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Improvement of combustion process of oil palm fruit fiber (Mesocarp) by adjusting of combustion air ratio between primary and secondary air

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ABSTRACT

Study of the oil palm fiber (mesocarp) combustion process in the laboratory scale has been conducted. The purpose of this research was to identify the effect of various combustion air ratio between primary air (PA) and secondary air (SA) to combustion qualities of mesocarp. The ratio of combustion air (PA:SA) were variated at (20:80), (35:65), (50:50), (65:35) and (80:20). The research experimental was conducted using by a fixed bed reactor. The combustion air flow rate is controlled using the anemometer, temperature measured using thermocouple, and gas emission measured using the gas analyzer. Based on the experimental design of the various combustion air ratio known to produce the combustion process of mesocarp with optimal result, the combustion air ratio between primary and secondary air (PA:SA) arranged at ratio 35:65.

Keywords: *Air fuel ratio, combustion air, biomass, fiber, secondary air, primary air.*

INTRODUCTION

The oil palm fiber (mesocarp) from the extraction process of palm oil in screw press is used as boiler main fuel at palm oil mill (POM). The heat energy from burning of mesocarp in boiler combustion chamber is used to change the water phase to be steam. The latent heat steam in the pressure of 21 kg/cm^2 has a temperature for $260^{O}C$ that produced by boiler is used to turn the steam turbine that move the electrical generator to supply the energy to the POM. The saturated steam from steam turbine has pressure 3 kg/cm^2 and temperature $130^{O}C$ that is used in production process in processing unit (Guthrie Plantation and Agriculture Service: 1995).

On the palm oil mill that have higher efficiency energy conversion unit did not required the supplement fuel, but in any POM with the lower combustion efficiency requires the supplement fuel such as the shell for 20 up to 30% of total available shell. The lower combustion efficiency will lower the combustion quality that indicated by the losses of fuel (in the form of gas) in the exhausted gas indicated by the black or white smoke in the flue gas stack during the combustion process.

The lower of combustion quality in boiler of palm oil mill is suspected caused by application of biomass oxidation process that did not consider the fuel characteristics. In which one of the causes is the air fuel ratio between the primary air and secondary air is not set in suitable ratio. The primary air flow from the lower of grate has a function to oxidize the fixed carbon (FC) and to cool the grate. While the secondary air (SA) flow in the upper of grate or fuel has a function to oxidize the volatile matter (VM) (Hallett, W. L. H: 2005).

Initially, the decomposition process of fuel is begining from the drying phase of water content (H_2O) in temperature of 100–200^{O}C. The second phase is devolatilization process as the releasing of volatile matter gas compound in temperature of 280–400^{O}C (Hagge, J. M.: 2007). The third phase is combustion of fixed carbon that produce CO and CO_2 gas in temperature of 400^{O}C or more, and the last one is degradation process of mineral content on fuel to be ash (ash forming) in temperature 1000^{o}C (C., Ryu: 2006).

Biomass is an organics matter that contains VM more than FC. Mesocarp has VM element for 14.47% and FC for 15.31% (Table 1). During in thermal decomposition process, the VM content is volatile rapidly to be gas than FC. In this condition, the secondary air in the same volume to the VM gas do its function immediately and accurately to oxidize the fuel. By set the volume of combustion air on secondary air-in accurately, the black or white smoke can be oxidized totally in order to increase the combustion quality.

The purposes of this study was to determine the effect of variation in the percentage of air fuel ratio between the primary air and secondary air to the quality of combustion of oil palm fiber (mesocarp) on fixed bed combustion reactor.

MATERIAL AND METHOD

Material

The material used in this study is the oil palm fiber (mesocarp) that supplied by PT. Perkebunan Nusantara (PTPN) IV in Palm Oil Mill (POM) of Adolina with the water content is 35.32% and oil content is 4.5%. Table 1 and Table 2 are showing the characteristics of oil palm fruit fiber.

Setup of Equipment

The equipment used in this study is a fixed bed combustion reactor with the primary air and secondary air ducts that completed by airflow meter and thermocouple that installed on 7 points and connected to the data logger. In addition, it uses the digital weighing and gas analyzer (Kane-May 9106). Before use, the gas analyzer is recalibrated according to the manual book especially in determining constants of K 1 g, K 1 n, K2, K3 and K4 for biomass based fuel analysis.

Table 1: Result of Proximate Analysis Oil Palm Fruit Fiber

Components	**Mass (%) d.b**
Moisture	9.35
Volatile matter	71.47
Fixed carbon	31
Ash	3.87
High heating value	4,278 (Cal/gram)

Table 2: Result of Ultimate Analysis Oil Palm Fruit Fiber

Components	**Mass (%) d.b**
Carbon (C)	44.97
Hydrogen (H)	6.99
Nitrogen (N)	0.45
Sulfur (S)	0.14
Oxygen (O)	43.58

Determining the Combustion Air

The combustion air used in oxidation process of palm oil fiber is classified into two types, i.e. theoretical combustion air and actual combustion air. Determining of theoretical combustion air is calculated based on the content of fuel element in the below equation (Djokosetyardjo, M. J.: 2003);

$$\mathrm{Uog} = \frac{100}{23{,}2} \mathrm{x}(2.67\mathrm{C} + 8\mathrm{H} -) + \mathrm{S}) \qquad (1)$$

Where

Uog: Theoretical combustion air (%)
C : Volume of carbon in oil palm fiber (%)
H : Volume of hydrogen in oil palm fiber (%)

O : Volume of Oxygen in oil palm fiber (%)
S : Volume of Sulfur in oil palm fiber (%)

The volume of theoretical combustion air required for the oxydation of fuel by consider the volume of elements of oil palm fiber is 5.74 kg air/kg fuel. In the combustion experiment, it use the oil palm fiber as fuel for 2.20 kg, so total required theoretical combustion air is 12.62 kg. By consider the air density based on the external air temperature, the mass volumetric flow rate of air is 11.15 (m^3/h).

After to determine the volume of theoretical combustion air, the next step is the combustion process of 2.20 kg oil palm fiber with the volumetric flow rate of combustion air is 11.15 (m^3/h) on fixed bed combustion reactor. During the combustion process, the data of O_2 gas emission is recorded using the gas analyzer for 6 times. The results of measurement of O_2 gas emission is used in determining the supplement of excess air (EA) on fixed bed combustion reactor that calculated by the below equation (Keison: 2004);

$$EA = \left[\frac{20{,}9\%}{20{,}9\% - O_2 m\%} - 1 \right] x100\% \quad (2)$$

Based on the combustion process of oil palm fiber it known that the volume of O_2 in emission of exhausted gas (O_2m) is 19.8%, so the excess air (EA) that flowed to the combustion air is 18% of theoretical combustion air or 2,007 m^3/h. Therefore, the oxidation of 2.20 kg fuel requires air 14.89 kg in the air mass flow rate is 13.16 (m^3/h). By consider the ratio of air fuel, the air fuel ratio (AFR) of oil palm fiber combustion is 1/6.77 or 0.15.

Determining the Combustion Quality

There are two main parameter used in determine the quality of combustion process, i.e. the percentage of unburn fuel burnt that contain in emission of exhausted gas and efficiency of combustion (UNEP: 2006). In order to monitor the quality of combustion reaction during the combustion process, the temperature of combustion and the volume of exhausted gas emission (O_2, CO, and CO_2) must be observed.

Determining the losses of fuel that contain in the exhausted gas emission and efficiency of combustion can be calculated by equation 3 and 4 (Keison: 2004)

$$Ufl = \left[\frac{65xCO\%}{CO\% + CO_2\%} - 1 \right] \quad (3)$$

Where

Ufl : The unburn fuel losses
CO : Volume of carbon monoxide in exhausted gas (%)
CO_2: Volume of carbon dioxide in exhausted gas (%)

$$Gf = 100 - \frac{20{,}9xK1gx(Tnet)}{K2x(20{,}9 - \%O_2m)} + (K3x(1 + 0{,}001xTnet)) \qquad (4)$$

Where

Gf : Gross efficiency (%)
K1g: Constant of heat value based on LHV calculation
K2 : Volume of theoretical carbon dioxide (CO_2 max) (%)
K3 : The heat loss caused by water content (%)
Tnet: Outlet temperature – inlet temperature

Experimental Design

The experimental activities were conducted based on the design of study shown in Table 3. Each treatment was conducted in two replications of data.

Table 3: Experimental Design

Independent Variable / **Dependent Variable**	***Primary Air* [PA] : *Secondary Air* [SA] (%)** [m^3/h]				
	80:20 [10,53: 2,63]	**65:35** [8,55:4,61]	**50:50** [6,58:6,58]	**35:65** [4,61:8,55]	**20:80** [2,63:10,53]
Carbon monoxide (CO)	$CO_{(80:20)}$	$CO_{(65:35)}$	$CO_{(50:50)}$	$CO_{(35:65)}$	$CO_{(20:80)}$
Carbon dioxide (CO_2)	$CO_{2\ (80:20)}$	$CO_{2(65:35)}$	$CO_{2\ (50:50)}$	$CO_{2\ (35:65)}$	$CO_{2\ (20:80)}$
Oxygen (O_2)	$O_{2\ (80:20)}$	$O_{2\ (65:35)}$	$O_{2\ (50:50)}$	$O_{2\ (35:65)}$	$O_{2\ (20:80)}$
Combustion temperature (RT)	$RT_{(80:20)}$	$RT_{(65:35)}$	$RT_{(50:50)}$	$RT_{(35:65)}$	$RT_{(20:80)}$
Unburn fuel loss (UFL)	$UFL_{(80:20)}$	$UFL_{(65:35)}$	$UFL_{(50:50)}$	$UFL_{(35:65)}$	$UFL_{(20:80)}$
Combustion efficiency (EP)	$EP_{(80:20)}$	$EP_{(65:35)}$	$EP_{(50:50)}$	$EP_{(35:65)}$	$EP_{(20:80)}$

RESULTS AND DISCUSSION

The Effect of Air Fuel Ratio between the Primary air and Secondary Air to the Combustion Temperature

Figure 5 show the heat released from the burning process of oil palm fiber with various ratio of air fuel between primary air (PA) and secondary air (SA). The data is an average value of results of descriptive analysis test that had conducted.

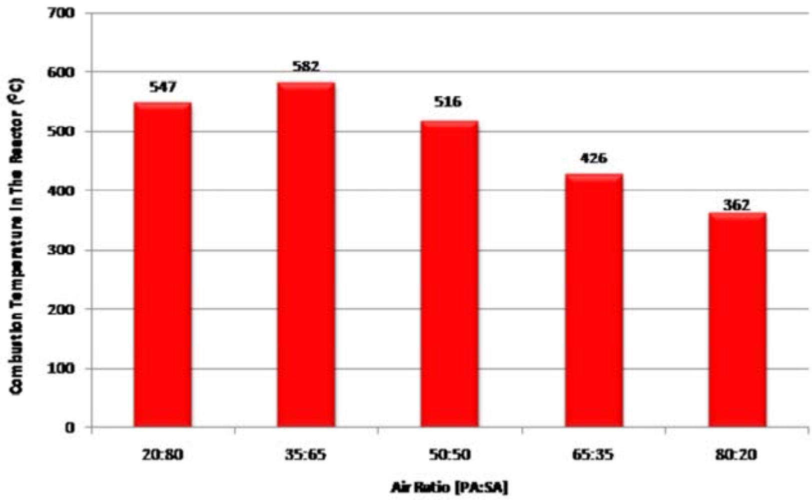

Figure 5: The Effect of Air Fuel Ratio Percentage (PA:SA) to the Combustion Temperature

Based on the results of experiment it is indicated that the higher combustion temperature found on air ratio (PA:SA) 36:65 with the temperature of 528^{O}C and the lower on air ratio (PA:SA) 80:20 with the temperature of 362^{O}C. The mesocarp burning by rapid oxidation process will produce the heat radiation and light. In combustion process, the content of oxygen has an important role in support the accuracy of combustion process. The excess oxygen volume will increase the heat losses in the exhausted gas emission. The lack of oxygen in combustion process causes the decreasing of combustion reaction because the oxygen used in fuel oxidation process is not sufficient and slows the combustion process. In the condition, the emission of exhausted gas is increased.

Figure 5 shows a pattern of the air ratio between primary air and secondary air (PA:SA) is higher, the lower of heat radiation. This is caused by the oxygen used in oxidation process of fuel in secondary air duct is smaller than air on primary duct. The oxidation process on volatile matter gas for 71.47% is more than carbon element has not been running well because the lack of oxygen on secondary duct. Because it is not all of element of volatile matter gas can be oxidized totally by air on secondary duct, the heat radiation of oxidation process of fuel is not higher significantly.

The amount of heat released during the combustion process will be used to help the next spontaneous combustion reaction because the main requirement of the perfect combustion is the availability of sufficient heat for decomposition process of fuel. (Culp, W. A: 1991).

The Effect of Combustion Air Ratio between Primary Air and Secondary Air to the Production of Exhausted Gas Emission

The by-product of the combustion process is the exhausted gas emission. The percentage of exhausted gas emission of the combustion process can used to determine the toxicity content and the quality of combustion process. There are 3 main components of exhausted gas emission of combustion process that can be used to predict the quality of combustion, i.e. emission of O_2, CO, CO_2 (Djokosetyardjo, MJ: 2003)

The results of study indicates that the lower percentage of O_2 emission found on the air ratio (PA:SA) 80 : 20 for 18,78% and the higher found on air ratio (PA:SA) 50:50 for 19.60% (Figure 6). The content of O_2 emission in exhausted gas indicates that it is not all of supplied oxygen for fuel oxidation process can be reacted in combustion process. While, the lower emission of CO gas is found on air ratio (PA:SA) 50:50 for 3.75% and the higher on air ratio (PA:SA) 20:80 for the value of 11.17%.

The lower of CO_2 gas emission is found on air ratio (PA:SA) 50:50 for 1.20% and the higher found on air ratio (PA:SA) 80:20 for 1.96%. The higher of CO_2 gas emission in exhausted gas, the better quality of combustion and in contrary, the lower of CO_2 emission, the poor of combustion quality.

The emission of carbon monoxide (CO) gas is a main parameter used to predict the quality of combustion process. The lower of percentage of CO gas in exhausted gas produce better combustion quality. In contrary, the higher of CO gas in exhausted gas, the higher of unburn fuel loss. Because the characteristics of CO gas emission is combustible gas, so the volume influences the efficiency of combustion process especially the heat loss. As known that each one kilogram CO gas emission in exhausted gas, it cause the heat loss for 5.654 kcal (UNEP: 2006). As mentioned previously, the radiation of combustion temperature has a significant effect to the quality of fuel oxidation. This also influences the emission of fuel.

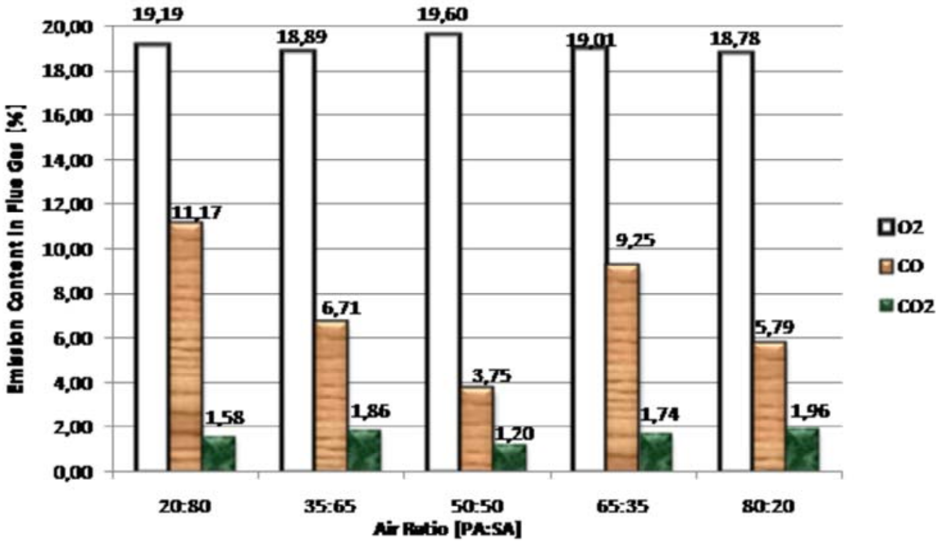

Figure 6: The Effect of Air Ratio [PA:SA] to the Production of Exhausted Gas

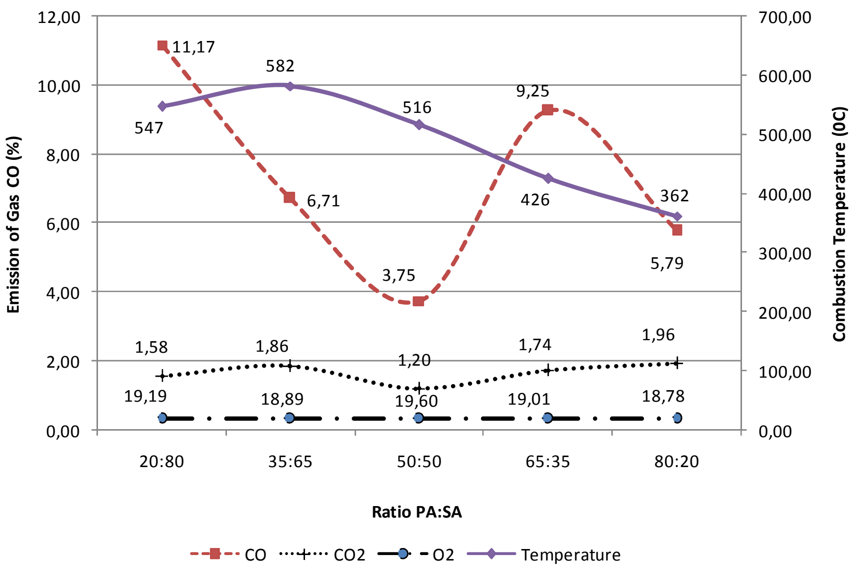

Figure 7: The Effect of Air Ratio [PA:SA] to the Combustion Product

Figure 7 shows that the combustion temperature can influence the content of exhausted gas emission especially CO. On the higher combustion temperature 582°C the emission of CO is lower and this condition is continued up to the ratio of PA:SA is 50:50). Then on the air ratio 63:35, the content of CO is increased and followed by the increasing of CO_2 emission and the lower of O_2 content. This indicates that the increasing of CO emission content on ratio 65:35 is caused by the lack of oxygen supplies that required in fuel oxidation and worsen by the lower of combustion temperature. The fluctuation of CO emission content on various condition also caused by the combination of two important things in combustion process, i.e. the lack of oxygen supply on secondary air and the lower of combustion temperature that influence the stability of the combustion process.

The Effect of Air Ratio between the Primary Air (PA) and Secondary Air (SA) to the Losses of Fuel in Exhausted Gas

Figure 8 displays the percentage of the loss of fuel in exhausted gas during in combustion process. The data is average value of the loss of fuel from the data collecting. Based on the results of descriptive analysis test indicates that the higher fuel loss found on air ratio (PA:SA) 65:35 for 52.20% and the lower found on air ratio (PA:SA) 35:65 for 49.13%.

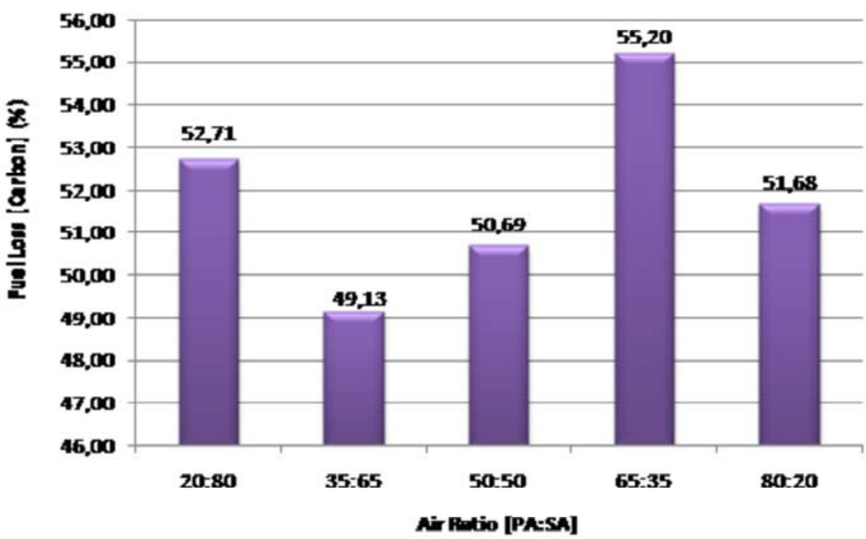

Figure 8: The Effect of Air Ratio [PA:SA] to the Loss of Carbon

The main indicator used in determining the percentage of fuel loss in this study is the content of carbon monoxide (CO) that contained into exhausted gas. As known that unburn the carbon monoxide in combustion process and contained in the exhausted gas will increase the percentage of fuel loss because the characteristics of carbon monoxide is the combustible gas and release amount of energy.

The Effect of air Ratio between Primary Air and Secondary Air to the Efficiency of Combustion

The oxydation process with various air fuel ratio between primary air (PA) and secondary air (SA). Based on the results of descriptive analysis test it indicated that higher combustion efficiency is found on air ratio (PA:SA) 20:80 for efficiency of 80.03% and the lower on air ratio (PA:SA) 80:20 with the combustion temperature is 72.11^{o}C.

Figure 9 shows the percentage of combustion efficiency of mesocarp. Efficiency of combustion is an indication of capability of combustion process to oxydize the fuel totally. In which the main parameter is determined by the unburn fuel loss and the volume of oxygen in exhausted gas.

The basis of determination of combustion efficiency in this study is the bases of calculation of gross efficiency. In which the gross efficiency of combustion include the dry flue gas loss and by consider the heat losses factor from the wet loss. In particular, the difference between gross efficiency and net efficiency is the net efficiency is higher for 8% than gross efficiency. Therefore, the basis of determination of combustion efficiency in this study is using the gross efficiency because it consider the head loss factor from exhausted gas and the heat losses from the water content in fuel (wet loss).

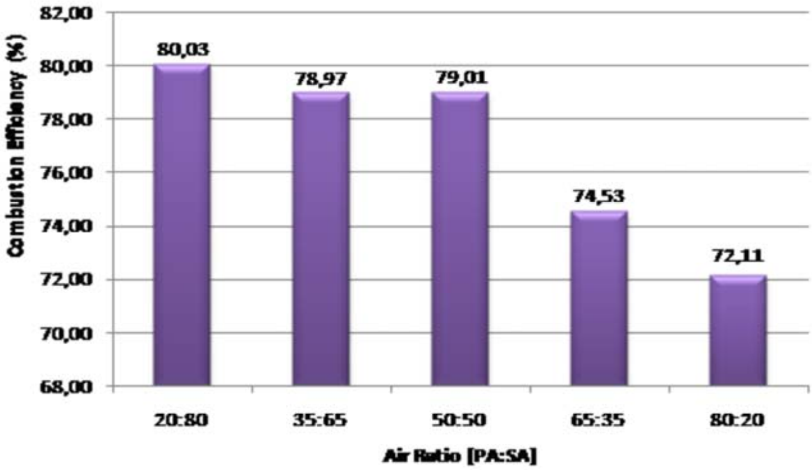

Figure 9: The Effect of Air ratio [PA:SA] to the Gross Efficiency of Combustion

Determining the Percentage of Ideal Combustion Air Fuel Ratio to Get the Optimal Combustion Quality

In order to determine the percentage of ideal air fuel ratio (PA:SA) in get the optimal combustion quality, the data of results of descriptive analysis test must be prepared in matrix form as shown in Table 3. The objective of this classification of the data of experiment results ion matrix form is to make easy the data scoring process, so the determination of percentage of air ratio (PA:SA) is more representative to the test group.

Table 4: Alternative of the Best Ratio of Air Percentage (PA:SA)

Components	20:80	35:65	50:50	65:35	80:20	Selection Criteria
Emssion of O_2	19,19	18,89	19,60	19,01	18,78	From the lowest
Emssion of CO	11,17	6,71	3,75	9,25	5,79	From the lowest
Emssion of CO_2	1,58	1,86	1,20	1,74	1,96	From the lowest
Fuel Loss	52,71	49,13	50,69	55,20	51,68	From the lowest
Combustion Efficiency	80,03	78,97	79,01	74,53	72,11	From the lowest
Combustion temperature	547,18	582,21	516,46	426,10	362,00	From the lowest

Note:

First Alternative Second Alternative Third Alternative

Table 4 shows the results of scoring in determining the ideal air ratio by considering the priority selecting criteria, based on the available requirement. for example, the scoring on component of O_2 emission on each treatment, the selecting criteria is based on the lower O_2 emission content, i.e. in ratio (PA:SA) 80:20 with the yellow color. Followed by selecting the lower O_2 percentage in the second position (after ratio 80:20), i.e. on ratio (PA:SA) 36:65 in red color. And then the selecting of the third lower O_2 emission (after ratio 35:65), i.e. on ratio (PA:SA) 65:35 in green color. The three scoring steps were conducted on the next five components, in which its selecting process based on the selecting criteria as presented in Table 4 the right column. The results of scoring indicates that the optimal air fuel ratio (PA:SA) is found on ratio 35:65.

CONCLUSION

Based on the experimental result using combustion fixed bed reactor in the laboratory scale, to obtain the combustion process of oil palm fruit fiber (mesocarp) with good combustion qualities, it is necessary to adjust the combustion air ratio from the inlet of primary air (PA) and secondary air (SA). The ratio of combustion air amount with exact condition to burn of oil palm fruit fiber is 35:65. The combustion process conducted with good condition, will obtain the energy saving (lower fuel consumption of oil palm biomass). The combustion process in palm oil mill will not require the unnecessary fuel addition especially oil palm shell. Except that, the environmental degradation as a consequence of increasing the gas emission from incomplete combustion be able to reduced.

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