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EI-05-032

EFFECT OF FLUIDIZATION RATIO ON THE PERFORMANCE OF AN INTERNALLY CIRCULATING AERATED FLUIDIZED BED GASIFIER WITH CONCENTRIC CYLINDERS

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ABSTRACT : Effects of fluidization ratio (R_Q) on the bed temperature, composition and heating value (HV) of producer gas (PG) during gasification of sawdust in an internally circulating aerated fluidized bed gasifier (ICAFBG) based on the indirect heating principle with concentric cylinders were studied. R_Q which is the ratio of aeration rate in annulus (Q_{an}) to the fluidization rate in the draft tube (Q_{dt}) strongly affect the ICAFBG performance as it is a driving force to transport the char from gasification to the combustion zones. The char combustion in the combustor (draft tube) is the heat provider to the gasification process in the gasification zone (annulus). The results showed that by increasing R_Q resulting in increased bed material temperature, PG composition and HV. However, increase R_Q further caused temperature reduction as well as PG composition and HV. The HV could be increased from 4.52 to 6.98 MJ/m^3 in the R_Q ranges from 0.14 to 0.43. However, by increasing R_Q further to 0.57 caused reduction in HV to 5.61 MJ/m^3. The highest bed temperature which can be achieved was 806 ^{o}C at 0.43of R_Q.
Keywords: Sawdust gasification, Internally circulating aerated fluidized bed gasifier. Bed material circulation

I. INTRODUCTION

An internally circulating aerated fluidized bedgasifier (ICAFBG) is an indirect heated gasification process, where the energy required is provided from a combustion zone through bed material circulation due to direct contact between the combustion and yrolysis zones. The advantage of this reactor toICFB is that the combustion zone operates in the vigorous bubbling regime with restricted aeration in the pyrolysis zone.Biomass is directly fed into the pyrolysis zone, whilst the char (pyrolysis product) moves into the combustion zone.The term aeration is used to describe the fluidization regime in the pyrolysis zone[26]. The basic principle of ICAFB is shown in Fig. 1.

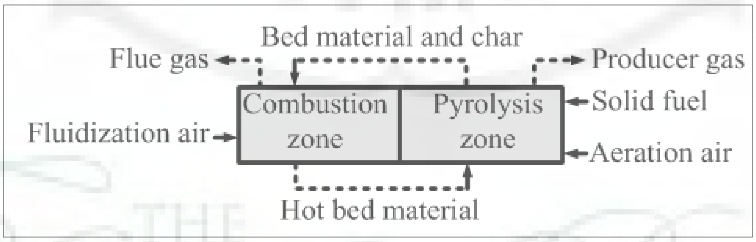


Fig. 1. Principle of ICAFB.

In this work the ICAFB pyrolyzer is constructed of two concentric cylinders. The inner cylinder (draft tube)acts as a combustion zone or heat generator providing heat to the annulusthat acts as a pyrolysis zone. Aeration in the annulus is needed to ensurethe circulation of the bed particlesbetween the annulus and the draft tubeand to purge the pyrolysis gaseous product from the annulus.Solid circulation rate (G_s) between the annulus and the draft tube is an important parameter to determine the overall performance of the ICAFB system. The novelty is in using an ER far below common gasification and a possible increase in the heating value. Restricted aeration in the pyrolysis zone causesa lowER. Therefore the main objective of this study is to evaluate the effect of ER on the operating temperature stabilization, composition and heating value of the producer gas.

II. METHODOLOGY

2.1. System Setup

The ICAFB pyrolyzer with a total height of 1.1m consists of two parts: an annulus (pyrolysis zone)with a diameter of 0.3 m and adraft tube (combustion zone)with a height of0.32 m and diameter of 0.1m.The two zones are connected via orifices at the lower section of the draft tube to enable the solids to move from the annulus to the draft tube. Eight equally spaced 0.02m diameter holes were drilled in the wall of the draft tube, 0.08m above its base.The ICAFB systemis shown in Fig. 2.

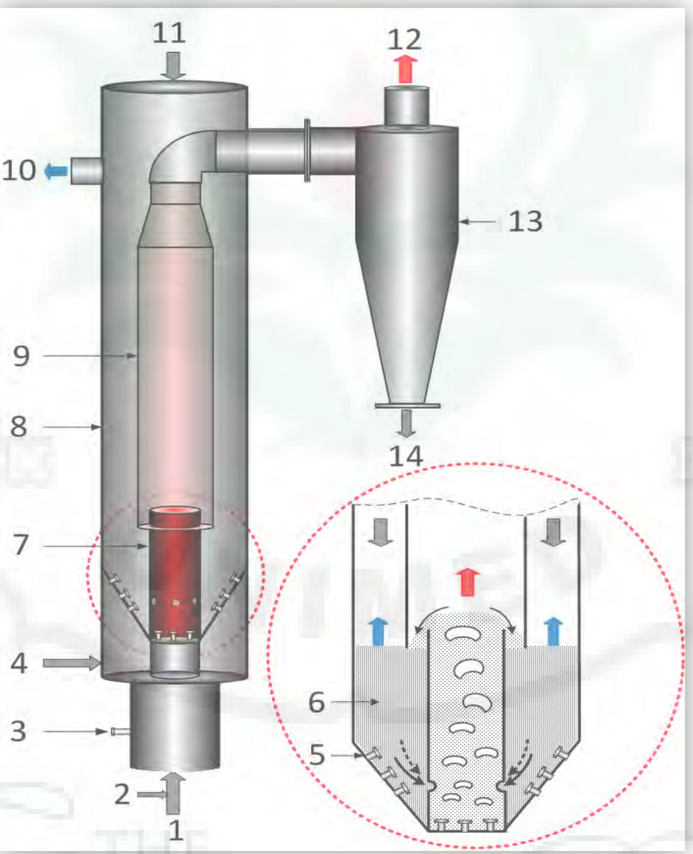


Fig. 2. Schematic diagram of the ICAFBG.

The biomass (sawdust) is fed directly to the annulusfrom the top of the reactor. Char,a byproduct of the pyrolysis process and the bed material moves toward the draft tube via the orifice. A dipleg is installed to separate the flue gas and the producer gas. The bed material overflow from the top of the draft tube to the annulus and the flue gas passes through the dipleg and enters the cyclone separator. The axial temperature in the bedwasmeasured using three K–type thermocouples mounted along the bed height from the distributor. The air chamber comprises of two plenums to separately supply fluidization air into the draft tube (Q_{dt}) and aeration air into the annulus (Q_{an}). The draft tube air supply consists of a distributor plate with seven bubble caps, whilst the annulus has a 60° conical base with 18 bubble caps.

Sawdust is fed from the top of the reactor through a screw feeder connected to a sawdust hopper. Since sawdust pyrolysis takes place in the annulus, sawdust is fed from the top of the reactor to provide a longer residence time before the sawdust becomes char and enters the combustor. A cyclone (0.20 m i.d. and0.43 m high) is installed at the outlet of the draft tube. Since no solid elutriation occurs at the annulus, a cyclone separator is not installed at the exit. The effects of equivalence ratio (ER) on the temperature system stabilization, composition, and heating value of producer gas at constant fluidization ratio ($R_Q = Q_{an}/Q_{dt}$) were studied.The ER was adjusted by controlling the feed rate of sawdust in the annulus (W_f). The R_Q used according to the optimum value of G_s obtained from experimental hydrodynamic test.

2.2. Material and preparations

2.2.1. Bed material

The bed material is sand,witha mean particle size of 425–600 mm anda density of 1520 kg/m^3, belonging to Geldart Group B particles. The static bed height in the annulus and the draft tubewere maintained at 0.28m. The bed was fluidized with air provided from a blower. The pressure drop across the draft tube is measured by a digital manometer through two pressure tappings, one at the disengaging zone and the other before the air distribution plate.Different air flow rate was performed in the draft tube and the annulus to induce circulation of the bed material between the draft tube and the annulus. $Q_{dt}$is set 350 Lpm, which is about 2.33 times of the minimum fluidization flow rate (Q_{mf} = 150 Lpm), while the $Q_{an}$is set to33%, 66%, 100% and 133% of the Q_{mf}.$G_s$is an important parameter for heat transfer and to control the pyrolysis zone temperature. Measurement of G_s was carried out experimentally using hydrodynamic studies. The solid circulation rate was determinedby collecting solids emerging from the top of the draft tube for a known interval of time and weighing to obtainthe circulation rate.

2.2.2. Biomass material

Biomass material issawdust obtained from local Malaysian rubber wood furniture home industries. Size distribution, ultimate and proximate analysis of the sawdust are presented in Tables 1 and 2 respectively.

Table 1. Size distribution of sawdust.

Size (mm)	Weight (%)
S>1.7-2.0	2.24
1.17-1.70	2.60
0.6-1.17	76.40
0.5-0.6	5.32
0.425-0.5	3.64
0.3-0.425	5.20

S<0.3	4.6
Sum	100.00

Table 2. Ultimate and proximate analysis of sawdust.

Ultimate analysis, wt.% (air dry basis)	
C	50.54
H	7.08
O	41.11
N	0.15
S	0.57
Proximate analysis, wt.% (air dry basis)	
Volatiles	82.29
Fixed carbon	17.16
Moisture	8.0
Ash	0.55
Heating value (dry basis)	
Low heating value (MJ/kg)	15.00

The sawdust feeding system consists of a hopper and a screw feeder with a variable speed drive (VSD). The screw feeder was calibrated to determine the sawdust load capacity or feed rate (W_f) through the feeding system.The average sawdust flow rate is plotted against the screw feeder operating frequency as shown in Fig. 3.

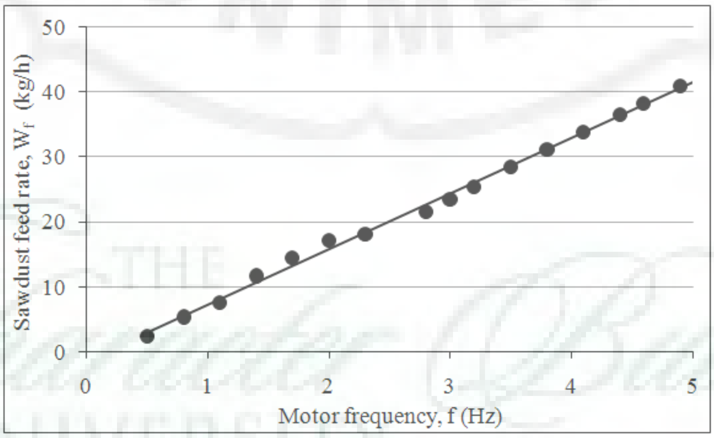


Fig. 3. Screw feeder calibration.

2.3. Start–up method

An important aspect of the operation of ICAFB pyrolyzer is the start–up process. The combustor was initiallyheated, using liquid petroleum gas (LPG). At the startof the experiment, air was supplied to the draft tube at 200 Lpm with LPG at 20 Lpm. The air and LPG mixture was ignited using a spark plug. The hot gas fluidizes the sand and increases the bed temperature. Temperatures at the annulus and the draft tube were recordedusing type K thermocouples. A thermocouple was also installed at the air–LPG combustor chamber to detect combustion during start–up process.

The difference between the annulus and the draft tube air flow rates promotes solid circulation from the two zones through the connecting orifices. Circulation of the bed material from the draft tube to the annulus providesheat transfer from the combustion zone to the pyrolysis zone.When the bed temperature in the annulusreached 400 ^{o}C (Tc–2),sawdust was fed into the annulus. The sawdust starts to pyrolyze and converts into volatiles and char. The char together with sand move under gravity, flow into the draft tube and are burnt to produce heat with excess air. When the temperature of draft tube reached 650–700^{o}C (Tc–1), the LPG was switched–off and the experimental parameter was setup to the desired value based on R_Q and ER. The heat produced by the char combustion in the draft tube further increases the temperature to the desired level. After 40 minutes at which timethe pyrolyzer operation reached a steady state, gas samples were collected.Temperatures at various points of the system, theaeration, and the fluidization air flow were recorded and controlled.

2.4. Producer gas sampling and analysis

The producer gas was collected using a gas sampling train that removes any moisture and particulates. The gas composition was determined using TCD gas chromatograph equipped with Carboxene 1000 (Supelco, USA) column (15 ft x 1/8 in, 80/100 mesh).

III. RESULTS AND DISCUSSION

a. *Effect of R_Q on draft tube and annulus bed temperature*

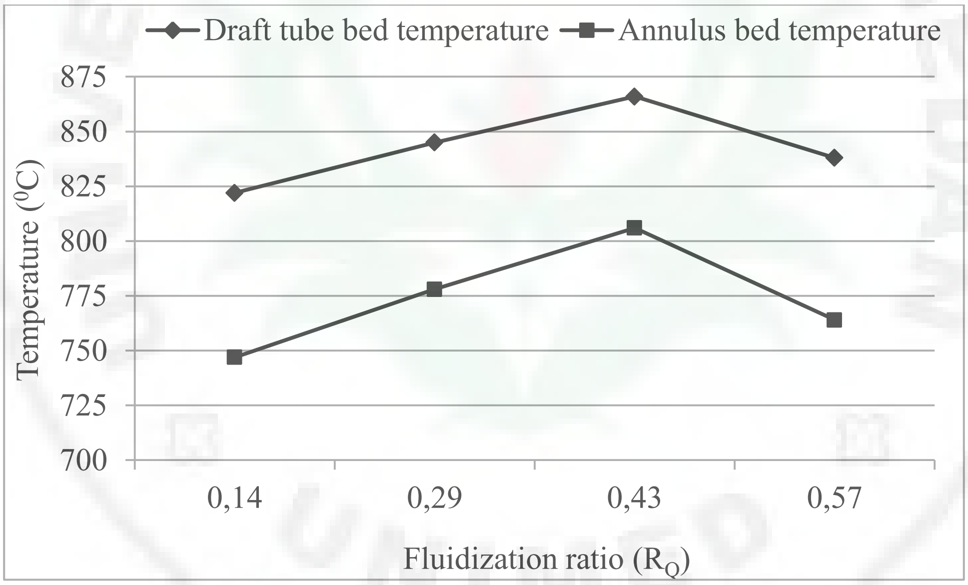
Bed temperature affects the chemical reactions in the pyrolysis process. In this work, the operating temperature is controlled by adjusting the ER based on R_Q and W_f. The range of ER used in this work was 0.047 to 0.075 which considerably lower than the normal range of ER for fluidized bed gasifier (0.20–0.40).[11]. However, in the ICAFB a low (ER<0.1) could be used, because the most important parameter is G_s, which is highly dependent on Q_{an}.Fig. 6 illustrates the effect of ER on the operating temperatures of the draft tube (Tc–1) and the annulus (Tc–2). The increase intemperature with ER is wellunderstood because ER increases withR_Q.By increasing $R_Q$at a constant W_f, ER increases as well as $G_s$and thus the amount of char released from the annulusto the draft tube also increases.

Increasing char formation in the annulus increases its flow into the draft tube resulting in higher heat production during the combustion process. But there is an optimum limit that should not be exceeded else it would lead to two effects: 1. The temperature inside the annulus becomes uncontrollable or overheats; 2. Char accumulates in the annulus because gas production is not balanced with feeding, resulting in an impaired pyrolysis process.

Increasing R_Q further leads to an increase in ER, but decrease in G_s. This causes the whole temperature to decrease.It wasfound that for Q_{dt}either below or above 350 Lpm, the temperature ofthe whole system gradually decreases. Below 350 Lpm, $G_s$is low and causes insufficient char transfer to the draft tube for heat generation. Above 350 Lpm however the fluidization regime become vigorous, causing some of the char to elutriate from the draft tube, and thus reducing heatgeneration during combustion. Therefore $Q_{dt}$is maintained constant at 350 Lpm for all tests.

In this study, the pyrolysis operating temperatures that can be achieved were in the range 725–800 °C. This temperature range is categorized in the intermediate temperature pyrolysis where the major product is gas [27, 28]. This temperatureis sufficient for char reaction with reactive gases such as O_2, H_2 and CO_2.

From Fig. 6, the highest combustion temperature was found to beapproximately866°C. This is an important issue in the design of fluidized bed combustor, because typical fluidized bed furnaces operateat 800–900°C to avoid fouling and NO_x[29]. However, high combustion temperature(900–1100 °C) contribute to better combustion efficiency where carbon fines are burnt completely before they escape from the combustor through the cyclone.



3.2. Effect of R_Q on PG composition

ERhas a strong effect on all chemical reactions in the pyrolysisprocess. Fig. 7shows the variation in the producer gascomposition from the annulus with respect to ER. Fig. 7 indicatesthe optimum operating conditionat an ER of 0.051 producing gas compositions of 3.13%, 25.8%, 8.2%, 17.39% and 41.21% for H_2, CO, CH_4, $CO_2$and N_2respectively. Carbon monoxide and methane are the largest constituents of the producer gas, and are much higher than typically found from air–blown gasificationas described in Table 3.

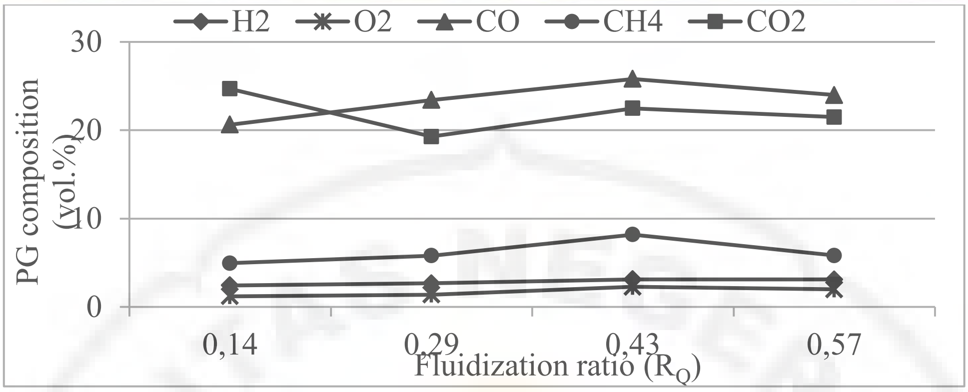


Fig. 7. Producer gas composition.

Table 3. Comparison of producer gas produced by air-blown ICAFB.

Ref	Fuel constituent (vol.%)					HV (MJ/m^3)
	H_2	CO	CH_4	CO_2	N_2	
[4]	16	10	-	30	-	3.90
[5]	7.5	27	3.5	7.5	-	5.7
[6]	14.61	25.71	2.45	12	-	6.67
[7]	9.5	18	4.5	13.5	-	6.3
[8]	19.5	17.5	2.5	13.75	-	5.88
[9]	9.27	9.25	4.21	13.28	-	5
[10]	7	16	3	18	-	5
[*]	3.13	25.80	8.20	17.39	41.21	6.96

[*] Current work

By increasing the ER the CO content increases, attributed to the Boudouard and water gas reactions where the CO_2 present in the methane reforming reactions reacts with char to produce CO, and the high temperature of the bed particles facilitates this reaction. The CO concentration of the producer gas markedly increases from 20.64% to 25.80% in the investigated ER range.

It was found that the highest concentration of H_2 was 3.13%. This is low compared to common air–blown sawdust gasification[4–10]. This is due to the effect of the pyrolysis reaction temperature.The composition of$H_2$is very dependent on the reaction temperature. A high pyrolysis temperature(800–1000 ^{o}C)favors the thermal cracking of the hydrocarbons in the gaseous products and thus sharply increases the yield of H_2 through Boudouard, water gas, methanation, and water gas shift reactions[30, 31]. However, in this study the pyrolysisreaction temperature is limited toa maximum of800°Cresulting in low H_2yield.

3.3 Effect of R_Q on PG composition

Fig. 8 shows the heating valueof the producer gas. The heating value increases with an increase in ER due to the increase in the percentages of CO and CH_4. The highest heating value of the producer gas was an average of 6.96 MJ/m^3.

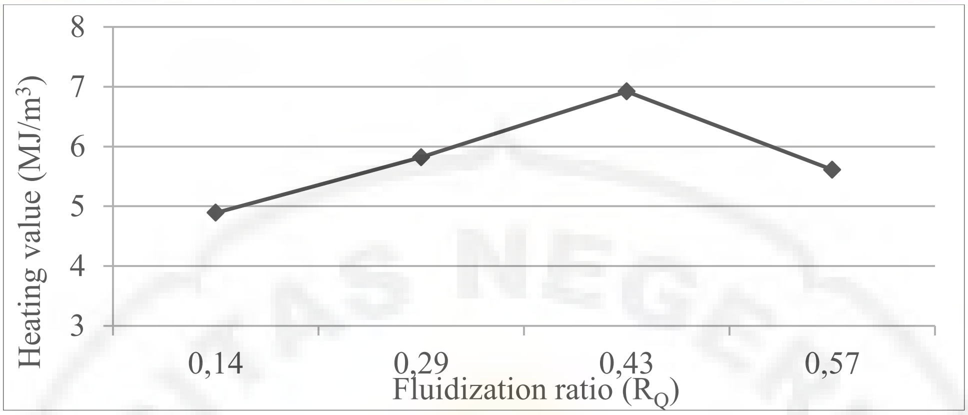


Fig. 8. Effect of equivalence ratio on heating value.

IV. CONCLUSIONS

A pilot–scale internally circulating aerated fluidized bed (ICAFB) pyrolyzerhas been successfully developed. The most important parameters in the ICAFB are the fluidization ratio (R_Q) that controls the solid circulation rate (G_s) and the ER in the pyrolysis zone. Circulation of the bed material from annulus to draft tube is the most important parameter and determines the heat transfer from the combustion zone to the pyrolysis zone. Fluidization ratio, R_Q is the key in solid circulation.

This study indicates that under the optimum operating conditionsat an ER of 0.051 and pyrolysis temperature of about 800°C, producer gas compositions of 3.13%, 25.8%, 8.2%, 17.39% and 41.21% for H_2, CO, CH_4, $CO_2$and N_2respectively with a heating value of about 6.96 MJ/m^3 was achieved. Significant amounts of carbon monoxide (CO) and methane (CH_4) were producedat an intermediate operating temperature of about 800 °C, where the reactions favor the production of CO and CH_4.

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