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Practical Achievements on Biomass Steam Gasification in a Rotary Tubular Coiled-Downdraft Reactor

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Abstract

Today, the impending stringent environmental norms and concerns about the depletion of fossil fuel reserves, have added impetus on development of cutting edge technologies for production of alternative fuels from renewable source, like biomass. Concept of biomass pyro-gasification offers platform for production a) of hydrogen b) hydrocarbons and c) value added chemicals etc. However, majority of these developments are either in nascent or in pilot/demonstration stage. In this context, there exists potential for hydrogen production from the raw gas of biomass steam gasification. In gaseous products of biomass steam gasification, there exist a lot of CO, CH_4 and other hydrocarbons that can be converted to hydrogen through cracking, steam reforming and water gas shift reactions. In the present work, the characteristics of biomass steam gasification in an in-house designed rotary tubular coiled-downdraft reactor for high value gaseous fuel production from rice husk was studied through a series of experiments. The effects of reactor temperature, steam-to-biomass ratio and residence time on overall product gas yield and hydrogen yield were investigated. From the experimental results, it can be deduced that an optimum reactor temperature of 750^oC, steam-to-biomass ratio (S/B) of 2.0 and a residence time (3.6 min.) contributed highest gas yield (1.252 Nm^3/kg-ash and moisture free biomass). Based on the obtained experimental results, a projected hydrogen purity of above 65 volume% at a potential hydrogen yield of 18.36 wt% of the biomass organic content is foreseen. Despite the fact that, the yield of hydrogen varies from biomass to biomass which depends on inherent composition of the species, this process opens up pathway for production of the cleanest fuel as compared to other liquid products from biomass, which require further treatments for making in final form.

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1. Introduction

Hydrogen is regarded as the cleanest fuel, which has zero emission on combustion and can be produced from a variety of renewable biomass resources. Biomass energy is an abundant resource all over the world. The conversion of biomass into hydrogen-rich gas provides a potentially competitive means for producing energy. It has been demonstrated that high hydrogen yields can be achieved through an adequate reactor design and the control of gasification conditions (Peng-mei et al., 2003). Much work has been done concerning biomass gasification and there are good amount of research publications on hydrogen production from biomass (Fredrik et al., 2015; Ligang et al., 2006; Midilli et al., 2001; Remon et al., 2014, 2015; Reza et.al., 2014; Siyi et al., 2009; Tianju et al., 2011; Xiao et al., 2014; Zakir et al., 2014). Less emphasis was given to experimental conditions and reactor design for continuous mode process for hydrogen rich gas production via. biomass gasification.

In the present work, one of the most abundantly available biomass feed stock, rice husk was used. This work reports results of initial biomass gasification tests over a range of reactor temperature, steam- to- biomass ratio (S/B) and residence time. The paper focuses on total gas yield and hydrogen yield.

2. Experimental

2.1 Feedstock

In this work, the rice husk biomass was sourced from Greater Noida. The material was pulverized into powder and sieved into a specific particle size in the range of 0.20- 0.30 mm. The elemental composition of biomass was analyzed by means of CHNO elemental analyzer. (Thermo Fisher Scientific make, Model- Flash EA 112).

2.2 Experimental set-up

The tests were performed at sub-atmospheric pressures, in the range of 0.85 -0.90 bara, in an externally heated rotary tubular coiled reactor system, as shown schematically in Fig.1. The reactor is made of SS 316L and is externally heated by a 3-zone tubular furnace. The total length of the reactor is 1540 mm. The biomass is fed into the reactor through a hopper at 90^o angle and superheated steam is supplied horizontally into the reactor. The steam of 200^oC is produced in a vaporizer. A helical coil conveyor was fixed inside the gasifier tube. Rotation of the gasifier tube can be adjusted with the help of a motor. The residence time of the biomass can be varied with the help of motor rpm control. The downstream of the gasifier tube is fitted with a char collection bottle immediately at the end of the gasifier and a gas-liquid separator pot for separation of liquids from the gasified vapour. The separator pot is equipped with a fine filter in its dip leg, which can be easily dismantled for removal of solid deposition and clean-up. This helps in separation of fine particles from the product gas under hot condition. The uncondensed product gas is driven out by a vacuum pump and the product gas from vacuum pump vent at positive pressure is routed into a second stage fixed bed catalytic reactor for further conversion. A sample line is taken into online gas analyzer (IR/TCD analyzer for CO, CO_2 and H_2) and refinery gas analyzer for detailed analysis.

2.3 Product gas analysis

After the char & condensate separation from the produced vapour, the volumetric flow rate is measured by a wet gas meter. The dry and clean gas was sampled from a slip stream and analysed by an online CO/CO_2- non-dispersion infrared method (NDIR) analyzer (FUGI make, model-ZRJ) and H_2 analyzer (thermal conductivity detector type, FUGI make, model-ZAF 3). A gas chromatograph (Agilent make, model 7890A) is also used for detailed hydrocarbon analysis. The char & ash yields were estimated based on the carbon balance obtained after the experimentation. Each experiment was carried out twice in order to ensure repeatability of results and to assure reliable operation of the system.