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Mitigation of Bridging Problem in Biomass Gasification by a Novel Approach

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ABSTRACT

The downward flow of the feedstock in the gasification process of fixed bed gasifiers is dictated by the force of gravity. However, in case of low density feedstock, such as agricultural crop straws, softwood chips, rice husk, etc., the flow is adversely affected by bridging and as a consequence the stability and results of the process can be hampered. In this study, a novel method is introduced for solving the problem of bridging in oil palm fronds gasification process. For the process of gasification single throat downdraft gasifier was used. In the experiment, after feeding the gasifier with 9 kg of oil palm fronds, 4 kg of 7 metal scraps were placed on top of the feedstock in order to increase the weight and enhance the downward flow. By applying metal scraps the problem of bridging was solved and stable gasification process was obtained. As a result of stable operation of the process, the percentage of combustible components of the syngas was improved. CO was increased from 15.4 to 22.8, CH_4 from 1.7 to 1.9 and H_2 from 8.4 to 9.6 in volume percentage. In addition, higher heating value was increased from 3.7 to 4.8 MJ Nm^{-3} and equivalent ratio was decreased from 0.29 to 0.27. The average oxidation temperature in the oxidation zone was also improved from 623 to 828°C.

Key words: Bridging, gasification, fixed bed gasifier, oil palm fronds, syngas, gasification temperature, bulk density

INTRODUCTION

Bridging is of one of the major problems of gasification process when fixed bed gasifiers are used for the process. Particularly, throated downdraft gasifiers are severely suffered with bridging problem due to the presence of the throat in the internal chamber of the gasifier (Chopra and Jain, 2007; Kumar *et al*., 2008; Guangul *et al*., 2011). As the downward flow of fixed bed gasifiers is dictated by the force of gravity, the feedstock that could be used for the process of gasification needs to have sufficient bulk density to overcome the frictional resistance and flow in the downward direction. Therefore, lower density feedstock like rice husk, cotton stalk, wheat straw, soft wood chips, etc., usually encounter bridging problem in downdraft gasification process. Bridging creates unstable and inefficient gasification process (Akay and Jordan, 2011). Particularly, if the gasifier operates in a stationary and rigidly fixed position and has no shaking mechanism, the only possible method to overcome bridging is by stirring and pressing the feedstock using long rod after opening the gasifier. Opening of the gasifier during operation can cause an abrupt drop of the gasification temperature which would have an adverse effect on the syngas quality (Stevens, 2001). The problem of bridging may also be worsened when the throat tapper angle is large enough to cause higher downward flow resistance due to high friction force between the feedstock and the wall of the gasifier (Ummadisingu *et al*., 2010). In the current gasification setup care was taken during the design and fabrication stage of the gasifier to reduce frictional resistance in the flow of the feedstock in the throat area.

Usually bridging is created above the combustion zone and as a result the combustion and reduction zone will face feedstock starvation (Ummadisingu *et al*., 2010). Hence, the air supplied into the gasifier becomes higher than the optimum equivalent ratio. Consequently, higher CO_2 and N_2 are produced in the process instead of other combustible gases. This problem will affect the continuous and smooth operation of downstream equipment which uses the syngas as a fuel (Chopra and Jain, 2007).

To solve bridging problem there are different mechanisms in use. These mechanisms can be employed in the design stage of gasifiers, during preparation of the feedstock, or during the process of gasification. Incorporating shaking mechanism in the design and fabrication stage is one option to solve the problem (Ummadisingu *et al*., 2010). In this case the feedstock can be agitated periodically or when the problem encountered during the gasification process using the built-in shaker without opening the gasifier. The second method is by increasing the bulk density of the feedstock by pelletizing and briquetting. These techniques have also additional benefits like reducing the moisture amount, attaining uniform quality, ease the handling of the feedstock, etc., (Grover and Mishra, 1996; Ahmad, 2004; Nayak *et al*., 2012). However, briquetting and pelletizing incur additional costs in the preparation of the feedstock. The other option is agitating and pressing the feedstock by using long rod after opening the gasifier during the gasification process. This action disrupts the gasification process and as a consequence the syngas output quality will be affected adversely (Grover and Mishra, 1996; Chopra and Jain, 2007).

In this study, a novel approach is introduced to solve the problem of bridging in fixed bed gasifiers. In the investigation pieces of steel metal scraps were used to solve the bridging problem by putting them on the top of the feedstock after feeding the gasifier. The scraps help the feedstock to facilitate the downward flow due to the pressure created on the feedstock by the weight of the scraps. The method improved bridging problem and as a result the syngas composition and stability of the process were improved.

MATERIALS AND METHODS

Material: In this experiment, Oil Palm Fronds (OPF) were used as a feedstock. The OPF was collected at Felcra Classic oil palm plantation in Bota Kanan, Perak, Malaysia. Leaves were shredded and the petioles were chopped to a maximum size of 25 mm using chopper as shown in Fig. 1. The chopped feedstock was kept for 20 days in the lab to be dried to a moisture content of 15 to 17% on dry basis.

Proximate analysis was done to determine the moisture content, volatile matter, ash and fixed carbon using Pyris 1 TGA analyzer. For the ultimate analysis Leco CHNS-932 analyzer was used and content of carbon, hydrogen, nitrogen and sulphur were determined. For calorific value C5000 KIA bomb calorimeter was used and gross calorific value was determined. The basic characteristics of OPF are shown in Table 1.

Experimental set-up: The experimental set-up consists of the gasifier, air heater, steam boiler, blower, thermocouples, flow measuring instruments, gas cooling and cleaning systems and gas

Table 1: Basic characteristics of OPF

Characteristics	Values
Proximate analysis (% dry basis)	
Volatile matter	83.50
Fixed carbon	15.20
Ash	1.30
Ultimate analysis (% dry basis)	
Carbon	44.58
Hydrogen	4.53
Oxygen	48.80
Nitrogen	0.71
Sulphur	0.07

Higher heating value (HHV) 17.28 MJ kg^{-1}, Moisture content (dry basis) 15-17%

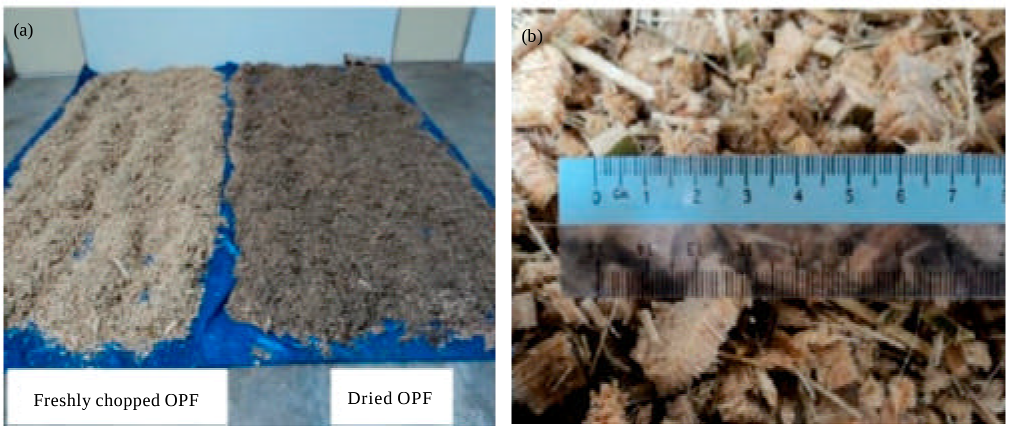

Fig. 1: Oil palm fronds (a) Un chopped and (b) Chopped

analyzer as shown in Fig. 2. For analyzing the syngas, X-Stream X2GP (Emerson) gas analyzer was used. In this experiment, only unheated air was used to study the effects of using metal scraps in the process on the improvements of bridging and syngas quality.

Experimental procedure: Before the gasification process started seven thermocouples were fixed in different positions and 9 kg of OPF feedstock was added. The experiments were done with and without metal scraps. On top of the OPF feedstock 7 metal scraps, shown in Fig. 3, with 4 kg of total weight were placed. The metal scraps served to increase the weight so that the feedstock can flow smoothly in downward direction as the lower part was consumed. The gas analyzer and the gas cooling and cleaning system were connected to the power supply to worm up for 40 min before it was connected to the sample gas line to measure the gas composition. To start ignition scrap paper and ignition lighter were used and ignition was started through the ignition starting hole. After starting the ignition, the opening was closed and air was supplied by the blower through the air inlet pipe and flow rate was adjusted and controlled by a rotameter and a valve. The temperature profile data was recorded in every 30 sec using a data logger and computer. For the gas composition study, sample gas was tapped from the syngas outlet pipe and the composition of the syngas was recorded manually on the gas analyzer display in two minutes interval. The remaining syngas was flared at the flare points. After the feedstock was consumed, the process was stopped by stopping

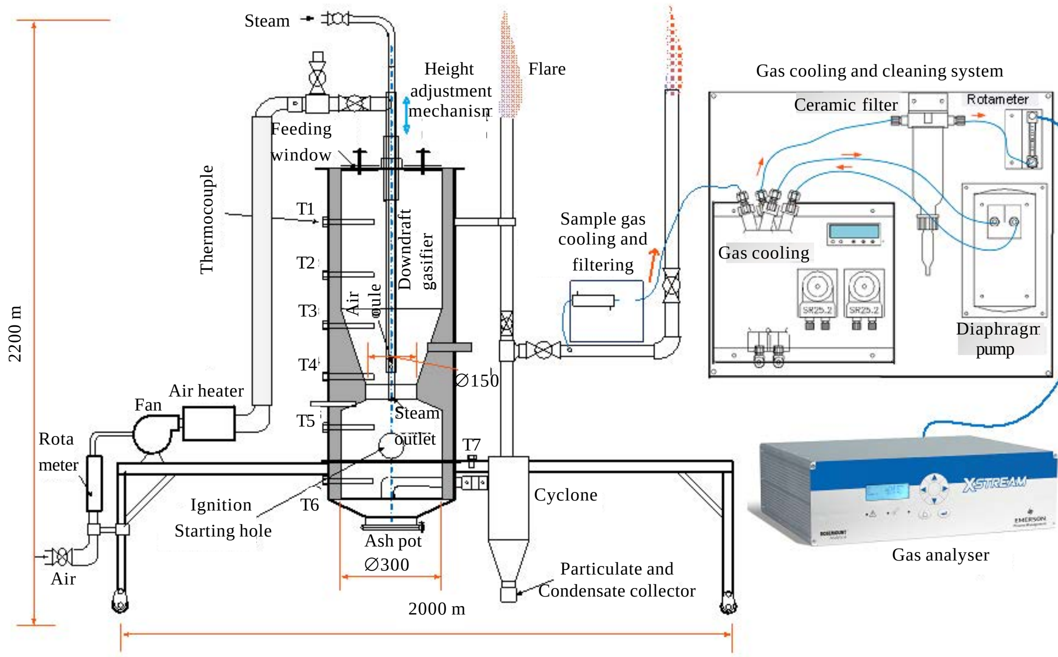

Fig. 2: Experimental set-up design

Fig. 3: Metal scraps

the blower. The tar and condensate were collected and volume measurement was taken. In addition, the char and ash were collected from the ash box and from the grate and weight measurement was taken. The scrap metals were also collected on the grate and kept for reuse to the next process.

RESULTS AND DISCUSSION

Figure 4a and b show temperature profile of the gasification processes without and with the application of metal scraps. As shown in Fig. 4, the temperature profile of (a) is unstable compared

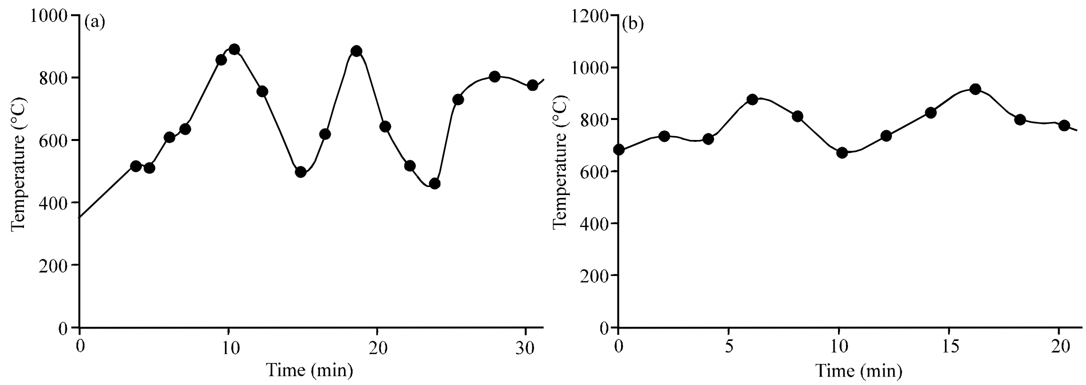

Fig. 4: Effect of time on change in oxidation zone temperature (a) Without and (b) With metal scraps

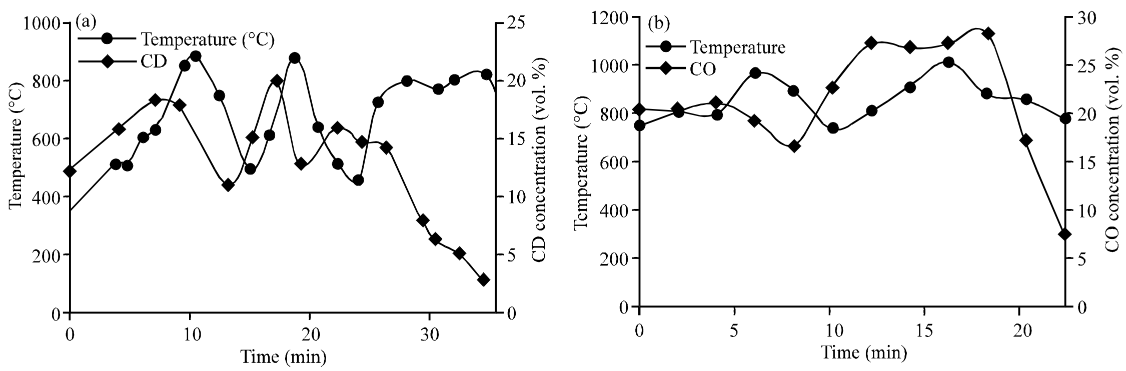

Fig. 5: Change in CO concentration and temperature (a) Without and (b) With metal scraps, with respect to time

to (b). In case of Fig. 4a, metal scraps were not applied and the process encountered sever bridging problem. The gasifier top lids were opened two times, at 10 and 18 min and the feedstock was stirred up and pushed with long iron bar to facilitate the downward flow. The fluctuation of the temperature indicated on the graph was caused by the opening of the gasifier top lids. When the gasifier was opened for the second time the oxidation zone temperature was dropped below 470°C. The maximum oxidation zone temperature recorded was about 870°C at the 10th min. A similar temperature fluctuation trend was observed in Fig. 4b, even though the fluctuation range was lesser. The minimum and maximum oxidation temperature recorded was 720 and 989°C. In the second gasification process, which was done by applying metal scraps, the process had continued without the need of opening the top lids of the gasifier and without noticeable gas composition fluctuation. Figure 5 to 8 show the effect of temperature fluctuation on compositions of syngas. The improvement on the syngas output by applying the metal scraps is also shown in the figures. In Fig. 5a, the fluctuation of the temperature and CO output have similar trend. But in the trend CO gas preceded the temperature fluctuation which seems in the reversed order as temperature has an effect on the composition output gas. The probable reason could be as the bridging problem occurred, the temperature in the oxidation zone raised due to increased equivalence ratio and as a result the amount of combustible gases started to drop. As shown in Fig. 5a and b, the fluctuation of CO was improved when metal scraps were used in the process. The average value of CO was improved from 15.4 to 22.78% by volume when metal scraps were applied, as shown in Table 2.

Table 2: Comparison of average outputs of oil palm fronds gasification with and without using metal scraps

	Without metal scraps	With metal scraps
CO (% volume)	15.400	22.80
CO_2 (% volume)	14.800	11.20
CH_4 (% volume)	1.700	1.90
H_2 (% volume)	8.400	9.60
Higher heating value (MJ Nm^{-3})	3.700	4.90
Combustion zone temperature (°C)	623.000	828.00
Equivalent ratio	0.290	0.27

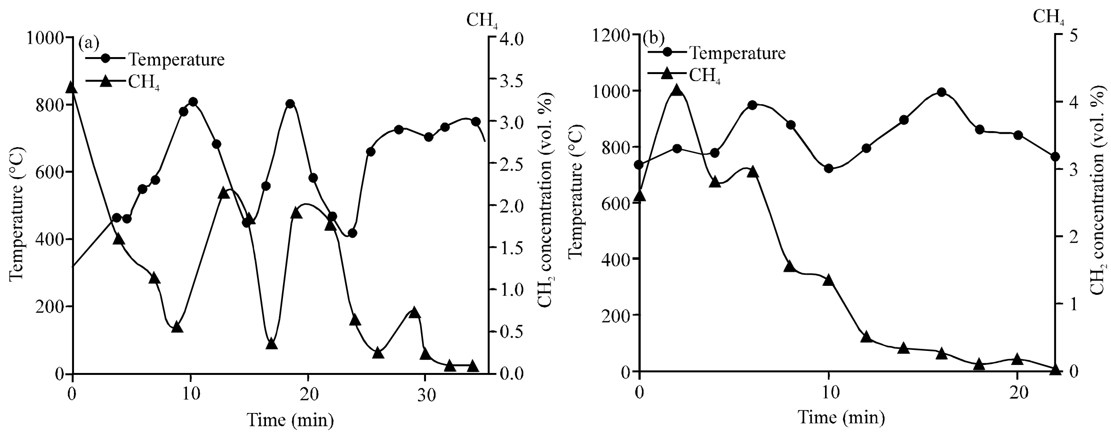

Fig. 6: Effect of time on temperature and CH_4 concentration (a) Without and (b) With metal scraps

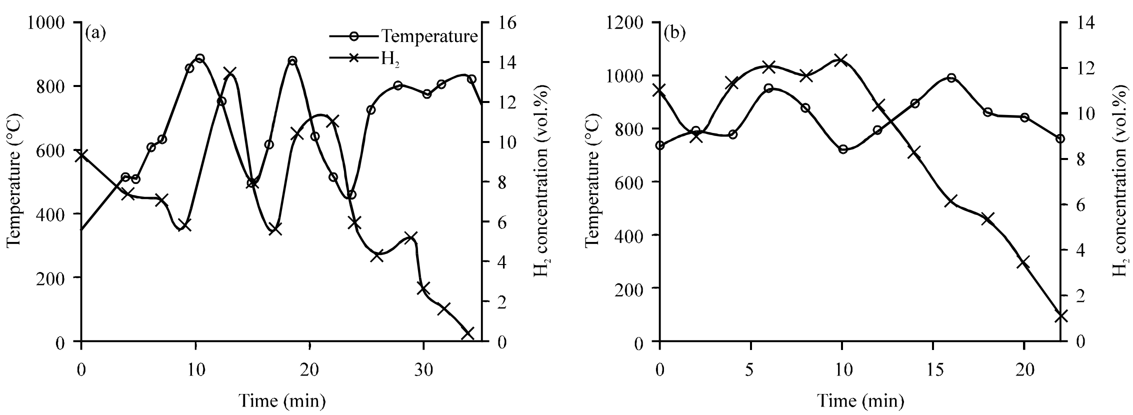

Fig. 7: Effect of time on temperature and H_2 concentration (a) Without and (b) With metal scraps

Figure 6a and 7a show similar trends of CH_4 and H_2 as CO showed in Fig. 5a. As shown in Fig. 7b the output gases CH_4 and H_2 have stable and better outputs compared to Fig. 6a and 7a. The average concentration of CH_4 and H_2 were improved from 1.7 and 8.4 to 1.9 and 9.6, respectively when metal scraps were applied in the process. In case of Higher Heating Value (HHV), as shown in Fig. 8, stable and better result was obtained when metal scraps were applied in the process.

The Higher Heating Value (HHV) and combustion zone temperature were also improved from 3.7 to 4.9 MJ Nm^{-3} and from 623 to 828°C, respectively when metal scraps were applied. In

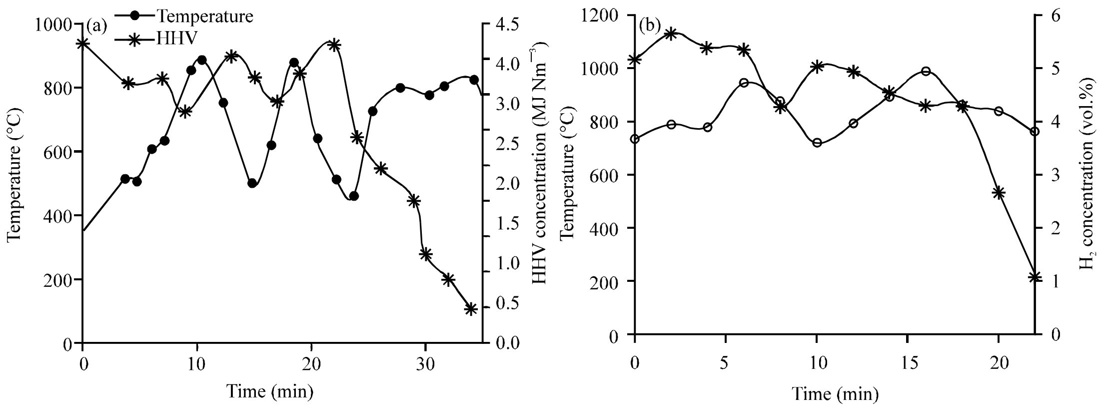

Fig. 8: Effect of time on temperature and HHV with time (a) Without and (b) With metal scraps

addition, the equivalent ratio was reduced from 0.29 to 0.27. As the ultimate aim of gasification process is producing syngas and utilizing it for power generation or for chemical synthesis, continuous and smooth supply of syngas to the downstream system is crucial (Higman and Burgt, 2008; Basu, 2010). Besides, achieving better results in the composition of the syngas, improving the stability of the gasification process in fixed bed gasifiers using the current method enables the downstream systems to function without interruption.

CONCLUSIONS

In the current study, a new approach for solving bridging problem in a single throat downdraft gasifier was investigated. For the study seven metal scraps with a total weight of 4 kg was used and put on the top of the feedstock to increase the weight and facilitate the downward flow of the feedstock. As a result, bridging problem was solved and the stability of the process was improved. The syngas quality, such as higher heating value and the average gasification temperature in the oxidation zone were improved. CO showed improvement from 15.4 to 22.8, CH_4 from 1.7 to 1.9 and H_2 from 8.4 to 9.6% in volume composition. Higher heating value and average oxidation temperature were also improved from 3.8 to 4.9 MJ Nm^{-3} and from 623 to 828°C, respectively. In addition, the method will help for realizing stable and continuous operation of the downstream equipments, like internal combustion engines, boilers, etc., by supplying continuous syngas from the process.

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