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Small-scale downdraft gasifiers for biomass gasification: A review

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ABSTRACT

Downdraft gasifier is very attractive for biomass gasification due to its easy fabrication and operation, and also due to low tar content in producer gas. However, drawbacks such as grate blocking, channeling, and bridging are found in the downdraft gasifiers, typically for feedstock with low bulk density. Another disadvantage is the downdraft gasifiers only suitable for feedstock with low moisture content. The design of the gasifiers is an important parameter that affects their performance. Various works on design improvements have been done for enhancing the performance of the gasifiers. This paper aims to review small-scale downdraft gasifiers for biomass gasification which is focused on design improvements and their effect on the performance of the gasifiers. Many works from previous researchers have been studied and cited. The result shows that the design of the gasifiers is an important parameter in gasification, besides biomass feedstock characteristics and process parameters.

1. Introduction

Biomass gasification is a thermochemical process of converting biomass feedstock into a mixture of combustible and non-combustible gas (producer gas) in a gasifier. Depending on biomass feedstock and producer gas flow in the gasifier, fixed bed gasifier can be categorized as updraft, downdraft, and crossdraft, [1]. In downdraft gasifier, biomass feedstock is fed from the top of the gasifier then subjected to drying, pyrolysis, oxidation, and reduction process during flowing downward in the gasifier as shown in Fig. 1. Producer gas, a product of gasification, exits the gasifiers through gas outlet at the lower part of the gasifiers. Typically, producer gas is a mixture of combustible gas such as CO, H_2, and CH_4 and non-combustible gas such as CO_2 and N_2.

Quality of producer gas depends on its heating value and tar content. Good quality producer gas has high heating value and low tar content. The quality of producer gas from biomass gasification is affected by some important parameters, such as biomass characteristics, process parameters, and gasifiers design. Biomass characteristics which have to be considered in gasification are size, density, elemental composition (C, H, O, N which are obtained from ultimate analysis), fixed carbon, volatile matter, ash content, and moisture content (obtained from proximate analysis). Operating parameters in gasification are equivalence ratio, gasification temperature, and biomass consumption rate. Producer gas formed during biomass gasification can be applied as fuels for gas burner or Internal Combustion (IC) engine.

Downdraft gasifier is more suitable for small-scale applications, [2–4]. Typically, downdraft gasifiers have a capacity of 10 kW–1 MW [5]. Some commercial applications for power generation are available from small to medium scale for woodchips feedstock [6]. Downdraft gasifier is very attractive due to its easy fabrication and operation, and also due to low tar content in producer gas. However, drawbacks such as grate blocking, channeling, and bridging are found in downdraft gasifiers, typically for feedstock with low bulk density. Another disadvantage is the gasifiers only suitable for feedstock with low moisture content. Feedstock with moisture content higher than 30% produces low quality producer gas, thus low gasification efficiency. Feedstock with higher moisture content requires more heat for drying than feedstock with lower moisture content. This means that more heat energy from oxidation process is used for drying the feedstock with higher moisture content. Hence, insufficient heat is available for other endothermic reactions during gasification. To encounter these drawbacks, various modifications of basic design of downdraft gasifiers have been performed and reported by researchers worldwide.

Design improvements of basic downdraft gasifier design can be categorized as a modification on feeding system, air supply system, producer gas recirculating system, and discharge system. For continuous operating gasifier, different type conveyor and grate type have been used for feedstock feeding and ash/char removal, respectively. Air supply unit was improved with the use of multi-stage air supply system, and additional air preheating system. In the multi-stage air supply system, air is supplied into the gasifier through two or more stage tuyer

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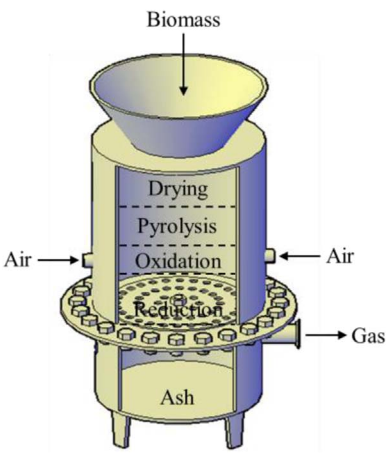

Fig. 1. Gasification in downdraft gasifier.

or nozzle. When heated air is used instead of atmospheric air, the air is heated up prior to entering gasifier. Producer gas recirculating system was developed for utilization of producer gas heat. The heat can be utilized for feedstock drying as well as for air heating.

Several review papers concerning downdraft gasifiers have been published, but none of the papers focused on the design parameter and its effect on the performance of the gasifiers. The purpose of the current paper is to present literature review on design improvements of downdraft gasifiers and its effect on their performance. Various works on design improvements of basic model of small-scale downdraft gasifiers and obtained results are listed in Table 2 at the end of the paper. Those works are cited and discussed.

2. Processes in downdraft gasifier

In downdraft gasifier, sequence processes from top to bottom are drying, pyrolysis, oxidation, and reduction as shown in Fig. 1. During drying process, moisture in biomass is driven off by heat from oxidation process. Besides for drying, heat released during oxidation process is also used for pyrolysis and reduction processes Volatile gases are released during pyrolysis process. Producer gas is formed during reduction process and exits the gasifier through gas outlet.

2.1. Drying

Typically, temperature in drying zone is about 100–200 °C [7]. Conversion of moisture to water vapor occurs during drying process. The conversion takes place due to heat transfer between hot gases from the oxidation zone to biomass in the drying zone. The amount of moisture released is equal to water vapor formed and can be expressed in term of mass balance as in Eq. (1).

$$m_{H_2O(l)} = m_{H_2O(g)} \tag{1}$$

Where $m_{H2O(l)}$ is the mass of moisture in biomass and $m_{H2O(g)}$ is the mass of produced water vapor. High moisture content biomass produces more water vapor and requires more heat for drying. One kilogram moisture in biomass uses 2260 kJ extra heat from the gasifier to vaporize a water [5] at atmospheric pressure. Normally, suitable moisture content in the biomass for downdraft gasifiers ranges from 5% to 35% [7].

2.2. Pyrolysis

During pyrolysis, biomass molecules are decomposed into condensable gases, tar, and char at temperatures between 200 and 700 °C in the absence of oxygen as shown in Fig. 2. The condensable gases in turns are decomposed into non-condensable gases (CO, CO_2, H_2, and

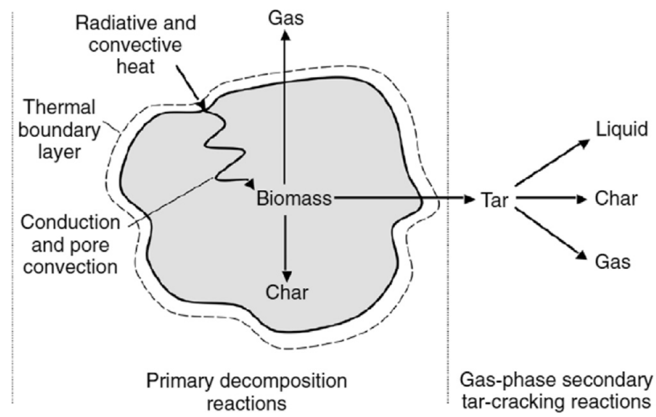

Fig. 2. Biomass pyrolysis [5].

CH_4), liquid, and char [5]. The decomposition occurs between gas-gas phase (homogeneous reaction) and gas-solid phase (heterogeneous reaction). The condensable vapor is cracked into non-condensable permanent gases (CO and CO_2). The biomass pyrolysis process is represented by reaction in Eq. (2) [5].

$$C_nH_mO_p(Biomass)\xrightarrow{Heat}\sum\nolimits_{liq} C_xH_yO_z + \sum\nolimits_{gas} C_aH_bO_c + H_2O + Char \tag{2}$$

2.3. Oxidation

Heat released during oxidation is used for drying, pyrolysis, and other endothermic reactions during reduction. The oxidation temperature is about 800–1400 °C [5]. Partial oxidation of char (C) produces carbon monoxide and heat (Eq. (3)), while total oxidation of char produces carbon dioxide and more heat (Eq. (4)). Amount of heat released during total oxidation is three times more than during partial oxidation. Partial oxidation releases 111 kJ/mol heat and total oxidation results 394 kJ/mol heat.

Partial oxidation

$$C + \tfrac{1}{2}O_2 \rightarrow CO - 111\ \text{kJ/mol} \tag{3}$$

Total oxidation

$$C + O_2 \rightarrow CO_2 - 394\ \text{kJ/mol} \tag{4}$$

2.4. Reduction

Main gasification reactions occur during reduction process [5]. Combustible gases in the producer gas are formed during reduction through the following reactions.

Bouduard reaction

$$C + CO_2 \rightarrow 2CO + 172\ \text{kJ/mol} \tag{5}$$

Water-Gas reaction

$$C + H_2O \rightarrow CO + H_2 + 131\ \text{kJ/mol} \tag{6}$$

Water-Gas Shift reaction

$$CO + H_2O \rightarrow CO_2 + H_2 - 41,2\ \text{kJ/mol} \tag{7}$$

Methane reaction

$$C + 2H_2 \rightarrow CH_4 - 74,8\text{kJ/mol} \tag{8}$$

Endothermic and exothermic reaction occur during reduction process. Bouduard and Water-Gas are endothermic reactions. Meanwhile, Water-Gas Shift and Methane reaction are exothermic reactions. The endothermic reactions use 303 kJ/mol heat and on the