers

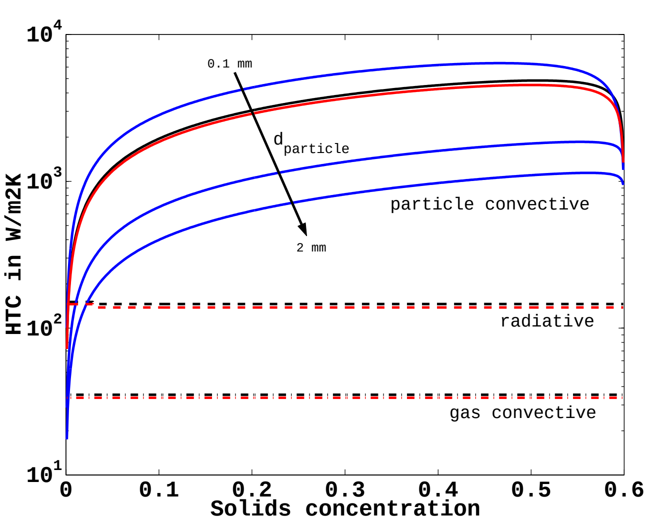

Figure 3: Bed-to-wall Heat transfer coefficient

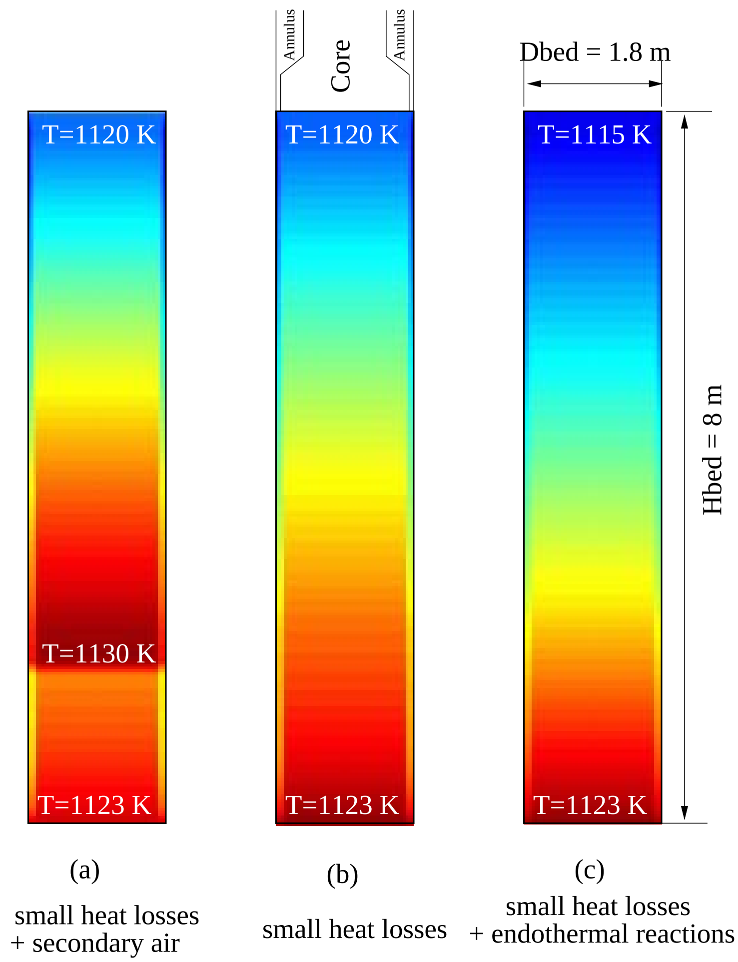

Figure 4: Calculated axial temperature profiles for the riser section