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Syngas production from air-steam gasification of biomass with natural catalysts

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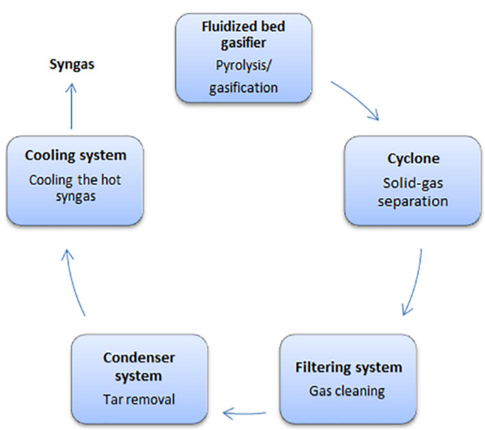
HIGHLIGHTS

- High quality gas can be obtained through catalytic gasification of biomass.
- The dolomite was more successful for tar destruction compared with olivine.
- The particle size has a weak influence on gasifier performance.

GRAPHICAL ABSTRACT



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ABSTRACT

Biomass has a great potential for production of syngas and chemicals; however, it has stood in the shadow of natural gas (NG) and coal due to technical problems and issues such as tar formation. In this paper, syngas production from catalytic air–steam gasification of biomass in a fluidized bed was investigated. To enhance the yield of produced syngas and reduce its tar content by cracking, limestone, calcined dolomite, and olivine were used as catalyst. The maximum mole fraction of H_2 was found to be 49.1 vol% at 1000 °C and a steam/biomass ratio (S/B) of 1.0 with dolomite present. Compared to olivine and dolomite, calcined dolomite was proved to be more effective for gas production and tar destruction. The results also showed that the particle size has a weak influence on gasifier performance, with only a slight decrease in tar content with decreasing biomass particle size.

1. Introduction

As biomass is a CO_2 neutral resource and considering the global economic crisis and environmental considerations, biomass use is now becoming attractive (Alauddin et al., 2010; Duan et al., 2018). Biomass gasification is recently receiving growing attention due to the reduced

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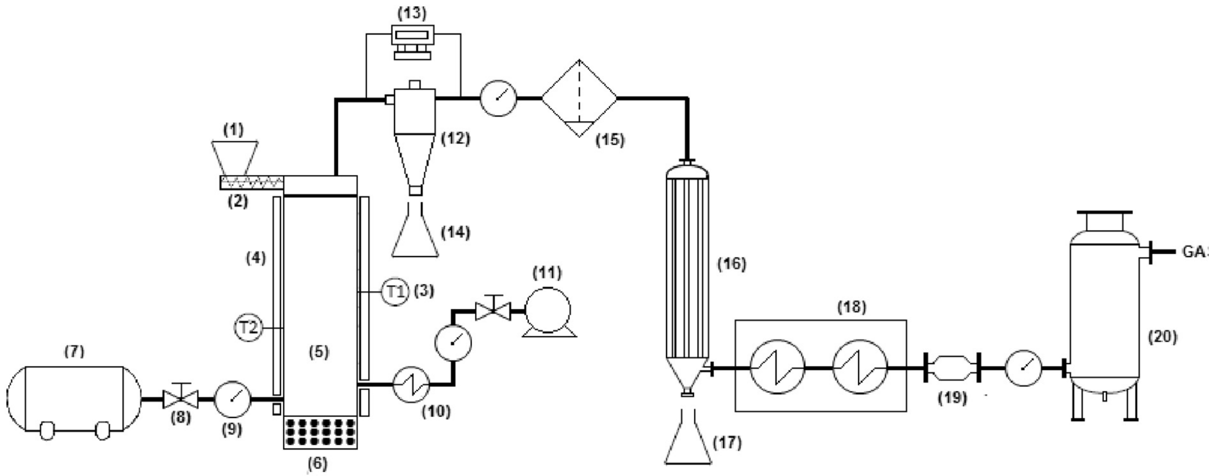

Fig. 1. A schematic diagram of fluidized bed gasification system. (1) Biomass hopper; (2) screw feeder; (3) thermocouple; (4) heater; (5) gasifier; (6) silica sand; (7) steam generator; (8) valve; (9) flowmeter; (10) heat exchanger; (11) air compressor; (12) cyclone; (13) temperature controller (14) solid storage tank; (15) filtering system; (16) condenser; (17) tar storage tank; (18) cooling system; (19) pressure release; (20) gas bag.

greenhouse gas emissions and economic benefits. Biomass is not only a renewable resource for producing a high quality syngas but is also more economical than other carbon-based fuels (Duan et al., 2015). The produced syngas can play a major role in producing several industrial products, such as hydrogen gas (Sharma and Sheth, 2016), Dimethyl ether (DME) (Semelsberger et al., 2006), Fischer–Tropsch liquids (Zhou et al., 2006), bio-methanol (Kempegowda et al., 2012) and bio-ethanol (Chang et al., 2012). Currently, syngas is generated from fossil fuels, including natural gas and naphtha. However, there is a great potential for production of chemicals from syngas after further processing (Chiaramonti et al., 2007).

As mentioned earlier, biomass has a great potential for producing syngas and chemicals; however, it has stood in the shadow of natural gas and coal due to tar formation. Tars can cause several operational problems such as blockage of pipelines and filters leading to unacceptable levels of maintenance costs for gasification set up. Tars can be cracked or removed by several ways consisting of (i) physical (non-catalytic) methods by collection and disposal of tars, (ii) catalytic tar conversion using Ni-based and alkali/alkaline catalysts (Wu et al., 2011); and (iii) co-gasification of biomass and coal which improves the endothermic nature of reactions involved. It should be noted that catalytic gasification is significantly more popular than that of co-gasification because of its high tar conversion activity, which produces high yields of hydrogen gas (Waheed and Williams, 2013).

Several scientific studies have been carried out using catalytic gasification for higher yield of syngas and tar destruction. Sutton et al. (2001) reviewed nine groups of catalysts that have a great potential for tar destruction and syngas production. Based on their observations, the authors summarized the advantage and disadvantage of various catalysts. Baratieri et al. (2010) used different kinds of calcined dolomite catalysts for tar destruction and char conversion in an atmospheric fluidized bed gasification system. They concluded that a high ratio of H_2/CO ranging between 700 and 800 °C can be obtained from birch wood in the presence of dolomite catalyst which is suitable for bio-methanol production. Corella et al. (2004) used two natural catalysts in biomass air-gasification to improve the percentage of syngas and decrease its tar content by cracking and reforming of condensable fractions. The authors found that dolomite is 1.4 times more active than olivine in biomass gasification. Courson et al. (2000) developed a Ni/olivine [$(Mg_{0.92}Fe_{0.08})_2SiO_4$] catalyst for the higher tar cracking and conversion of char to useful syngas (H_2, CO and CH_4). They concluded that the catalyst shows a high activity in dry reforming (95% CH_4 conversion) and steam reforming (88% CH_4 conversion). Zhang et al. (2017) evaluated the reactivity of dolomite, limestone and NiO/dolomite during steam gasification of biomass. The highest hydrogen yield (510 cm^3/g) was achieved with 2 wt% NiO/dolomite. Husmann et al. (2016) compared the different CaO-based H_2S sorbents (dolomite and limestone) in a bubbling fluidized bed. A significant difference (20%) was observed for converting limestone to CaS in fully calcined dolomite as compared to other CaO-based H_2S sorbents. Andrés et al. (2011) reported that the dolomite and alumina are more active for tar reduction compared to olivine. They also showed that olivine is more attractive due to the advantage of high attrition resistance compared to dolomite. Soomro et al. (2018) showed that the Ni-based catalysts are much more active than natural catalysts, but they can be deactivated at higher temperatures.

Therefore, it can be easily recognized that few studies referred to biomass gasification in the presence of dolomite, olivine, and lime. Hence, further catalytic studies are needed in this direction. Thus, this study aimed to compare the catalytic properties of calcined dolomite with those of olivine in tar reduction and syngas production during biomass gasification. Moreover, the effect of operating conditions on gas composition and tar content in the gas steam was studied in the study.

2. Apparatus and procedures

The gasification system shown in Fig. 1 consists of five main parts: (i) a gasifier (OD 120 mm and height 610 mm); (ii) a cyclone; (iii) a cleaning system; (iv) a fuel feeding system; and (v) a cooling system. Three sizes ranging from 5 mm, 3–4 mm, and 2–3 mm were used for tests. The gasifier was made of stainless steel pipe with a thickness of 7.5 mm and was indirectly heated by two 2 kW electrical heaters with a heating rate of 10 °C/min to reaction temperature (800–1000 °C). The gasification process carried out in a fluidized bed where a blend of air and steam was used as the gasification agent and pumped into the gasifier below the feeding system. At the beginning of the process, 25 g silica sand as the bed material was added to the gasifier, which

Table 1
Elemental composition and metal analysis of biomass (*Enteromorpha intestinalis*), wt% (on dry basis).

Elemental composition		Metal analysis	
C	35.2	Al	0.1
H	5.3	Fe	0.3
N	1.4	Ca	0.7
S	1.1	Mg	0.4
Ash content at 510 °C	23.8	Na	3.1
Ash content at 750 °C	16.1	K	2.8