Applied Thermal Engineering 59 (2013) 278–282

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

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

Gas generation by co-gasification of biomass and coal in an autothermal fluidized bed gasifier

Li-Qun Wang*, Zhao-Sheng Chen

School of Energy and Power Engineering, Jiangsu University, 301 Xuefu Road, Zhenjiang 212013, China

HIGHLIGHTS

- An innovative steam co-gasification process for gas production was proposed.
- Co-gasification of biomass and coal in an autothermal fluidized bed gasifier was tested.
- High temperature favors H_2 production.
- H_2 and CO contents increase, whereas CO_2 and CH_4 levels decrease with increase in *T*.
- Exergy and energy efficiencies of gases increase with increase in *T*.

ARTICLE INFO

Article history:
Received 21 January 2013
Accepted 24 May 2013
Available online 3 June 2013

Keywords:
Renewable energy
Coal
Co-gasification
Autothermal fluidized bed gasifier
Reaction temperature

ABSTRACT

In this study, thermochemical biomass and coal co-gasification were performed on an autothermal fluidized bed gasifier, with air and steam as oxidizing and gasifying media. The experiments were completed at reaction temperatures of 875 °C–975 °C, steam-to-biomass ratio of 1.2, and biomass-to-coal ratio of 4. This research aims to determine the effects of reaction temperature on gas composition, lower heating value (LHV), as well as energy and exergy efficiencies, of the product gas. Over the ranges of the test conditions used, the product gas LHV varies between 12 and 13.8 MJ/Nm^3, and the exergy and energy efficiencies of the product gas are in the ranges of 50.7%–60.8% and 60.3%–85.1%, respectively. The results show that high reaction temperature leads to higher H_2 and CO contents, as well as higher exergy and energy efficiencies of the product gas. In addition, gas LHV decreases with temperature. The molar ratio of H_2/CO is larger than 1 at temperatures above 925 °C. Our experimental analysis shows that co-gasification of biomass and coal in an autothermal fluidized bed gasifier for gas production is feasible and promising.

1. Introduction

Biomass gasification is a renewable and CO_2-neutral energy resource, and a fluidized bed is an important technique for biomass gasification [1,2]. Different gases, such as air [3], pure steam [4], carbon dioxide and air-steam [5], can be adopted as gasifying media, among which pure steam has been recognized as the most likely to obtain high-grade product gas [6]. Steam gasification requires heat from burning or exothermic reaction. However, this method also has some disadvantages. When biomass is reacted with both steam and air in the same reactor, nitrogen (N_2) is present in the product gas stream, which is costly to remove [7]. When pure oxygen is used instead of air, the content of N_2 in the product will decrease but the operating costs will increase due to O_2 production [8].

To overcome these problems, an innovative steam gasification process that considers the time-segregated hybridization of air combustion and steam gasification stages in the same fluidized bed reactor is proposed. The air combustion stage is designed for coal combustion fed with air. As the bed temperature rises to the desired temperature, biomass and pure steam are added in the gasification stage to serve as gasification raw materials during the process. The gasification-required heat is provided by the combustion stage. Direct contact between the combustion and gasification stages is avoided. This gasification technology operates in the same reactor; thus, all the heat of coal combustion can supply the gasification stage, which is better for tar cracking and can effectively prevent the sintering of raw materials in the gasification process [9]. Hydrogen-rich gas is generated free of nitrogen dilution. In

* Corresponding author. Tel.: +86 18706109387.
E-mail addresses: thwlq2000@163.com (L.-Q. Wang), zhaoshengchen2010@126.com (Z.-S. Chen).

1359-4311/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.applthermaleng.2013.05.042

addition, the gas production technique we independently developed is suitable for China and can greatly reduce investment and operational costs.

Based on this technology, an experiment on gas generation from co-gasification of biomass and coal was conducted in an autothermal fluidized bed gasifier to determine the effects of reaction temperature on gas composition, lower heating value (LHV), as well as energy and exergy efficiencies of the product gas.

2. Methods

Experiments were performed on an atmospheric pressure, autothermal, and fluidized bed co-gasification system. Fig. 1 presents the schematic of the co-gasification system, which mainly includes an autothermal fluidized bed gasifier, two separated feeders (biomass and coal), a high-temperature cyclone separator, a PID temperature controller, a tube type heat exchanger, two wet scrubbers, a bell-type gas holder, a chimney, and a root blower. As shown in Fig. 1, 1-1 is the air control valve (solenoid valve); 1-2 is the flue control valve (pneumatic valve); 2-1 is the steam control valve (solenoid valve); and 2-2 is the gas control valve (pneumatic valve).

The fluidized bed gasifier is a cylindrical, stainless steel shell with a supporting structure; its total height is 2000 mm, with an inner diameter (id) of 300 mm. Two pressure taps are mounted at the center of the wind room and at 1006 mm above the air distributor to monitor the pressure drop of the fluidized bed reactor. Bed temperatures at the three different points along the height of 160, 600, and 1056 mm above the distributor are measured by K-type thermocouples with a diameter of 18 mm. An air distributor is installed at the bottom of the fluidized bed reactor for better air distribution. The distributor is 16 mm in thickness with 126 holes (id = 2 mm) uniformly perforated on it. Coal and biomass are separately fed to the fluidized bed reactor by two different screw feeders. The feeding point is 480 mm above the air distributor, and the feeder pipes have external water-cooling heat exchanger to avoid raw material pyrolysis before they enter the fluidized bed reactor. Air is introduced into the fluidized bed reactor below the distributor as an oxidizing medium for coal combustion in the combustion stage, which is provided by a root blower. Approximately 300 °C steam is used as the gasification medium introduced from the bottom. However, in the gasification stage, the steam is provided by a steam generator, and its mass flow rate is measured by a steam flow meter. Solid particulates (ash, dust, and char) from the high-temperature hot gas are separated by the high-temperature cyclone separator and collected at the bottom. The high-temperature hot gas is cooled to about 200 °C by a water-cooled shell and tube-type heat exchanger, after which it is passed through a wet scrubber to condense the organic vapors (tar) and further cool the gas with tap water. Finally, the purified gas is introduced into the bell-type gas holder for storage.

The experiment procedures, which consist of two separate stages of combustion and gasification in the same gasifier, are described below. Two working stages are formed through two pairs of control valves (Fig. 1): 1-1 and 1-2 valves and 2-1 and 2-2 valves. During combustion, the first pair of valves is opened, whereas the second pair is closed. Coal and air are added to the gasifier when coal is combusted in fluid state, and the bed temperature rapidly increases. When the bed temperature rises to the desired value and remains steady, the combustion stage ends, air and coal supply ceases, and the first pair of valves is closed. Meanwhile, the second pair of valves is successively opened. Biomass and steam are added to the gasifier, thereby inducing the high-temperature materials to undergo pyrolysis gasification reaction with pure steam in a fluid state. This process produces H_2-rich gas without N_2 dilution and has a high LHV. Given that the reaction is of an intensive endothermic nature, the bed temperature rapidly decreases. When the bed temperature decreases to the predetermined value, the gasification stage ends, the biomass and steam supply ceases, and the second pair of valves is closed. The control valves then return to the combustion stage. Both stages automatically occur by controlling the two pairs of control valves dominated by the preprogrammed temperatures. Given that the fluidized bed gasifier has uniform temperature characteristics, temperature control in the bed for the two stages is conducive to the stability of the production quality; temperature can be arbitrary to obtain the product gas components. In the gasification stage, the sample of the product gas is collected from the bell-type gas holder with a gas bag and analyzed for major components (H_2, CO, CO_2, and CH_4) with a gas chromatograph [GC-2010, Shimadzu International Trading (Shanghai) Co., Ltd., China].

In this work, lean coal and corn core obtained from Jiangsu Province, China were used as coal and biomass feedstock,

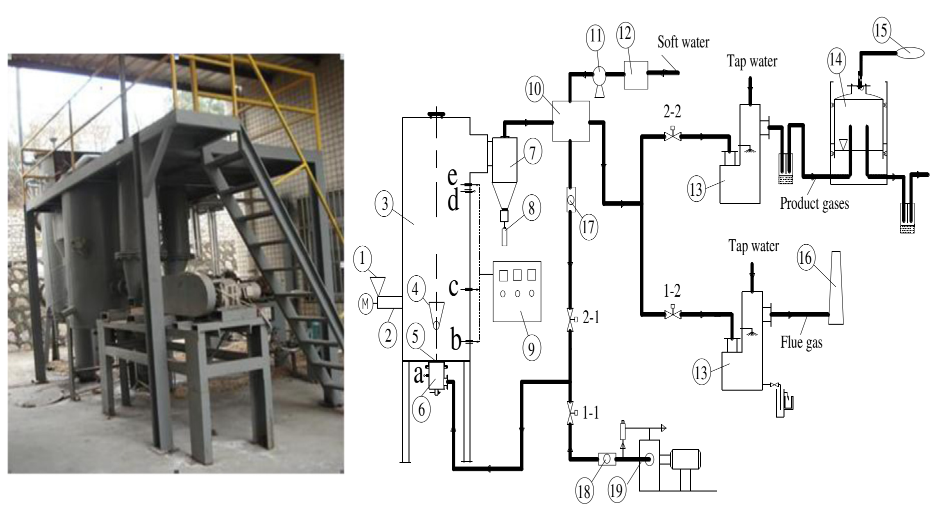

Fig. 1. Co-gasification pilot plant (left) and co-gasification schematic (right). (1) Biomass hopper (2) screw feeder (3) autothermal fluidized bed gasifier (4) coal feeder (5) air/steam distributor (6) wind room (7) cyclone separator (8) char collector (9) PID temperature controller (10) tube type heat exchanger (11) soft water pump (12) soft water tank (13) wet scrubber (14) bell type gas holder (15) gas sample bag (16) chimney (17) steam flow meter (18) air flow meter (19) roots blower. (b, c and e): K-type thermocouple, (a and d): pressure taps, (1-1) air control valve (solenoid valve), (1-2) flue control valve (pneumatic valve), (2-1) steam control valve (solenoid valve), (2-2) gas control valve (pneumatic valve).