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Experimental investigations on a 20 kWe, solid biomass gasification system

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ABSTRACT

When the objective is to generate motive or electric power via I.C. engine, the overall pressure drop through the suction gasification system in addition to gas quality has become a sensitive issue. This work, therefore, presents an experimental study on a suction gasifier (downdraft) arrangement operating on *kiker* wood or Acacia nilotica (L). Studies were conducted to investigate the influence of fluid flow rate on pressure drop through the gasifier system for ambient isothermal airflow and ignited mode, pumping power, and air-fuel ratio, gas composition and gasification efficiency. Results of pressure drop, temperature profile, gas composition or calorific value are found to be sensitive with fluid flow rate. Ignited gasifier gives much higher pressure drop when compared against newly charged gasifier bed with isothermal ambient airflow. Higher reaction temperatures in gasifier tends to enhance gasifier performance, while, overall pressure drop and thus pumping power through the system increases. Both ash accumulated gasifier bed and sand bed filters with tar laden quartz particles also show much higher pressure drops.

1. Introduction

Biomass has been recognized as an ideal energy resource for decentralized energy systems [1]. In tropical countries like India, biomass grows more productively, which can be converted efficiently into modern energy carriers such as gaseous, liquid fuels and electricity that can be used in more affluent society. Presently, thermochemical gasification and biological conversion are largely complimentary technology, which are widely accepted for biomass utilization. Biological conversion is limited to non-lignaceous matter, while thermochemical conversion route can process any solid organic matter. Harnessing of biomass and urban wastes via thermochemical route is not only environmentally benign but also economically viable [2]. For air gasification, the gas quality or gas composition including tar (as a result of incomplete oxidation of volatiles) and quantity varies widely depending on the gasifier configuration, chemical composition of the feedstock, its moisture and ash content, its size and density, equivalence ratio, reaction temperature profile and turn down of power level [3]. Out of different gasifier design, downdraft gasifier produces relatively low content of tars in the gas (~0.1%) [4], therefore, it may be a preferable choice for small scale decentralized power generation systems via gas engine.

Several designs have been developed in past for utilization of woody biomass in different size and shapes [5–10]. The development of open top, twin air entry, re-burn gasifier for solid biomass[5] and commercial version of gasification system (1.08 GJ h^{-1}) for low-density biomass was developed in past[6]. Di Blasi designed a laboratory scale countercurrent gasification system for variety of biomass such as beechwood, nutshells, olive husks, and grape residues [7], while [8,9] employed multi-stage gasification concept in their design in order to reduce the tar content in final gas. Numerous investigations were performed in past on different types of biomass species using downdraft gasification system. The influence of

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equivalence ratio on the gas quality and quantity was investigated in [10] using *wood chips* and *charcoal* feedstock; gasification potential of *hazelnut shells* [11] and *rubber wood* [12] were also investigated. In order to assess the potential of the *saw dust*, a downdraft, stratified and open top gasifier was used [13], while [14] studied the effect of woody biomass components (i.e., Cellulose, xylan, and lignin) on air-steam gasification. Sheth and Babu [15] measured the downdraft gasifier performance using furniture waste mainly rose wood and results were compared from literature data.

The pressure gradient across the packed bed is a function of system geometry, medium porosity, permeability and physical properties of working medium. In order to describe the behavior in complete flow regime, Ergun combined the Carman–Kozeny equation and Blake–Plummer equation in form of Forchheimer equation [16,17]. Sharma [3,18] reported an experimental and theoretical study to relate flow rates with the pressure drop through gasifier bed using Ergun equation.

From the above literature survey, it can be revealed that numerous experimental studies have been reported in past on different kind of gasification systems relating the operating and design parameters to the gas quality and quantity with special focus on minimization of tar content in final gas. The detailed study on packed bed pressure drop through a suction gasifier bed (maintaining at widely varying temperature specifications with different particle size distribution and with variable bed porosity) is limited in open literature. Pressure drop monitors not only the health of gasifier system but also the volumetric efficiency of engine and net engine power output as well. If objective is to couple a gasifier with a gas engine, the study of pressure drop at component as well as system level and pumping power of a suction gasifier system arrangement (including cooling-cleaning train) may be essential. In the present work, therefore, experiments were planned and performed on 20 kWe suction gasifier (downdraft) arrangement to obtain elaborate trends for pressure drop for newly loaded gasifier, quiescent and ignited gasifier at different operating conditions. Further experiments were performed to obtain temperature profile, pumping power, gas composition or calorific value and gasification efficiency and air-fuel ratio as a function of flow rate.

2. Experimental description

An advanced version of *downdraft biomass gasifier* of capacity 20 kWe developed in Indian Institute of Science, Bangalore [19], has been employed in the present work (refer Plate 1). The schematic diagram of suction gasifier and cooling-cleaning unit is given in Fig. 1. In this gasifier, both gas and biomass feedstock move downward as the reaction proceeds. While biomass flows due to gravity, airflow is induced through the reactor by a blower. The air for gasification is partly drawn from the open top, and partly from the three air tuyers placed radially around the circumference of the oxidation region. The biomass slowly moves down along with air or gas to convert into producer gas. In order to recover the heat from gas, this gas is used to pass through the annular region through a re-circulated duct. For engine use, cooling of hot producer gas is carried out by the combination of two spray towers, while for cleaning the gas a coarse and fine sand bed filter are used. The two-stage filtering ensures that the gas is cleaned to the desired level for use in the engines. Downstream of the fine filter, the gas has to the flare through the blower. Just before the flare, a water bubbler is installed in the path for safety reasons to avoid backfire from the flare. For further details consult operational manual of the gasifier (NETPRO, [20]).

2.1. *Instrumentation*

For measuring the reaction temperatures inside the porous bed of the gasifier, a special arrangement was tried, which involves a structure made up of a hot rolled coils and fully galvanized (GI) pipe with inclined branches to position the thermocouple beads at desired locations inside the reactor (refer Fig. 2). Calibrated K-type (chromel-alumel) thermocouples of length 2.1 m was used for temperature measurement. Thermocouple wires were electrically separated from each other using ceramic beads. Two single-channel digital temperature indicators were used to read out the temperature values. The structure was suspended from the open top with the help of a holder prior to charging of the gasifier. The pressure drop across the three main components in the system, viz., the gasifier, the spray tower and the sand bed filters was measured using U-tube water manometers at various locations P_1–P_4 as shown by the Fig. 1. Proper calibrated venturi attached with a 15° inclined tube water manometer was used to measure the pressure difference.

A Gas Chromatograph (NUCON-5765) was used to measure gas composition. Well cooled and properly cleaned samples of the gas at various gas flow rates were collected in air tight sampling bags for calibrated GC to predict composition of gas sample on the computer software.

3. Experiments on gasifier system

When present work was taken up, the gasifier components were badly damaged. These components were re-fabricated and refurbished. The experiments were done on a refurbished unit with particular attention to leak tightness to obtain the pressure drop across the gasifier (isothermal ambient airflow and reactive gasifier) as well as its accessories (spray towers and sand bed filters) and pumping power as a function of fluid flow rate. Here isothermal ambient airflow represents a limiting case with zero biomass consumption. For reactive gasifier, the experiments were also performed to relate the reaction temperatures, gas composition, calorific value and combustion efficiency with the fluid flow through the bed. For obtaining the pressure drop characteristics for case of isothermal ambient airflow, the experiments were conducted for two types of bed arrangements; (i) newly charged or freshly loaded gasifier bed and (ii) quiescent gasifier bed (earlier was in use and extinguished latter). In newly charged gasifier, the biomass particles are arranged uniformly with nearly constant average particle size throughout the bed so that bed porosity could be maintained uniform throughout the bed, on the other hand, in quiescent gasifier both the bed porosity and particle size progressively decrease along the bed (due to chemical reactions when gasifier was reactive) [3,18]. For