Preliminary improvements in the radiative heat transfer modeling for fluidized bed biomass gasification: bed section

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Fluidized bed biomass gasification processes are very suitable for gas generation. Advantages over more conventional technologies include superior degree of controllability, lower pollutant emission rates and high turn-down ratios. As far as design and optimization are concerned, a comprehensive mathematical model and its corresponding computational program play a major role for predicting operational parameters for each specific application.

A comprehensive simulation program for bubbling fluidized bed gasifiers (and combustion boilers as well) has been developed [1] and tested against experimental data, which were reproduced within small deviations. The mathematical model now counts on almost 100 coupled non-linear differential equations and correlations, many of them were incorporated in later versions of the program (see for instance ref. [2]). Such aspect evidences the ability of the simulation program to be updated with newly published information and to be extended, allowing more complex mathematical approaches.

Inside the reactor, high temperature levels are commonly achieved and then thermal radiation becomes an important heat transfer mode. Accordingly, adequate treatment of the radiative heat transfer is crucial to the mathematical model. In the present work, preliminary improvements are introduced in the model as to simulate properly the radiative heat transfer taking place in the gasifier.

Radiative heat transfer inside the gasifier

The current program simulates the steady state operation of fluidized bed gasifiers and boilers. Carbonaceous material, inert and/or limestone are continuously fed and materials are continuously withdrawn. This is a one-dimensional model, i.e., axial symmetry is evoked and all radial dependences are neglected.

Inside the fluidized bed reactor, several heat transfer modes may take place. As far as the bed section is concerned, the current model assumes that heat transfer through thermal radiation occurs between:

- Different solid particles in the emulsion, namely, carbonaceous particles, inert and limestone;
- Solid particles and the bed wall; and
- Solid particles and immersed tubes (if any).

For each particle type, associated expressions for the above phenomena are evaluated and introduced in the corresponding energy balance differential equation. The model also assumes that the interstitial emulsion gas and the gas inside the bubbles are transparent to thermal radiation. As a mathematical consequence, the gas energy balance equations lack of radiative heat transfer terms.

The radiative transfer equation

Heat transfer by thermal radiation in participating media is governed by the so-called (radiative) transfer equation [3]. This equation represents the balance of the radiative intensity I as it travels a distance $\mathrm{d}\ell$ through the participating media along an arbitrary direction and it is expressed as

$$\frac{\mathrm{d}I}{\mathrm{d}\ell} = -(K_\mathrm{a} + K_\mathrm{s})I + K_\mathrm{a} I_\mathrm{B} + \frac{K_\mathrm{s}}{4\pi}\int_{4\pi} I(\omega')\,\Phi(\omega')\,\mathrm{d}\omega' \qquad (1)$$

where I_B is the blackbody radiation intensity or Planck function, which depends on local temperature, and $\Phi(\omega)$ is the scattering phase function. The absorption and scattering coefficients K_a and K_s are strongly dependent on the particulate media composition. This is an integro-differential equation and its solution for engineering applications is by no means a simple task.

When I is azimuthally independent, the transfer equation assumes a simpler form

$$\mu \frac{\mathrm{d}I(z,\mu)}{\mathrm{d}z} = -(K_a + K_s) I(z,\mu) + K_a I_B(z) + \frac{K_s}{2} \int_{-1}^{1} I(z,\mu') \Phi(\mu,\mu') \mathrm{d}\mu' \quad (2)$$

where $\mu = \cos\theta$ and $\mathrm{d}z = \mathrm{d}\ell \cos\theta$. An additional simplification is to consider isotropic scattering for which $\Phi = 1$ over the entire solid angle.

The 2-flux model approach

The problem is further simplified by using approximate methods as for instance the flux models, which provide approximations for the directional dependence of I. The basic idea of the 2-flux model (also known as the Schuster-Schwarzschild approximation) is to assume the radiative intensity to be isotropic (i.e., constant at distinct values) over the lower and upper hemispheres [3],

$$I(z,\mu) = \begin{cases} I^{-}(z) & , \quad -1 < \mu < 0 \\ I^{+}(z) & , \quad 0 < \mu < 1 \end{cases} \quad (3)$$

After integration over the upper and lower hemispheres separately, the transfer equation reduces into two space dependent equations. For isotropic scattering ($\Phi = 1$), these equations are [3]

$$\begin{aligned} \frac{1}{2}\frac{\mathrm{d}I^{+}}{\mathrm{d}z} &= -(K_a + K_s) I^{+} + K_a I_B + \frac{K_s}{2}(I^{+} + I^{-}) \\ -\frac{1}{2}\frac{\mathrm{d}I^{-}}{\mathrm{d}z} &= -(K_a + K_s) I^{-} + K_a I_B + \frac{K_s}{2}(I^{+} + I^{-}) \end{aligned} \quad (4)$$

It is worth to observe that the 2-flux approach preserves the basic structure of the current complete mathematical model and simulation program. In this sense, modifications suggested by the 2-flux approach for the radiative heat transfer calculations are then introduced in the mathematical model. The resulting new version of the simulation program is tested for a case of wood gasification and numerical results are compared to those obtained with the earlier radiative heat transfer approach and also to experimental data.

Conclusion

The set of equations concerning thermal radiation phenomena in biomass gasifiers represent only a small portion of the whole set of equations in a comprehensive mathematical model for fluidized bed equipment. Nevertheless, radiative heat transfer plays a major role inside the reactor since high temperature levels are commonly achieved. The preset work presents a two-flux model proposal for the radiative heat transfer in the bed section of a fluidized bed biomass gasifier. Improvements related to the flux model incorporation are investigated for test case involving wood gasification.

References

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