Journal of the Energy Institute xxx (2016) 1–10

Contents lists available at ScienceDirect

Journal of the Energy Institute

journal homepage: http://www.journals.elsevier.com/journal-of-the-energy-institute

Experimental study on steam gasification of pine particles for hydrogen-rich gas

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A R T I C L E I N F O

Article history:
Received 5 April 2016
Received in revised form
10 July 2016
Accepted 18 July 2016
Available online xxx

Keywords:
Pine particles
Steam gasification
Self-built downdraft gasifier
Limonite

A B S T R A C T

Adopting the self-built experimental setup on high temperature steam gasification of biomass, which takes advantages of the downdraft gasifier, the experimental study uses pine particles made of pre-treatment sawdust for hydrogen-rich gas. Experimental tests show that the pine particles are converted into hydrogen-rich synthesis-gas efficiently, and the output is more stable in the course of the experiment. According to the experiments, the gasification reaction becomes severer with the increase of temperature, the volume fraction of H_2 increases from 23.38% at 700 °C to 44.79% at 950 °C, which nearly doubles, but this value drops slightly because the CO-steam shift reaction is inhibited after the temperature reaching 900 °C. The volume fraction of CO reaches the minimum value at 850 °C, and then increases with the increase of temperature. The volume fraction of CO_2 decreases slowly with the increase of temperature. The increasing of gasification temperature intensifies the reforming reaction of hydrocarbons with high temperature steam. With the increase of steam flow from 0.3 $kg \cdot h^{-1}$ to 0.9 $kg \cdot h^{-1}$, the volume fraction of H_2 increases from 37.1% to 47.7% at the gasification temperature of 900 °C. The change of the volume fraction of CO is stable, while the volume fraction of CO_2 increases after it reaches the minimum value of 13%, and the volume fraction of C_nH_m decreases slowly. Considering the quality of gasification gas, when the steam flow rate is 0.6 $kg \cdot h^{-1}$ and gasification temperature is 900 °C, gasification gas yield and hydrogen yield reach the maximum value of 2.69 $m^3\ kg^{-1}$ and 1.02 $g\ kg^{-1}$ respectively, and the ratio of the amount of steam and biomass is about 0.95 at this time in the reaction. In addition, under the conditions of the same temperature and steam flow rate, with the increase of mass percent of limonite added, the biomass carbon conversion and gas yield show an increasing trend while the lower calorific value of gasification gas decreases. When the gasification temperature is 700 °C and steam flow rate is 0.9 $kg \cdot h^{-1}$, addition of 15% of iron ore powder causes the increase of the volume fraction of H_2 to 64.8%, while the volume fraction of CO, CH_4 and C_nH_m ($n \geq 2$) decreases, the volume fraction of CO_2 increases relatively. This indicates that iron ore powder is helpful for promoting the reforming reaction of hydrocarbon with steam and reducing the energy consumption in the gasification reaction.

1. Introduction

Biomass wastes, as a renewable energy, can produce domestic gas or raw gas for biosynthesis with clean gasification technology. And the hydrogen production from steam gasification of biomass, as a hot spot in the field of new energy sources, becomes more and more popular among experts and scholars [1–3]. Compared with developed countries in Europe and United States, China can make use of the huge reserves of biomass resources. Inner Mongolia Autonomous Region, as an important energy resources base in China, produces large number of biomass wastes that are equivalent to half of the Ordos coal production [4–6]. However, improper treatments of biomass wastes lead to serious environmental pollution and resource waste.

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http://dx.doi.org/10.1016/j.joei.2016.07.006
1743-9671/

At present, the main bottlenecks of biomass gasification technology are: high content of tar, low gasification efficiency, difficult gas quality control and high production costs. So, some scholars [7–10] increased the temperature of water steam to above 600 °C, and found that the hydrogen content and the fuel adaptability could be improved and high gasification efficiency and carbon conversion rate were achieved in the experimental results. Although theoretical discussion on high temperature steam gasification has been made by some scholars, it is limited to laboratory research on physical and chemical mechanism. And the amount of raw material used in the experimental study of the reaction is of small value. The above mentioned reasons with the lack of experimental theory on mass production together make it difficult to support the actual engineering theory [11–13]. So it is necessary to study the industrialization of high temperature steam gasification of biomass.

The self-designed downdraft with experimental setup about high temperature steam gasification is employed for a series of gasification experiments of pine molding particles. In this paper, experimental results will be analyzed under conditions of different gasification temperatures and steam flow rates. And this will provide technical support for actual production.

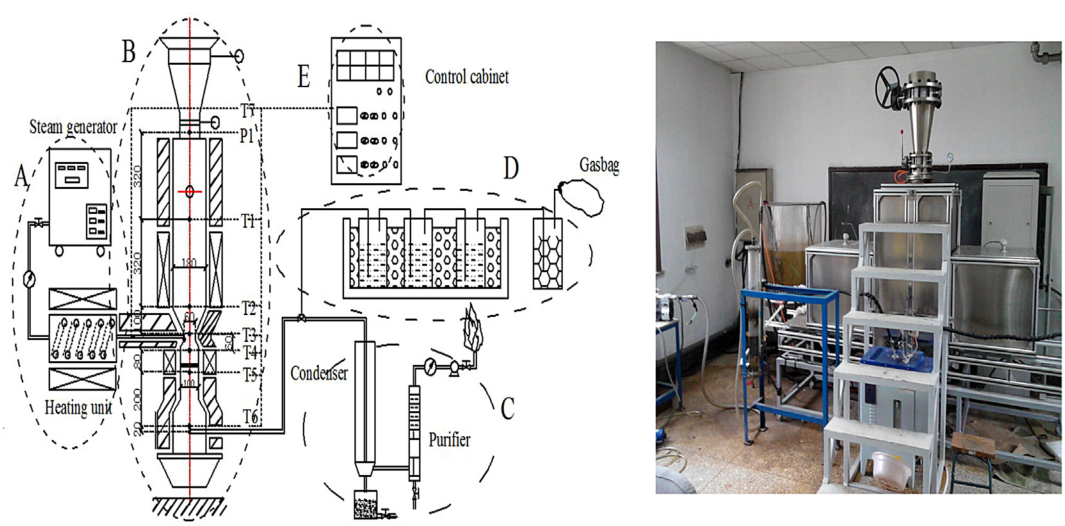
2. Experimental setup

The self-built experimental setup of steam gasification of biomass is shown in Fig. 1, including steam generator (A), downdraft gasifier (B), gas purification and acquisition system (C and D) and process control system (E). The steam generating system comprises an electric steam generator (JX-LDR0.008–0.4) and a self-made rectangular steam heating chamber. Steam is produced by electrical steam generator and its flow rate is controlled by the valve opening degree. The steam participates in gasification reaction in the furnace after heated in the rectangular steam heating chamber.

At present, it is difficult to obtain the high temperature steam (600–1000 °C) used in gasification of biomass. Ahmed I and other scholars [14,15] used the equal proportions of mixed hydrogen and oxygen to produce high temperature steam, but this method is difficult to control and the amount of steam production is small, and thus it is not suitable for practical application. Using the heat storage chamber to produce high temperature steam [16,17] is another approach, but it has the problems of poor operation and complex control of temperature. In order to produce the steam with controllable flow and temperature, a rectangular steam heating chamber with silicon kryptol embedded in the heating cavity on both sides was designed. In order to increase the area and time of heat transfer, heating pipes winds spirally in the cavity. The chamber is protected by insulating brick. The steam heating chamber has the advantages of more simple structure and convenient operation. And higher heating efficiency can be achieved as large as 80%.

The design of gasification furnace affects the production stability, gasification efficiency, tar content and thermal efficiency of the system directly. Therefore, this gasification furnace has a roar with a double cone structure. Gasification reaction occurs at the roar mainly, and this structure meets the feature of volume narrowing of materials after their pyrolysis in the furnace, while the volume of the lower cone expands gradually for the convenience of material descending. The structure is favorable for the continuous passing of materials through gasifier throat. Besides, the bridging and arching phenomenon can be alleviated effectively [13]. Experimental setup needs good air tightness because high temperature steam is used as the gasification agent and no mixed-air is allowed in the gasification furnace. So, hopper with double turning plate is used in the experimental setup to feed biomass sealed.

The control system is divided into two parts, one is used for temperature control of electric heating device of the steam heating chamber. Artificial intelligent temperature controller (AI-518P) is used as temperature control system, which ranges from 0 °C to 1200 °C. The other is for the temperature of different locations in the gasification furnace, which uses E type thermocouple (0–1300 °C). Heating space from the top to the bottom of the furnace body is divided into the drying zone, the pyrolysis zone, the zone of throat, the oxidation zone and the reduction zone. Temperatures of the five zones are monitored by thermocouple and named as T1 to T5. The outlet temperature of gas is measured and named as T6. T4. The temperature of throat is defined as the temperature of gasification reaction. The temperature of the steam through the furnace is detected and named as T7.



(a) Schematic diagram of the experimental setup (b) Real diagram of the experimental setup

Fig. 1. Self-built experimental setup of steam gasification of biomass.

Please cite this article in press as: Y. Niu, et al., Experimental study on steam gasification of pine particles for hydrogen-rich gas, Journal of the Energy Institute (2016), http://dx.doi.org/10.1016/j.joei.2016.07.006