Chemical Engineering Journal 282 (2015) 170–178

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Advanced reforming of agro-waste by modular gasifier for fuel generation

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HIGHLIGHTS

- Modular gasifier for conversion of cassava rhizome.
- Product gas upgrading by pyrolyzed char from cassava rhizome.
- Satisfactory raw material conversion to valuable fuel gases.
- Very low tar formation at optimal operating condition.

ARTICLE INFO

Article history:
Available online 14 March 2015

Keywords:
Biomass
Cassava rhizome
Downdraft gasifier
Gasification

ABSTRACT

Cassava rhizome, a bulky residue from cassava plantation, was reformed using a modular downdraft gasifier in order to produce a high temperature fuel gas with low tar content. Effects of biomass particle size between 5 and 15 mm, inlet air flow rate of 1.98–3.06 m^3/h and additional 5% Ni/char catalyst for secondary syngas cleanup were investigated. The air flow rate had integrated effects on product yield and composition; higher air flow rate resulted in higher gas yield with less tar and char. The conversion to H_2 and CO increased with the biomass particle size, whereas the conversion to CH_4 and CO_2 decreased. The optimal operating conditions without catalyst addition were obtained with air flow rate of 2.5 m^3/h and particle size of 10 mm where carbon and hydrogen conversions were 94.02% and 65.92%, respectively. In the presence of catalyst, the yield of CO_2 was reduced whereas the CO increased. The carbon and hydrogen conversions were 92.87% and 55.69% with air flow rate of 1.98 m^3/h and particle size of 10 mm, respectively. At this condition, tar formation was relatively low with gas heating value of 4.45 MJ/m^3 and H_2/CO of 1.22. Obviously, prepared Ni/char catalyst enhanced condensable tar reforming to smaller gases resulting in increased gas heating value and cold gas efficiency with superior synthesis gas yield. The produced gas contained quality combustible gases, which can be readily used in heat and power applications.

1. Introduction

Gasification is a thermo-chemical process that can be used to convert solid or liquid carbonaceous material into valuable gaseous fuel or chemical feedstock. In this process, gasifying agents such as air, oxygen or steam partially oxidize biomass and hydrocarbons and convert them to low molecular weight gases like CO and H_2 [1,2]. A downdraft gasifier is a co-current flow reactor where biomass is fed at the top and the air intake also enters at the top or the side of the reactor and flow in the same direction as that of biomass. The product gas flows downward and leaves through a bed of hot ash [3]. Due to gas passes through a high-temperature zone, this enables cracking of tar during the gasification process. For this reason, the advantage of a downdraft gasifier was higher conversion efficiency with a low tar and particulate matter generations. In this work, a modular gasifier is a modified close top downdraft gasifier with a throat in the reactor core. The throat section in the gasifier is the area where the cross sectional area of the reactor is gradually reduced and the air input was radially introduced through air nozzles just above the point with the smallest cross sectional area creating a highly uniform temperature field and better mixing condition. This would generate intense heat from combustion within small volume and large oxygen availability around the throat section and thus effectively reduce tar content that generated from the preceding pyrolysis zone [3–5]. As a result,

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http://dx.doi.org/10.1016/j.cej.2015.03.019
1385-8947/

the throat in the gasifier design plays an important role in reducing the tar concentration in the producer gas [4]. Reasons for modifying conventional gasifier as a modular downdraft gasifier used in this experiment are from its suitability for remote area since collection and costly transportation of biomass raw material are not required, flexibility on utilization of various wastes from the local agriculture and industry, low upfront capital cost as well as ease of system expansion for greater throughput, if needed. In addition, further addition of electrical generation module may be achieved with ease. Cassava rhizome is the neck between trunks and tuberous roots which is considered as biomass residues from cassava plantations. According to recent survey, the planted area of the cassava in Thailand is approximately 7 million acres producing 25 million tons of cassava roots [6]. Usually, cassava rhizome residue is subjected to open field burning, releasing greenhouse gases and other pollutants. As a result, utilization of cassava rhizome as energy source by gasification will lessen this environmental problem while generating useful fuel gas products.

Typical to any gasification processes, tar is formed as by-product and may caused operational problem and also considered as loss of combustible materials. Many commercial nickel catalysts are available to assist on tar reduction. Nickel catalysts are highly effective and work best in the secondary reactor. These catalysts are generally supported by natural materials such as dolomite, olivine, and active charcoal [7]. Char, a carbonaceous product of pyrolysis, also catalyzes tar reforming when used in the secondary reactor. Char has been reported to be inexpensive support and also an excellent adsorbent [7]. It could be easily produced from the slow pyrolysis of biomass. Many researchers have study Ni and metal catalyst on char support for biomass gasification to reduce tar content in product gas. Wang et al. [8] investigate char and char support nickel catalyst for secondary syngas cleanup and upgrading. Ni-based catalysts were made by mechanically mixing NiO and char particles at various ratios. They found that at 15% NiO loading and 0.3 s residence time, Ni/coal-char and Ni/wood-char convert 97% of tar in syngas at 800 °C. In addition, Wang et al. [9] reported that catalyst granular size was a factor for tar removal and syngas composition enhancement. The tar removal efficiencies increased with the decreased of Ni/char granular size, which can be attributed to the higher active surface area with smaller granular size. As the catalyst granular size increased, the H_2 content in the syngas was increased and the CO content was significantly decreased. Shen et al. [10] studied tar conversion via in-situ dry reforming and found that tar could be removed effectively by reaction with the char supported catalyst. At optimized conditions, the conversion efficiencies of condensable tar reached 92.3% and 93% using Ni–Fe char and Ni char with calcination, respectively. Zhang et al. [11] also studied the iron supported on biomass char and iron supported on brown coal char as hot gas cleaning catalysts at atmospheric pressure and 800 °C The result showed decreased CO_2 and CH_4 concentrations and increase H_2 and CO concentration of product gas on any catalysts. The iron-containing species in char would favor the formation of H_2. Tar contents of below 100 mg/Nm^3 in the product gas could be obtained by using iron catalyst supported on biomass char or just biomass char.

The purpose of this experiment was to investigate the effect of cassava rhizome particle size and inlet air flow rate of 1.98–3.06 m^3/h on gas production performance of modular gasifier. Effect of addition of 5% Ni/char catalyst module for secondary syngas cleanup on gasification efficiency was also examined. The performance of cassava rhizome gasification was evaluated in term of attainable zone temperature, producer gas composition, conversion, gasification efficiency, air superficial velocity, biomass consumption rate, and specific gasification rate.

2. Experimental and procedures

2.1. Experimental set-up

The experimental system set-up consists of a modular downdraft reactor, feeding system by auger motor and control with fuel level sensor, air supply system, swirl burner. The gas clean-up system consists of cyclone, packed bed filter of char coal, and two condensers. The schematic of a modular downdraft gasifier system is similar to our previous reported and reproduced in Fig. 1 for clarity [12]. The height of the reactor is 610 mm and

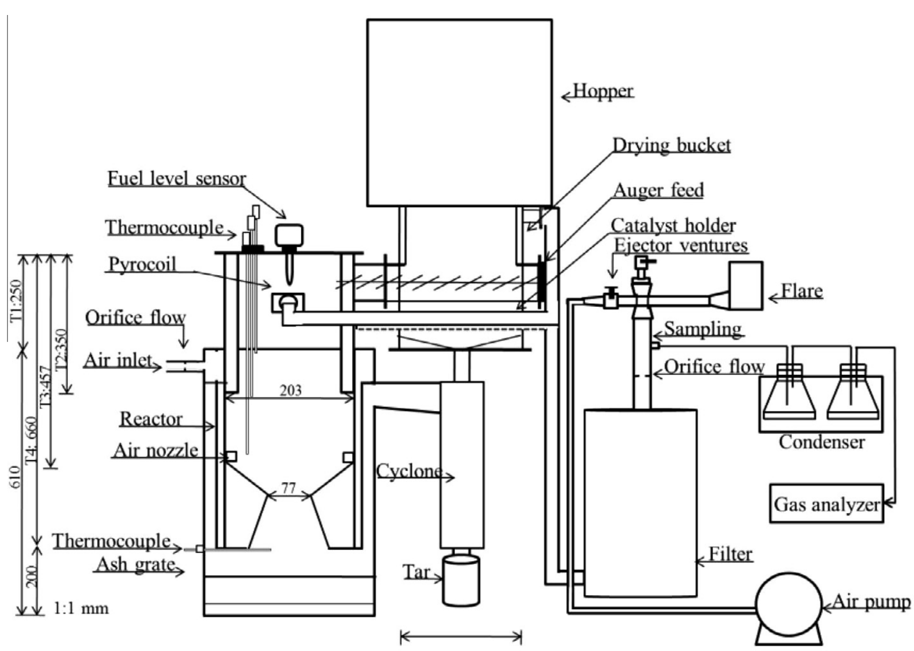

Fig. 1. Schematic of a modular downdraft gasifier system used in the experiment.