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Effect of Coal with High Moisture Content on Boiler Operation Parameters at Thermal Coal Fired Power Plant

[1] *S. Salmi*, [2] *A.A. Nuraini*

[1] Department of Mechanical and Manufacturing, Universiti Putra Malaysia, Serdang, Selangor,

[2] Department of Mechanical and Manufacturing, Universiti Putra Malaysia, Serdang, Selangor

Email: [1] nasmiesan@gmail.com, [2] nuraini@upm.edu.my

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ABSTRACT

Focus on developing county, the electricity industry plays important roles. In fact, energy drives the national growth in supporting the other industries. Most developing country produce electrical energy through thermal coal plant and is recorded above 70 percent of total Asian capacity. Coal is still a choice as the main fuel in thermal coal plant due to cheaper price compared to another type of fuel, distillate or gas. However, coal performance is uncertain due to the different characteristics and coal types. Coal must be tested and analyzed before fired into the boiler. Problematic coal may cause issued to the boiler furnace such as ash slagging and fouling, ash corrosion, tube leak, and consequently impacts to the boiler efficiency. Therefore, this study purposely to investigate the effects of sticky coal on the boiler operation parameters. The study found boiler pressure deviation was fluctuated badly to minus 25bar, coal flowrate was decreased to minus 5 tonnes per hour during firing coal with high moisture content. By looking at pulverizer parameters, mill different pressure at bowl was decreasing, mill motor current was increased about 5 Amps and primary air to carry the pulverized fuel increased accordingly. From this study, the main factor of sticky coal is due to high moisture contents. Hence, to minimize the high moisture contents, coal not recommended to remain in the yard for a long time.

1. Introduction

Thermal energy in Asia remains a major electricity source, with coal-fired power plants in China alone generating almost 75 percent of electricity.

According to EDF website, Coal-fired power plants in China are expected to continue to account for the majority of the country's electricity till 2030 [2], [14]. The medium term outlook for thermal coal in Southeast Asia is positive. The region is likely to see a continuation of growing energy demand on the back of strong demographic trends which underpin a strong regional economic growth profile. Southeast Asia today is viewed as the last likely bastion of strong growth in coal demand globally. But just as Indian coal-fired power generation fell an entirely unprecedented 26TWh or -3% during 2019, with expected for sustained decades-long growth in Southeast Asian coal-fired power generation is far from a locked-in certainty. Southeast Asia has been seen as a potential growth market for big thermal coal producers such as Australia and Indonesia as other parts of the world move toward cleaner energy [4] [6]. The International Energy Agency (IEA) has forecast coal-fired generation in the region to grow by around a third over the next five years to meet strong electricity demand growth. Of all the fossil-fuel sources, coal is the least expensive for its energy content and is a major factor in the cost of electricity in most countries [12]. However, there are several types of coal with different characteristic.

Coal is the combustible product. The coal rank refers to the increase of fixed carbon number and proportionally to the decrease of volatile matter and moisture content [2]. The sub-bituminous coal is commonly used for the thermal coal power plant because the coal is softer with higher content energy density [2] [3]. The selection of the coal types is the main aspect during the design stage for the boiler at the coal plant. Total carbon content, percentage of ash, sulphur content, oxygen contents, percentage of moisture are the coal specification to analyse before fired in the boiler. Hence, the impact of ash slagging and ash fouling from the combustion product affected to boiler performance [2], [13]. Consequently, the problematic coal can cause molten ash during combustion in the furnace, overheat of the boiler tube, and limited generation of the boiler capacity [3].

Most scholars agreed, the rank of coal indicates its chemical constituents. The content of volatiles, porosity, inherent moisture and reactivity for the coal is the criteria for coal classification [3] [9]. There are different classifications of coal or coal ranks between countries. The coal heating value is the energy of coal calorific value when measuring the ability of the coal to produce heat. Consequently, coal with high moisture content and high ash content, relatively with low calorific value [2], [3]. Moreover, coal behavior also reflected with fixed carbon which coal fixed carbon means carbon not held in hydrocarbon compounds [2]. Carbon will react and oxidation occurs even at ambient conditions. However, the moisture content of the coal significantly reduces the rate of reaction of the coal fix carbon to the environment.

Coal pulveriser or called as mill or grinder purposely to pulverized coal to fine particles for efficient combustion in the boiler [19] [22]. A pulveriser or grinder is a mechanical device for the grinding of many different types of materials. Moreover, pulveriser in the thermal coal plant is to deliver light fuel oil or coal as one of the primary elements of fuel in an ideal condition for combustion to take place in the boiler combustion chamber [4] [21]. Therefore, heat energy is released to convert the boiler water into superheated steam for electricity generation [11].

thermal Coal fired power plant

The power plant designed to produced 700MWn, installed with boilers are of sub-critical pressure, single reheat and controlled circulation type [9]. This boiler is fired with pulverised coal to produce steam for the continuous generation of 700 megawatts (MW). The boilers are designed to fire coals within the bituminous rank. The combustion circuit consists of a single furnace, with direct tangential firing and a balanced draught system [4] [17].

The firing equipment consists of four elevations with 16 burners, remote-controlled fuel oil burners equipped with high energy ignitors, used to start-up the boiler and to support combustion of the pulverised coal at low firing rates. Boiler Maximum Continuous Rate (BMCR) was designed 40 percent of an oil burner, seven elevations of pulveriser with a total of 28 coal burners located just above or below a fuel oil burner [4], [15]. The capacity of coal burners is 100% BMCR when firing coal within the design range. All the burners are located in the furnace corners with designed as tangential firing. Figure 1 shows the two-pass drum types opposed-fired boiler with a single back pass thermal coal plant.

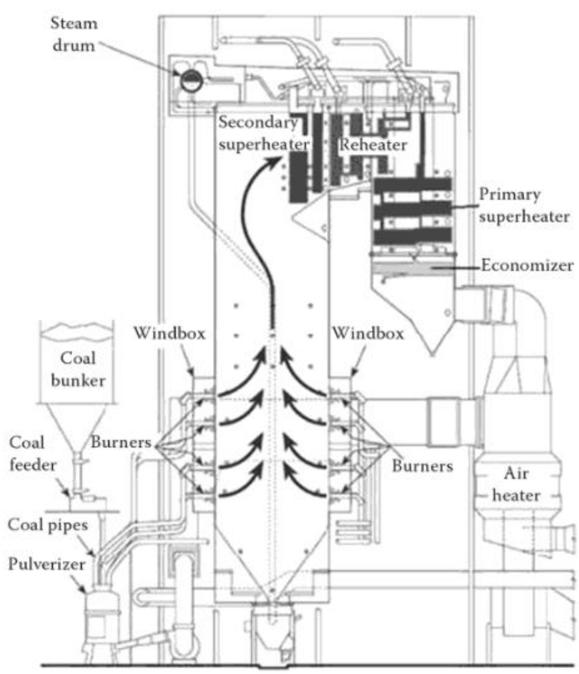

Fig I: Two pass drum types opposed-fired boiler with single back pass

At BMCR, the main superheated steam operation at temperature 540 ˚C and 185 bar boiler pressure. Superheated steam flow produce 2390 tonne/ hrs with steam temperature at reheater operating at 540 ˚C with pressure at 32 bar reheater steam pressure. In normal operation, sub-bituminous coal was used as main fuel with coal calorific value above 4800 kcal/kg and ash content below

10 percent. At full capacity of the BMCR, the total combustion air flow for this power plant is 2120kNm3/hrs and total primary airflow required for mill to transport the pulveriser fuel is about 570kNm3/hrs [16].

For this coal plant, was installed with 7 vertical bowl pulveriser or called as mills [4]. The firing equipment consists of seven elevations with 28 coal burners located just above or below a fuel oil burner. The capacity of coal burners is 100 % BMCR when firing coal within the design range. The pulverizes and burners system provides pulverized coal to the boiler as primary fuel. Coal enters the plant from the coal handling system where it has been crushed to consistent sizes where it can be handled by the pulverizes [8], [22]. It is delivered to the coal bunkers which are located directly above their respective pulverizes, also called mills. Hot and cold primary air is used to maintain the pulverized coal temperature. The air enters the pulveriser through nozzles in the air pot ring, which surrounds the grinding table to dry and transport.

2. PROBLEM STATMENT

Industries are going to face critical demand when there are restrictions on coal stock, limited coal with good quality. Hence, as a preparation for future needs, the firing of distinct types of coal need to be studied as it will give an impact on the boiler parameters. It is crucial to conduct the study especially when the coal is not meet the designed boiler operation in the thermal plant. This is because the effect on boiler performance will give an impact on boiler performance efficiency.

3. METHADOLOGY

Coal specification, 2 types of coal with different characteristic was used for this study. Coal types A is a preferred coal which means coal was fired during commissioning of this plant. During commissioning period, the boiler operation parameters was recorded as benchmarked and operated to meet the coal specification and characteristic [7], [11]. Coal types B, alternative coal with different coal specification was introduced to this power plant. Alternative coal was fired for 5 days as trial burn period to measure and indicate the impacts at the boiler operation parameters.

Table I: Sub bituminous coal specification for coal type A and coal type B

Coal Specification	Unit	Coal Type A	Coal Type B
Calorific value	kcal/kg	4852	5113
Carbon	%	74.30	74.13
Hydrogen	%	4.97	5.42
Nitrogen	%	0.91	1.49
Oxygen	%	19.67	18.33
Ash	%	2.50	6.20
Moisture	%	28.4	23.4
Sulphur	%	0.10	0.45
HGI	Number	47	43

The coal analysis was carried out at the coal supplier laboratory. For the coal quality, the measurement was carried out through proximate analysis and ultimate analysis [4], [6]. During the trial burn period, boiler is fired with the same coal for 3 days continuously without any interruption. Data were collected using the numerical plant performance data. Average of the parameters was firmly keep recorded.

During unloading coal process, visual inspection was carried out at coal yard. Coal was unloading from shipment to coal stock yard. Before transport to the coal bunker for firing, sample of coal was taken to verify the coal characteristic [10], [11]. Analysis of coal was performing and compared with the existing Coal of Analysis (COA) delivered from the supplier. There is no issues and problem accrued during handling coal types A. From visual observation at coal yard for coal types B, there is no significant issues on handling this types of coal as well. Indeed, coal handles properly and there are no incidents of belt skewing due to coal sticking to the belts. Several incidences of self-heating were observed and no significant slumping observed. However, there were 2 incident of mill chute block was reported. Figure II shows the stacker and reclaimer at coal stock yard attached at this plant. Figure III shows the coal at conveyor line transport from the coal yard to the coal bunker.

Figure II: Stacker at coal yard

Figure III: Coal transport via coal conveyor line

performance and data analysis

For the plant performance, boiler operation parameters and pulverise operation parameters was monitor and record. Boiler operation parameters was recorded to ensure boiler operating within limit and generate with full capacity 700MW during the trial burn period. Besides, boiler parameters essentially important to measure the power plant performance in total [4]. Table II shows the boiler operation parameters during trial burn period for coal type A and coal type B.

From the table, coal type A operating at normal parameters with load output average at 685 to 700 MW. Steam superheated at 540 ˚C and in normal condition which supported with superheated steam flow is still below 100 tonne/hrs. Hence, the boiler temperature easily manages and control by the machine. Reheater steam temperature and reheater spray water is manageable and operate within the acceptance limit. Flue gas temperature for coal types A is between 160 ˚C to 185 ˚C before enter the electrostatic precipitator (ESP) installed and power plant, indicated normal discharge of flue gas temperature at stack below 40 ˚C which allowable by this country.

Table II: Boiler operation parameters recorded during trial burn period for coal type A and coal type B.

Operation	Unit	Coal Type A			Coal Type B		
Parameters	Day	1	2	3	4	5	6
Measured MW (gross)	Megawatt	737.2	737.3	737.1	733.1	734.2	733.4
Measured MW (net)	Megawatt	685.5	685.8	685.9	681.7	681.4	681.2
Boiler actual pressure	Bar	185	186	186	188	187	188
Boiler sliding pressure	Bar	186	186	187	185	185	185
Boiler pressure deviation	Bar	0.1	0.2	0.2	-3.1	-2.6	-2.8
Steam superheated	˚C	540	540	540	538	539	543

temperature		.7	.2	.2	.4	.4	.1
Reheater steam temperature	˚C	540.5	539.0	540.3	538.7	539.5	543.9
Superheated spray water flow	Tonne/hrs	50.1	65.5	65.9	119.1	130.1	125.1
Reheater spray water flow	Tonne/hrs	0.3	0.1	0.2	0.9	1.6	1.0
Furnace rear path temperature	˚C	743.2	741.0	734.5	781.0	785.8	761.8
Flue gas temperature	˚C	165.1	166.8	169.1	174.6	180.9	172.5

Boiler operation parameters for coal type B is slightly higher compared to coal type A. Steam superheated temperature and reheater steam temperature still within limit but spray water was indicating at high volume. Spray water for superheated steam and reheater steam opening was increase to control the temperature [4], [9]. From the table, is significantly different on boiler pressure deviation between coal type A and coal type B. Boiler pressure deviation indicates the pressure required by the boiler in generating same amount of steam to produce same megawatt. Decrease on boiler pressure shows that not enough energy to convert the heat.

In addition, the pulveriser operation and parameters was recorded accordingly during trial burn period. Pulveriser is important to process the coal become pulverise fuel by reducing the size of coal. As shown in Table 3, the motor amps for coal type B is slight less compared to the coal types A which indicated the hardness of the coal. Besides, coal feeder flow for coal type B is more compared to coal type A in generating the same amount of megawatt. Looking at the PA flow and temperature, is shows the coal types B is more wet compare to coal type A. More air flow requires for coal type B to meet the coal temperature setting at 280 ˚C before enter to the boiler furnace. Summary of pulveriser parameters including motor amps, coal flow, and PA flow was shows in Table III.

Table III: Average mill operating parameters with mill 10 in standby mode

Parameter	Unit	Coal Type A			Coal Type B		
Duration	Day	1	2	3	4	5	6
Coal mill motor power	KW	457.1	454.8	439.0	428.6	426.2	421.0
Mill motor current	Amps	86.6	92.6	89.7	84.7	84.0	82.4
Feeder coal flow	Tonne/hrs	54.2	53.5	54.1	57.4	57.6	58.3
Mill PA corrected inlet flow	kNm3/h	101.5	101.3	101.4	106.5	109.6	107.3
Mill PA inlet temperature	˚C	273.7	265.9	255.9	289.2	305.3	286.3

During boiler operation, observed the load was disturbance between range 5-6 MW which is due to pressure deviation. Reheater temperature inlet and outlet not meet the set target value 540 ˚C. Reheater temperature is between 520 ˚C to 530 ˚C and cause efficiency decrease. Mill coal flow about 56-58 ton/hrs which is slightly different compared to previous coal type A about 55-53 t/hrs. Mill motor current shows minimum impacts on motor amps but not significantly affects to the pulverize performance in total. Figure IV shows the pulverizes performance for the power plant on generating at steady load, 700MW.

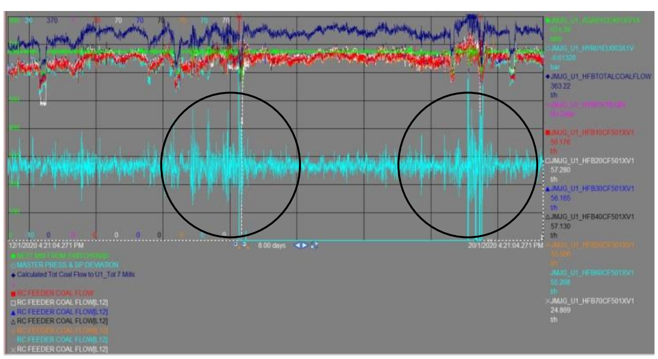

Fig IV: Pulverise performance

Nominal designs for pulveriser equipment require coals with moisture content between 8 percent and 12 percent. Each two percent of moisture increase will reduce output by approximately 5 percent to 6 percent, up to hot air flow limit. Once hot air capacity is reached, each two percent of moisture would result in approximately 15 percent fall in output. Increase in the moisture content of the fuel will cause a fall in the mill outlet temperature, which in turn will demand that the mill inlet temperature should rise. Consequently, the hot air density is reduced, and since the air/fuel ratio is a function of mass flow, the net result is a fall in the mill output capacity.

Figure V shows some typical effects of increasing moisture on mill output performance. The percentage of the moisture will influence the percentage of the mill performance because of the need of more air inlet to the mill system. More air will be required to dry the moisture content of the coal before it enters the boiler for combustion. In fact, coal with high moisture content will give significant impact to the combustion process.

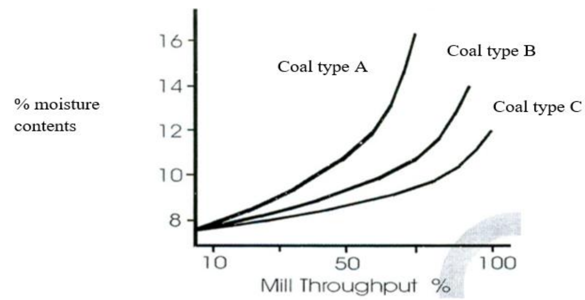

Fig V: Moisture content and mill performance

Some Ball Tube type mills however have a “Boost Gas” arrangement, which allows furnace bottom gas to enter the mill system in order to boost this temperature and thus aid the drying process [2]. This type of mill has a much greater mass of metal necessary to dissipate the heat and prevent the mixture temperature from rising to abnormal levels, while limiting oxygen content in the atmosphere. Therefore, the risk of spontaneous ignition is greatly reduced. Similarly, other systems use steam, CO2 or nitrogen as inerting media, but these are systems provided for the safety of the plant and are not to be used for general operation of the plant. Indeed, use of these systems to control the plant have resulted in catastrophic and dangerous mill system fires [5], [6].

Further investigation was carried out; the boiler furnace was fluctuating between -1.0 to – 2.5 mbar. This is due to melt coal was fall down at furnace area. Induced drought (ID) fan was responding accordingly to ensure boiler furnace pressure at optimum level, setting at – 1 mbar. In facts, when the pressure in combustion area of the boiler is less than atmospheric pressure [4] [11]. This is achieved in balanced draft boilers by using Forced draft fans to force air into boiler (pressuring it) and Induced draft fans to remove air from the boilers to create negative pressure. Observation during firing coal type B during trial burn period as shows in Figure VI.

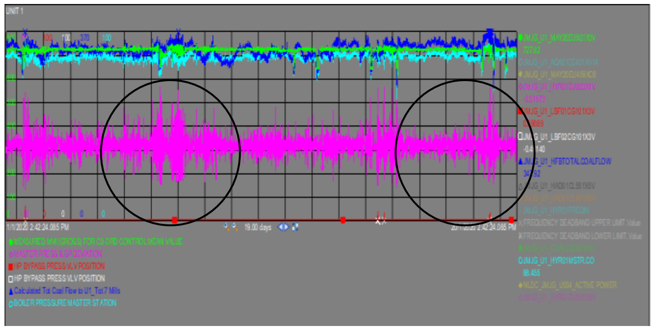

Fig VI: Boiler operation parameters

Figure VII shows the boiler furnace rear path temperature fluctuated during firing wet coal. Furnace rear path increase up to 780℃ compared to normal operation value between 700-760℃. Increasing of rear path temperature impacts to the heat transfer process at the back path of the boiler, consequently cause high temperature at the boiler tube surface.

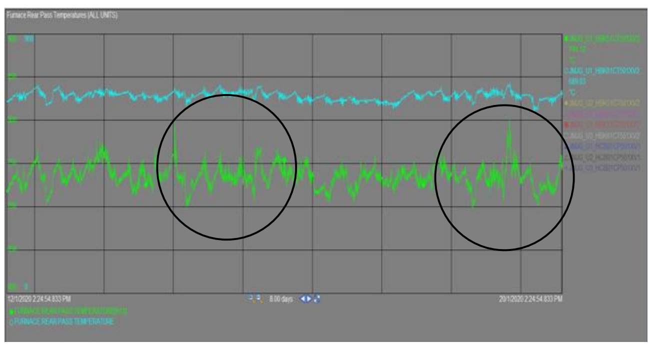

Fig VII: Boiler furnace rear path temperature

From the data captured during trial burn period, the coal type B to retest the coal analysis. The coal testing was carry out at local laboratory. For the coal retesting, the measurement was carried out through proximate analysis and ultimate analysis. Table IV shows the retesting result for coal type A and coal types B at the laboratory.

Table IV: Retest result for coal specification Type B

Coal Specification	Unit	Coal Type A	Coal Type B
Calorific value	kcal/kg	4830	4810
Carbon	%	73.80	74.01
Hydrogen	%	5.25	5.45
Nitrogen	%	1.29	1.47
Oxygen	%	19.10	19.45
Ash	%	5.70	5.80
Moisture	%	30.5	32.4
Sulphur	%	0.45	0.45
HGI	Number	45	45

The results show coal type B has high moisture content which is 32.4 percent. The moisture value given for a proximate analysis is the moisture measured as mass lost from a sample under specified conditions after heating in a moisture oven to 104 to 110°C (ASTM method D3173-11 [2], [17]. Moisture absorbs heat, so high moisture content in coal reduces the relative efficiency of heating when a coal is combusted [14]. The coal calorific value and carbon content for coal type A and coal type B almost similar. More volume tonnage of coal is requiring to produce full capacity of BMCR of the boiler.

4. Conclusion

The critical moisture content at which the coal is most highly prone for spontaneous combustion was also obtained. It was found that different ranks of coal have different critical moisture contents [2], [19]. For lignite and anthracite, the critical moisture content was 25% and 20%, respectively. It was found that, for different ranks of coal, the effect of the moisture content can be quite different and for the same rank of coal, different moisture contents will affect the coal's performance in very different ways.

Moisture absorbs heat, so high moisture content in coal reduces the relative efficiency of heating when coal is combusted [20], [21]. This is why low-rank, high-moisture coals have lower calorific values (Btu/lb) than high-rank, low-moisture coals [2]. Moisture adds weight to coal, and also contributes to spontaneous combustion in low-rank coals. Therefore, the coal with high moisture content impacts the boiler performance parameters and pulveriser system as well.

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