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Thermodynamic Modeling and Optimization of Operating Parameters for Downdraft Gasification of Pongamia Shell Pellets

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Extended Abstract

With the global demand for sustainable and renewable energy rising, biomass gasification is becoming an increasingly popular alternative to fossil fuels. Gasification is a process that converts chemical energy from biomass into gaseous fuel. This gaseous fuel can be utilized directly for heat and power generation [1]. One of the valuable byproducts of the biodiesel industry is the Pongamia shell, which can be used as biomass feedstock. The pelletization of Pongamia shells increases their bulk density, which improves the utilization of Pongamia shells in a downdraft biomass gasifier without any blockage in the throat [2]. In this work, a numerical investigation was conducted for the gasification of Pongamia shell pellets (SP) in a downdraft gasifier using air as a gasifying medium. Thermo-chemical equilibrium model was used to investigate syngas composition during the gasification of SP. Additionally, response surface methodology (RSM) was used to obtain optimal operating conditions for maximizing lower heating values of syngas (LHV_{gas}), cold gas efficiency (CGE), and hydrogen (H_2) content and minimizing carbon dioxide content (CO_2) in the product gas.

There are various purposes for which mathematical modeling can be used, ranging from the detailed simulation of a particular unit to the early design of an industrial process [3]. The process of gasification can be better understood by simulating it.

Here, a thermo-chemical equilibrium model was used to predict product gas composition from the gasification of SP in a downdraft gasifier with air as a gasifying agent. The model results were verified using experimental data from [4] to ascertain the syngas composition. The RMSE (root mean square error) was computed to check the accuracy of model results. The Effects of operating parameters (Gasification temperature; T_g, Equivalence ratio; ER, Moisture content; MC) on the syngas composition and the performance (specific gas production, LHV_{gas}, CGE, and CCE) of the biomass gasifier were investigated. This sensitivity analysis was performed by varying gasification temperature, ER, and MC in the range of 823 K–1123 K, 0.22–0.4, and 10%–30%, respectively.

Subsequently, a multi-objective optimization tool using response surface methodology (RSM) was used to develop a model correlating decision parameters to output responses through the analysis of variance (ANOVA) tool. In this work, Minitab software was used for statistical study of RSM. Equilibrium model results were used as input to Minitab software to create a design matrix. Most frequently, RSM uses a quadratic polynomial model known as a regression model to determine the response, which can be expressed as follows [5]:

$$y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} \beta_{ii} x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{ij} x_i x_j + \varepsilon$$

Where y is the output response; β_0 β_i, β_{ii}, and β_{ij} are constant, linear, quadratic, and interaction coefficients, respectively; n denotes the number of the factors x_i, epsilon is the statistical error.

For the present work, the best operational conditions of the gasification temperature (T_g), ER, and MC for maximum LHV_{gas} CGE, H_2 concentration, and minimum CO_2 concentration were derived as 1112.2 K, 0.16, and 16.1%, respectively, with the corresponding optimal response values of 7.69 MJ/Nm^3, 74.74%, 32.2%, and 5.2%, from the RSM optimizer tool.

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