Modeling of a heat-integrated biomass downdraft gasifier: Influence of feed moisture and airflow

Houda M. Haidar[1], James W. Butler[2], Samira Lotfi[2], Anh-Duong Dieu Vo[3], Peter Gogolek[3], Kimberley McAuley[1]*

1 Department of Chemical Engineering, Queen's University, Kingston, ON, Canada; 2 National Research Council of Canada, 1200 Montréal Rd, Ottawa, ON, Canada; 3 CanmetENERGY Ottawa, Natural Resources Canada, 1 Haanel Dr, Ottawa, ON, Canada

**Corresponding author: kim.mcauley@queensu.ca*

Highlights

- A steady-state model for a heat-integrated biomass downdraft gasifier is developed.
- Model accounts for pyrolysis, combustion and gasification reactions and transport phenomena.
- Gasifier is divided into four zones to account for heat-integration system and air feed.
- Model was validated using data and used to study influence of feed moisture and air flow.

1. Introduction

Burning fossil fuel releases carbon dioxide to the atmosphere and leads to serious environmental problems including global warming.[1] Biomass gasification is a promising method for replacing fossil fuel for power generation in isolated communities. Gasification makes producer gas consisting of CO, CO_2, CH_4, H_2, N_2 and tar, which is used to generate electricity. Downdraft gasifiers are attractive due to their simple construction and operation and low cost making them preferable in small-scale applications. An undesirable feature of downdraft gasifiers is low thermal efficiency, which can be overcome by heat integration. Modeling of downdraft gasifiers helps in understanding the effects of operating conditions on gasifier performance. Including heat integration in the model is important for developing a clear understanding of system operation. The objective of the current study is to develop a 1-D steady-state model for the downdraft gasifier in Figure 1, which has a heat integration system.

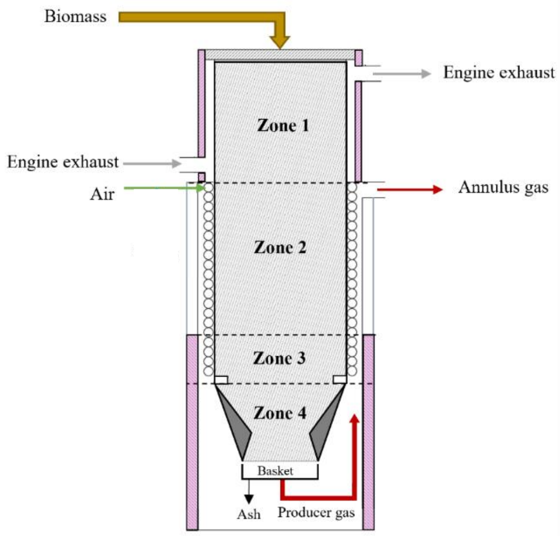

Figure 1. Schematic diagram for heat-integrated downdraft biomass gasifier.

2. Methods

The gasifier is divided into four zones. The first is used for preheating and drying the biomass. The second and the third are used to pyrolyze the biomass in the absence of oxygen, producing gaseous species, tar and solid char. Zone 4 is used for partial combustion of the process gas and char, producing heat for endothermic reduction reactions. Char exits at the bottom of the gasifier, along with producer gas, which passes upward through an annulus so heat can be recovered. Producer gas exiting the annulus at the top of Zone 2, passes through a clean-up system and enters an engine to produce electricity [2]. Exhaust gas from the engine is fed to the annulus of Zone 1. Seventeen material-balance ordinary differential equations (ODEs) and five energy-balance ODEs describe the gasifier operation, resulting in a model with 40 parameters (29 kinetic and 11 transport). The model, which accounts for 14 reactions, is a boundary value problem (BVP) where the temperature and flowrate of producer gas at the bottom must match the conditions of the gas fed to the annulus, which flows in the opposite direction.

3. Results and discussion

Model predictions were validated using experimental runs with pine wood as the feedstock. The model was used to simulate the influence of important process inputs on the gasifier temperature profile and producer gas composition. Figure 2a) shows predicted temperature profiles for the three simulated runs with different air flowrates and Figure 2b) shows resulting CO and CO_2 compositions in Zones 3 and 4. As expected, the simulation with the highest air flow results in the highest predicted temperature profiles in Zones 2 and 3 and the highest maximum temperature in Zone 4. It is interesting that feeding more air results in an increase in the CO mole fraction in the producer gas and a decrease in CO_2 due to faster gasification reactions at higher temperatures. The run with the highest air flow rate gives the highest producer gas flow rate leaving the bottom of the gasifier. Additional simulations were performed to study the effects of biomass moisture content on gasifier performance.

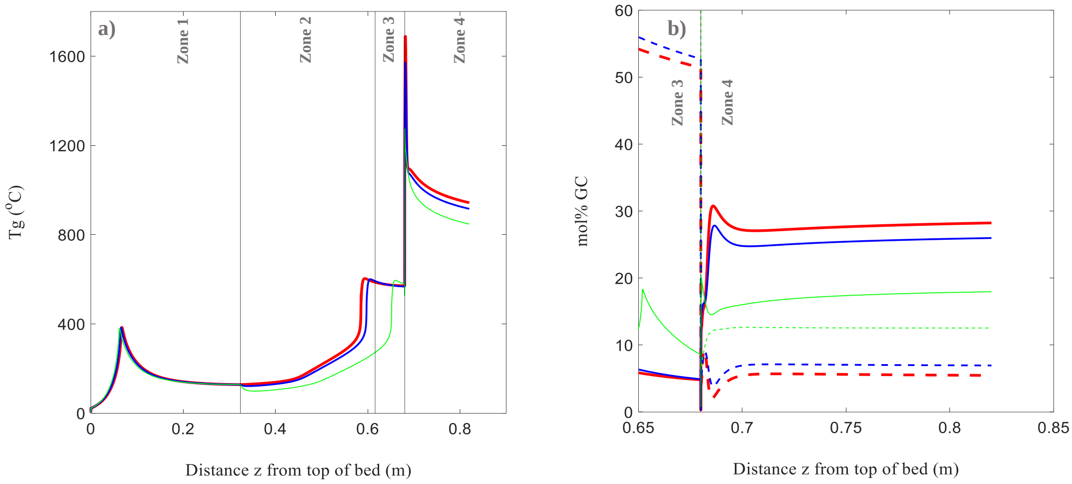

Figure 2. a) Temperature profiles of process gas for different air flowrates: 0.2 $m^3\ min^{-1}$, 0.164 $m^3\ min^{-1}$ and 0.09 $m^3\ min^{-1}$ and b) Gas composition for different air flowrates: CO at 0.2 $m^3\ min^{-1}$, CO at 0.164 $m^3\ min^{-1}$, CO at 0.09 $m^3\ min^{-1}$, CO_2 at 0.2 $m^3\ min^{-1}$, CO_2 at 0.164 $m^3\ min^{-1}$ and CO_2 at 0.09 $m^3\ min^{-1}$.

4. Conclusions

A mathematical model was developed for a heat-integrated biomass downdraft gasifier, accounting for 14 reactions. The model was validated using two runs with pinewood feedstock. Simulations with higher air flow result in the higher temperatures, more CO and less CO_2. To increase the model accuracy, parameter estimation using 15 gasifier runs is the next step.

References

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Keywords

Downdraft gasifier; Biomass; Model; Heat integration system.