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SO2 IN FLUE GAS DESULPHURIZATION FOR DIFFERENT TYPES OF SUB-BITUMINOUS COAL

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Abstract

The energy landscape transform globally including Malaysia. Thermal coal fired power plants are the backbone of the power generation industry in Malaysia in ensuring sustainable electricity power supply to the national grid system to cater for the ever growing demands of a developing country. By comparing with others fuel as distillate in power generation sectors; natural gas and medium oil, coal is the best prefer due to lower price market. As reported in Malaysia Energy Outlook, several new coal power plants coming into the system in the next 5 years, gas consumption is expected to decrease roughly by about 12 percent in 10 years' time. On the other hand, being the base load fuel in the generation mix due to price advantage, coal consumption is expected to increase to more than 30 million tonnes per annum. In the medium term, coal is expected to maintain its position as the most used fossil fuels in the electricity generation. However, one of the major downside of combusting coal to produce electricity is that the flue gases (exhaust gases) produced has high concentration of contaminants such as SO2 and NOx, which has various negative impacts on the environment. The Flue Gas Desulphurization (FGD) plant is designed to remove SO2 from the flue gas, which is a bypass of combusting coal. This study analyses the effective SO2 reduction achieved by the FGD system. Several types of sub bituminous coal with different specification are used for combustion in the boiler. The results of this study clearly shows that the different types of sub bituminous coal lead to varying percentage of SO2 removal. Besides, the study shows the relative correlation between sub bituminous SO2 content and the SO2 emission at the stack.

Keywords: Thermal Power Plant, Sub-bituminous Coal, Sulphur Dioxide, Flue Gas Desulphurization (FGD).

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1. Introduction

Response to the economic constrain, coal was selected as the main fuel for the thermal power plant in generating the electricity. Cost and price of the coal become the main factors in the selection compared to the others fuel type; oil and gas. However, combustion product of coal contributes to the largest source of CO and SO2 to the global. Consequently, the phenomena affect to the emission of greenhouse gases and anticipated change in the climate. Indeed, the selection to the types of coal is critically important due to different characteristic between coal rank; high volatile bituminous coal, bituminous coal, sub bituminous coal, and lignite coal. Besides, the amount of fixed carbon content in coal and the amount of volatile matter in coal determine the coal ranking in various types of coal. In addition, the high rank coal also presents the coal with low moisture percentage and the coal with high ash content.

The coal characteristic is measure through ultimate analysis and approximate analysis. The sulphur contents were measuring follow the ASTM D4239, ISO 351, AS1038.6 and British Standards (BS). It is important to measure the sulphur content in coal samples to evaluate the potential sulphur emissions from coal combustion, or for contract specifications purposes. As described before, proximate analysis method measures the coal characteristic such as percentage of sulphur contents, moisture content, weighted of percentage for volatile matter, amount of ash percentage, and fixed carbon content. Meanwhile, for chemical composition in coal, the ultimate analysis method applied, which is more comprehensive. The ultimate analysis measuring the chemical content such as carbon, hydrogen, sulphur, oxygen, and nitrogen which are present in coal. From the ultimate analysis, the analysis is presenting in percentage of the total mass of the original coal from the coal yard.

According to United State and Canada, sub bituminous coal is rank between lignite and bituminous coal, firmly coal in dark brown colour. According to Spitz et al. (2008), the sub-bituminous coal contains with high moisture and high volatile matter which is more reactive in combustion compare to the bituminous coal types. However, this sub-bituminous coal present lower sulphur contents as below as 2 percent by weight in coal. As non-coking coal and less sulphur contents, sub-bituminous coal has 10 to 45 percent of volatile matter with more moisture compared to bituminous coal types. The carbon content for sub-bituminous coal is between 35 to 45 percent with ash content about 10 percent and below. Approximately is about 0.5 to 2.0 of nitrogen content from the coal weight and is about 2 to 5 percent of hydrogen content from the coal weight. In addition, the sub-bituminous coal was found near the ground surface and not involves with high cost. Relatively, it’s easy to get the coal but high risk in managing the coal during mining activities. From the ultimate analysis results, its conclude the sub-bituminous coal easily drive to emission hazard which consist with particulate matter (PM), sulphur oxides (SOx), nitrogen oxides (NOx), and mercury (Hg). In-term of combustion purpose, the sub-bituminous coal can burn in the boiler, but the combustion product must be managing properly (Nuraini, Salmi, & Aziz, 2018).

The main by-products of combusting coal are the flue gas. In a coal fired power plant, the boiler acts as the furnace for combustion to take place. The flue gases are then continuously removed from the boiler by the means of two Induced Draught (ID) fans to maintain an optimum pressure in the boiler. Furthermore, the rotary air heater (RAH) uses the recovered heat from the flue gas to heat cold primary air entering the boiler, thus efficiency of combustion is increases. Next, the flue gas passes through the flue gas desulfurization (FGD) if the levels of sulphur dioxide (SO2) detected are higher than the allowable

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environmental limits, thus the FGD is placed downstream of the ID fans. Figure 01 explained the FGD process installed at thermal coal power plant.

The FGD system installed to the thermal coal plant purposely to minimise the production of SO2 present in the flue gas before release to the atmosphere through the stack. The FGD flue gas fan is designed to extract the correct amount of flue gas for desulfurization, while the remaining flue gas bypasses the FGD and is used to reheat the treated flue gas upstream of the stack. The FGD plant can be put on-line or off-line without affecting the power generation process provided sufficient control of the ID fans. The FGD plant consists of absorber system and associated seawater treatment system. The SO2 is removed by way of absorption in seawater inside a packed column or namely the absorber.

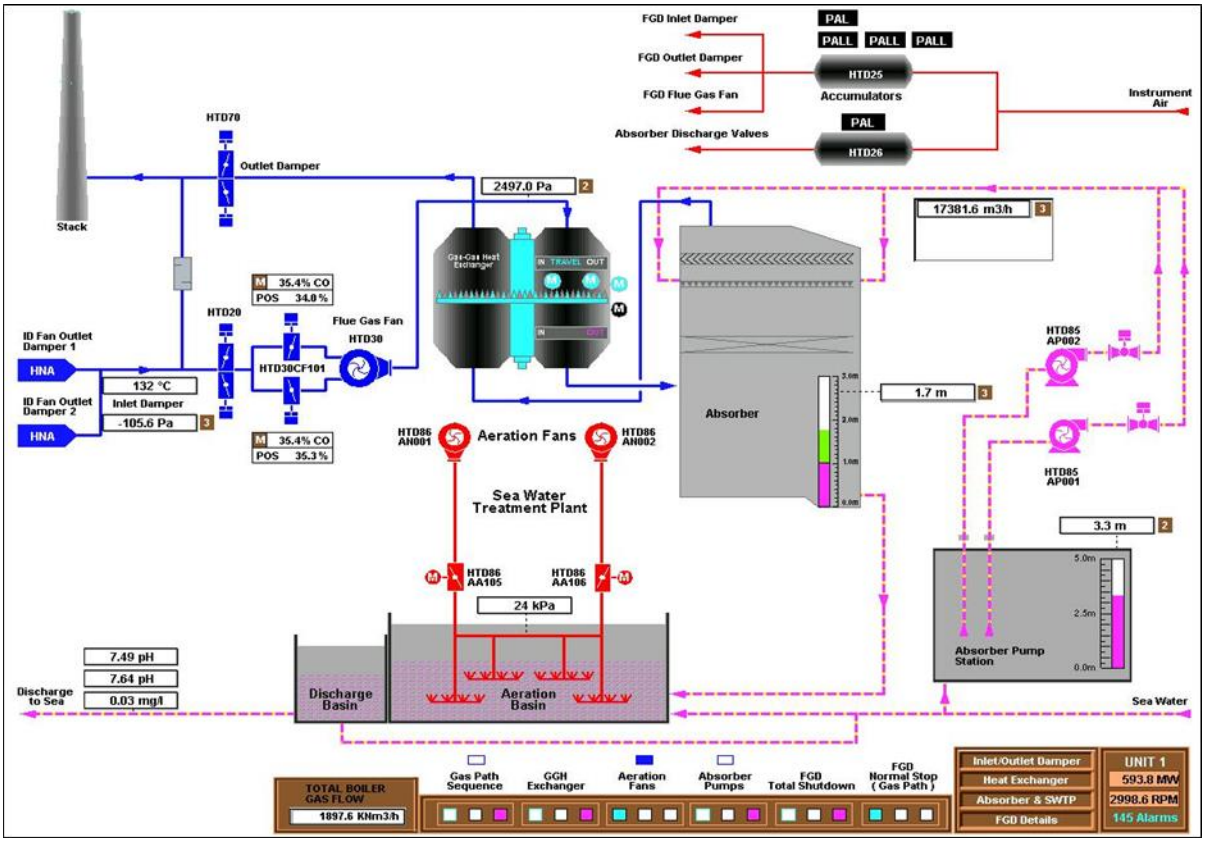

Figure 01. FGD process installed at thermal coal power plant

2. Problem Statement

The levels of emission for such harmful contaminants are heavily regulated throughout the globe – although with varying degrees of allowed levels differ greatly between countries. In Malaysia, the Environment Quality Act 1974 (Act 127) was introduced with a holistic view of protecting both the people and the environment. Section 22 of Act 127 provides general provision for the control of air pollution. As such, utility companies throughout the world are battling to minimize the release of such harmful gases by employing a number of mechanisms. The power generation plant is committed in ensuring that it always complies with the most stringent environmental requirements in order to remain in harmony with both the environment and the people (Mustafa, 2012). 70 percent from the total capacity of coal thermal plant in

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Malaysia used sub-bituminous coal as main fuel. Due to that, the FGD system is required to install at thermal power plant to cater the emission issues (Poullikkas, 2015). However, the effectiveness of the FGD system is subject to the for sub-bituminous coal specification used in thermal power plant.

3. Research Questions

For this study, the research question is to find the relationship between coal sulphur content in sub-bituminous coal to the SO2 production in flue gas outlet before discharging to the stack. The research question is: What is the relationship between coal sulphur content in sub-bituminous coal to the SO2 production in flue gas outlet?

4. Purpose of the Study

FGD systems are growing in demand and popularity as they are able to control SO2 emissions in coal fired power plants. For power plants located at coastal areas, utilization of seawater from the cooling system of the plant to scrub SO2 is an attractive alternative to using other alkaline chemicals such as limestone and magnesium hydroxide which would incur a continuous procurement cost which is undesirable. The basics of FGD operation are described as follows: SO2 is absorbed by a counter-flowing seawater stream, after which it is oxidized to sulphate by blowing air (oxygen) into the stream. Before discharging, the neutralization process was take place when the acidified from seawater effluent is used in mix up with the present seawater of bicarbonates. The chemical process was undergoing accordingly.

Comparing with the existing FGD system which use the wet limestone system, the seawater FGD system compromise with several advantages including the process, efficiency and economically saving in operation and maintenance. Sea water scrubbing is the most economical FGD process for removing SO2 from flue gases for the cases of power stations which located close to the sea. In this process, seawater is used to absorb SO2 due to the two key properties of sea water. The process begins with the existing bicarbonates which is already alkaline in the seawater. The reaction of alkaline bicarbonate and response to the addition acid. The process continuously reacts to absorbed SO2 with transformed into natural chemical of seawater, sulphate ions. Figure 02 illustrates the flow for seawater scrubbing. The main stages for seawater scrubbing process is dust collector system, sea water scrubber system and water treatment plant system for effluent seawater treatment process at discharging stage.

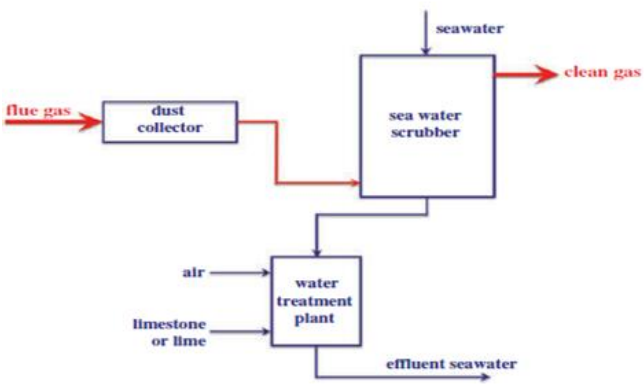

Figure 02. Seawater Scrubbing

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The two important stage of sulphur dioxide was present in the water and perform as sulphite. Acidic condition is performing where the sulphate and hydrogen is containing in chemical composition. Thus, the seawater as natural alkaline agents are used in the process by mixing before discharging to the open sea (Ryan & Ledda, 1997). The chemical reaction process is stated below:

SO2 + H2O SO24 + H2 (1)

SO2 + O2 SO24 (2)

As mentioned, the FGD system installed in power plant to control SO2 emission within acceptance limit. Due to that, the study intent to investigate the relationship of coal sulphur content in the sub-bituminous coal to the SO2 come out at the stuck in the flue gas as combustion product.

5. Research Methods

For the purpose of this research, the study was carried out in coal fired thermal power plant located in Malaysia. The plant, which was connected to the national grid since 2003, features a sub-critical boiler with reheat at a nominal rated power output of 700MW. Table 01 shows the boiler designed main characteristic for the thermal coal power plant used for this research.

Table 01. Sub critical designed main characteristics

Thermal system	Column Heading	Column Heading	Column Heading
Main steam	175	540	2213
Hot reheat	38	540	1927
Condenser	70	-	-

As stated in the Table 01, main characteristic for the boiler design, the main steam piping, cold rehear steam piping and hot reheat steam piping was attached to this power plant. The plant was designed with following the ASTM and ASTME standard accordingly. For the power plant process, the boiler drum with boiler circulation pump was installed together with following to two-type concept. In addition, the plant is intended for steady state operation, two shifting transient operation, frequency response, load cycling, load rejection and overload operation in line with other operational requirements. The plant with 35 percent efficiency was tested in terms of process; combustion, firing, load generation, heating process, heat transfer, thermodynamic, chemical reaction which are indicating total plant performance. Several types of sub bituminous coal in particular content less than 2 percent of SO2 was used during firing in the boiler.

5.1. Sub-bituminous coal

There are six types of sub bituminous coal is used for this study. The coal analysis involves with ultimate analysis and approximately analysis was carried at the coal supplier laboratory before depart to the thermal plant coal yard. As mentioned before, the coal quality measurement was carries out thru proximate analysis and ultimate analysis according to the international standard such as IEA coal sampling and analysis standard and ASTM Coal Sampling Standards. The coal quality parameters and coal characteristic was presented in the coal certification analysis, then. For the purpose, the certificate of analysis (CoA)

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contains relevant information about the coal composition for a particular batch of coal types. Table 02 shows the results for six types of coal characteristic tested in the laboratory used for this study.

Table 02. Sub critical boiler designed main characteristics

Coal types	A	B	C	D	E	F
Calorific value (kcal/kg)	4946	5013	5208	5365	5410	5765
Carbon (%)	73.3	69.85	74.19	74.70	75.2	77.36
Hydrogen (%)	5.18	4.99	5.51	5.59	5.40	5.30
Nitrogen (%)	0.93	1.02	1.61	1.27	1.50	1.47
Oxygen (%)	20.43	20.33	17.99	17.07	17.21	14.92
Ash	1.7	2.8	4.4	4.6	5.1	4.8
Moisture	27.8	25.0	23.5	22.3	21.1	18.3
Sulphur	0.11	0.21	0.45	0.72	0.74	0.95
HGI	47	54	45	50	44	44

5.2. Measure sulphur contents

The origin of Sulphur contents with sea water, mineral from the fresh water, vegetation with additional of superfluous material. After transforming from syngeneic process to epigenetic process through the ground water, the second phase of coal sulphur was present. During the process, the organics sulphur and inorganic sulphur is performing when the originate sea water in the coal decrease. The chemical reaction take place and separately firm as organic and inorganic sulphur. According to Ryan and Ledda (1997), maceral structure of coal consists with organic sulphur which is between 0.1 to 0.5 percent from the total weight.

For this study, ASTM D4239-14 method was applied in measuring the sulphur content in coal. The tube furnace with high-temperature used to determine the sulphur content from coal sampling. Pulverized coal sampling, size 250-µm was used for both methods which is at different temperature.

- Combustion Method A (1350 °C): Pulverized coal sampling was tested with minimum operation temperature at 1350°C in the tube furnace. Sulphur dioxide was presented after decomposed and oxidized during combustion process in the tube furnace. Thus, Infrared (IR) absorption detector is used to measure the Sulphur dioxide as the element of combustion product. In addition, the calibrated sulphur analyzer was used in comparing the results; BBOT (2,5-di 5-tertbutylbenzoxazol- 2-yl) thiophene, C26H26N2O2S). The sulphur analyzer with pure substance about 7.47 percentage of sulphur was used for calibration purposes.
- Combustion Method B (1150 °C): Pulverized coal sampling was tested with minimum operation temperature at 1150°C in the tube furnace. The tube furnace with stream of oxygen burned in a quartz combustion temperature with excess the tungsten trioxide (WO3). During the combustion process in the furnace, the sulphur was present after oxidizing process at the WO3 temperature. The result of sulphur contents in sub-bituminous coal is comparing by using the sulphur analyzer.

5.3. FGD process

In order to monitor and control the effectiveness of the FGD system, parameters for FGD system was measure during the experiment, such as firing time of the coal, FGD operational status as well as the amount of SO2 released to the atmosphere. As mentioned before, the FGD plant is installed to the thermal

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coal plant in order to minimize the SO2 production in the flue gas outlet. The amount of SO2 production in the flue gas outlet is subject to the amount of sulphur content in the coal. The FGD system could be put in service and take off which is relatively refer to sulphur content in the flue gas. Economically, the FGD system can be taking off without affecting the power plant generation process if the sulphur contents produce within the acceptance limits. The FGD plant consists of one gas handling system and an associated seawater treatment system. For this thermal plant, the FGD is designed only to treat 65 percent of the total flue gas flow.

The flue gas duct from the outlet of each ID fan is merged into one duct, hereafter named the main duct. From here, up to 65 percent of the flue gas may be routed through the FGD inlet damper by the action of the FGD Flue Gas Fan. The FGD Flue Gas Fan boosts the pressure in the flue gas sufficiently to overcome the pressure drop through the FGD system. Guide vane control is used to adjust for the correct flue gas flow through the FGD Flue Gas fan. Downstream the fan, the gas enters the gas-gas heat exchanger (GGH). The untreated flue gas enters the GGH at the top, and flows downward through the GGH to the absorber inlet (TNBJ Operation & Maintenance Manual, 2003).

The flue gas enters the absorber in the bottom section. The absorber is designed as a packed tower. Seawater is introduced above the packing in the absorber top section. Subsequent to passing through a mist eliminator, the treated gas leaves the absorber through the top, and enters the lower section of the GGH. In the GGH heat from the untreated hot gas is transferred to the cold treated gas coming from the absorber. The reheated gas passes the FGD outlet damper before it is mixed with the remainder of the hot, untreated bypass gas in the main duct. The temperature thus increases further to reach the design value. The flue gas is subsequently conducted to the stack. In cases of emergency situations that require shutdown, the FGD plant may be 100% bypassed. The main duct will, in such a situation, transport all the flue gas directly to the stack. This situation will imply trip of the FGD flue gas fan/closing of the guide vane dampers, succeeded by closing of the FGD inlet- and outlet dampers (Oikawa, Yongsiri, Takeda, & Harimoto, 2004). Figure 03 explained the FGD plant with absorber process flow.

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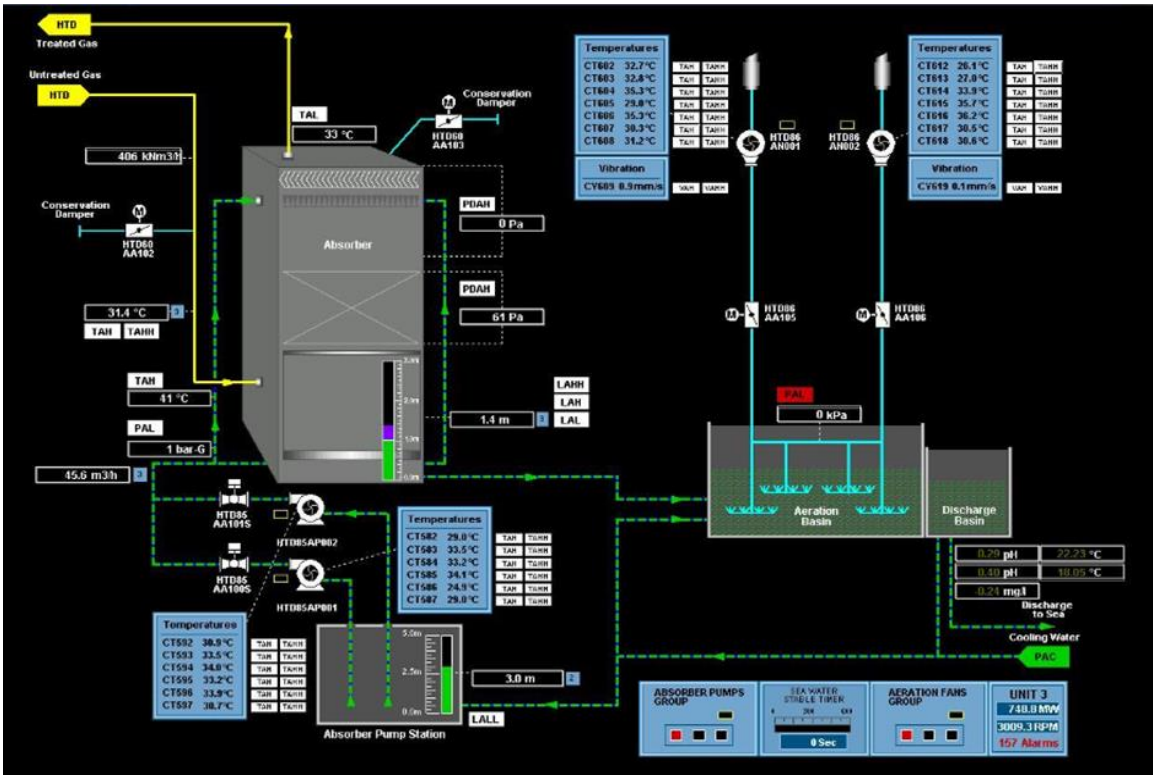

Figure 03. FGD plant with absorber process flow

SO2 is removed from the flue gas by virtue of bringing into contact seawater and flue gas through the counter current flow within the absorber packing (Oikawa et al., 2004). As a result, SO2 is trapped and transferred to the seawater. The seawater treatment plant which is aeration basis - oxidases the seawater rich with SO2 to harmless sulphate prior to discharge back into the sea by blowing into the seawater. At the same time, the pH of the seawater discharge back to the sea is also raised.

6. Findings

Six types of sub bituminous coal were used for firing in the furnace and continuously generating 700 megawatts. For each types of coal, the units were continuously generating 700 megawatts, without no load reduction, no load deration within 5 days. Boiler parameters performance was measured during the experiment period; average load generation, temperature for superheated steam, temperature for reheat steam, temperature for metal superheater tube, temperature for metal reheater tube, economizer outlet temperature, flue gas outlet temperature, superheater spray water, and reheater spray water. The boiler parameters performance is closely monitored during the experiment because its indicates the boiler efficiency and abnormalities. Table 03 shows the average of boiler parameters performance for sub bituminous coal.

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Table 03. Average of boiler parameters performance for sub bituminous coal

Boiler parameters (average value)	Coal types					
	A	**B**	**C**	**D**	**E**	**F**
Load generation (MWn)	695	696	694	695	696	696
Mean superheater spray flow, (t/h)	20	18	85	75	80	85
Mean reheater spray flow, (t/h)	0	0	0	0	0	0
Final superheat steam temperature, °C	540	541	540	541	541	540
Final reheat steam temperature, °C	540	541	541	541	540	541
Superheater metal temperature, °C	541	545	544	543	543	545
Reheater metal temperature, °C	538	539	539	541	538	537
Economiser outlet temperature, °C	385	389	381	379	384	383
Flue gas outlet temperature, °C	171	173	175	181	180	182
Plant efficiency , %	35.2	35.1	35.0	35.4	35.2	35.5

From the boiler performance parameters presented in the table, shows normal value throughout firing all the six various of sub-bituminous coal within 5 days. Boiler was good performing in producing maximum loading about 700MWn. Superheater spray water and reheater spray water operation in minimal opening which is less than 85 tonnes per hours for six selected types of sub-bituminous coal. Directly, the spray water indicates the heat transfer was sufficiency performing in the furnace. Besides, the critical parameters such as temperature at superheater steam, temperature at reheat steam, metal temperature at superheater and metal temperature at reheater values behaviours within the acceptance operation limit, which is 540°C. Meanwhile, the flue gas outlet temperature come out from the furnace for each types of sub-bituminous coal recorded different temperature reading which is between 171 to 182°C. In average, the plant efficiency is about 35 percent during presenting this study.

In general, the flue gas outlet temperature is affected by coal properties, slagging and fouling index, based acid ratio, ash contents and fuel air ratio. As mentioned before, the plant efficiency during the experiment is about 35 percent in average which describes the percentage of the total energy used in fuel for the power plant to produce the electricity to the national grid. This is normal values for plant efficiency which are applied around the world (Nuraini et al., 2018). The balance of generated energy lost to the environment as unused heat or perform as district heating in surrounding.

Table 04 shows the FGD performance data measured for all the six types of coal. Data collection for the emission was done during the combustion period which applied the Malaysia Department of Environment (DOE) through Systems Engineering Methodology (SEM). SEM is describes the standard system development lifecycle (SDLC) used for information systems developed and maintained for the Department of Environment, Malaysia.

Table 04. FGD performance data measured for all the six types of coal

FGD parameters (average value)	Unit	Coal types					
		A	**B**	**C**	**D**	**E**	**F**
Furnace outlet temperature	°C	385	389	381	379	384	383
FGD inlet pressure	Pa	165	180	173	183	195	185
FGD inlet temperature	°C	156	157	163	173	171	168
FGD gas flow measurement	kNm3/h	1524	1440	1490	1478	1510	1488
Total flue gas flow	kNm3/h	2540	2640	2583	2610	2578	2605

Absorber packing different pressure	Pa	431	358	441	341	440	398
Absorber mist different pressure	Pa	41	39	54	43	47	45
Absorber outlet temperature	°C	48	45	47	54	50	57

FGD data captured represent the FGD performance and efficiency in operating the SO2 process. As mentioned before, SO2 is removed from the flue gas by virtue of bringing into contact seawater and flue gas through the counter current flow within the absorber packing. The mist eliminator plays the important roles to the environment. The gas-gas heat exchanger (GGH) operating to cool the untreated flue gas from the FGD before it enters the absorber and increase and increase the temperature of the treated gas before it is discharge to the stack. The untreated flue gas in the absorber will go throughout mist eliminator. The mist eliminator functions to trap the droplets from discharging to the environment. The more efficient the mist elimination, the less risk there is of wasting energy through clogged heat transfer surfaces. By looking at the table above, absorber mist different pressure recorded normal reading which are in range. The absorber outlet temperature is measured purposely to meet the requirement before discharge to the open sea. Therefore, the effectiveness of overall process is determining by the mist eliminator. Efficient of mist eliminator increase the effectiveness of FGD system operation, fully function. Besides, the mist eliminator protects and prevent the equipment and infrastructure of the FGD system from corrosion. Economically, its extending the life cycle of the plant to be in service.

From the study, the SO2 distribution in flue gas outlet is increase with the SO2 production in stack. Figure 03 shows the SO2 content in flue gas outlet at the stack with the FGD process. As expected, the most SO2 that can be treated throughout FGD system, the more SO2 can be produce at the stack. Therefore, there are important to ensure the complete process of FGD plant in order to meet the simultaneous production of SO2.

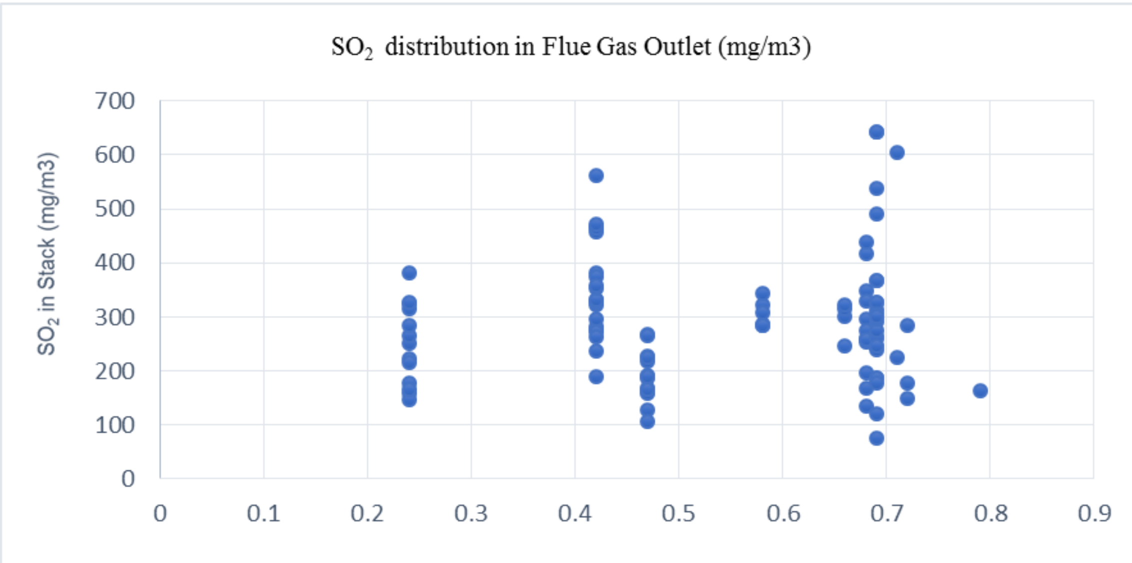

Figure 03. SO2 distribution in Flue Gas Outlet (mg/m3)

The relationship between coal sulphur content to the SO2 production in stack represented in Figure 04. The amount of SO2 production in stack increase with the percentage of SO2 content in sub-bituminous

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coal. Therefore, the selection of sub-bituminous coal used for firing in the furnace operation can be predicted the SO2 production in stack. Consequently, the operation of types of sub-bituminous with high SO2 is avoided.

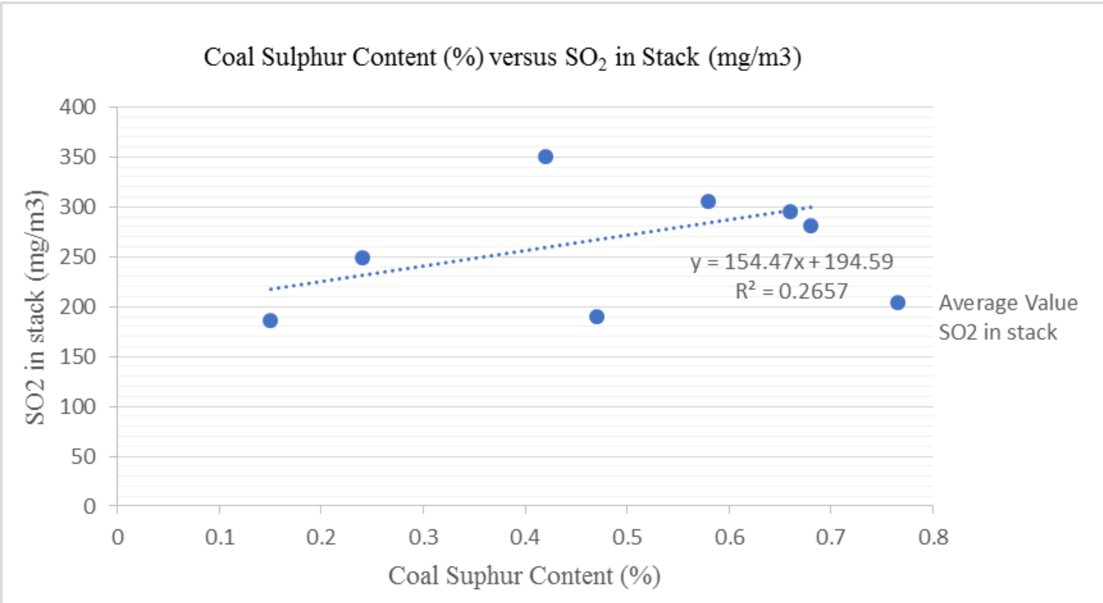

Figure 04. Coal Sulphur Content (%) versus SO_2 in Stack (mg/m3)

7. Conclusion

The FGD system process about 50-70 percent of total flue gas outlet from the combustion in furnace. FGD system successfully reduce the SO2 emission and comply with the CAR 2014, Malaysian act. The study was found the linear correlation on the sulphur content in coal to SO2 production at stack. The higher sulphur content in sub bituminous coal, the higher sulphur production during combustion in furnace and result the high SO2 at stack. However, the high efficiency FGD process SO2 production at stack will reduce accordingly. Eventually, the industry can predict SO2 in advance. Besides that, the FGD system utilization can be sufficient to improve the SO2 emission. Figure 05 shows the percentage of coal sulphur content to the sub-bituminous coal GCV.

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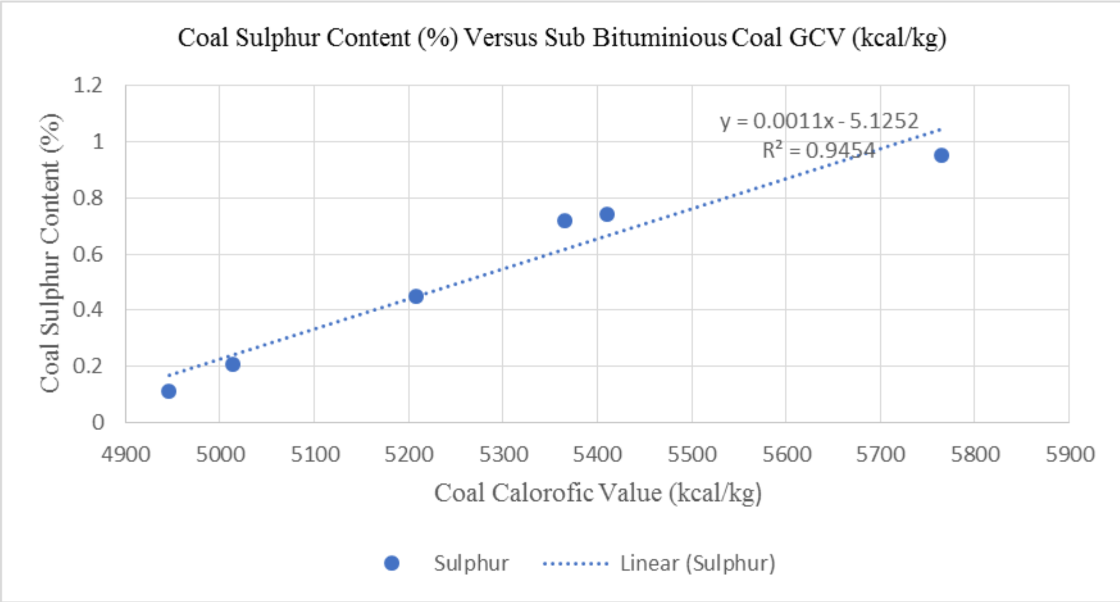

Figure 05. The percentage of coal sulphur content to the sub-bituminous coal GCV

As mentioned by Srivastava and Jozewicz (2001), SO2 emissions are known to have detrimental impacts on the human health and the environment. Many flue gas desulphurization (FGD) methods, such as wet limestone FGD process, have been developed and put into use in the coal-fired power plant. However, there is very few methods that could achieve desulphurization and decarburization simultaneously from the coal-fired flue gas. In removing SO2 from exhaust flue gases through flue gas desulphurization (FGD) it can be too easy to miss a golden opportunity to enhance profitability.

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