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Effectiveness of the Flue Gas Desulphurization (FGD) Operation in Thermal Coal-Fired Power Plants

Salmi Samsudin, Nuraini Abdul Aziz, Abdul Aziz Hairuddin, Siti Ujila Masuri

Department of Mechanical & Manufacturing, Faculty of Engineering,
University Putra Malaysia, Serdang, Selangor, Malaysia

*Corresponding Author Email: salmis@tnb.com.my

ABSTRACT

The generation of electrical power by thermal plants is critically for national security reasons, namely to ensure the sustainability of the grid system. The thermal plant was forced to reduce the emission emitted into the atmosphere, which is emitted through the coal combustion process. Faced with these issues and problems, installation of the FGD system at thermal plants is necessary to improve these conditions. This experimental study was conducted at a 700-megawatt coal fired power plant in order to determine the effectiveness of the FGD system. Findings show that different types of sub-bituminous coal led to varying percentages of SO_2, NOx, CO, CO_2, and Opacity and about 30% to 50% of the contaminate gasses reduce with FGD in system. Findings also show that the coal Gross Calorific Value (GCV) above 5000 kg/kcal recorded high temperatures at the flue gas outlet and it did not affect the amount of gas released into the atmosphere.

KEYWORDS

Thermal Plant; Coal; Emission; Sulphur Dioxide; Flue Gas Desulphurization (FGD).

INTRODUCTION

Energy sustainability has been widely discussed in numerous countries. Energy sustainability is related to the balance of human needs, economic constrains, climate change policies and social life. In moving forward, the organization must lead and critically find new alternatives to meet future needs. Electricity supports national growth and continuity of electricity power generation [1, 2]. Various sources electric power such as thermal plant, hydro power, solar, wind, battery and other recent resources [5]. As the global energy landscape shifts toward with various aspects, such decarburization, decentralization and greater efficiency, accelerated by the emergence of disruptive and innovative technology, the organisation must prepare to comply with surrounding needs [4, 12]. Organisations must come out with strategies by looking at various mechanisms, such as upgrading materials, innovating plant processes, monitoring and inspection of risks, investing in high impact technology and modernizing equipment as well as improving existing processes [7].

Generating electricity from thermal coal-fired power plants contribute to the environmental emission, which includes Green House Gases (GHG). According to the International Energy Agency (2019), thermal coal fired power plants are in operation until the year 2040. The IEA report also stated that 70% of the power generated in Asian countries is produced by thermal coal fired power plants, mainly due to the low cost of coal fuel, which is cheaper compared to other types of fuel, such gas and oil [3, 7]. Besides, operation of thermal coal power plants ensures the security of energy supplies to most Asian countries. Faced with these issues, various strategies have been implemented. Impressively, its results show a decrease in CO_2 emission by 3.3%, which is about 450Mt for 2020. Faced with the pandemic since the end of 2019, the demand for electricity has reduced and consequently led to a decline in emissions from the power sector. In fact, the generation of power electricity from renewable energy sources contribute to lesser emissions into the environment. Figure (1) shows the global electricity mix from 2010 to 2020 [3].

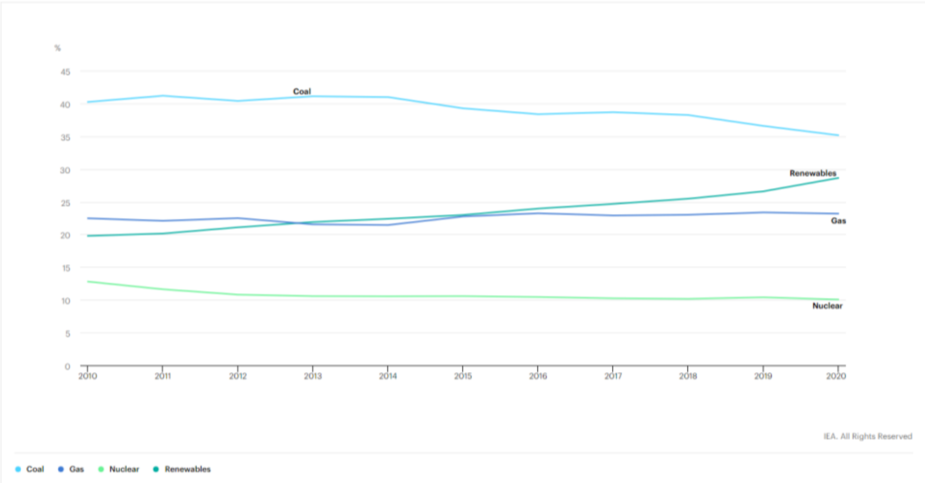

Figure 1. Global electricity mix from 2010-2020

Looking at the change in the power sector from 2010 to 2020, there is a reduction in power generation by thermal coal plants. Reports indicate a 30% reduction in power generation from coal fired thermal plants [7, 16, 18]. This is aligned with the reduction of CO_2 released into the atmosphere from coal and gas plants [5, 12]. Figure (2) shows the change in CO_2 emission according to the power sector.

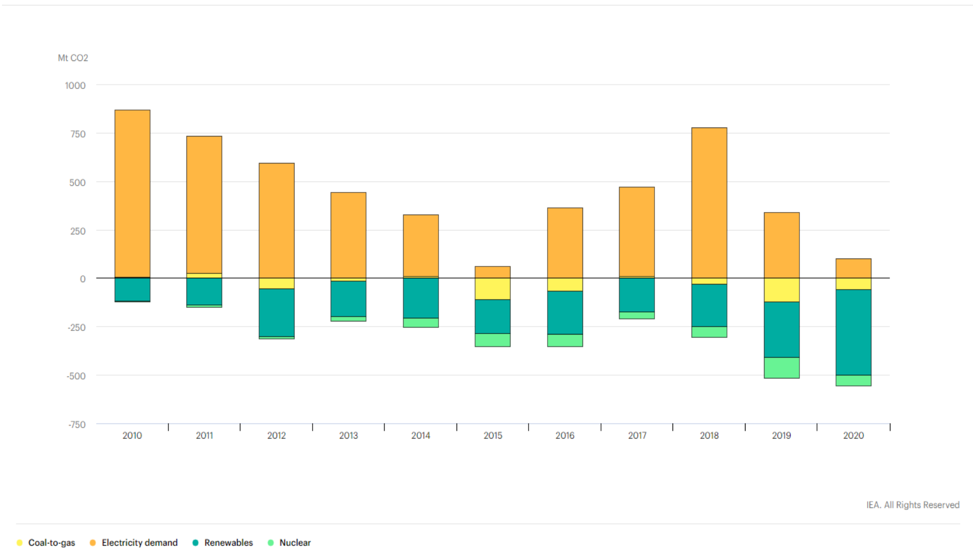

Figure 2. Change in CO_2 reduction by effects

Realizing the commitment to comply with environmental policies, organisations are challenged to improve the amount of emission into the atmosphere. A number of mechanisms, processes and procedures need to be established in the meantime to harmonise the operations electricity producing thermal coal plants [6, 7]. However, to sustain low tariff electricity production, coal was selected to remain in operation. Most Asian countries such as India, China, Thailand, and Indonesia run their thermal plants using coal as the main fuel for producing more than half of the market demand. Besides, the price of coal is the major factor that leads to the economic constrain [6, 9]. Price for coal is cheaper compared to other types of fuel, such as gas and distillate. Coal, as a fossil fuel, contains carbon, hydrogen, sulphur, oxygen and element of acidic. Therefore, the combustion of coal contributes to the emission of SO_2, CO_2, and NOx into the atmosphere [14]. CO_2, NOx and SO_2, which is combustible, is produced during the coal combustion process.. As discussed earlier, the release of CO_2, NOx and SO_2 impacts the emission of greenhouse gases and contributes to the climate change [9].

The release of gas emissions can be minimized by controlling the combustion process. Boiler furnace is the place and function to firm the combustion process in thermal coal plant. The selection of coal for combustion is important for minimizing the impact on the environment as well as optimising performance [14, 15]. Coal is classified according to the coal rank based on different coal characteristics and behaviours. Lignite coal, brown coal, bituminous coal and sub-bituminous coal form the coal rank available in the market. Normally, the coal rank refers to the fixed carbon content in the coal and when the amount of the coal's fixed carbon increases and the amount of volatile matter also increases [7, 9]. Besides that, other coal specifications also impact the coal rank, such as moisture content, ash percentage, and the Hard Grove Index (HGI). Coal combustion in the boiler furnace produce steams with a high temperature and under pressure [5, 16]. Flue gas is a by-product released during the combustion process in the boiler. The boiler is a chamber where the combustion process takes place in the thermal coal plant [8, 9].

Coal, as source of fuel, together with the igniter and oxygen, forms the combustion process. The boiler is a complex medium of change that converts the water phase to the steam phase with the desired temperature and pressure. In order for boilers to create the thermodynamic energy found in steam, they must release energy from a fuel source throughout the combustion process. Combustion is the process of igniting and burning a fuel source [9, 11]. As the fuel source burns, it releases energy in the form of heat which is then used to transform water into steam. In fact, combustion is needed to power the boilers. A combustion reaction occurs when a substance reacts quickly with oxygen (O_2). Coal, as a fuel, contains a percentage of oxygen. Combustion is commonly called burning, and the substance that burns is usually referred to as fuel [5, 9]. The products of a complete combustion reaction include carbon dioxide (CO_2) and water vapor (H_2O). The reaction typically gives off heat and light as well. The general equation for a complete combustion reaction is:

$$\text{Fuel} + O_2 \rightarrow CO_2 + H_2O \qquad (1)$$

The flue gas that is produced during the combustion process is namely the exhaust gas from the combustion chamber or furnace. The flue gas is then continuously removed from the boiler by means of two Induced Draught (ID) fans to maintain an optimum pressure in the boiler [5, 12]. The rotary air heater (RAH) uses the recovered heat from the flue gas to heat cold primary air entering the boiler, thus, increasing the efficiency of the combustion. Next, the flue gas passes through the flue gas desulfurization (FGD) if the level of sulphur dioxide (SO_2) detected is higher than the permissible environmental limit, thus, the FGD is placed downstream of the ID fans [8, 9]. The main purpose of the FGD system is to reduce the amount of SO_2 present in the flue gas prior to being released into the atmosphere through the stack [12, 13]. The FGD flue gas fan is designed to extract the right 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 there is sufficient control of the ID fans. The FGD plant usually consists of one gas handling system and an associated seawater treatment system.

The SO_2 is removed by way of absorption in seawater inside a packed column or also known as the absorber [4, 13]. Components of the FGD operation are described as follows. SO_2 is absorbed by a counter-flowing seawater stream, which is then oxidized to sulphate by blowing air (oxygen) into the stream. Prior to discharge, the acidified seawater effluent undergoes a neutralization process that uses the natural alkalinity present in seawater due to the presence of bicarbonates [5, 19]. In comparison to the conventional wet limestone system, the seawater FGD system offers several distinct advantages in terms of processes, simplicity in design, ease of operation and cost effectiveness [20]. Sea water scrubbing is the most economical FGD process for removing SO_2 from flue gas in the case of power stations located close to the sea. In this process, seawater is used to absorb SO_2 due to the two key properties of sea water [4, 13]. Firstly, seawater is naturally alkaline since it contains bicarbonates that assist in buffering the addition of acid and secondly, the absorbed SO_2 is transformed into sulphate ions, which are natural constituents of seawater. Figure (3) illustrates the flow for seawater scrubbing. The main stages highlighted are the dust collector, sea water scrubber and water treatment plant for treating effluent seawater [5].

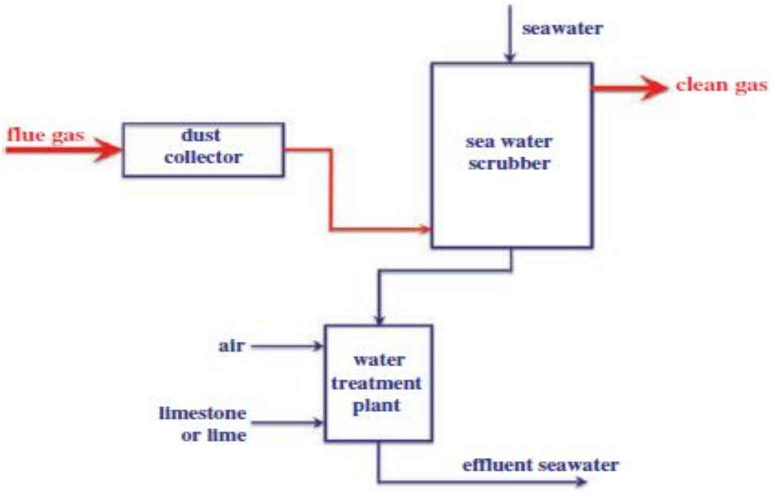

Figure 3. Seawater Scrubbing

The normal water reacts with sulphur dioxide in two stages, which results in sulphite, sulphate and hydrogen ions. The neutralization process occurs in nature [5, 6]. Its acidic condition reacts with the seawater to form a neutral condition. The natural alkalinity forms throughout the mixing process involving seawater and fresh water before it is discharged.

$SO_2 + H_2O \rightarrow 2H+ + SO-$ (2)

$SO_3 + H_2P \rightarrow 2H+ + SO-$ (3)

It is important to understand the FGD process and its function in the thermal coal plant. The FGD procedure and process acts to reduce gas emissions from the thermal coal plant [4, 19]. Therefore, a study is needed to determine the effectiveness of FGD installed at the thermal coal plant. This FGD system could be considered compulsory in a thermal power plant in order to meet environmental requirements [20].

MATERIALS AND METHODS

This experimental method study involved a thermal coal fired power plant, which was installed together with a FGD system for flue gas treatment.

Thermal Plant

This study was conducted at a thermal coal-fired plant that generated a total of 700 megawatts nett to be exported to the national grid system throughout the country. The plant's design was according to world standards, such as the ASME, British and ISO standards. Table 1 shows the specifications of the plant.

Table 1. Thermal Plant Specifications

Thermal System	Value	Unit
Total main steam flow	2235	Tonne/hrs
Reheat steam flow	1950	Tonne/hrs
Main Steam pressure	185	bar
Main Steam temperature	545	°C
Hot Reheat pressure	36	bar
Hot Reheat temperature	540	°C
Condenser pressure	70	bar
Mill coal flow	350	Tonne/hrs
Superheat metal temperature	545	°C
Reheat metal temperature	538	°C

As for the power plant process, the boiler drum and the boiler circulation pump were installed together following two-type concept. According to the power plant design, the thermal plant's efficiency is 35%. This plant was designed with coal-type combustion, condensate and feeding water systems, thermodynamic concept, chemical reaction, standard demineralized water processing, heating the process with high-pressure and low-pressure heaters, pulverization, and flue gas circulation system. The flue gas process and circulation are designed to perform at nominal flow gas, as required by the combustion process. Figure (4) shows the schematic process for the flue gas system at this thermal coal plant.

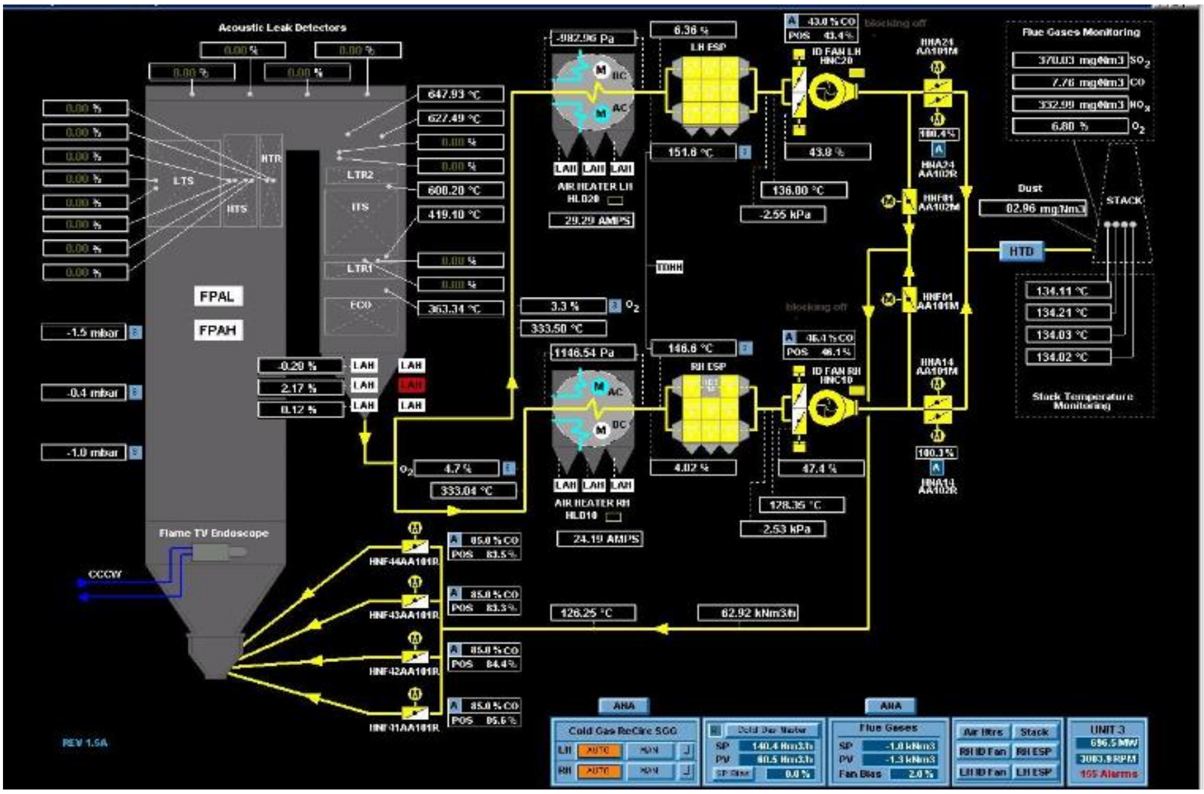

Figure 4. Gas recirculation system

Oxygen in the combustive air mixes with the coal as fuel and produces heat and combustion gases from the furnace chamber. This plant was installed with two Induced Drought (ID) fans, which function to remove flue gas from the furnace into the atmosphere through the chimney. The hot flue gas was induced with energy, which followed the sequences of the process before getting to the ID fans.

FGD Plant Process

The FGD plant process starts with the delivery of the gas to the gas path channel and it is associated with the seawater treatment system. The FGD system installed in this thermal plant has a processing capacity of about 65%, which is about 250 Nm3/hours from the total flue gas flow. Figure 5 shows the FGD schematic diagram at this thermal coal plant.

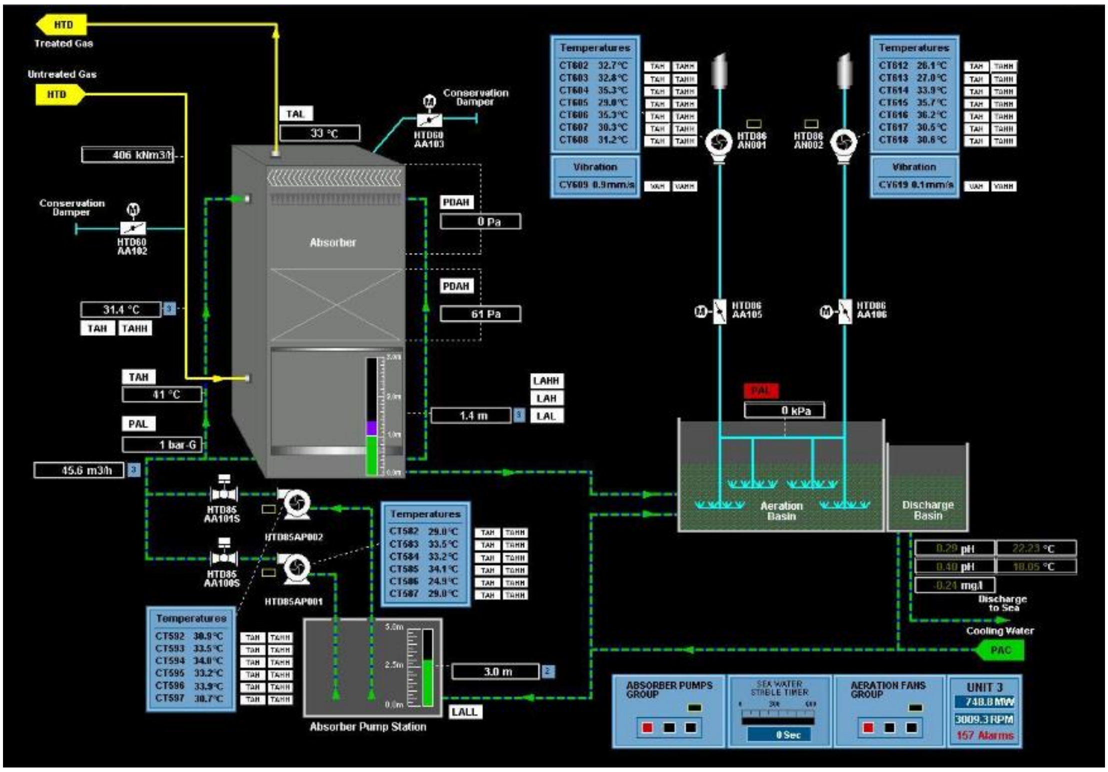

Figure 5. Schematic diagram of the FGD system

The flue gas going into the FGD system was tapped from the main duct of the flue gas outlet and merged into one duct. The flue gas passes through the FGD inlet damper which is handled by the FGD flue gas fan. The FGD flue gas fan functions to boost up the pressure to arrive at the require pressure [7, 9]. In the meantime it avoids a pressure drop at the duct. The guide vane functions to operate and adjust the correct flue gas flow to the FGD flue gas fan. The flue gas goes into the downstream of the gas-gas heat exchanger (GGH). Top of the GGH is for untreated flue gas and it passes through the GGH and downward by entering the absorber inlet. Figure (6) shows the component installed at the FGD system.

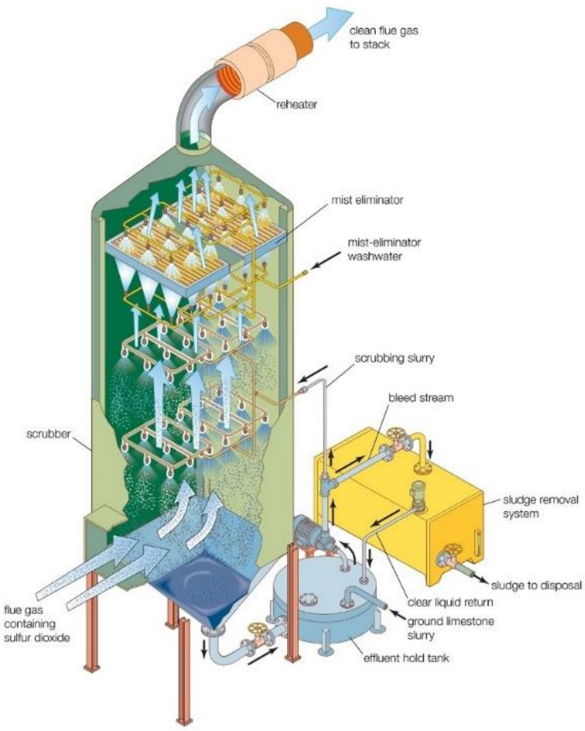

Figure 6. FGD system’s Process Diagram

The flue gas treatment process starts when the flue gas enters into the absorber at the bottom side. The absorber, which functions as a packed tower, is designed to carry out the treatment of flue gas. Seawater flows into the top section of the absorber. Subsequent to passing through a mist eliminator, the treated gas leaves the absorber through the top, and enters the lower section of the GGH. The untreated hot gas in the GGH is transferred by crossing the coal treated gas 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 then increases further to reach the design value. The flue gas is subsequently conducted to the stack. In emergency situations that require a shutdown, the FGD plant may be fully (100%) bypassed.

The main duct will, in such a situation, transports 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, which is succeeded by closing the FGD inlet and outlet dampers. The contaminate flue gas is removed by virtue of bringing into contact seawater and flue gas through the counter current flow within the absorber packing. The flue gas is trapped and moves to the seawater, which leads to seawater being mixed with the flue gas. The seawater treatment plant consists of an aeration basin that functions to oxidise the contaminate flue gas. For example, the seawater treatment removes the SO_2 in the flue gas to the sulphate and the water is then discharged back to the sea. The seawater pH is also measured to determine the acidity of the discharged seawater. The seawater's pH must be below the accepted value according to the environmental guideline and policy.

Coal

Coal is a fossil fuel produced from chemical reactions and contains carbon, hydrogen, nitrogen, oxygen, sulphur and others mineral acidic in nature. For example, coal was analysed through proximate analysis and ultimate analysis. Coal was tested and categorized according to coal calorific value, volatile matter, Hard Grove Index (HGI), amount of carbon content, sulphur content, percentage of ash and moisture content. Coal is categorized according to coal behaviour and coal specification. Currently, the types of coal available in the market are anthracite, lignite coal, brown coal, bituminous and sub-bituminous coals. In fact, different types of coal will result in different performances during combustion and thus, influences the performance of the boiler in thermal plants. As mentioned before, this study was conducted at a thermal coal-fired power plant, which used sub-bituminous coal as the main fuel source. In order to maintain the designed specifications and boiler parameters, six types of sub-bituminous coals were used in this study. Before the coal firing, a coal Certificate of Analysis (CoA) was presented to verify the coal specifications. Table 2 shows the coal quality and characteristics for 6 types of coal selected for this study.

Table 2. Coal quality and characteristic

Coal types	Unit	A	B	C	D	E	F
Calorific value	kcal/kg	4946	4966	4986	5365	5410	5765
Carbon	%	73.3	69.8	74.1	74.7	75.2	77.3
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	%	20.4	20.3	17.9	17.0	17.2	14.9
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	No	47	54	45	50	44	44

RESULTS AND DATA ANALYSIS

FGD performance was measured during the firing of all the six types of coal. For each type of coal firing, the FGD performance was measured based on furnace outlet temperature, FGD inlet temperature, FGD outlet temperature, FGD gas flow, total flue gas flow, different pressure for absorber packing, different pressure for absorber mist and outlet temperature for the absorber. Tables 3 and 4 show the FGD parameters for each type of coal fired for this study. Table 3 shows the FGD parameters for coal type A, B and C with the coal Gross Calorific Value (GCV) of less than 5000 kcal/kg, meanwhile Table 4 shows the FGD parameters for coal type A, B and C with a coal GCV of more than 5000 kcal/kg.

Table 3. FGD parameters for coal types A, B and C

FGD parameters	Unit	Coal Types		
		A	B	C
Furnace outlet temperature	°C	385	389	381
FGD inlet temperature	°C	165	180	173
FGD outlet temperature	°C	156	157	163
FGD gas flow	kNm3/h	1524	1440	1490
Total flue gas flow	kNm3/h	2540	2640	2583
Absorber packing different pressure,	Pa	431	358	441
Absorber mist different pressure,	Pa	41	39	54
Absorber outlet temperature	°C	48	45	47

Table 4. FGD parameters for coal types D, E and F

FGD parameters	Unit	Coal Types		
		D	E	F
Furnace outlet temperature	°C	379	384	383
FGD inlet temperature	°C	183	195	185
FGD outlet temperature	°C	173	171	168
FGD gas flow	kNm3/h	1478	1510	1488
Total flue gas flow	kNm3/h	2610	2578	2605
Absorber packing different pressure,	Pa	341	440	398
Absorber mist different pressure,	Pa	43	47	45
Absorber outlet temperature	°C	54	50	57

FGD data represent the FGD performance and efficiency when operating the SO_2 process. As mentioned earlier, SO_2 is removed from the flue gas by virtue of bringing it into contact with seawater and flue gas through the counter current flow in the absorber packing. The mist eliminator plays an important roles in the environment. The gas-gas heat exchanger (GGH) functions to cool the untreated flue gas from the FGD before it enters the absorber and increases the temperature of the treated gas before it is discharged to the stack. The untreated flue gas in the absorber will go through the mist eliminator, which functions to trap the droplets from being discharged into the environment.

Mist elimination functions to filter the flue gas that passes through the chamber. Mist elimination indicates the efficiency of the FGD process to trap and spray the passing flue gas. Meanwhile, mist elimination function as clogged thru heat transfer on the surface. Before discharging the water to the open sea, the absorber outlet temperature must be below 40°C. By looking at the overall FGD performance, the FGD parameters are plotted on the graphical radar. The graphical radar diagram in Figure (7) shows FGD parameters patterns for all types of coal used in this study. Results show that the equilibrium pattern for all types of coal, which designates the normal reaction and meets the stipulated FGD parameter design.

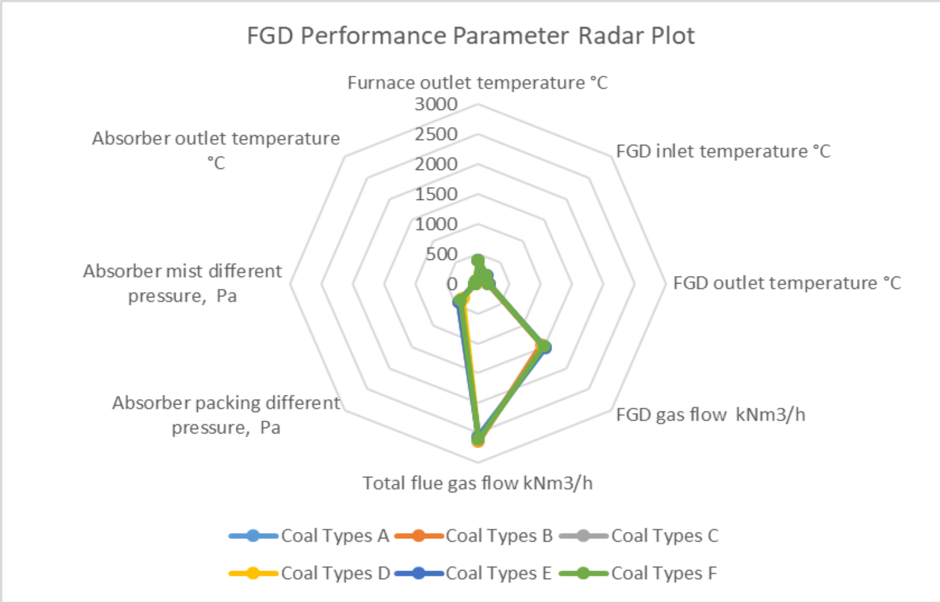

Figure 7. FGD Performance Parameters

Effectiveness of overall process is determined by the mist eliminator. Efficiency of the mist eliminator increases the effectiveness of the FGD system's operations when fully functioning. In addition, the mist eliminator protects and prevents the equipment and the FGD system's infrastructure from corrosion. Thus, from an economical aspect, it extends the life cycle of the plant. This study also measured the SO_2 mg/Nm3 in flue gas production for all types of coal. Table 5 shows the amount of SO_2 mg/Nm3 emitted into the atmosphere in responses to the FGD vane opening percentage. This study found that the greater the vane opening percentage in the FGD treatment process, the greater the SO_2 released into the atmosphere. The FGD bypass indicates that the flue gas system goes thru the draught system without treatment process in the FGD system. This indicates that the coal type F with a coal CV at 5765 kcal/kg releases more SO_2 compared to other coal types.

Table 5. Flue gas monitoring for SO_2 mg/Nm3

Coal Type	FGD Bypass	FGD 25%	FGD 50%	FGD 75%	FGD 100%
A	295	280	245	221	198
B	303	271	262	218	215
C	315	302	281	256	224
D	333	300	285	275	245
E	331	298	262	255	231
F	356	300	287	243	221

Table 6 represents the amount of CO mg/Nm3 emitted into the atmosphere in response to the FGD vane opening percentage. With the FGD bypass condition, coal type F with a coal CV of 5765 kcal/kg releases about 92.5 mg/Nm3 of CO, which the highest compared to other coal types. Meanwhile, coal type A, the lowest coal CV at 4946 kcal/kg releases less CO compared to other coal types. Thus, it indicates the relationship between CO and the coal CV that is released into the atmosphere.

Table 6. Flue gas monitoring for CO mg/Nm3

Coal Type	FGD Bypass	FGD 25%	FGD 50%	FGD 75%	FGD 100%
A	69.8	65.1	64.1	60.3	58.4
B	76.5	75.0	73.0	68.2	65.0
C	80.5	80.2	68.0	65.2	62.3
D	86.1	78.2	75.4	70.2	65.4
E	88.5	85.3	80.4	77.4	70.2
F	92.5	90.1	85.2	80.2	75.2

This study also measured the percentage of CO_2 emitted into the atmosphere based on the types of coal fired in the boiler furnace. Based on the results shown in Table 7, coal type A released more CO_2 compared to other coal types. This indicates that the more FGD vane opening throughout the FGD for the treatment, lesser the amount of CO_2 percentage released into the atmosphere.

Table 7. Flue gas monitoring for CO_2 %

Coal Type	FGD Bypass	FGD 25%	FGD 50%	FGD 75%	FGD 100%
A	3.99	3.67	3.43	3.33	2.70
B	3.75	3.56	3.33	3.25	3.10
C	3.77	3.50	3.40	3.25	2.85
D	3.60	3.48	3.33	3.15	2.60
E	3.43	3.32	3.15	2.80	2.53
F	3.32	3.21	3.11	2.65	2.34

The NO_2 was measured during the firing of all coal types in this study. The results shown at Table 8, coal type A released less NO_2 at 443 mg/Nm3 compared to other coal types at the FGD bypass condition. Meanwhile, coal type F released more NO_2 at 480 mg/Nm3 under the FGD bypass condition. In fact, more NO_2 was released into the atmosphere if the FGD vane opening was less, and a lesser treatment for the flue gas.

Table 8. Flue gas monitoring for NO_2 mg/Nm3

Coal Type	FGD Bypass	FGD 25%	FGD 50%	FGD 75%	FGD 100%
A	443	400	388	345	325
B	450	420	414	410	388
C	445	440	400	368	354
D	454	442	430	412	397
E	475	454	431	388	354
F	480	456	434	421	412

Dust is made of fine particles of solid matter. This study measured the percentage of dust released during the firing of all coal types. Coal types F released a greater percentage of dust compared to another coal types, and coal type D released less dust at 45 percent only. Besides, the result for coal dust percentage is uncertainy and insignificant to the coal CV relationship. However, to minimize the percentage of dust released into the atmosphere, opening of the FGD guide vane should be increased. During this study, the coal dust was in the form of a fine powdered coal, which was created by the crushing, grinding, or pulverizing of coal. Results for the percentage of dust for all types of coal are shown in Table 9.

Table 9. Flue gas monitoring for Dust %

Coal Type	FGD Bypass	FGD 25%	FGD 50%	FGD 75%	FGD 100%
A	69	60	55	51	47
B	65	60	51	45	30
C	60	44	40	25	20
D	45	42	35	30	25
E	74	70	67	61	52
F	86	78	71	66	60

Fly ash and condensed sulphur trioxide (SO3) are the major components of flue gas that contribute to the opacity of a coal plant's stack emission. Therefore, the percentage of opacity content in the flue gas was measured for this study. It was found that coal type A recorded the highest percentage of opacity compared to other coal types with the same FGD bypass condition. Meanwhile, coal type F recorded the lowest percentage of opacity content in flue gas, at 15 % compared to other types of coal.

Table 10. Flue gas monitoring for Opacity %

Coal Type	FGD Bypass	FGD 25%	FGD 50%	FGD 75%	FGD 100%
A	19	18	16	15	11
B	18	18	15	12	10
C	16	18	14	13	12
D	20	20	18	16	15
E	18	18	15	13	12
F	15	12	10	10	10

The study also found that SO_2, NOx, CO, CO_2 and Opacity at the flue gas outlet increased when the sulphur content in the coal increased. SO_2, and other gasses were measured online at the stack, which was 200 meters high. Figure (8) shows the plot graph comparing the SO_2 and the sulphur content for each coal type.

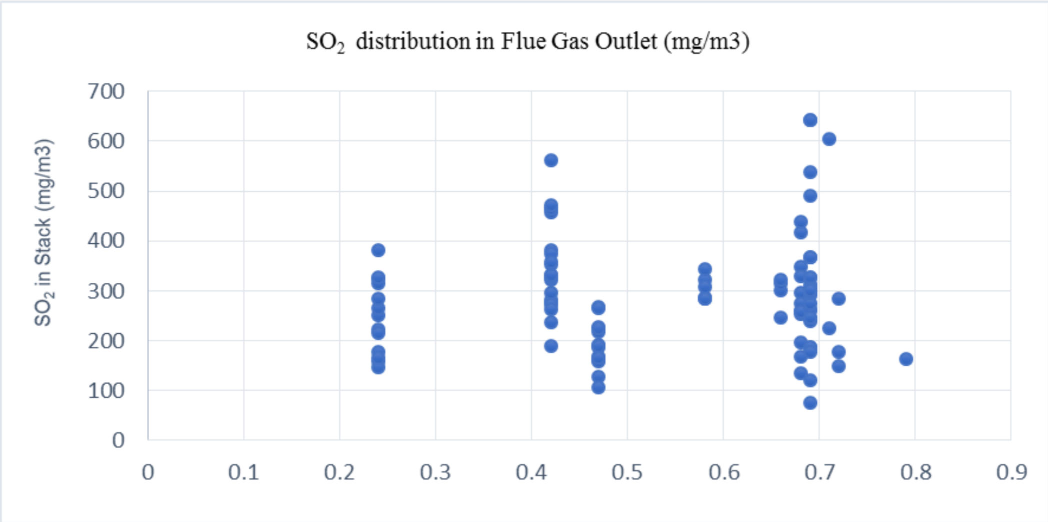

Figure 8. SO_2 distribution in Flue Gas Outlet (mg/m^3)

DISCUSSION AND CONCLUSIONS

As the main fuel for thermal coal-fired power plants, coal consumption increased on a yearly basis. The US is projected to increase coal consumption by about 16% this year compared to 2020. The global coal demand reached a peak of 946.3 million tons in August 2015 and increase by 1-2% until the year 2020. Flue gas emission impacts human health, the environment and contributes to environmental disasters. In efforts to balance human needs, the environment, and economics, power generation that uses coal-fired power plants are required for maintaining the grid system. Sustainability and security of the grid system are essential factors that help maintain the operation of coal-fired power plants. The FGD system can comprehensively reduce flue gas emission into the atmosphere. This study was conducted to gauge the effectiveness of FGD. FGD operational parameters, such as FGD flue gas outlet temperature, different pressures for absorber packing, FGD flue gas inlet temperature, flue gas discharge temperature and other FGD parameters must be closely monitored and managed. FGD parameters are a significant indication of the effective operations of the system.

In order to determine the effectiveness of the FGD system, this study was conducted in one of the thermal coal power plants located in an Asian country with a total capacity of 700 megawatts. The study found that different types of sub-bituminous coals led to the removal of varying percentages of SO2 and other gasses, such as NOx, CO, CO2, and Opacity. Findings show that when the FGD system is in service in a thermal power plant, approximately 30% to 50% of contaminate gasses are emitted, resulting in a high effectiveness level of 30% to 50%. This study also found that coal with a high GCV of more than 5000 kg/kcal recorded high temperatures at the flue gas outlet and did not affect the amount of gas emission released into the atmosphere. Further studies are needed to investigate the efficiency of FGD's performance. An efficient FGD process affects the auxiliary power consumption of the thermal coal plant.

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