

## CHARACTERIZATION OF THE PARTICULATE FROM THE COMBUSTION OF COAL OIL AND C-HEAVY FUEL

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### ABSTRACT

This study discusses the characteristics of particulate emission for the combustion of coal fuel and heavy fuel oil. Combustion process was set up in a laboratory scale experiment on a 2.75 m horizontal boiler with four annular segment tubes, a water jacket system, and a measurement system for remaining particulate from the combustion. Four sampling points at 60 cm, 110 cm, 160 cm, and 210 cm from the centre of the boiler were used to obtain the data. The particulate was collected by using filtering method with Poly-tetra flour ethylene (PTFE) coated composite filter. The concentration of dry soot and soluble organic fractions are measured based on the data from samplings. The soluble organic fractions that derived from unburned hydrocarbon were identified using dichloromethane. From this study, the steady combustion of coal oil was achieved and the combustion of coal fuel produced more particulate than the heavy oil. It also concludes that the Application of coal oil as the substitute of the heavy oil still can be a consideration without ignoring the impact to the environment.

**Keywords:** *Coal oil, Heavy oil, Combustion, Particulate, Dry soot, Soluble organic fractions*

### 1. INTRODUCTION

There are many research and experiment activities carried out vigorously by many researchers around the world to find the substitute of fossil energy. The condition of uncontrolled uses for fossil energy causes their demands now are in the critical condition. An effective and environmental friendly of the energy substitute are urgently needed to avoid much damage to the environment and to the human being. Moreover, fossil fuel mainly gives an impact from the hazardous of human health such as; respiratory illnesses and cancer to the hazardous for the environment such as acid rain and global warming. Research on alternative energy now is being a trend, ranging from the application of the alcohol to the extraction of vegetable oil. Bio energy is the most widely experimented and it is as one available of renewable energy in the world (Coda Zabetta, *et.al*, 2006). The benefit of using bio fuels is that it can reduce or eliminate the formation of pollutants, particulates and hydrocarbon as well as the toxics from metals inside the fuel. The similarity between fossil fuels and bio fuels comes from the fact that fossil fuels are hydrocarbons formed during the fossilization of carbohydrates in biomass. In other hand, coal that having huge availability and potential of energy source, did not managed for a good to be an alternative energy source. Converting coal into the liquid by a liquefaction process has been achieved, and it is believed as backup energy of the fossil fuel and one of the available alternative energy.

Air pollution comes from many sources; much of it was generated from the processes that related to the energy use, transportation, consumer products, and equipment from industrial. Transportation sector contributes the second biggest source for the pollution after the industrial sector. Transportation and equipment sources, such as; cars, trucks, buses, airplanes, trains are using fossil fuel for the operational. The different characteristics of the engine and also fuel that supplied to the engine in the transportation sector generally are divided into two big groups; gasoline and diesel engine. The combustion process for both engine types could not convert a hundred percentage of the energy in the fuel into heat and work. Some of the fuel components were not burned completely that create the pollutants in both gasses and unburned carbonaceous particulates. Gasses pollutants from the combustion appear in the forms of sulphur oxide (SO<sub>x</sub>), nitrogen oxide (NO<sub>x</sub>), carbon monoxide (CO) and other pollutants material. Thus, the carbonaceous particulate emitted from the combustion is known as particulate matter (PM). It consists an elemental of carbon chain, with several organic compounds, sulphate, metals, acid, fuel vapor, and unburned lubricating oil that also absorbed into its surface (D`ana, A. *et.al.*, 2001). The size and concentration of these particulates are varying depending to the engine load, speed, and fuel composition.

Coal is the most abundantly available fossil fuel, and as a result it has proven to be commercial fuel meeting half of primary energy demand. Coal is a complex heterogeneous mixture sedimentary rock. It consists of organic and

inorganic constituents, which containing mixed of solid, liquid and gaseous. Coal inside are also composed from some hydrocarbon that important for the combustion process. The availability of the coal is predicted to be up to three times to fossil fuel, made it as a potential substitute for the transportation sector such as ship operational. Coal has been in use as an energy source for a very long time. The low technology that applied to the coal combustion impacts to the higher production of pollutants, from coal dust and fly ash to the emission of  $\text{NO}_x$ ,  $\text{SO}_x$ , and  $\text{CO}_2$ . Now, new process of converting coal bracket to liquid fuel is known as a liquefaction process gives a solution for better combustion. This process outcome creates coal as liquid fuel oil, and or the coal as additive. The use of coal liquid fuel to be the substitute of C heavy oil in the diesel engine now is in a debating process. Before the application to the diesel engine, the preliminary research of coal as fuel has to be conducted in the laboratory scale experiment such as in a boiler. This process is important to know the difference of the combustion conditions, characteristics of steady combustion, as well as the particulate's formation. The objective of this research is to create, develop, and apply a new system for the steady coal combustion for liquid coal fuel in the boiler. Furthermore, the investigation of the emitted particulate from combustion is also conducted.

## 2. PARTICULATE EMISSION

Particulate emission is defined as tiny particles of solid or liquid suspended in the exhaust gas. These particles mainly formed when the hydrocarbon in the fuel did not completely oxidized during the combustion process, create the semi organic particle that flows together in the exhaust gas stream. Moreover, the burn of lubricant oil along combustion can be one other source. The formation of PM depends on the fuel quality, combustion process, as well as the available time for the combustion process (Apple J, *et.al.*, 1994). PM consists of two big parts; soluble organic fractions and dry soot. The dry soot formed when the fuel burned not completely, then it changes by a very high temperature from combustion process. Thus, the soluble organic fraction is derived from the unburned hydrocarbon which inside particles are still containing of organic material that needs to be oxidized.

The formation of PM was by two processes; as a product of the combustion in a single particle formation, and it grows from the nuclei or single nano particles (M. Frenklach, *et.al.*, 1994). As a single particle formation, the nucleation formation step involves the transformation of vapour or liquid after combustion into the cluster formation of nano particle. It remains on the organic material result from the combustion that forms large particles. The formation process is supported by the decrease of temperature in a series of reversible steps. The stability of this process is influenced by the time, and merge of a single particle into the clusters. Another way of cluster formation is by a growing process of a single particle and a chemical reaction after the combustion. Multi steps of chemical reaction from the inorganic oxide produced wider of the agglomerated particle (J.J. Helble, *et.al.*, 1988).

The size of particulate is ranging from a tiny size of single particle formation than merges or oxides into wider size. In the outside part, the compositions of PM are dominated by liquid condensed hydrocarbon particles and the incomplete oxidation of sulphur. Thus, in the inside is composed by solid carbon spheres that covered by absorbed hydrocarbon. There is a classification of the particulate from the combustion process as;  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ ,  $\text{Pm}_1$ ,  $\text{PM}_{2.5} - \text{PM}_{10}$ , and ultra fine particle (JH Seinfeld, *et.al.*, 1998). These classifications are based on the size of the formed particle.  $\text{PM}_{10}$  means that these particulate diameters are in the range of  $10 \mu\text{m}$ , and it is same meaning for  $\text{PM}_{2.5}$  as well. The ultra fine particle referred to the individual particle less than 100 nanometre.  $\text{PM}_{2.5} - \text{PM}_{10}$  is consisting of varying range particle from  $2.4 \mu\text{m}$  to  $10 \mu\text{m}$  which in the inside was mainly filled by coarse of the merged single particle. Detail of the clustering size particle is shown in table 1.

Table 1. The classification of Particulate size

Fraction	Size range
$\text{PM}_1$	$\leq 10 \mu\text{m}$
$\text{PM}_{2.5}$	$\leq 2.5 \mu\text{m}$
$\text{PM}_{2.5} - \text{PM}_{10}$	$2.5 - 10 \mu\text{m}$
$\text{PM}_{10}$	$\leq 10 \mu\text{m}$
Ultrafine Particle	$\leq 0.1 \mu\text{m}$

## 3. EXPERIMENT AND APPARATUS

The experimented fuels in this experiment are coal oil and C-heavy oil, with A-heavy oil is used from cleansing process. The detail properties of C heavy oil and coal oil were shown in table 2. The density of the coal oil is  $1.1937 \text{ g cm}^{-3}$ , while the C heavy oil is  $0.9612 \text{ g cm}^{-3}$ . Sulphur content as the source of the  $\text{SO}_x$  in the coal oil is lower than

C heavy oil at 0.5 Vol.% out of 2.20 vol.% in C heavy one. The calorific value of the coal oil was confirmed at  $38.26 \text{ MJ kg}^{-1}$ , while the C heavy fuel is at  $43.29 \text{ MJ kg}^{-1}$ . The systems used in the experiment have three main lines; coal oil, C-heavy oil, and A-heavy oil. All the lines were designed as an independent system and have no relation to each other. The A-heavy oil was burned for cleansing the line before and after the experiment. At that time, there is no heating process was applied to the system.

Table 2. The properties of experimented fuels

Components	Unit	Fuel oils	
		Coal oil	C Heavy Oil
Density (15/4°C)	$\text{g cm}^{-3}$	1.1937	0.9612
Kinematic viscosity	cSt	100	170
Residual carbon	Wt%	25	0.010
Flash point	°C	116	82
H <sub>2</sub> O	Vol.%	0.1	0.00
Ash content	Vol.%	0.05	0.01
Sulphur	Vol.%	0.5	2.20
N	Vol.%	0.72	0.21
High calorific value	$\text{MJ kg}^{-1}$	38.26	43.29
Low calorific value	$\text{MJ kg}^{-1}$	37.17	40.90

When the coal and C-heavy oil was applied, the whole line pipes were heated using 45 mm in width and 500 mm length of the rope heaters as well as the tank's heating process for up to  $100^\circ\text{C}$ . The heating system was monitored by using a unit of digital automatic control panel. The combustion air and atomization air was supplied from the operational of a blower and a compressor. The combustion air was supported by a series of the supply pipe directly supplied to the combustion region soon after the nozzle burner. The average of air supplied to support the combustion was  $4500 \text{ L min}^{-1}$ . Thus, the compressor for the atomization of the fuels was operated at 0.15 Mpa out of 0.2 Mpa, the maximum pressure output. The high pressure tank was also used to keep the steady supply of the air from the compressor to the burner. The average of the air flow to the burner was set at 0.08-0.09 MPa. Two strainers are located in the fuel line before fuel comes into the burner to avoid any disturbance from the unmovable disperses particle that flows together inside the fuel. The system for fuel line flow is shown in figure 1.

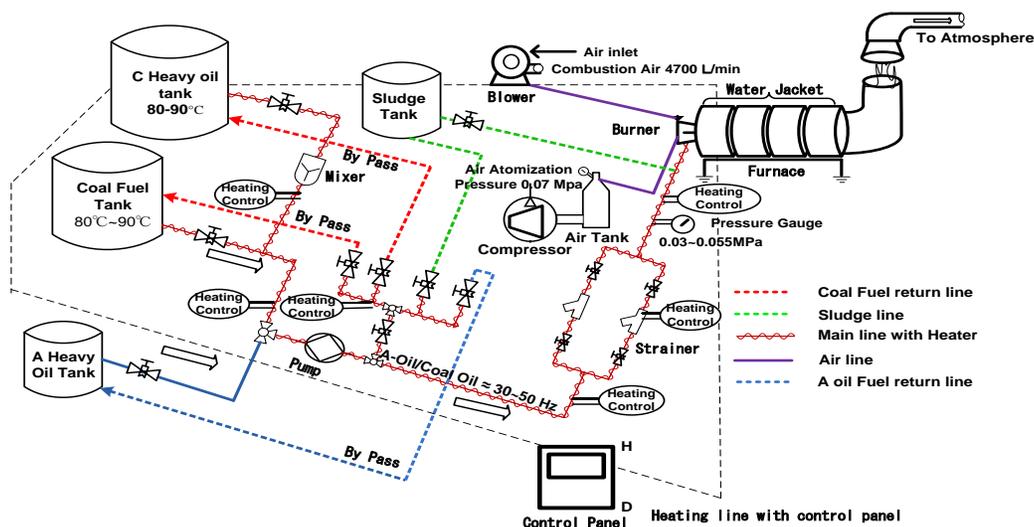


Figure 1. Fuel oil system for supporting the experiment

In the experiment, a 2.75 m horizontal boiler with four annular segment tubes, a water jacket system, and a measurement system for particulate component was used. The sampling points were set at 60, 110, 160, 210 cm from the centre of the boiler. The burner for the atomization of fuel and air was directly located at the centre of the boiler. The main hole with small support hole's series inside for air to support the combustion is placed in a same direction with the burner. Four annular tubes with 500 mm length are used to transfer the heat from the combustion

to the water media. At each of the annular tubes, there is a water jacket system in the inner boiler wall with the thermometer for measurement the temperature of water cooling. In the centre of the tube, the sampling hole with diameter 42.7 mm and 250 mm length from the edge of the tube are made. Then, from this sampling point, the sampling probe is inserted to get a data. The physical inspection of the combustion was gotten from the hole at the end of the boiler. Detail of boiler illustration can be seen in figure 2.

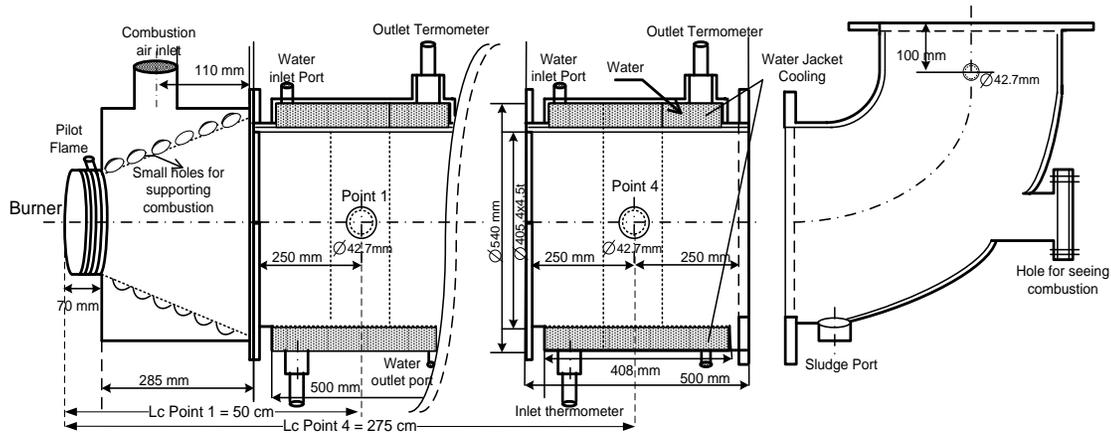


Figure 2. Boiler for the experiment

The experiment was begun from the cleaning process for the fuel line and the burner. The A heavy oil was supplied into the fuel supply pipes, and burned within 10 minutes. Thus, the tank and fuel lines were heated up to 100°C, controlled by a digital control panel. Before supplying to the system, the heated fuels were stirred using the mixer. Then, it pumped to the system by using a gear pump at 60 Hz with average flow rate 2.5 L min<sup>-1</sup>. In another side, 0.15 Mpa of the air from the compressor was supplied to the air high pressure tank to supply 0.08 Mpa of air pressure to the burner. When the fuel and air completely mixed, the combustion process was begun. The steady combustion was performed after a proper of fuel and air mixed setting by manual setting using throttle in the burner.

A stainless steel sampling probe with 6 mm in diameter of sampling hole and 500 mm of length produced by Akano was used for gas sampling. A thermocouple for real temperature measurement was located at the tail of the eyes probe. The high temperature of the exhaust gas was cooled down using a century water cooler before entering the measurement tools. It was followed by a filtering sampling using PG-60 (Produced by Advantec), which the filter it is covered with poly-tetra flour ethylene to measure the particulate concentration. Filter is hydrophobic and low absorption. Flour-polymer is used as the binder and not affected by the air. The properties of used filter are shown in table 3. Principally, PM concentration was calculated by measuring the weight difference of filters before and after an experiment. 20 liters of exhaust gas were taken with 8.5 L min<sup>-1</sup> flow rate at the ambient temperature 35-50°C. For measurement of dry soot, the filters from experiment were dissolved in dichloromethane, and then it was heated up until 50°C for two hours. Soluble organic fractions (SOF) are measured by the reduction of the particulate concentration with dry soot one.

Table 3. Characteristics of filter

Grade	PG-60	
Weight	g cm <sup>-2</sup>	60
Thickness	mm	0.15
Pressure drop	kPa	0.3
DOP Retention	[% <sub>0.3μm</sub> ] <sup>2</sup>	99.9
Water Break Through	[kPa] <sup>3</sup>	>7.8
Max. Operating Temperature	°C	260

#### 4. EXPERIMENT RESULTS AND DISCUSSION

The combustion of C heavy fuel and coal oil in the boiler is similar; consisting of mixing of air and fuel, then following by a past of diffusion combustion. The combustion of C heavy fuel oil was characterized by a normal setting for the combustion process, while the coal needs more setting for the stable condition one. The difficult for

controlling a proper mixed between air and coal fuel happened when the manual setting is taking a long time. The manual setting was conducted by changing the quantity of fuel and air together. If the fuel was too much supplied and atomized, the exhaust gas turned into black, but when the air is too much supplied the exhaust turned into thin white. Some conditions for the steady combustion were gained, where the fuel pressure of the burner was at 0.07 Mpa for the coal oil and at 0.08 Mpa for the C heavy oil. The average of the heating process for both fuels was at 100°C, and pressure of air supplied to the burner was at 0.1 Mpa for the coal and 0.09 Mpa for the C heavy fuel. Detail of parameters for stable condition for both coal and C heavy oil is shown in table 4.

Table 4. Parameters for the steady combustion for both coal oil and C heavy oil

Components	Coal Oil	C Heavy Oil
Water cooling (On), flow rate (L min <sup>-1</sup> )	24.09	24.09
Exhaust gas fan (On/Off)	On	On
Tank heating (On), temperature (°C)	90	80
Fuel line heating (On), temperature (°C)	120	96
Pressure from compressor (Mpa)	0.86	0.1
Pressure inlet of burner (Mpa)	0.1	0.09
Temperature inlet of burner (°C)	110	90
Heater setting of inlet burner (°C)	110	100
Pressure of fuel oil (Mpa)	0.07	0.08
Pump flow rate (Hezt)	60	60
Fuel oil flow rate (L min <sup>-1</sup> )	2.5	2.2137
Water jacket cooling outlet (°C)	60	65
Combustion air (L min <sup>-1</sup> )	4700	4700

Reducing fuel consumption means saving money and, more importantly helping the protection of environment. Generally, different fuel oil has different property and characteristics of the combustion process. Fuel that has good properties will lead the combustion run more completely, and it impacts to the low consumption of fuel. The fuel consumption for the experiment was measured by the difference of the height for oil surface of the tank for the beginning of the experiment and the end one by a function of time. Fuel consumption for both oil was shown in figure 3. Both fuel gives a near result that C heavy oil consumption was 0.2355 L min<sup>-1</sup> and coal fuel was 0.25 L min<sup>-1</sup>.

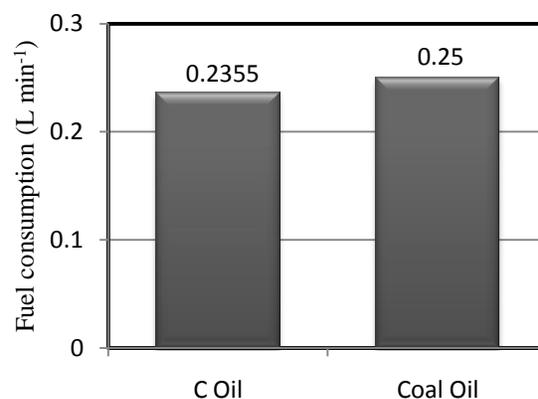


Figure 3. Fuel consumption for both experimented fuels

Heat transfer to the cooling surfaces is a key parameter for the control of furnace temperature in a boiler. The average heat transfer from the bed can be obtained from the temperature rise of water in the boiler tubes. The accuracy of measurement depends on the water temperatures, which can be measured for rather high precision if the temperature difference is large enough. This section shows the measurement of the heat transfer from the boiler to the water jacket system. The different of temperature and heat transfer obtained from the experimented fuels are presented in the table 5. The increase of temperature for C heavy fuel oil was drastically occurred in the length 110

cm. It was about 14°C, indicated that the combustion runs, and it impact to the heat transfer of the water cooling up to 1410.76 kJ min<sup>-1</sup>. The application of coal resulted in a different temperature that was only 9°C, 5°C lower than C heavy oil. It was influent to the heat transfer from the combustion to water jacket system that certified was only 906.92 kJ min<sup>-1</sup>. The difference was 503.84 kJ min<sup>-1</sup>. At the 210 cm, the heat transfer of the coal oil was 1612.29 kJ min<sup>-1</sup>, and it was 201.54 kJ lower than C heavy oil. It indicated that the combustion process of C heavy oil was in a better combustion process than the coal oil one.

Table 5. Average of heat transfer in the experiment

Sampling point	Heavy fuel oil		Coal oil	
	Temp ( $\Delta T_i$ ;K)	Qi kJmin <sup>-1</sup>	Temp ( $\Delta T_i$ ;K)	Qi kJ min <sup>-1</sup>
60	2	201.5369	6	604.6108
110	14	1410.7586	9	906.9162
160	19	1914.601	19	1914.601
210	18	1813.833	16	1612.296
Average	13.25	1335.182	12.5	1259.606

## 5. WATER COOLING TEMPERATURE

It is clear from Figure 4, that both inlet and outlet water jacket temperature relatively increases around the burner as the furnace length increases. This may be due to the higher turbulent mixing rates, and the combustion taking a complete condition that corresponding to the longer tail of flame lengths. The temperature levels at the end of the afterward zone relatively increase when the furnace length increase. Heat transfer rates increase with the increase of the furnace length. The inlet temperature for second and forward sampling points was already in the heated condition that makes the next heating process faster than in the sorter length of the furnace. The different temperature of C heavy oil at 60 cm of sampling point was 2°C from 12°C to 14°C, while the coal oil produced higher different temperature around 6°C from 10 °C to 16°C. For the second sampling point, the C heavy oil created stable linear increasing of the temperature due to the increase of length, from 14°C for the 100 cm of sampling point, follows by 19°C, and 18°C. The coal oil combustion created lower combustion quality indicated by the heat transferred to the cooling water in the wall. The transferred heat was confirmed at 9°C for the 100 cm of sampling point, and it increase to 19°C and 16°C.

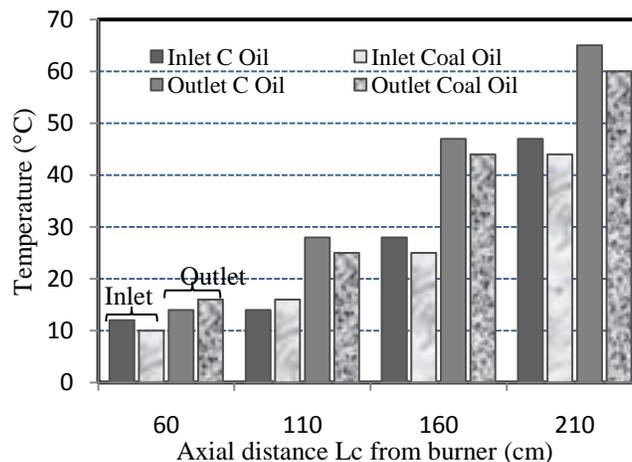


Figure 4. The inlet and outlet temperature of water cooling system

## 5. PARTICULATE MATTER

During combustion or gasification, the hydrocarbon component reacted with the available air, producing the heat as energy and also gas CO<sub>2</sub> and others side product of the unburned hydrocarbon and gasses. Furthermore, the inorganic mineral impurities in fuels are converted into solid, liquid and gaseous compounds, which finally leave the system as bottom ashes, fly ashes or vapor. Due to the condensation and other processes of some vapors solidify the

merged particulate pass the system to the atmosphere as the particulate matter. Figure 5 shows the filter PG-60 from the experiment. The difference of the color brightness at each of the filters indicated the density of particulate that trapped inside the filter was different.



Figure 5. Filter for particulate measurement

The shape and dimension of the particles have also a direct interaction with the risk assessment for human health. We used Scanning Electron Microscope (SEM) for measuring the dimensional and morphological characterization of PM on filters. This method allows in obtaining dimensional or morphological information, at the same time, crucial for the identification PM formation. These dimensional and morphological results could be related with the characters of the particle, due to the different possible formation pathways (chemical reaction in atmosphere, nucleation, condensation, coagulation and cloud processes). The sample result of SEM photograph that related to the formation and agglomeration process of the PM is shown in figure 6. From this SEM photograph, the different formation of the PM from the experimented fuels, C heavy fuel and coal fuel were certified. The combustion of coal fuel derived to the higher production of the PM and also faster in the agglomeration process. The large number of particles for both C heavy oil and coal oil could be analyzed to obtain quantitative results either for the number distribution of the particles or for the morphological characterization but it will not discussed in this paper.

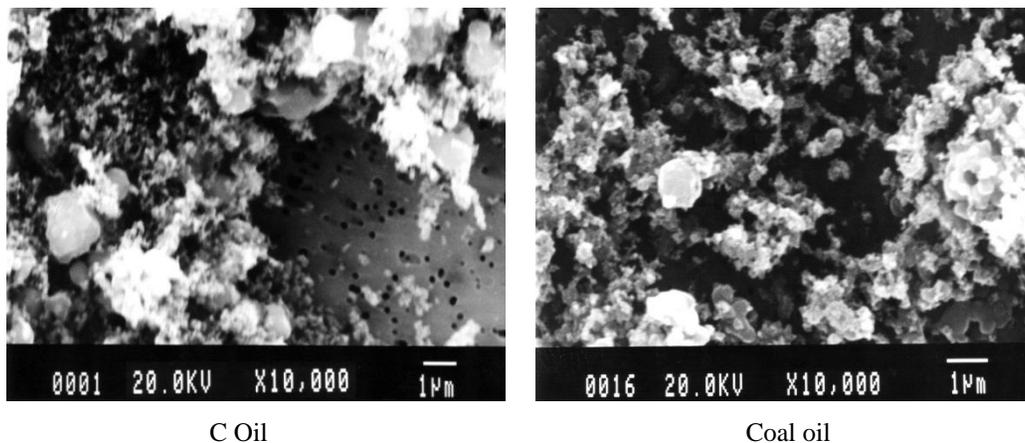


Figure 6. PM image using SEM

The formation and distributions of the PM concentration at the constant mass flow rate of fuel, and the stable of the combustion process is shown in figure 7. General results exhibit that PM concentration values in the forward region soon after the burner centerline resulted in the highest concentration. It decreases rapidly towards the ceiling of the furnace to become very low at the forward flow region. Moving to side against the stream, the PM formation levels in the forward region longer from the burner were influenced by the temperature of the combustion itself. The temperature of flame at 60 cm was measured at around 900 °C and decreases to around 500 °C at 275 cm. It impacted to the concentration of PM, which it was in the 60 cm from the burner indicated at 0.948 g m<sup>-3</sup> for the coal fuel and 0.759 g m<sup>-3</sup> for the C heavy oil. Then, it decreases drastically for more than 50% to 0.295 g m<sup>-3</sup> for coal fuel and 0.1295 g m<sup>-3</sup> for C heavy oil at 160 cm of the sampling point. Afterward, the concentration of PM decreased slightly at 0.2155 g m<sup>-3</sup> for coal and 0.0905 g m<sup>-3</sup> for C heavy oil for 275 cm of the sampling point.

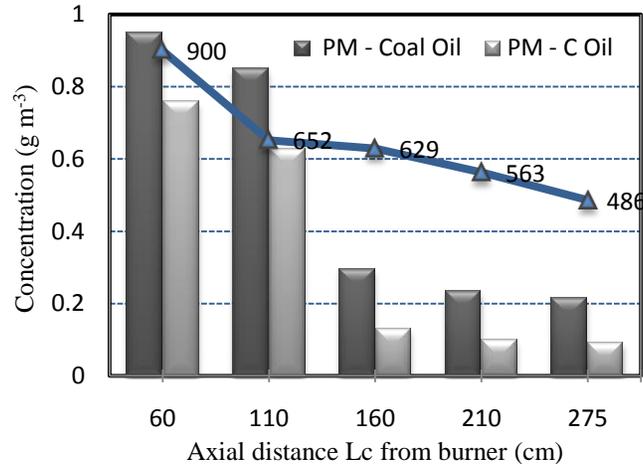


Figure 7. PM concentration from the C heavy oil and coal oil

## 6. DRY SOOT AND SOLUBLE ORGANIC FRACTION

The processes of soot formation are: pyrolysis, nucleation, coalescence, surface growth and the agglomeration. Dry soot from this experiment was calculated from the weight of used filters in the experiment after it diluted in the dichloromethane. The result states that the concentration of dry soot decreases remarkably as the indication of the completion of combustion. In the frontward zone from the burner when the combustion was taking place, because of the limited available time, the possibility of main hydrocarbon inside the fuel was being oxidized to be heat was low. It could be seen also from figure 8, that the concentration of dry soot by using of coal oil resulted in higher concentration than C heavy oil. The concentration of dry soot at 60 cm of sampling point was at  $0.2255 \text{ g m}^{-3}$  for coal oil, and it was  $0.128 \text{ g m}^{-3}$  for the C heavy oil. The lowest concentration was gained at 160 cm of sampling point, at  $0.0685 \text{ g m}^{-3}$  for the coal oil and  $0.061 \text{ g m}^{-3}$  for the C heavy oil.

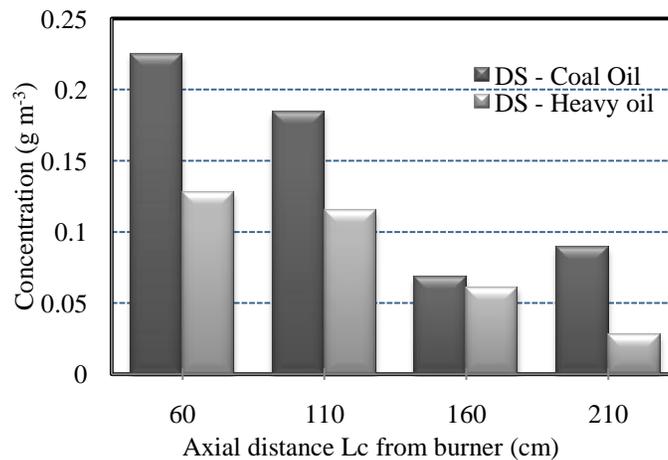


Figure 8. Dry soot concentration of C heavy oil and coal oil

## 7. SOLUBLE ORGANIC FRACTIONS

The soluble organic fractions were formed as the incomplete oxidation of hydrocarbon, on which the formed object is still having same characteristics as the material before, and it is burnable. A soluble organic fraction from this experiment was measured from the reduction weight of the used filter after an experiment with the weight of filter after diluted in the dichloromethane. The concentration of the soluble organic fractions for the coal fuel decreased from  $0.007225 \text{ g m}^{-3}$ , to  $0.00664 \text{ g m}^{-3}$ ,  $0.002265 \text{ g m}^{-3}$ , and  $0.00144 \text{ g m}^{-3}$  for all sampling points. Thus, the decrease of soluble organic fractions for C heavy oil was confirmed from  $0.00631 \text{ g m}^{-3}$ , to  $0.00513 \text{ g m}^{-3}$ ,  $0.000685 \text{ g m}^{-3}$ , and  $0.00071 \text{ g m}^{-3}$ . All the soluble organic fraction data was shown in figure 9. The small concentration of the soluble organic fraction gained from the experiment can be the indicator that the combustion process was run in a better condition.

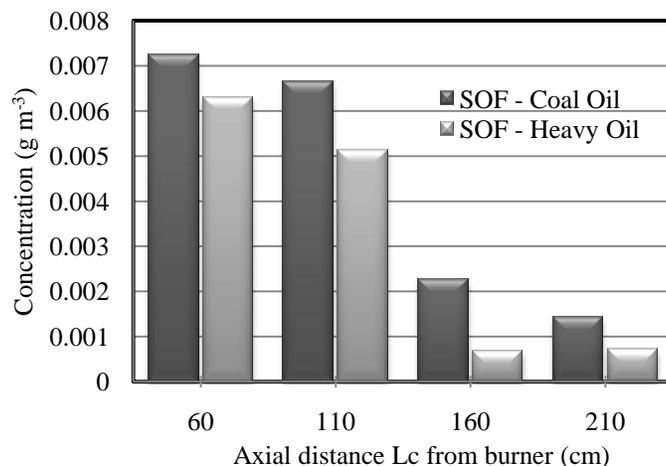


Figure 9. Soluble organic fractions concentration of C heavy oil and coal oil

## 5. OVERALL CONCLUSIONS

An experiment study was conducted for the steady combustion of liquid coal fuel and C heavy oil at laboratory scale on a 2.75 m horizontal boiler with four annular segment tubes, a water jacket system. The preparation process, combustion parameters, and control of the equipment for the stable of coal and C heavy oil combustion was explained detail in this paper. The measurement of the particulate matter that emitted from the combustion at several designed sampling points was also investigated. The average result of PM and its component measurement when the steady combustion for both fuels were at  $0.58113 \text{ g m}^{-3}$  for the coal oil, and it was at  $0.40387 \text{ g m}^{-3}$  for C heavy oil. It indicated that the difference of PM formation was 80.79%. For the PM component; the difference of the soluble organic fraction measurement was 38.96%, with the average concentration of soluble organic fraction of coal oil was  $0.00439 \text{ g m}^{-3}$ , and  $0.00321 \text{ g m}^{-3}$  for the C heavy fuel. Thus, in the dry soot component, the difference percentage was 91.6897%, with average of dry soot from coal oil was at  $0.14188 \text{ g m}^{-3}$ , and C heavy oil at  $0.083 \text{ g m}^{-3}$ . Generally, it is concluded from the laboratory experiment on boiler that there is a possibility of using coal oil, but an after combustion treatment is needed to overcome the particulate problem.

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