Numerical study of coal and woody biomass co-gasification in oxygen-fed gasifier

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Abstract. The use of biomass in the energy sector is associated with two important tasks: reducing the dependence of energy systems on expensive high-quality fuel, and increasing the environmental efficiency of thermal power plants (by processing carbon-containing waste and, in some cases, reducing harmful emissions). In addition to co-combustion, other methods of fuels co-processing are possible, including co-gasification. The process of gasification of low-grade fuels can be unstable because of their low calorific value, often accompanied by the formation of tar products, so the addition of coal improves the efficiency of co-conversion. On the other hand, the high reactivity of biomass can contribute to the stabilization of combustion and gasification regimes of fuels with low-reactivity, such as coals with high degree of metamorphism or petcoke. In this paper, the process of pulverized fuel gasification is considered, and limitations on the efficiency associated with the melting of ash are investigated.

1. Introduction

In this paper, the process of gasification of pulverized fuel in entrained flow is considered, which allows obtaining gaseous fuel for various purposes (gas turbine cycle, chemical technology [1, 2]). Gasification of carbonaceous industrial wastes and biomass in the form of an additive to the main fuel was realized at operating coal plants [3-5]. Theoretical and experimental studies of such processes were carried out in [6-8].

Co-gasification of fuels with significantly different properties not only displaces the optimal operating modes of the gasifier (by the specific consumption of the oxidizer and slag conditions), but also significantly affects the processes associated with the preparation of raw product gas for use in a combustion chamber or catalytic reactor. Often additional cleaning (which is related to the loss of the physical heat of the product gas) or the regulation of the fuel mixture composition (such as dilution with air, nitrogen, steam, etc.) are required. The mineral part of the fuels also influences the gasification process, because the biomass ash can shift the temperature boundaries of slagging [9] and enhance the corrosion properties of the slag [10].

Theoretical and experimental studies show that when coal and biomass gas is co-gasified, there is often an optimal ratio at which a sufficiently effective conversion of fuel mixture is obtained with a slight change in technical efficiency [11]. The present work is devoted to the study of thermal regimes of fuel particles conversion in the reaction zone of entrained-flow gasifiers.

2. Initial data and results of modelling

Mathematical model described earlier in the previous works of the authors [12, 13] was used for calculations. This model is a system of one-dimensional stationary heat and mass transfer equations
with a kinetic-thermodynamic block describing the processes of pyrolysis and gasification of fuel particles.

The parameters of the reactor are taken from [7, 14]. We consider a cylindrical reactor with a fuel consumption of \( G_C + G_{BM} = 70 \) t/h, the working pressure in the reactor is 4.4 MPa. Geometrical dimensions of the reactor are as follows: the length of the reaction zone is 6.7 m; inner diameter is 3.7 m. The temperature of the fuel entering the reactor is 25°C; steam temperature is 200°C; the temperature of blowing oxygen is 200°C. The steam-fuel ratio (SFR) varies from 0 to 0.2 mol/mol(C). The oxidizer consumption factor \( \alpha \) varies from 0.1 to 0.7 (in increments of 0.05). The gasification agent consists of technical oxygen (purity 95%) and water vapors. However, compressed nitrogen is used to supply fuel, so the oxygen concentration in mixing zone is assumed to be 85% [7]. Another variable is the fraction of biomass mixed with coal \( G_{BM}/(G_C + G_{BM}) \): this value varies from 0 to 1 with increments of 0.1. Fuel properties are given in Table 1. The melting point of mixed ash is defined as a linear function of the composition.

### Table 1. Properties of coal and biomass

| Property          | Coal     | Biomass  |
|-------------------|----------|----------|
| \( W'_r, \% \)     | 2        | 2        |
| \( A^d, \% \)      | 14.2     | 1.1      |
| \( V^{daf}, \% \)  | 27       | 83       |
| \( C^{daf}, \% \)  | 85.33    | 50.05    |
| \( H^{daf}, \% \)  | 4.77     | 8.19     |
| \( N^{daf}, \% \)  | 1.98     | 0.08     |
| \( S^{daf}, \% \)  | 0.93     | 0.02     |
| \( Q'_r, \text{MJ/kg} \) | 27.8   | 17.5     |
| Density, \( \text{kg/m}^3 \) | 1200  | 900      |
| Mean particle diameter, \( \mu m \) | 100   | 100      |
| Ash fusion temperature, K | 1723  | 1523     |

In the calculations, the oxidizer consumption factor \( \alpha \), calculated for mixtures of coal and biomass, was changed. Therefore, the mass flow of the oxidant depends not only on the oxidizer consumption factor, but also on the composition of the fuel. Optimal specific consumption of oxidant for wood (\( \alpha = 0.33 \)) is approximately 1.24 kg/kg(fuel), for coal (\( \alpha = 0.38 \)) 2 kg/kg(fuel). The chemical efficiency with a fixed fuel composition and with change in the oxidizer consumption factor also has a single maximum [15]. With an increase in the fraction of biomass, the chemical efficiency increases, which agrees with the results of [7]. The maximum chemical efficiency (91%) is achieved with biomass gasification without coal additives. The area of steady-state biomass gasification regimes begins at \( \alpha \sim 0.25 \). When coal is added, this area expands due to an increase in the fuel combustion heat. The optimum oxidizer consumption factor for all cases is in the range \( \alpha = 0.3-0.4 \). Bold lines from efficiency surface at Fig. 1 could be projected to compare co-gasification regimes at different steam-to-fuel ratios. Dependency of cold gas efficiency at ash fusion line on fuel composition and steam addition is presented at Fig. 2.
Fig. 1. Dependence of the cold gas efficiency and the raw gas temperature on the fuel composition and the oxidizer consumption ratio (steam consumption if fixed at 0.1 mol/mol(C)). The solid bold line is ash fusion temperature condition; the dashed line is for optimum cold gas efficiency.

Fig. 2. The cold gas efficiency of the process of coal and biomass co-gasification at the ash fusion temperature at different steam-fuel ratio (mol/mol(C)).

As can be seen from Fig. 2, there is an inversion point (with a biomass fraction of about 20%), above which the addition of steam ceases to be effective. Water vapors are generated in sufficient quantities during combustion of biomass (which is more hydrogen-rich than coal), so additional steam supply is useless. Nevertheless, in all cases, the addition of biomass makes it possible to improve the efficiency of fuel-to-gas conversion (compared to pure coal).

With biomass fraction increase, the difference between the maximum cold gas efficiency and the cold gas efficiency at the ash fusion point increases. To enhance the efficiency of co-conversion, biomass should have a more fusible ash, or interact with coal ash with the formation of fusible ash [9, 16].

3. Conclusions
1) Stationary regimes of the process of coal and biomass co-gasification under a wide range of conditions are investigated using mathematical modeling.
2) Calculations show that the ash fusion conditions shift the area of feasible regimes from the line of maximum chemical efficiency toward increasing of oxidizer consumption ratio.
3) With the increase in the biomass fraction, the addition of steam to oxygen becomes ineffective due to water vapours generation during biomass conversion.

4. References
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Acknowledgements
The work is carried out as a part of the project III.17.1 of Fundamental Researches Program of SB RAS, No. AAAA-A17-117030310448-0