Chapter 13
Effect of Fuel Properties on Reaction Front in an Open-Top Downdraft Gasifier

Chandan Kumar and Sadhan Mahapatra

Abstract The effect of biomass physical properties, i.e., particle size, particle density, and moisture content on propagation rate at various air mass fluxes is studied. The biomass fuel samples used in the study are Bamboo (*Bambusoideae*) and Krishnachura (*Delonix regia*). The increase in moisture content decreases the reaction front propagation because the endothermicity of bed increases and peak bed temperature decreases. The peak front propagation rate for Bamboo and Krishnachura is 0.14 mm/s and 0.24 mm/s, respectively. The front propagation rate decreases as the particle size increases for the same operating conditions. The larger particle size leads to incomplete pyrolysis and thus, affects the front propagation and gasification performance. Particle density has an inverse relationship with flame propagation. The result of this study provides an understanding on the effect of biomass physical properties on the front propagation rate.

Keywords Biomass gasification · Propagation rate · Downdraft gasifier

1 Introduction

Gasification is an efficient technology used for the conversion of lignocellulosic biomass into gaseous fuels. The gasification is a heterogeneous reaction process in which solid fuel reacts with sub-stoichiometric amount of oxidizer present inside the gasifier and generates producer gas along with some amount of tar. Different types of gasifier viz., updraft, downdraft, fluidized bed, etc., have been developed over a period of time and classified on the basis of fuel feeding, gas extraction direction, and behavior of oxidizer. The downdraft gasifier is the simplest type of gasifier, widely used because of low tar generation, ease of operation, and lower maintenance cost. The performance of gasifier, i.e., composition of the output gas and amount of tar generation is influenced by the physical properties of the fuel and the amount of oxidizer [1].

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Mahapatra and Dasappa investigated the effects of air mass flux and moisture content of the biomass on reaction front propagation in a packed bed gasifier [2]. The result shows that with the increase in air mass flux, propagation rate increases, attains a peak and with further increase in air mass flux, the propagation rate decreases. It is also reported that with the increase in the moisture content of biomass, propagation rate decreases. This decrease in propagation rate with the increase in moisture content is because of the increase in endothermicity of the gasifer, i.e., reduces the heat transfer rate between the fuel particles [2]. Porteiro et al. measured the ignition front propagation for different biomasses [3]. The result shows that with the increase in air flow rate, ignition mass flux increases and after attaining a peak, it reduces. The effect of excess air shows a quenched flame, whereas with the increase in moisture content the ignition front decreases [4]. Tinaut et al. reported that biomass particle size has no effect on the bed temperature, but the bed temperature increases with the increase in airflow [4]. The increase in airflow means increasing the turbulence and it increases the diffusion rate and due to this, the bed temperature increases. The flame propagation characteristic inside the gasifier is an important parameter which needs to consider in designing the gasifier [5]. In the present study, experimental investigations have been carried out to study the effect of particle size, moisture content, and particle density for two different types of biomass on the reaction front in an open-top downdraft gasifier. The present study will be helpful for designing a downdraft gasifier based on multi-fuel and to enhance the gasifier performance.

2 Experimental Procedure

An open-top downdraft gasifier is used for the experiment and the schematic diagram of the experimental setup is shown in Fig. 13.1. The inside reactor diameter is 130 mm and the height of the reactor above the ignition nozzle is 600 mm. The flame propagation rate is measured for various air mass fluxes. The temperatures along the length of the reactors are measured using K-type thermocouples at different heights of the reactor for a set of experiment. The flame front propagation rate is estimated by using the following relation.

$$R_{\mathrm{FP}} = \frac{\Delta x}{\Delta t}$$

where R_{FP} is the flame front propagation rate, Δx is the distance between two adjacent thermocouples, and Δt is the time required to reach the reference temperature between two consecutive thermocouples attached at different heights of the reactor. The reference temperature used for the calculation of the reaction front propagation rate is 500 °C [2].The bed movement is measured through topping up method at a regular time interval of 10 min. The output gas from the gasifier is cleaned through a two-stage water spray system and after that, cooled in a chiller. The gas flow rate is measured through a calibrated orifice plate.

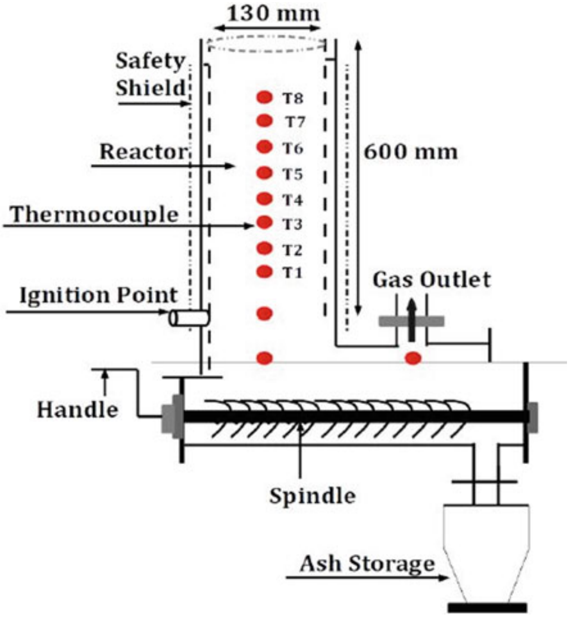

Fig. 13.1 Reactor configuration of the open-top downdraft gasifier

Charcoal is filled into the reactor up to 100 mm above the height of the ignition nozzle and rest of the reactor is filled with biomass fuel samples of specific sizes. Ignition is done through ignition nozzle and once the charcoal started burning, ignition nozzle is closed during the experiment. The complete amount of required air for the gasification process comes from the reactor top. The ignition front tends to move upward opposite to the bed movement as the air is coming only from top of the reactor. Bamboo and Krishnachura are used as biomass fuel samples. Two different moisture content biomass fuel samples (bone-dry and 10% moisture) are used in the experiments. The fuel sample shape is cuboid and having dimensions 12 × 8 × 6, 18 × 8 × 6, and 24 × 8 × 6 mm. The ultimate and proximate analysis of the biomass fuel samples are shown in Table 13.1. The bed density for different sizes of bamboo samples at bone-dry condition is presented in Table 13.2.

3 Results and Discussion

A typical temperature profile inside the reactor at a particular air mass flux is presented in Fig. 13.2. The reactor front propagation rate is estimated from the temperature profiles at various air mass fluxes. The bed movement is movement of bed per unit time in the downward direction due to fuel consumption. Biomass consumption is the fuel consumption per unit time during the gasification process. The effective propagation is the summation of flame front movement which is in the upward

Table 13.1 Ultimate and proximate analysis of biomass samples

Parameters	Bamboo (%)	Krishnachura (%)
Proximate analysis		
Moisture	12.32	9.20
Fixed carbon	16.85	12.77
Volatiles	68.42	72.82
Ash content	2.41	5.21
Ultimate analysis		
Carbon	45.13	47.63
Hydrogen	2.23	6.16
Nitrogen	1.24	1.89
Oxygen	51.40	44.32

Table 13.2 Bed density for different bamboo particles

Particle size (mm)	Equivalent diameter (mm)	Surface area/volume (mm^{-1})	Bed density (kg/m^3)
12 × 8 × 6	10.32	0.75	410 ± 12
18 × 8 × 6	11.80	0.69	355 ± 16
24 × 8 × 6	13.00	0.67	315 ± 11

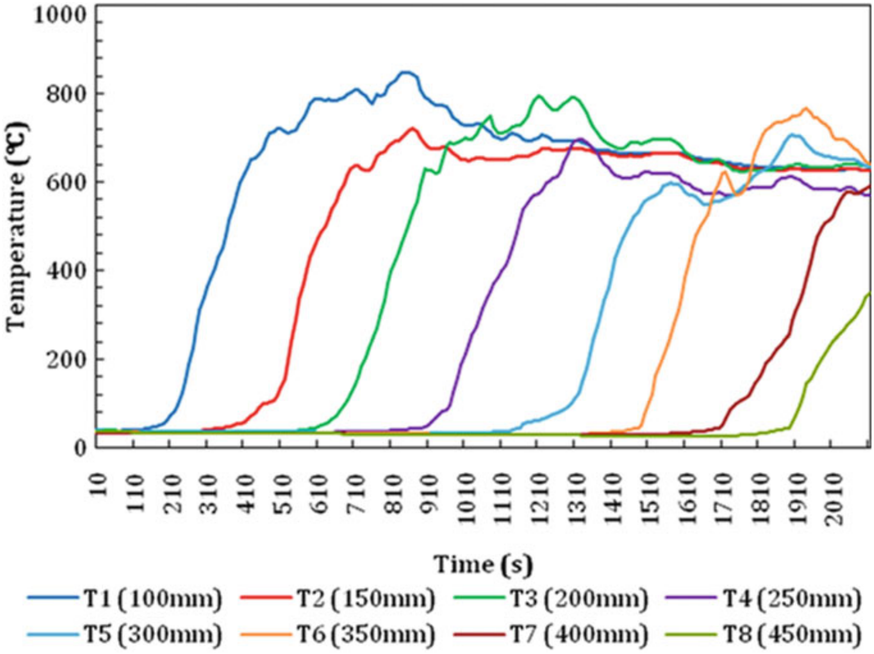

Fig. 13.2 Temperature profile along the reactor length

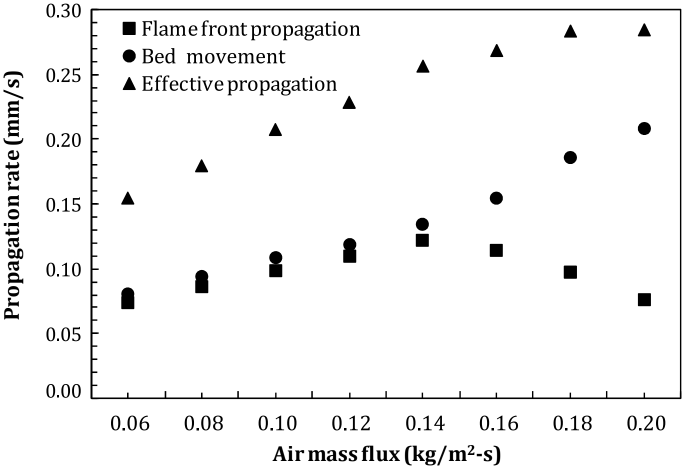

Fig. 13.3 Flame front, bed movement, and effective propagation for bone-dry bamboo

direction and bed movement which is in the downward direction in a downdraft gasifier.

Figure 13.3 presents the flame front propagation, bed movement, and effective propagation for bone-dry fuel sample at various air mass fluxes. The flame front propagation initially increases with the increase in air mass flux, attains a peak and then with further increase in air mass flux, front propagation decreases. This result is very similar to that found by different studies related to propagation rate [2–4]. As the air supply increases in the reactor, it carries away more heat from the bed compared to the heat generation, and thus, at higher air mass flux, the reaction front decreases. The bed movement depends on the biomass consumption. The biomass consumption increases with the increase of air mass flux. Hence, the bed movement linearly increases with the increase in air mass flux. The effective propagation rate also increases with the increase of air mass flux. The effective propagation rate is found very similar to the result presented by Horttanainen et al. [6].

3.1 Effects of Moisture

Figure 13.4 presents the front propagation for bone-dry and 10% moisture content bamboo fuel sample with particle size of 12 × 8 × 6 mm. The flame front propagation rate is found to be higher for bone-dry fuel samples. The peak propagation rate obtained is 0.14 and 0.10 mm/s for bone-dry and 10% moisture content bamboo samples. This is due to the particles containing higher moisture content need more energy in drying and that leads to decrease in the propagation rate. The bed contains higher moisture content absorbs more heat and this decrease in flame propagation and also the bed temperature. The combustion depends on the surrounding environment

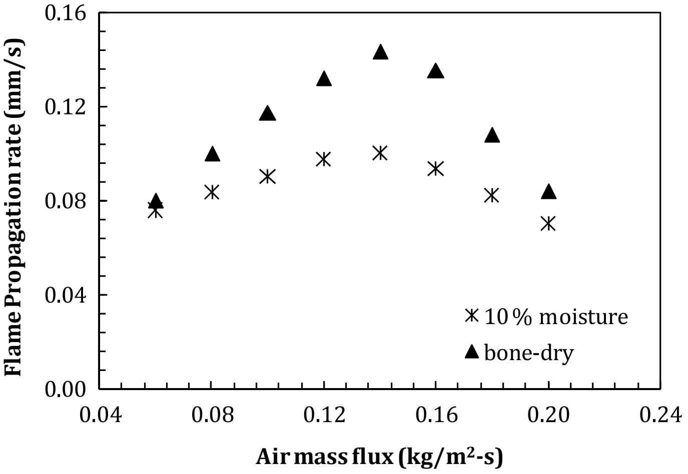

Fig. 13.4 Flame front propagation for various moisture contents in bamboo samples

and change in moisture content in bed increases the endothermicity of bed and thus lower the propagation rate. The effective propagation increases with the increase in air mass flux. The effective propagation for bone-dry and 10% moisture content fuel samples are 0.34 mm/s and 0.26 mm/s, respectively, at an air mass flux of 0.20 kg/m^2 s. There is a decrease in effective propagation by 23% and peak reaction front decrease by 29.5% due to increase in 10% moisture content.

3.2 Effects of Particle Size

Figure 13.5 shows the effect of particle size on the flame front propagation rate. It is observed that flame front propagation rate decreases with the increase in particle size of the fuel samples. The decrease in flame front propagation rate is due to a decrease in available surface area of the fuel samples for combustion and increase in bed density which restricts the air flow through the bed. Bed porosity also affect the propagation rate, higher porosity means lower heat transfer coefficient. It can be concluded that packing factor of the bed also effects the front propagation. The maximum propagation rate for 12 × 8 × 6 mm and 24 × 8 × 6 mm particle sizes are 0.14 mm/s and 0.12 mm/s, respectively. The peak reaction front decreases by 15% with the increase in 26% in equivalent diameter of the fuel particle. The effective propagation also decreases for the higher size particles. It is due to the exposed surface area per unit volume for is higher for 12 × 8 × 6 mm particle size compare to 24 × 8 × 6 mm particle size. The heat diffusion time is higher for the larger particle size and thus, reaction front propagation rate reduces. The inter-particle heat transfer rate is also lower in larger size particles than smaller particles. It is found

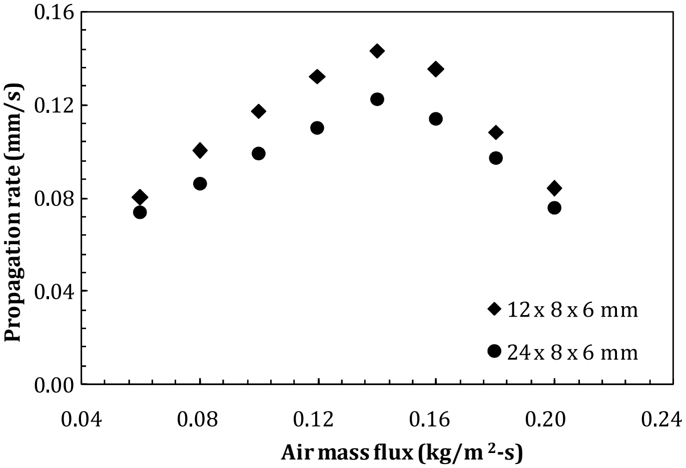

Fig. 13.5 Propagation rate for various particle size

that for larger particle, there is a chance of incomplete pyrolysis and this leads to an increase in the concentration of tar in output gas.

3.3 *Effects of Particle Density*

Figure 13.6 represents the effect of fuel particle density on propagation rate. It is found that the front propagation is higher for lower density biomass sample. The

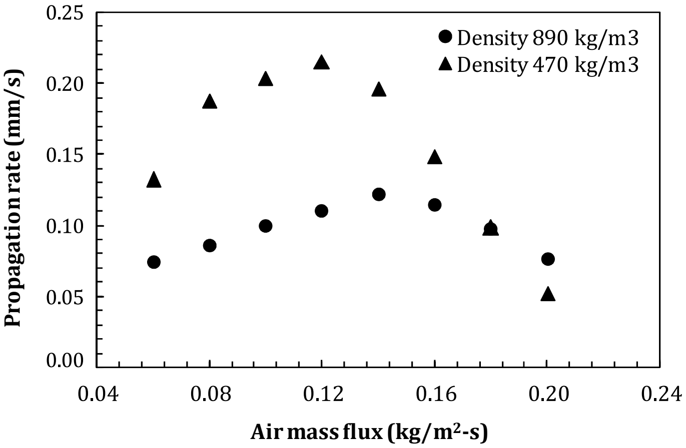

Fig. 13.6 Propagation rate for various biomass density

rate of devolatilization depends on the particle density of solid fuel. The particle density directly relates to the porosity, less dense particles are more porous in nature. The heat diffusion into the core of the fuel depends on the porosity of fuel particle. Higher heat diffusion with oxidiser to the core of the particle resulted in a reduction in burning time. Moreover, the higher density fuel particles have lower heat diffusion rate and hence the propagation rate decreases. Again, higher density particle has more thermal inertia, so it requires more energy for thermal decomposition of the particle. The peak propagation rate for krishnachura with density 470 kg/m^3 is 0.22 mm/s at air mass flux of 0.12 kg/m^2 s. In case of bamboo with particle density of 890 kg/m^3, it is 0.12 mm/s at an air mass flux 0.14 kg/m^2 s. The peak reaction front propagation for Krishnachura occurs at lower air mass flux compare to bamboo. This might happened due to higher devolatilization rate, lower thermal inertia for krishnachura compared to bamboo.

4 Conclusions

The present study shows that the reaction front increases with the increase in air mass flux attain a peak and with further increase in air mass flux reaction front decreases. The reaction front propagation is higher for bone-dry than 10% moisture content biomass. Smaller particle size fuel samples have higher propagation rate compared with the larger size fuel particles. The reaction front is higher for lower density biomass than the higher density biomass fuel samples. The peak propagation rate obtained for lower density biomass at lower air mass flux than the higher particle density fuel samples. The peak bed temperature difference is higher between bone-dry and 10% moisture content at lower air mass flux. However, this difference in peak temperature decreases at higher air mass flux. This experimental investigation provides a clear understanding on the effect of fuel samples physical properties on the reaction front propagation.

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