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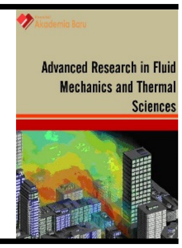

Development of Mini Pilot Fluidized Bed Gasifier for Industrial Approach: Preliminary Study Based on Continuous Operation

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ABSTRACT

A small pilot scale of bubbling fluidized bed gasifier was designed and fabricated. The diameter of reactor (D) is 20 cm and the total height of the reactor from the bottom end of the cone to the top is 160 cm. The feedstock used was palm kernel cake which the size range of 1-10 mm. The mass feeding rate of feedstock was fixed at 0.05 kg/min, and flow rate of air was varied according to Equivalent Ratio (ER) at 0.03, 0.06, 0.19, 0.31, 0.49, 1.17, 1.43 and 2.64, respectively. In the first phase of this work is to focus on continuous gasification operation that expected approximately for 8 hours without shut down or malfunction. Based on the result obtained in this study, it was found that the ER which can be provided for continuous operation was 0.19≥ER≥1.17. For the syngas production study at the ER of 0.06 and 1.43 could not run continuously. Moreover, the gasification run at ER=0.03 and 2.64 was found that the syngas production was incombustible.

1. Introduction

Gasification is the thermochemical conversion of solid fuel into the fuel gas which contains mainly hydrogen, carbon monoxide, carbon dioxide, methane and nitrogen. The product gas from the reactor also contains some contaminants like char particle, ash and some higher hydrocarbons or tar [1, 2]. A limited supply of oxygen, air, steam or a combination of these serves as gasifying agent. The gasification consists of four different steps e.g. drying, pyrolysis or devolatilization, combustion or oxidation and gasification or reduction.

Several types of gasifier reactors are currently available: fixed bed, fluidized bed and entrained flow as shown in Figure 1 - 3. For the selection, it depends on technology, heat load, the types of materials, the use of energy, environment and economy. Fixed bed, which includes of up-draft, down-draft and cross-draft, is classical type of gasifier; however, these types have limitations for using of non-uniform fuel size and variation of thermal loads. Recently, fluidized bed reactor, that can

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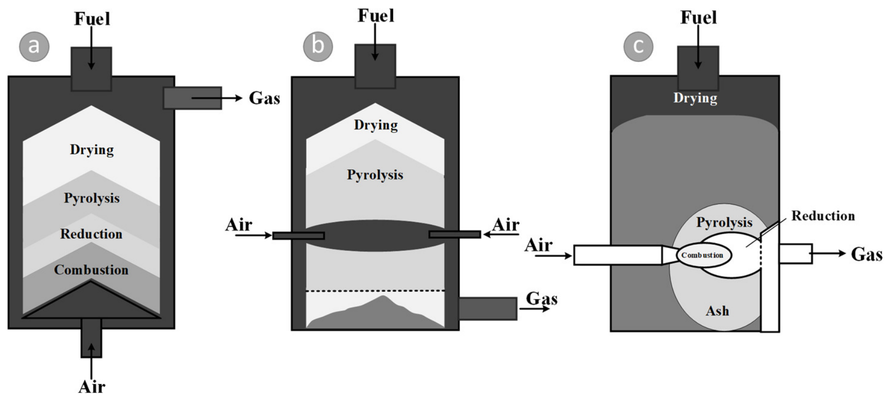
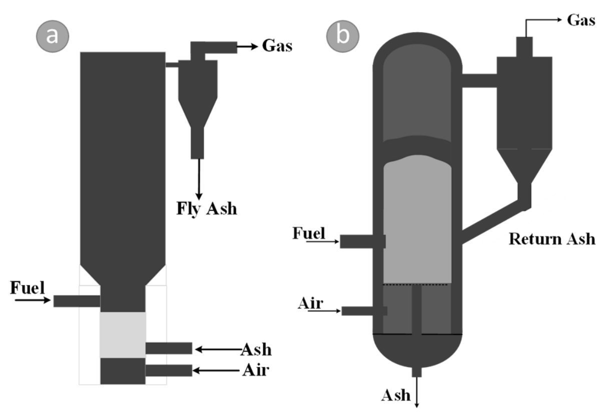
combust fine solid fuels having non-uniform size, is applied in thermal industries, especially in medium power plant. The comparison of fixed bed and fluidized bed reactors was summarized by Warnecke [3], He reported that the advantage of fluidized bed can be designed in the wider range of feedstock and operating conditions. Therefore, fluidized bed gasifier is the main concern in this work.



(a) Updraft (b) Downdraft (c) Cross-draft

Fig. 1. Several types of Fixed bed gasifier reactors



(a) bubbling fluidized bed (b) Circulating fluidized bed

Fig. 2. Several types of Fluidized bed gasifier reactors

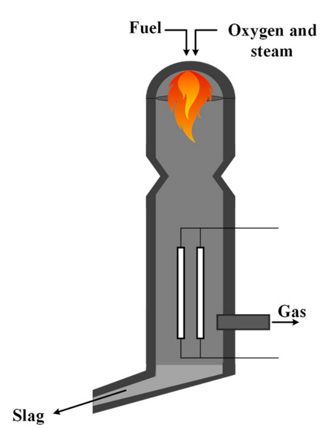


Fig. 3. Several types of Entrained bed gasifier reactors

From previous works, the investigations of regarding fluidized bed gasifier have been done in laboratory scale reactor that used electrical heater as heat sources due to simplify for controlling of temperature operation [4-7]. In fact, the heat source of an industrial gasifier is from internal combustion in the reactor, and flammable syngas is also from concentration of combustible production. In order to design of continuous operation, there are several parameters that need to be specifically investigated such as reactor geometries, the size range of solid fuel and operating conditions such as the air flow rates and feedstock feeding rate. A few works have reported the operating conditions of fluidized bed gasifier using pine sawdust [8], rice husk [9] and lignite [10] as feedstock.

Narváez *et al.,* [8] was successful to fabricate and operate a pilot scale of bubbling fluidized bed gasifier using fine feedstock as pipe sawdust. They suggested that the operating conditions for having high gas yield was the equivalence ration in the range of 0.2-0.45, reaction temperature in the range of 750-850 ^{o}C.

Ramírez *et al.,* [9] designed the pilot scale of 70-kW fluidized bed gasifier using rice husk as feedstock. The diameter and the height of reactor were 0.3 m and 3 m, respectively. The outcomes in this work should be beneficial for preliminary prediction of the equivalence ratio, low heating value, volumetric yield, gas power and cold efficiency obtained in the experimental gasification.

Recently in 2017, Herdel *et al.,* [10] reported the circulating fluidized bed gasifier that was designed to use in an industrial scale for 0.5-MW power plant in Germany. This work presents the success of the first operation and experiences gained within the commissioning of the pilot plant using pre-dried lignite as feedstock. Seven days of steady operation at different feed rates were accomplished with no gasifier shut down or malfunction.

One of an important consideration for applying fluidized bed gasifier in industries is continuous operation without shut down or malfunction as applied in power plant by Herdel *et al.,* [10]. The system of loading feedstock and removing char or ash from the reactor must be sequential operation.

In this study, the main objective is to design and fabricate a small pilot scale gasifier that expected produced 30 kW of power using bubbling fluidized bed gasification system. In the first phase of this work is to focus on continuous operation that was expected running about for 8 hours without shut down or malfunction.

2. Methodology

2.1 Gasifier System

The diagram of experimental setup is shown in Figure 4, and the photo of the setup is shown in Figure 5. The diameter of reactor (D) is 20 cm and the total height of the reactor from the bottom end of the cone to the top is 160 cm. The Double air inlet pipe with inner diameter of 46.8 mm was assembled tangentially to the bottom of the reactor, it was designed by using commercial CFD software, ANSYS Ver. 15.0 (Fluent) in our work [11]. A cyclone was assembled at the top of reactor to separate particles from the syngas before leaving. The blower accelerated the air which flow through the calibrated orifice flow meter. The flow rate of air jet was controlled by adjusting rotating speed of blower with an inverter.

The feedstock of palm kernel cake which is in the range size of 1-10 mm, was fed by a screw conveyor into the gasifier reactor. The mass feeding rate of feedstock was controlled by adjusting rotating speed of driving motor. The ignition port was opened for direct burning the internal, palm kernel cake using gasoline. During internal, palm kernel cake burning, the flow rate of air was decelerated to maintain a condition of syngas producing. The gas leaving from the cyclone is suddenly burned, which can be visually observed combustible gas product.

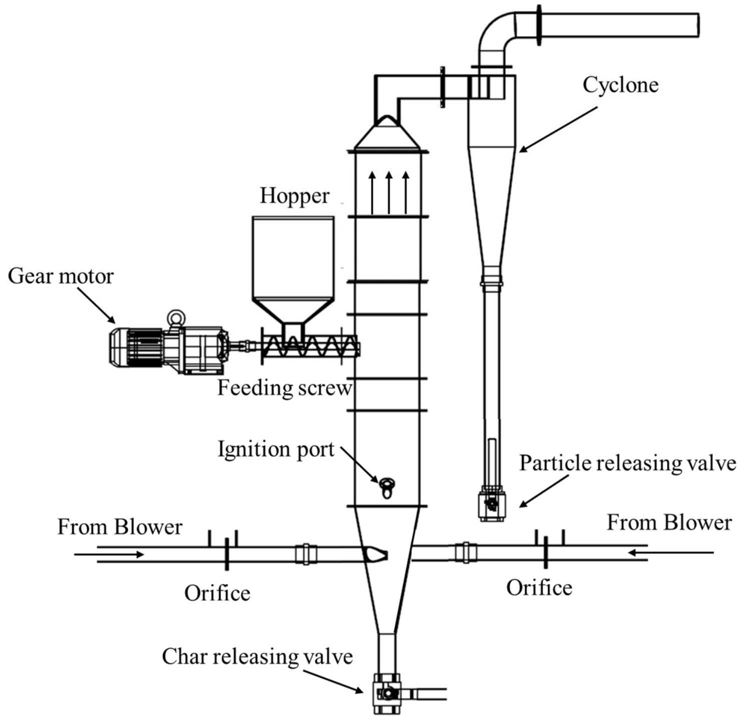


Fig. 4. Schematic diagram of mini pilot fluidized-bed gasifier system

Fig. 5. The photo of mini pilot fluidized-bed gasifier system

Type-K thermocouples were located along the center of the reactor to measure gas temperature at several positions of the reactor. In order to reduce heat loss, the reactor was insulated using high temperature insulator (KAOWOOL, ASK-7912-H 8P Blanket 1,400 ^{o}C). During operating, accumulated particles in the cyclone and accumulated char in the bottom of the reactor were periodically removed.

2.2 Properties of Feedstock

The Feedstock types are palm kernel cake (Figure 6) which was taken from palm oil milling factory, Songkhla, Thailand. The size of feedstock was in the range size of 1-10 mm, approximately. The properties of feedstock, which were evaluated by using CHNS/0-2000 and MACEO TGA at Scientific Equipment Center, Prince of Songkhla University, are shown in table 1.

Fig. 6. The photo of feedstock from palm kernel cake

Table 1
Properties of feed stock

Parameter	Unit	Evaluated	Value
Carbon (As received basic)	% wt.	CHNS/0 Analyzer	47.0111
Hydrogen (As received basic)	% wt.	CHNS/0 Analyzer	6.2030
Nitrogen (As received basic)	% wt.	CHNS/0 Analyzer	1.1716
Oxygen (As received basic)	% wt.	CHNS/0 Analyzer	39.1761
Sulfur (As dried basic)	% wt.	CHNS/0 Analyzer	0.1636
Moisture content (As received basic)	% wt.	ASTM D7582	6.12
Fixed carbon (As received basic)	% wt.	ASTM D7582	17.67
Volatile matter (As received basic)	% wt.	ASTM D7582	70.61
Ash (As received basic)	% wt.	ASTM D7582	5.60

2.3 Experimental Parameters

In order to observe a continuous operation of the system, the mass feeding rate of feedstock was fixed at 0.05 kg/min, and flow rate of air was varied according to Equivalent Ratio (ER) at 0.03, 0.06, 0.19, 0.31, 0.49, 1.17, 1.43 and 2.64. The ER is defined as the ratio of the actual F/A divided by the stoichiometric F/A [12] where F and A were the amount of fuel and air in a reaction, respectively.

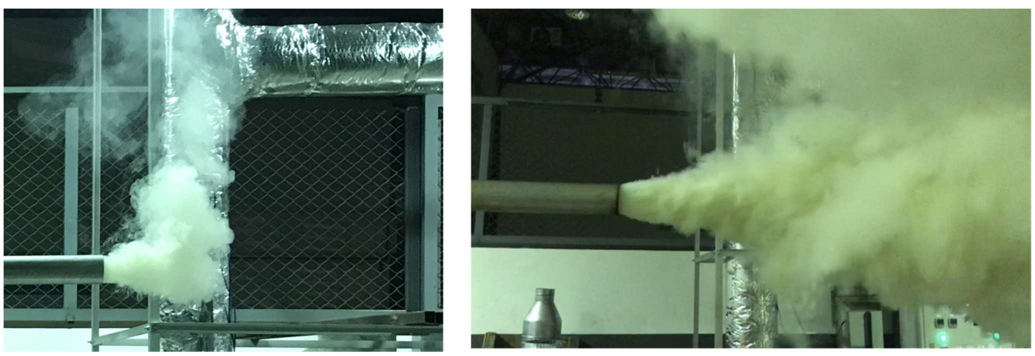
The ratio can be written on a molar basis (moles of air divided by moles of fuel) or on a mass basis (mass of air divided by mass of fuel) [13].

3. Results and Discussions

3.1 Visual Syngas and Flame

Syngas discharging from pipe outlet is shown in Figure 7. It shows that the incombustible gas (Figure 7(a)) is white which can be attributed low combustible syngas properties as carbon dioxide (CO_2) carbon monoxide (CO), methane (CH_4), hydrogen (H_2) [14]. It is contrast to the case of combustible gas (Figure 7(b)) which is yellow-orange and have higher combustible syngas properties as compared to the case of Figure 7(a). Noted that this is first phase of the work. The properties of syngas are not determined yet. Low or high combustible syngas properties was identified from continuous combustion syngas that will be discussed in next section.

The visual flame from different Equivalent Ratios (ER) is shown in Figure 8. The visual flame which can provide 8 hours continuous syngas combustion is in the range of 0.19≥ER≥1.17. It can be seen that the flames become stronger when ER was smaller (amount of air is larger); but not exceed ER=0.19. This is from direct effect of increasing amount of air in the reaction. In addition, the flame temperature from syngas measured using IR camera is shown in Figure 9. It is show that the highest of the flame was approximately 400°C.



(a) Incombustible gas (b) Combustible gas

Fig. 7. Comparison of syngas from small fluidized-bed gasifier

(a) ER= 1.17 (b) ER=0.49 (c) ER=0.31 (b) ER=0.19

(less amount of air → large amount of air)

Fig. 8. Photos of flam from variant Equivalent Ratio (ER)

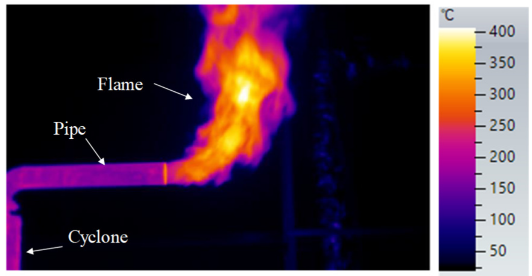


Fig. 9. Flam temperature from syngas measured using IR camera (ER=0.31)

3.1 Continuous Operation

Effect of equivalent ratio on continuous operation of pilot gasifier system is shown in Table 2. Here, the definition of continuous operation is consistency of combustible syngas which can be visually observed the flame (Figure 8) without shut down or malfunction of the system. The results show that the range of ER which can be provided for continuous operation was 0.19≥ER≥1.17. The syngas combustion for the higher or lower ER range than afore mentioned ER as ER=0.06 and 1.43 was not continuous. Moreover, the syngas at ER=0.03 and 2.64 was found incombustible.

At ER=1.43, the syngas in this case was combustible, but the combustion is not consistency. This is from low concentration of combustible properties of syngas due to low amount of air in the interaction. Vice versa, at ER=0.06, amount of air is larger resulting in partially-completed combustion which case to decrease combustible syngas properties. Moreover, the syngas of ER=0.06 and 2.64 can't be combusted due to having very low combustible syngas properties.

Table 2
Effect of equivalent ratio on continuous operation (8 Hrs.)

Equivalent Ratio (ER)	*operation*
2.64	*No burning*
1.43	*discontinuous*
1.17	*continuous*
0.49	*continuous*
0.31	*continuous*
0.19	*continuous*
0.06	*discontinuous*
0.03	*No burning*

3.2 Temperature in the Reactor

The variation temperatures at the center of the reactor are shown in figure 10. It shows that the temperatures at the 30 cm (point 1) from the reference point were the highest due to interaction zone. The range of temperature, around 900 – 1,300ºC, was almost higher than the combustion temperature in the fluidized-bed gasifier which was reported in the literature [15-17]. The variation temperatures in the reactor can be categorized by 2 groups: (1) large amount of air (ER=0.19 and 0.31) and less amount of air (ER=0.49 and 1.17). The temperature at the reaction zone (point 1) for the case of large amount of air was higher than that of less amount of air. However, the temperature in the rage of 85 – 150 cm (point 3 - 6) for the case of large amount of air was lower than that of less amount of air.

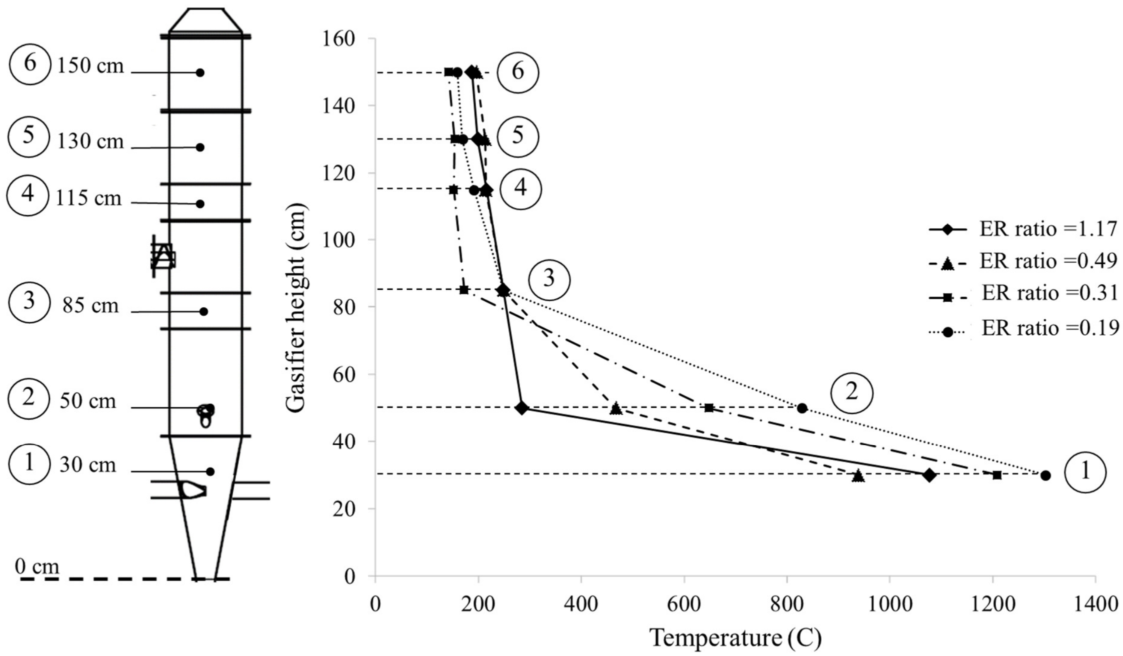


Fig. 10. Variations of temptation at the center of reactor

4. Conclusions

A mini pilot scale of bubbling fluidized bed gasifier was successfully designed and fabricated. In the first phase of this work is to focus on continuous operation that was expected approximately run for 8 hours without shut down or malfunction. This study shows that the range of ER which can be provided for continuous operation was 0.19≥ER≥1.17. The syngas combustion for the higher ER (1.43) or lower ER (0.19) than that of 0.19≥ER≥1.17 was not giving run gasification process continuously. Moreover, the syngas at ER=0.03 and 2.64 was also found incombustible process.

Acknowledgement
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References
[1] Basu, Prabir. *Combustion and gasification in fluidized beds*. CRC press, 2006.
[2] Basu, Prabir. *Biomass gasification and pyrolysis: practical design and theory*. Academic press, 2010.
[3] Warnecke, Ragnar. "Gasification of biomass: comparison of fixed bed and fluidized bed gasifier." *Biomass and bioenergy*18, no. 6 (2000): 489-497.
[4] Matsuoka, Koichi, Daisuke Kajiwara, Koji Kuramoto, Atul Sharma, and Yoshizo Suzuki. "Factors affecting steam gasification rate of low rank coal char in a pressurized fluidized bed." *Fuel Processing Technology* 90, no. 7-8 (2009): 895-900.
[5] Loha, Chanchal, Himadri Chattopadhyay, and Pradip K. Chatterjee. "Thermodynamic analysis of hydrogen rich synthetic gas generation from fluidized bed gasification of rice husk." *Energy* 36, no. 7 (2011): 4063-4071.
[6] Karimipour, Shayan, Regan Gerspacher, Rajender Gupta, and Raymond J. Spiteri. "Study of factors affecting syngas quality and their interactions in fluidized bed gasification of lignite coal." *Fuel* 103 (2013): 308-320.

[7] Azargohar, Ramin, Regan Gerspacher, Ajay K. Dalai, and Ding-Yu Peng. "Co-gasification of petroleum coke with lignite coal using fluidized bed gasifier." *Fuel Processing Technology*134 (2015): 310-316.

[8] Narvaez, Ian, Alberto Orio, Maria P. Aznar, and Jose Corella. "Biomass gasification with air in an atmospheric bubbling fluidized bed. Effect of six operational variables on the quality of the produced raw gas." *Industrial & Engineering Chemistry Research* 35, no. 7 (1996): 2110-2120.

[9] Ramirez, J. J., J. D. Martinez, and S. L. Petro. "Basic design of a fluidized bed gasifier for rice husk on a pilot scale." *Latin American applied research* 37, no. 4 (2007): 299-306.

[10] Herdel, Philipp, David Krause, Jens Peters, Brigga Kolmorgen, Jochen Ströhle, and Bernd Epple. "Experimental investigations in a demonstration plant for fluidized bed gasification of multiple feedstock's in 0.5 MWth scale." *Fuel*205 (2017): 286-296.

[11] Suksuwan, W., Wae-hayee, M., Mel, M., "*The Effect of Single and Double Air Inlets on Swirling Flow in the Reactor of a Fluidized Bed Gasifier*." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 44 (2018): 157-166.

[12] Sergio C. (2014), Chapter 10 - *Introduction to biomass energy conversion*, Taylor & Francis Group.LLC, Page 365-367.

[13] Michael, J., Howard, N., Daisie, D.,and Margaret, B. (2011), Chapter 13 - *FUNDAMENTALS OF ENGINEERING THERMODYNAMICS seventh edition*, John Willey & Sons.Lnc, Page 779-781

[14] Jared, P. and John, J.(2002). "*Benchmarking Biomass Gasification Technologies for Fuels*", Chemicals and Hydrogen Production. U.S. Department of Energy National Energy Technology Laboratory.

[15] Borhan, A. (2013), Chapter 4 - *Design of a gas-solid fluidized bed reactor at hight temperature and hight pressure*",Borhan Abdelgawad.Page 97-105.

[16] Ajmal, l. (1999), Chapter 3 - *A study of the design fluidized bed reactors for biomass gasification*, London University of London. Page 19-26.

[17] Xiao, Rui, Baosheng Jin, Hongcang Zhou, Zhaoping Zhong, and Mingyao Zhang. "Air gasification of polypropylene plastic waste in fluidized bed gasifier." *Energy Conversion and Management* 48, no. 3 (2007): 778-786.