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# Abstract

As humanity gropes for sustainable solutions to the developmental problems of the world, biomass gasification technology emerges as a promising alternative for both thermal and power applications from biomass. While the gasification technology dates back to World War II, the understanding of science behind gasification is still a matter of research. Guidelines for design and successful operation of gasifiers are reliably available in the literature. However, it is still not scientifically explained how these parameters result in good performance of a gasifier. Most downdraft gasifiers are known to operate smoothly and produce engine-grade fuel quality over a reasonably wide range of airflow rates, from 20% to 110% of the rated capacity of the gasifier. It has also been observed that the variation in air-biomass ratio over this range of airflow rates is not substantial, nor is the variation in producer gas composition.

A significant number of papers have been published on modelling and simulation of the gasification phenomena over the past three decades. However, even today, there has been no comprehensive understanding of the effect of the design parameters such as hearth load and superficial velocity, used in the design process of gasifiers, on the phenomena and performance of gasification. The present work intends to address this question and attempts to provide explanations to several questions related to the effect of operational and design parameters on the phenomena that occur in a biomass gasifier, and hence on the performance of the gasifier.

The present research focuses on modelling the phenomena in a biomass gasifier, viz., multi-component fluid flow, heat transfer, drying, pyrolysis, oxidation, and reduction

using the appropriate mathematical equations. The mathematical models of all phenomena have been adopted from the literature. An in-depth research for working mathematical models from the literature reveals several gaps and inconsistencies in the available models. Thus, the search for consistent, working mathematical models and model parameters, especially those for the thermochemical reactions through global reaction kinetics, became quite laborious. Every reaction rate expression had to be cross-checked against the respective reference cited in each work and traced back to the original publication and verified for consistency in systems of units and values of Arrhenius rate parameters, viz., the pre-exponential factor and activation energy, before the model could be used.

A one-dimensional transient model of a downdraft biomass gasifier has been developed using conservation equations for mass, momentum, energy and species of the multi-component mixture in gaseous phase. Since the model involves simultaneous flow of solids and gases and their inter-conversion, accurate book-keeping of solid species conservation is implemented. Since multiple timescales are involved particularly in chemical reaction kinetics, the equations behave stiff, and specialized codes for stiff equation solver, the LSODE subroutines, have been adopted from the Lawrence Livermore Laboratories. A FORTRAN code has been developed to implement the model as part of the present work. The simulated results were compared with available experimental results to validate the developed model.

A parametric analysis has been carried out to investigate the influence of operating parameters, viz., fuel type, fuel size, fuel moisture content and gasification airflow rate on the performance of downdraft biomass gasifier. The results are presented in the form of transient evolution of temperatures at different locations in the gasifier, and the exit gas composition. Axial variation of temperature, velocities of gaseous and solid flows, mass flow rates of various species and the molar composition of gaseous species and mass fractions of solid species are plotted and analysed to understand the influence of the parameters on the behaviour of the gasifier and its performance. It was found that wood with a lower lignin content produced a higher quality of producer gas and a higher gasification efficiency. Smaller particle sizes resulted in better carbon conversion and hence better gas quality and efficiency. Higher airflow rates resulted in higher hearth temperatures, leading to better utilization of char and hence higher performance. Moisture content, when increased from 1% to 10%, shows marked improvement in gasification, beyond which water vapour content in producer gas starts increasing.

A new design parameter, Superficial Air Velocity (SAV), defined as the airflow rate at 1 atm and $0^{o}$C per unit area of the throat of the gasifier, has been proposed in the present work to substitute for hearth load or superficial velocity defined in the literature. This is necessitated because in operating a gasifier, one has direct control over the airflow rates, but not on the flow rate of producer gas, which is required to calculate hearth load or superficial velocity. Using this as a design parameter, the hearth sizes were varied at fixed SAV, and SAVs were varied at each hearth size, to understand its effect on gasifier performance. The study brought out the fact that unless particle sizes are varied corresponding to increase in hearth sizes, the biomass consumption rate per unit throat area increases substantially, accompanied by high hearth temperatures, indicating that there may be dusting of char particles in this case, which is not modelled. Other design parameters investigated were the lengths of converging and diverging sections and ratio of maximum to minimum hearth diameter. It was observed that decreasing the length of divergent section below recommended value resulted in difficulties in ignition of gasifier, but otherwise the lengths of these sections did not alter the performance of the gasifier much. The present model could not predict any change in gasifier performance due to change in the ratio of minimum to maximum reactor diameter. This result is surprising, and could be because the model does not capture multi-dimensional effects. However, the model does indicate abnormalities in behaviour either in the form of difficulty in ignition or larger deviations from experimental data on gas quality when the parameters go towards limits of recommended ranges. This behaviour of the model holds promise for detecting limits of parameters when a more comprehensive parametric study is made using the model.

The present study was begun with an ambitious goal of explaining the relevance and validity of design recommendations, and to broaden the scope of the recommendations. It is recognized that in order to achieve the goal, a much broader and more systematic parametric analysis is necessary. However, the present in-depth study yielded a substantial insight into the functioning of a gasifier and the details of the physico-chemical phenomena involved.