Down-draft Gasification of Biomass/Coal Blends

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Abstract

Over 80% of the world energy generated presently is by fossil fuels where petroleum oil contributes 41%. By the end of this century with the present rate of extraction, the petroleum resources will be depleted. Depletion of global fossil resources as well as increasing of fossil fuel prices with deteriorating of the environmental quality from energy generation become major global problems. Alternative energy should be found and developed through research and development of new energy resources to replace the non-renewable fossil fuels. A potential renewable energy, which could replace the fossil fuels, is biomass energy such as wood, agricultural residues, municipal solid waste and forest residues. The largest biomass source that is easily available in Malaysia is the oil palm *(Elaeis guineensis)* solid wastes.

In this research, oil palm shell and Sarawak coal have been used as raw feeding materials in a downdraft gasifier. Pressurized primary air was supplied to the gasifier to assist the gasification process. An air ejector and gas burner was attached at the outlet of the gasifier. The producer gas produced in the gasifier was induced out by a secondary compressed air, through an air ejector. The air-producer gas mixtures were re-burnt at a gas burner. An orifice cylinder with vane was coupled inside of the gas burner to enhance the mixing process of air-producer gas mixtures. Oil palm shell, Mukah-Balingian coal, and their blends were investigated as feedstocks in this work. Emissions produced at the outlet of gas burner with different orifice cylinders diameter were investigated. Suitable orifice cylinder was attached with a 40^{o} swirler to investigate the effect of emissions and combustion efficiency. Temperatures of various zones in gasifier and emissions produce at the outlet of the gas burner with the variation of sizes of orifice cylinders and fuel ratio were given and discussed at constant induced pressure condition.

1 Introduction

Gasification is one of the thermochemical processes, which can convert the biomass solid residues and coal to the valuable form of gaseous fuel known as producer gas. The producer gas contains carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2) and methane (CH_4). Mixed with air, the producer gas can be used in gasoline and diesel engines with little modifications. In a downdraft gasifier, the air is introduced in downward flow through packed bed of solid fuels and gas is drawn off at the bottom. Downdraft gasifier is suitable to run internal combustion engines and other thermal energy applications.

Gasification process generally uses reactants such as oxygen or steam to increase gas yields while consuming char. In the gasifier where solid fuels are gasified in the presence of sub-stoichiometric air, several chemical reactions occur. The downdraft gasification reactions and temperature zone are shown in Figure 1.

In the reduction zone, there is a surplus of solid fuel, carbon dioxide and water vapor from the combustible zone can be passed through the glowing layer of charcoal and are reduced to carbon monoxide (CO) and hydrogen (H_2) in the region known as the reduction zone. In the combustion zone, the reactions which are exothermic are:

$$C + O_2 \rightarrow CO_2 \quad (1)$$

$$2H_2 + O_2 \rightarrow 2H_2O \quad (2)$$

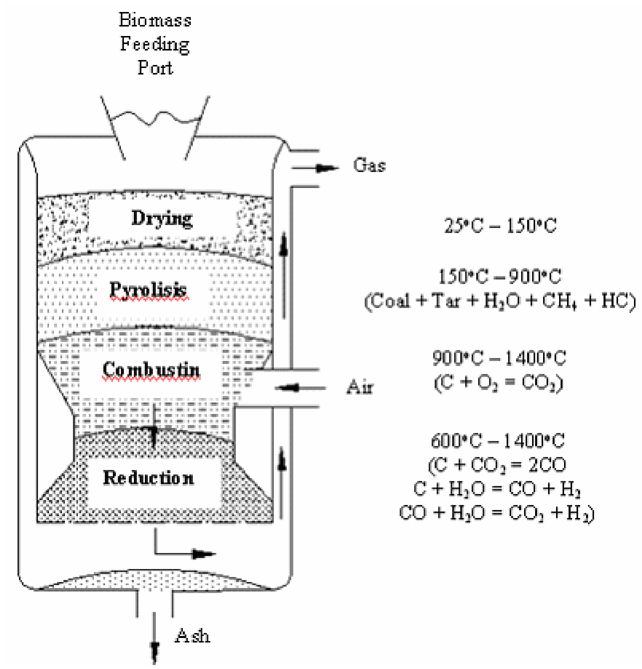

Figure 1: Downdraft gasification reactions and temperature zone

The reaction in the reduction zone which are endothermic, will decrease the temperature during the reduction process are :

$$C + CO_2 \rightarrow 2CO \quad (3)$$

$$C + H_20 \rightarrow CO + H_2 \quad (4)$$

$$C + 2H_2 \rightarrow CH_4 \quad (5)$$

$$CO + 3H_2O \rightarrow CH_4 + H_2O$$

$$C + 2H_2O \rightarrow CO_2 + H_2$$

$$CO + H_2O \rightarrow CO_2 + H_2 \quad (6)$$

Producer gas is therefore a mixture of the gaseous such as hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen (N_2), methane (CH_4), and small amount of other hydrocarbons. The combustible components of the gas are CO, H_2, CH_4 and C_xH_x, the percentages of which should be made as high as possible. The quantity of CO in the gas depends on the temperature in the reduction zone. To achieve complete reduction, the temperature in the reduction zone must be at least 1100 °C [1].

If water vapor is present, reaction (4) play an important role to enrich the gas with H_2 and thus enhance its heating value. However, if too much water is present, CO may react with H_2O to form CO_2 and H_2, as indicated by reaction (6) and the quantity of CO may be reduced.

In the present research, a downdraft gasifier has been used. Pressurized primary air was supplied to the gasifier to assist the gasification process. An air ejector and a gas burner were attached with the gasifier. Producer gas produced in the gasifier was induced out by the secondary compressed air at 2 bar, through the air ejector. The air-producer gas mixtures were re-burnt at the gas burner. Orifice cylinder and vane was coupled inside of the gas burner to enhance the mixing of air-producer gas mixtures.

Oil palm shell, Mukah-Balingian coal and the blend of both them were used as feedstocks in this work. Emissions produced from the combustion process at the gas burner with different orifice cylinders were investigated. Orifice cylinder produce the lowest emissions was attached with a 40° swirler to investigate the effect of emissions and combustion efficiency.

2 Experimental Set-up

2.1 Downdraft Gasifier, Air Ejecetor and Gas Burner

Downdraft gasifier as shown in Figure 2 was designed and fabricated on 1988 by Salim in Universiti Teknologi Malaysia, Skudai, Johor, Malaysia [2]. Capacity of the gasifier is 43,000 cm^3, but only half of it can be used to get the best possible gasification process. A layer of refractory material was covered around the bottom of the gasifier for high temperature insulation around 1000°C. There is also having a component called throat at combustion zone. The throat is function to increase the temperature concentration at combustion zone.

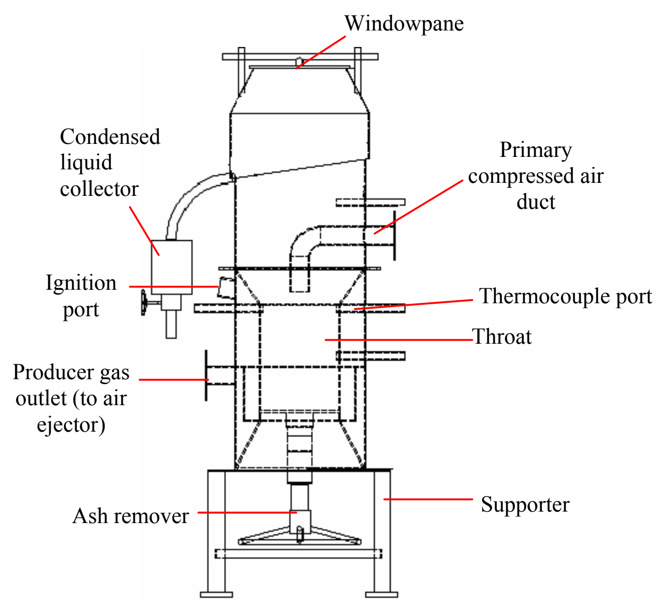

Figure 2: Downdraft gasifier

An air ejector as shown in Figure 3 is designed to supply secondary air to gas burner. The ejector also acts to induce producer gas from gasifier to the gas burner before its being burnt. An orifice cylinder was installed inside of gas burner to increase the air-producer gas mixing. The diameters of orifice cylinders are 80, 100 and 120 mm with same 30 mm length.

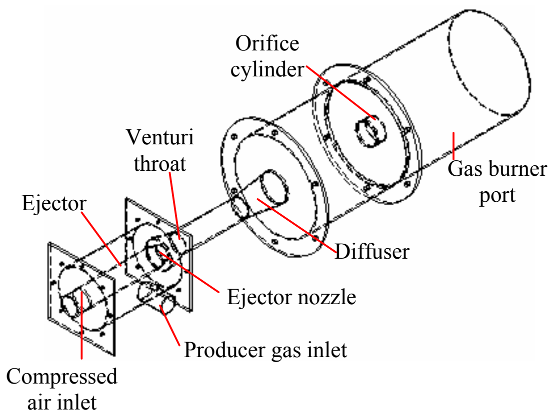

Figure 3: Gas burner and ejector

Gas burner without orifice cylinder is known as “GB”, gas burner with 80 mm orifice cylinder is known as “GB80”, gas burner with 100 mm orifice cylinder is known as “GB100”, gas burner with 120 mm orifice cylinder is known as “GB120”, and gas burner with orifice cylinder that produced the lowest emission and installed with 40^{o} vane is known as “GB80V”.

2.2 Experimental Procedures

Oil palm shell is obtained from Federal Land Development Authority (FELDA) Palm Oil Mills, Kulai, Johor, Malaysia while Mukah-Balingian coal is obtained from Genesis Forces Sdn. Bhd., Sarawak. Oil palm shell solid density and apparent density is 1.53 g/cm^3 and 1.47g/cm^3, respectively [3]. The proximate, ultimate analysis and calorific values oil palm shell [4] and Mukah-Balingian Coal [5] [6] are shown in Table 1.

Analysis	**Oil palm Shell**	**Mukah-Balingian Coal**
Proximate analysis (wt. %)		
Ash	2.50	2.13
Volatiles matter	77.20	35.81
Fixed carbon	20.30	50.60
Moisture (wt. % air dry)	8.40	11.46
Ultimate analysis (wt. %)		
Carbon	55.35	51.31
Hydrogen	6.27	5.60
Oxygen	38.01	43.09
Nitrogen	0.37	0.00
Calorific Value (MJ/kg)	19.56	23.50

Table 1: Proximate and ultimate analysis of oil palm shell

Air ejector, gas burner (without orifice cylinder), air compressor, thermocouples, gas analyzer, pressure regulator, and gas-torch were placed to the gasifier. 4 kg oil palm shell was put in gasifier and was ignited. Primary air at 0.75-1.25 bar was supplied to gasifier. When thick white smoke appeared, another 1 kg oil palm shells were added to the gasifier. When the smoke became thicker, 2 bar secondary air were supplied to gas burner through air ejector. The air-producer gas was ignited and flame appeared at gas burner.

The emissions, combustion efficiency and flame temperatures were determined by using gas analyzer. Then, the oil palm shell feed was replaced with Mukah-Balingian coal, followed by the blend of oil palm shell and Mukah-Balingian coal. An 80 mm orifice cylinder was installed to gas burner and same tests were done, followed by 100 mm and 120 mm orifice cylinders. Orifice cylinder produced the lowest emission was coupled with 40^{o} vane to see the different in emission produced.

3 Results and Discussions

Three results have been investigated which are temperature variation inside of gasifier, emissions produced at gas burner and the flame colour and shapes.

3.1 Temperature Variation

By using oil palm shell as feed, the temperatures produced inside of gasifier are in the range of 351-1342 K, where 351 K is at drying zone, 573 K is at pyrolisis zone, 1342 K is at combustion zone and 1120 K is at reduction zone. When Mukah-Balingian coal is used, the temperature changed to 329 K at drying zone, 436 K at pyrolisis zone, 1183 K at combustion zone and 981 K at reduction zone. The values are lower than temperatures based on oil palm shell as feed as shown in Figure 4. By using the blend of

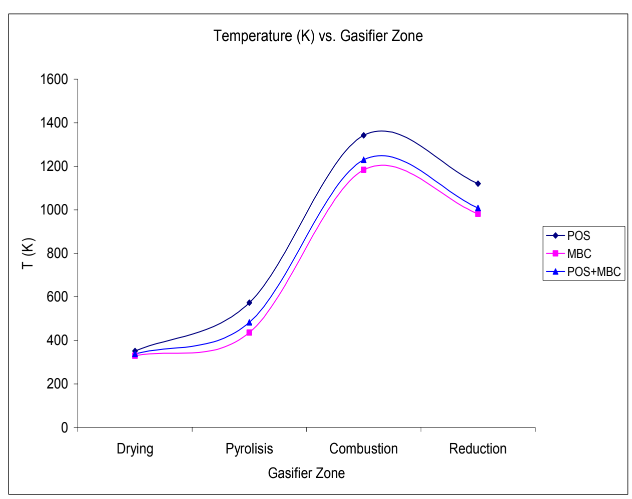

Figure 4: Temperature comparison for oil palm shell (POS), Mukah-Balingian coal (MBC) and the mixture of them (POS+MBC) as feed

oil palm shell and Mukah-Balingian coal as feed, the average temperatures inside of gasifier are 338 K at drying zone, 483 K at pyrolisis zone, 1230 K at combustion zone and 1008 K at reduction zone.

3.2 Emissions

Emission data contains NO_x (ppm), CO (ppm), percentage of CO_2, O_2 and excess air, flame temperature (K), and combustion efficiency (%). The NO_x value is high base on oil palm shell as feed. When Mukah-Balingian is used the NO_x was reduced. The blend of both fuel produced NO_x value in between of them. GB80V produced the lowest NO_x value for all fuel used, followed by GB80, GB100, GB120 and GB. The lowest NO_x value is 52 ppm, while the highest is 139 ppm as shown in Figure 5. CO produced is almost same with the NO_x profile as shown in Figure 6. The value is high based on oil palm shell feed, followed by the blend of oil palm shell and Mukah-Balingian coal, and the lowest is Mukah-Balingian coal. GB80V is also produced the lowest CO for all feed used, followed by GB80, GB100, GB120 and GB, while the highest and the lowest value is 258 ppm and 152 ppm.

CO_2 is increased when oil palm shell is changed to Mukah-Balingian coal feed, while GB80V produced the highest, followed by GB80, GB100, GB120 and GB as shown in Figure 7. The highest and the lowest value are 14.9 % and 12.2 % respectively. O_2 produced is contrasted with CO_2 profile as shown in Figure 8. Oil palm shell produced the highest with 8.7 % at GB, followed by the blend of oil palm shell and Mukah-Balingian coal. The lowest is Mukah-Balingian coal with 4.9 % at GB80V. Equivalent to O_2, percentage of excess air is also high base on oil palm shell fuel, and then decrease when the feed is changed to Mukah-Balingian coal. The value is high at GB for all feed base, with 19.5 % is the maximum. Minimum excess air is at occurred at GB80V, with 17.1 %, 15.5 % and 14.6 % base on oil palm shell, the blend of oil palm shell and Mukah-Balingian coal, and Mukah-Balingian coal, respectively, as shown in Figure 9.

Combustion efficiency is low base on oil palm shell as feed with 69 % for GB, 75.4 % for GB80, 72 % for GB100, 71.7 % for GB120, and 78.1 % for GB80V. This value is increase to 88.1 % for GB, 92.1 % for GB80, 91.7 % for GB100, 90.2 % for GB120, and 94.2 % for GB80V when the oil palm shell is changed to Mukah-Balingian coal. For the blend of them, the combustion efficiency is in between of them as shown in Figure 10. Flame temperature is almost equivalent to the combustion efficiency profile. Mukah-Balingian coal produced the highest temperature, followed by the blend of oil palm shell and Mukah-Balingian coal. Oil palm shell feed used produced the lowest. GB80V produced the highest flame temperature with 870 K as shown in Figure 11, followed by GB80, GB100, GB120 and GB with 863 K, 858 K, 838 K, and 828 K, respectively.

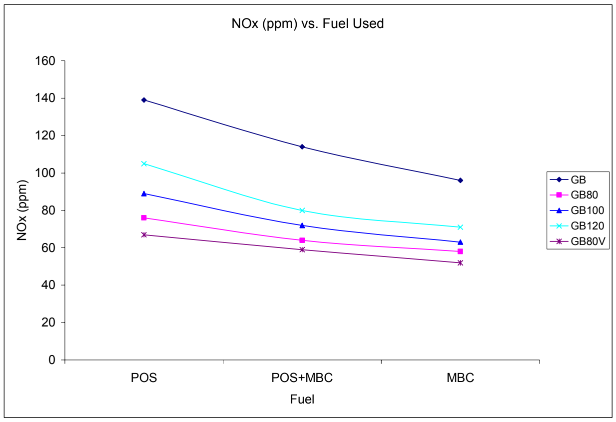

Figure 5: NO_x vs. type of fuel used

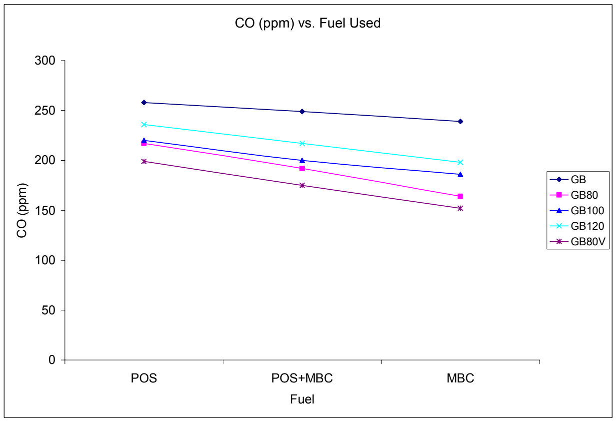

Figure 6: CO vs. type of fuel used

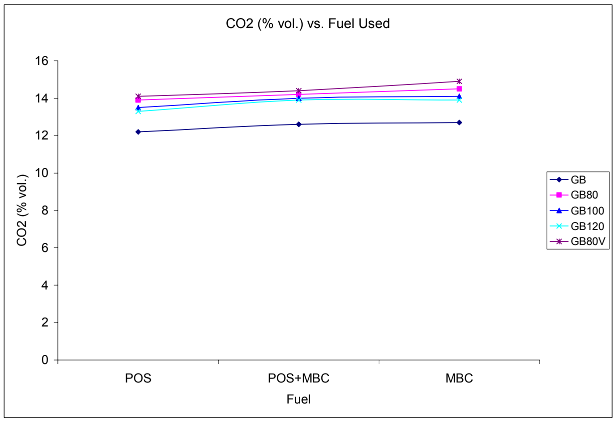

Figure 7: CO_2 vs. type of fuel used

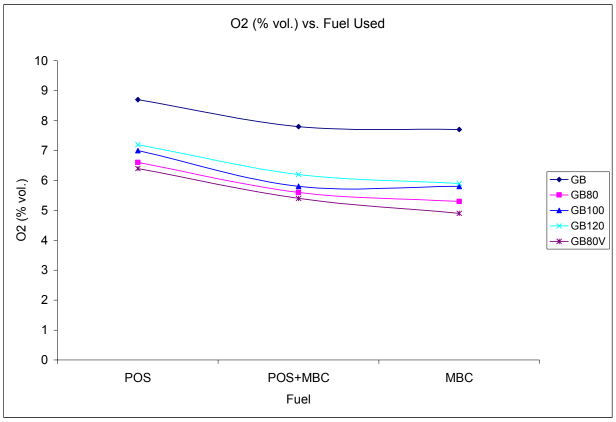

Figure 8: O_2 vs. type of fuel used

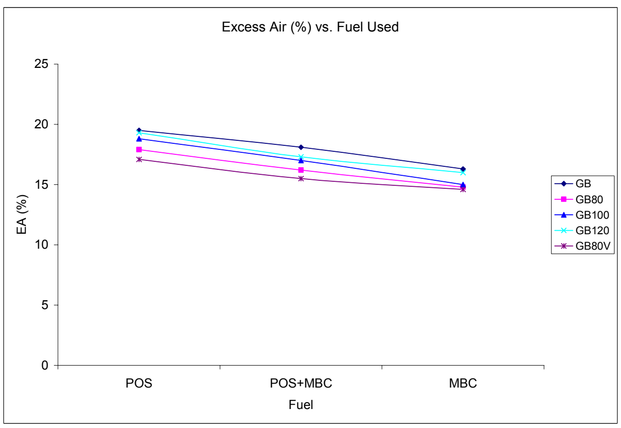

Figure 9: Excess air vs. type of fuel used

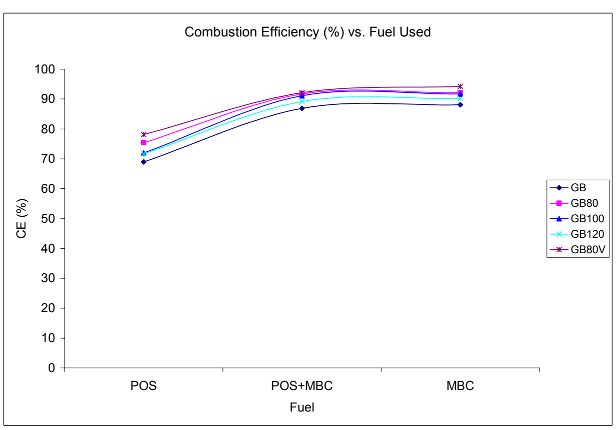

Figure 10: Combustion efficiency vs. type of fuel used

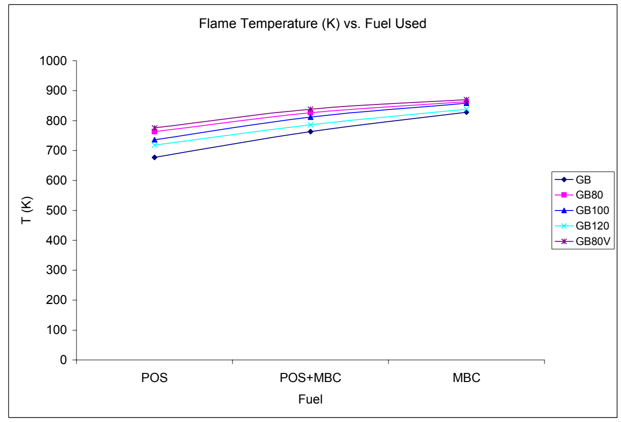

Figure 11: Flame temperature chart vs. type of fuel used

3.3 Flame Colour and Shapes

Blue and shorter flames were obtained at the burner port as the amount of coal increases in the feed mixtures. Coal gasification produces intense flames compared with biomass flames which produces disperse flames as seen in Figures 12, Figure 13 and Figure 14. The effect of using 40^o swirler inserted in the orifice port also gives control flames shape as compared without using swirler with the premixed gaseous fuel and air.

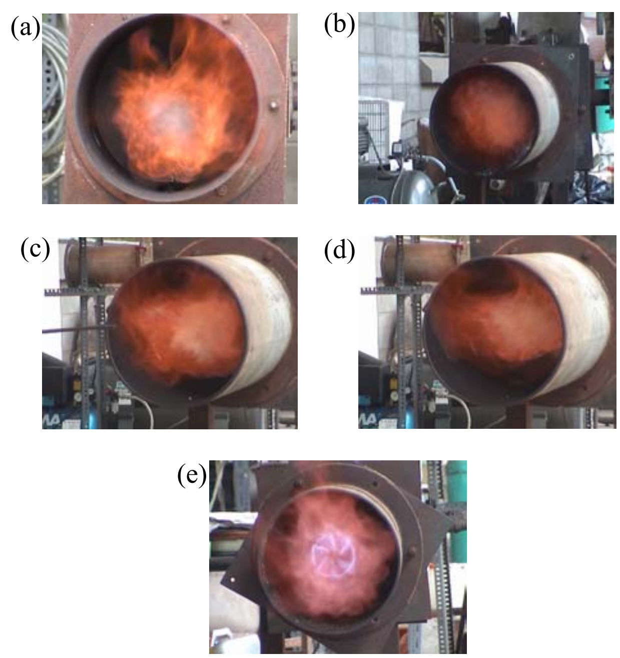

Figure 12: Flame emitted at (a) gas burner without orifice cylinder, (b) gas burner with 120mm orifice cylinder, (c) gas burner with 100mm orifice cylinder, (d) gas burner with 80mm orifice cylinder and (e) gas burner with 80mm orifice cylinder and 40^o swirler based on palm oil shell as feed.

Figure 13: Flame emitted at gas burner with 80mm orifice cylinder and 40° swirler based on the blend of palm oil shell and Mukah-Balingian coal as feed.

Figure 14: Flame emitted at gas burner with 80mm orifice cylinder and 40° vane based on Mukah-Balingian coal as feed.

4 Conclusions

The temperature profiles inside the gasifier for both coal and biomass were obtained, oil palm shell feed contribute a higher temperature profile inside of the gasifier, while Mukah-Balingian coal feed is the lower profile. Gas burner with 80 mm diameter of orifice cylinder produced the lowest emission compared to 100 and 120 mm, thus was installed with 40° swirler. NO_x, CO, O_2 and excess air value is reduced when the oil palm shell fuel is changed to Mukah-Balingian coal. The decreasing values are 22.4 %, 23.6 %, 23.4 % and 14.6 %, respectively for gas all types of gas burner. GB80V produced the lowest, followed by GB80, GB100, GB120 and the highest is gas burner GB. For CO_2, combustion efficiency and flame temperature, the value is increased when the Mukah-Balingian coal is replaced the oil palm shell. The increasing is about 5.7 %, 12.1 % and 20.6 %, respectively. GB produced the lowest, and GB80V produced the highest with 17.3 %, 5 % and 6.9 % increasing, respectively. Blue and shorter flames were obtained as the amount of coal increases in the feed mixtures and when using the swirl burner.

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