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Review

Syngas production in downdraft biomass gasifiers and its application using internal combustion engines

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ABSTRACT

Biomass downdraft reactors, coupled with reciprocating internal combustion engines (RICEs), are a viable technology for small scale heat and power generation. This paper contains information gathered from a review of published papers on the effects of the particle size and the moisture content of biomass feedstock and the air/fuel equivalence ratio used in the gasification process with regard to the quality of the producer gas. Additionally, data on the parameters of producer gas, such as its energy density, flame speed, knock tendency, auto-ignition delay period and the typical spark ignition timing, are systematised. Finally, information on the typical performance of various diesel and spark ignition RICEs fuelled with producer gas is presented.

1. Introduction

Gasification is a process of conversion of any solid or liquid carbon-based material (feedstock) into gaseous fuel through its partial oxidation with air, oxygen, water vapor or their mixture. It could also be defined as the thermo-chemical process limited to a partial combustion and pyrolysis [1–5]. This process can be considered as a thermo-chemical treatment which unlike the full combustion uses air/fuel ratios noticeably below the stoichiometric value. Such a deficit in the supply of the oxidation agent prevents the complete conversion of the carbon and the hydrogen present in feedstock into CO_2 and H_2O, respectively, and results in the formation of combustible components such as CO, H_2 and CH_4. In addition to those components, the producer gas also contains typical products of combustion, namely CO_2, N_2, O_2 and H_2O. Although the process takes place with a sub-stoichiometric amount of air, it is usual to find a low concentration of oxygen in the gasification products. Finally, hydrocarbons such as ethylene (C_2H_4) and ethane (C_2H_6) are also present in very small quantities in the producer gas. A detailed description of the thermo-chemical processes taking place during biomass gasification is presented in [1–4,6–11].

Currently, small scale electricity generation using biomass gasification is attracting increasing interest as a prospective way to provide remote districts with electrical power using local renewable fuels. An additional benefit in such a rural electrification mechanism is the possibility of the utilization of various organic wastes from the local industry and agriculture with a considerable CO_2 emission reduction. In this context, downdraft gasification has the advantage of higher conversion efficiencies with a low rate of tar and particulate matter generation. Combustion properties of a product of biomass gasification (producer gas), such as its calorific value, flame speed and knock tendency, are often inferior to those of conventional hydrocarbon fuels, such as gasoline and natural gas. However, they are satisfactory for this gas to be used as fuel in RICEs or, in some cases, for gas turbines after an appropriate cleaning process [12].

For small scale applications biomass gasification in downdraft reactors has been studied extensively and currently is considered to be a mature technology [1,2,13,14]. Downdraft gasifiers are the most widespread reactors for small scale biomass and carbon conversion for a power generation using RICEs [13,15–17]. With the realization of the negative environmental and social effects caused by a rapid depletion of resources of natural gas and crude oil, research and development projects on electricity generation with biomass gasification have gained a new momentum.

Results of theoretical and experimental investigations of downdraft biomass gasifiers are presented in a large number of publications. For example, the influence of the gasification process parameters such as equivalence ratio, biomass particle size, its moisture content, etc., on gas composition, heating value, yield,

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power output and process efficiency are studied by Jain and Goss [15], García-Bacaicoa et al. [18], Zainal et al. [19], Dogru et al. [20], Jayah et al. [21], Wander et al. [22], Lv et al. [23], Wang et al. [24], García-Bacaicoa et al. [25], Tiangco et al. [26], Yamazaki et al. [27], Sheth and Babu [28], Tinaut et al. [29] and Ryu et al. [30].

The aim of this work is to present a review of theoretical and experimental research undertaken on biomass gasification employing downdraft reactors with air as an oxidation agent and the application of producer gas in reciprocating internal combustion engines.

2. Downdraft gasifiers

The main advantage of this type of reactor is the lower tar concentration in the producer gas, which is very important for the durability of RICEs. The lower tar concentration is due to gas passing through a high temperature zone (the combustion zone), which enables the cracking of the tars formed during the gasification process. According to Bhattacharya et al. [31], tar concentrations in the producer gas during biomass gasification in a moving bed are in the range between 10 and 100 g/m^3 and from 50 to 500 mg/m^3 for downdraft and updraft gasifiers, respectively.

Other advantages of the downdraft gasifier are the high char conversion and the lower ash carry over since gases pass through the charcoal bed allowing its filtration and catalysis and a quick response to any load change.

The downdraft gasifier implementation is limited to small capacities and according to Reed and Das [17] there are difficulties in obtaining the homogeneous distribution of air in reactors with large diameters so preventing the scale-up of this type of gasifier. The largest downdraft gasifiers which exist have the power output in the range from 1.5 MWt to 5 MWt. For reactors with a throat section, Beenackers [13] recommends a maximum capacity of 1 MWe. Others disadvantages of downdraft gasifiers are the potential difficulties with ash fusion and the necessity to have feedstock with a moisture content less than 25% [20]. Additionally, the fuel to be gasified needs to have an adequate particle size in order to sustain a certain biomass consumption rate (or a chemical reaction rate), as well as to maintain an acceptable pressure drop inside the reactor without the formation of preferential channels (bridging). The recommended maximum particle size to be used in the Imbert downdraft gasifier is equal to one-eighth of the reactor's throat diameter [20].

Downdraft gasifiers which can be used with RICEs can be categorized as open and close top designs, respectively. The open top design (or stratified) configuration, see Fig. 1 has an open top, forcing air (by suction) to move downwards homogeneously throughout the gasifier in order to prevent hot spot formations. The homogeneous airflow also reduces inefficiencies in the thermo-chemical process taking place in the reactor, as well as a possibility of the formation of preferential channels and internal bridges. The stratified downdraft gasifier demonstrates high versatility and relatively high efficiency in operation with solid fuels of poly-dispersed nature, such as rice husk of small particle size and low density. A number of authors have highlighted the ratio of the biomass mass flow rate and the reactor area, called the specific rate of gasification, as an important optimization and scaling variable. Jain and Goss [15] found this parameter value to be optimal at 192.5 kg/(h•m^2) for a rice husk gasification reactor with an internal diameter of 152 mm at 58% cold efficiency. Tiangco et al. [26] found this ratio to be 200 kg/(h•m^2) for a similar rice husk gasifier with a 300 mm internal diameter at 60% cold efficiency. Singh et al. [32] in experiments with cashew nut shells found the optimum value of the specific rate of gasification to be 167 kg/(h•m^2) at 70% gasification efficiency.

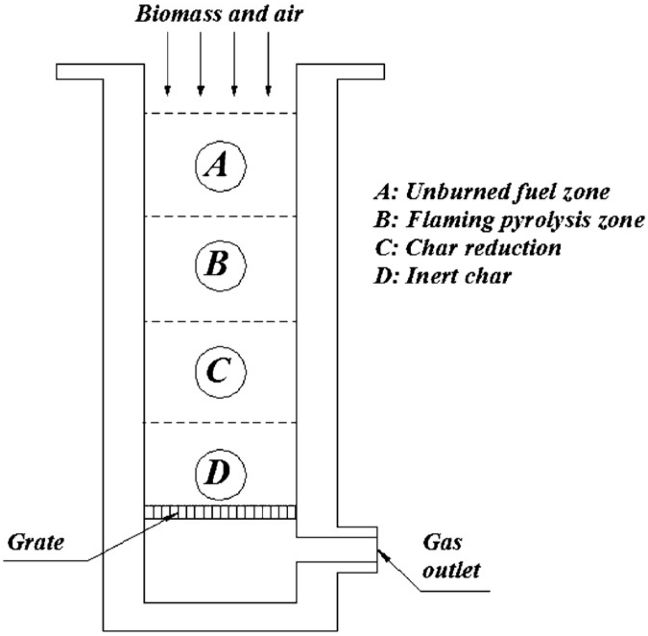

Fig. 1. Gasifier with open top.

The closed top gasifiers have two different designs, namely one with a conventional downdraft with a straight cylindrical reactor as shown in Fig. 2 and one with a throat in the reactor core, see Fig. 3, also called Imbert gasifier [17]. The throat in the second design plays an important role in reducing the tar concentration in the producer gas. In such gasifiers air is introduced just above the throat and this creates a highly uniform temperature field and better mixing conditions [13]. However with the increase of gasifier dimensions, some low temperature zones appear in the throat zone resulting in a rise of tar content in the producer gas [13]. In

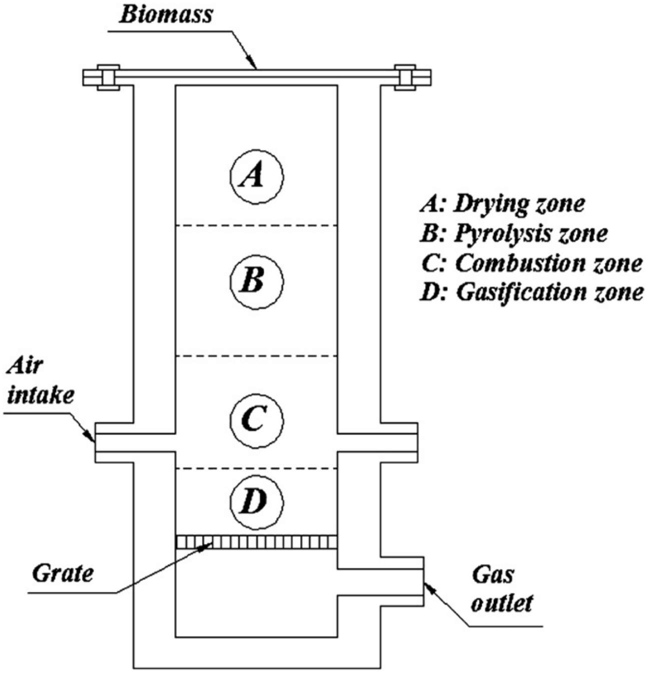

Fig. 2. Conventional downdraft gasifier.