UNIVERSITI PUTRA MALAYSIA

EFFECTS OF SUB-BITUMINOUS COAL ON BOILER PERFORMANCE

SALMI BIN SAMSUDIN

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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January 2018

Chairman : Nuraini bt Abdul Aziz, PhD
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In Malaysia, coal-fired generation represents about one-third of the installed power generation capacity and accounted for nearly 43% of the electricity produced in 2014. Due to low cost in power generation, most of the developing countries use coal as the main fuel at power generation plants. During commissioning stage, boiler operation will be designed and tuned as per coal specification and environmental requirement factors. With limited source of coal for sub-critical boiler, this study measure the available coal that can be used. However, coal with different characteristic will affect the boiler performance and parameters. The objective of the study is to analyze the boiler operation performance, boiler efficiency, energy losses which is accomplished during combustion process which used from sub-bituminous coal as the main fuel. The best coal will be determined during the study and can be chosen to replace the existing coal by considering the results. The study was performing at a thermal coal power plant which has sub-critical boiler, reheat and coal fired boilers with a nominal rated power output of 700MW. The technical specification of the boiler includes the specification of main-steam piping, cold reheat steam piping and hot reheat steam piping. The boiler concepts are two-pass type boiler and drum with control circulation. During the study, numerical plant performance data was extracted from the data logging system for the whole period and presented in graphical view showing the pattern. Boiler efficiency was measured using direct method and indirect method, was found that coal with different Calorific Value (CV) and properties give different efficiency values to the boiler. The results show the sub-bituminous coal with CV 5013 kcal/kg similarly perform similar to designated coal with CV 4852 kcal/kg. Besides that, the superheated steam and reheater steam for coal CV 5013kcal/kg perform at normal value which is close to 540°C setting point. The desuperheater spray water flows operate between 18-25 t/h with minimal operational to achieve the target value, 540°C. The metal temperatures for superheated and reheater tube still within limit value, 550°C. In addition, the results convey the properties of coal contribute to the major energy losses during the combustion process in the furnace.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KESAN ARANG BATU JENIS SUB-BITUMIN KEPADA PRESTASI DANDANG

Oleh

SALMI BIN SAMSUDIN

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Di Malaysia, penjanaan arang batu mewakili kira-kira satu pertiga daripada kapasiti penjanaan kuasa yang dipasang dan menyumbang hampir 43% daripada tenaga elektrik yang dihasilkan pada tahun 2014. Berikutan kos yang rendah dalam penjanaan tenaga, sebahagian besar negara-negara membangun menggunakan arang batu sebagai bahan api utama di loji penjanaan kuasa. Semasa sesi mula tugas, operasi dandang akan direka dan mengikut spesifikasi arang batu tertentu dan juga keperluan faktor alam sekitar. Dengan sumber arang batu yang terhad, untuk dandang separa kritikal, kajian untuk penggantian arang batu alternatif perlu dilakukan. Namun begitu, arang batu dengan ciri-ciri yang berbeza akan memberi kesan kepada prestasi dandang dan parameter. Justeru, objektif kajian ini adalah untuk menganalisis prestasi operasi dandang, kecekapan dandang, dan pengauditan tenaga yang dicapai semasa proses pembakaran yang menggunakan arang batu jenis sub-bitumen sebagai bahan api utama. Jenis arang batu terbaik akan diketahui selepas melihat kepada hasil kajian dan arang batu terbaik ini boleh menggantikan jenis arang batu sedia ada. Kajian ini telah dijalankan di loji kuasa arang batu termal dengan dandang subkritikal, bersama proses pemanasan semula dan arang batu dandang dengan nilai output kuasa sebanyak 700MW. Spesifikasi teknikal dandang juga diberikan termasuk spesifikasi paip utama stim, paip panas semula wap sejuk dan paip stim panas semula panas. Dalam kajian ini, semua data berangka prestasi loji diekstrak daripada sistem historian bagi sepanjang tempoh ujikaji. Data kemudian dibentangkan dalam bentuk paparan grafik untuk melihat pattern keseluruhan. Seterusnya, kecekapan dandang diukur dengan menggunakan kaedah langsung dan kaedah tidak langsung pada akhir kajian. Selain itu, kajian turut dijalankan kepada faktor sususan kongfigurasi pengisar dalam proses pembakaran dan kesannya kepada dandang dan pengoperasian dandang. Hasil kajian mendapati bahawa arang batu dengan berbeza Nilai Kalori (CV) dan ciri memberikan kecekapan yang berbeza untuk dandang. Keputusan juga menunjukkan arang batu sub-bitumen dengan CV 5013 kcal/kg memberi ciri-ciri dan impak yang hampir sama

seperti arang batu CV 4852 kcal/kg yang digunakan semasa loji mula tugas. Selain itu, wap panas lampau dan wap pemanas semula untuk arang batu CV 5013kcal/kg juga memberi nilai ketetapan yang sama iaitu 540°C. Aliran air semburan beroperasi antara 18-25 t/h yang mana melibatkan minimum operasi untuk mencapai nilai sasaran, 540°C. Selain itu,bacaan suhu tiub untuk panas lampau dan tiub pemanas semula masih dalam had nilai, 550°C. Di samping itu, keputusan kajian juga telah mengenalpasti faktor yang menyumbang kepada kehilangan tenaga utama semasa proses pembakaran dalam dandang.

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I had a very enjoyable study at Universiti Putra Malaysia (UPM). Not only, does it have a beautiful natural environment but the university also has helpful staff.

InsyaAllah, I will keep all the awesome memories, permanently parked in my heart. Thanks to all involved. May Allah bless all of you.

I certify that a Thesis Examination Committee has met on 24 January 2018 to conduct the final examination of Salmi bin Samsudin on his thesis entitled "Effects of Sub-Bituminous Coal on Boiler Performance" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Degree Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ASTM	American Standard for Testing and Materials
BCP	Boiler Circulation Pump
BFP	Boiler Feed Pump
BMCR	Boiler Maximum Capacity Rate
CEP	Condenser Extraction Pump
CV	Calorific Value
DC	Direct Current
DCS	Display Control System
DOSH	Department of Safety and Health
EC	Energy Commission
EIMAS	Environmental Institute Malaysia
EPA	Environment Protection Agency
ESP	Electro Static Precipitator
FD	Force Drought
FGD	Flue Gas Desulphurization
GCV	Gross Calorific Value
GV	Governor Valve
HGI	Hard Grove Indexs
HTR	High Temperature Reheater
HTS	High Temperature Superheater
HP	High Pressure
HPH	High Pressure Heater
Hz	Hertz
ID	Induced Draft
IPP	Independence Power Produce
ITS	Intermittent Temperature Superheater
LTR	Low Temperature Reheater
LTS	Low Temperature Superheater
LP	Low Pressure
LPH	Low Pressure Heater
NLDC	National Load Despatch Centre

NOx	Nitrogen Oxides
OEM	Original Equipment Manufacturing
O&M	Operation And Maintenance
OFA	Over Fire Air
PA	Primary Air
PC	Pulverize coal
PPA	Power Purchase Agreement
RAH	Regenerative Air Heater
RH	Reheater
SA	Secondary air
SOx	Sulphur Oxides
SV	Stop Valve
TMCR	Turbine Maximum Capacity Rate
TPP	Thermal Power Plant
UOR	Unplanned Outage Rate

CHAPTER 1

INTRODUCTION

1.1 Background

In Malaysia, coal-fired generation represents about one-third of the installed power generation capacity and accounts for nearly 43 percent of the electricity produced in 2014. Due to low cost in power generation, most of the developing countries use coal as the main fuel at power generation plants (Energy Commission Bulletin, 2014). Coal as main fuel combust in the furnace and heat up the water at high temperature and pressure in the boiler. Boiler is one of the main device in power generation plant especially for thermal power plant plants functioned to separate the water and steam phase. In order to fulfil government laws and rules, boiler operation was designed and tuned as per coal specification and environmental requirement during the commissioning stage. In line with that, the boiler design must be of a good standard, at optimum quality and with high capability for continuous operation.

The term of boiler in a power plant as a device to generate steam by producing power which involves processing or heating purposes. The function of the boiler also is to produce hot water for heating purposes or hot water supply during operation. According to Berry and Clyde (1983), the heat transmitted to the boiler was transferred through conduction, convection and radiation whereby producing the high pressure of steam. The purpose of the boiler in power generation is to commendably recover the heat generated by combustion of the coal in order to produce steam. Steam forms as superheated steam before entering the high pressure stage of the turbine and reheats the steam before it returns to the later stages of the turbine. Steam which enters the turbine system also preheats the feed water in the economizer as well as the combustion air in the air heater. In a nutshell, the boiler acts as a medium separating two phases between water and vapor. According to American Standard for Testing and Materials (ASTM) 2010, a boiler was classified based on the capacity of boiler pressure during operation. To ensure that a boiler operates in a safe condition, all insurable equipment must be constructed in accordance to the design code.

Subcritical boiler operation is the instrument that has the purpose of separating the molecule phase between water and vapour at the subcritical point which forms the superheated steam. Superheated steam performs at 540°C with 175 bar boiler pressure. The operation of the subcritical boiler in a thermal plant is aligned with the Rankine Cycle thermodynamic process flow (Woodruff, Bowman, Herbert and Thomas, 1998). Superheated steam comes out of the boiler drum as steam generator. Steam generator was equipped with an economiser, superheater and reheater section and circulating water pumps. The Rankine Cycle process or namely as thermal plant process involves four phases which were isentropic compression process, isobaric heat process, isentropic expansion process, and isobaric heat rejection process (Wei et al., 2007; Murehwa, et al., 2012; Liu et al., 2004).

Due to its low cost, coal is selected as the main fuel for combustion purposes in the boiler furnace (TNB Fuel Report, 2015). The sub-bituminous coal is used as the main fuel. Sub-bituminous coal is the lowest cost coal but has high moisture content compared to the bituminous coal. The other criteria and specifications of sub-bituminous coal similar to the bituminous coal such as, low sulphur content which results in low SOx emission, high volatile matter and low ash content. Sub-bituminous coal has high moisture and lower Hard Grove Index (HG1) and affects poor coal fineness. High volatile matter of sub-bituminous coal can lead to spontaneous combustion and even explode in the pulveriser. However, there are disadvantages using sub-bituminous coal. For example, sub-bituminous coal has low ash fusion temperature (AFT) which can cause slagging and fouling (IHI Boiler Performance Report, 2015).

The type of coal refers to the coal characteristics. Coal with different characteristics will perform differently during the combustion process. Due to that, there is an importance on the selection on the type of coal for firing as the main fuel in the boiler. For example, slagging and fouling form from the ash product of coal combustion in the furnace. Chemical reactions take place and create ash accumulation. Slagging and fouling can cause poor heat transfers and affects the boiler efficiency. Slagging and fouling can lead to boiler tube failure and degrade the tube metal integrity and performance (Ahmad, et al., 2015).

By looking at the boiler performance, the boiler parameters were corresponding to the combustion process in the furnace. The combustion process involves rapid chemical combination of a substance with oxygen, comprising the production of heat source and fuel. Coal as the main fuel contributing to the combustion presentation pointedly affect boiler performance. Thus, there is an importance to analyze and identify the boiler performance parameters during the combustion process which involves coal as the main fuel. Furthermore, a mitigation plan must be establishing to maintain and sustain the boiler performance (IHI Boiler Performance Report, 2015). In line with that, the study carried out an energy assessment for the power plant in order to measure the operational boiler performance towards energy consumption.

1.2 Problem Statement

Malaysia’s energy supply conventionally depends on four resources, namely oil, gas, coal and hydro for fuel and for power generation (Khalid & Audrey, 2012). Coal resource is the issue still being discussed in the utilities industry especially for coal thermal power plants. In fact, in certain countries such as China, Japan, and Australia, coal is still the main fuel used in generating electricity (TNB Fuel Report, 2015).

However, due to limited stock of applicable coal in the market, the organization must look alternative coal types to ensure continuous power generation (Eberhard, 2011).

Furthermore, different types of coal give different results to the boiler performance. During commissioning stage of the boiler in power plant, the boiler tuning process is referring to the coal characteristic (Power Purchase Agreement, 2000). The right coal must be used to sustain the boiler performance in order to optimize the power generation. Due to that, the best coal must be determined to meet the boiler performance. The boiler performance such as efficiency, heat rate and other boiler parameters which consist of superheated steam temperature, reheater temperature, furnace rear path temperature, consumption of water spray, must be closely monitored to ensure the parameters are operating are within the set limits (Alstom O&M Training Note, 2010).

Driving to optimum the operation process in thermal plant, it is an important element to indicate the energy losses during the combustion process. Energy losses consequently affect the boiler efficiency and boiler heat rate (Campbell, 2013). Different types of coal used during combustion process will result in different rates and amounts of energy losses. By identifying the type of coal which contributes to the major energy losses, a mitigation plan during operation can be develop to minimise such losses (Clarke & Sloss, 1992; Kiga et al., 1997; Van, 2003; Tan, et al., 2006; Peng, 2008; Smoot & Smith 2013; Kimi, 2015).

Besides ensuring the power generation operating at optimum level, other parameters should be closely monitored to ensure minimum heat losses. Identification and assessment on the plant availability and reliability will help the operators improve the plant operations. Justification on the energy losses could be needed to mitigate the occurrence. Therefore, the energy audit activity was required to identify and monitor the important parameters to the plants. Numerous study on energy audit had been conducted in the power plant (Ahamed and Masjuki, 2009; Umar and Javed, 2015; Kuryika and Chaudhary, 2012; Kumar and Rao, 2013; Varpe and Kathwate, 2016; Mitra and Ghosh, 2015).

Therefore, the ideal boiler performance should be referred by making a comparison and have a clear understanding of the actual boiler performance (IHI Performance Report, March 2010). Optimizing the boiler performance with firing corrected sub-bituminous coal is for better availability to the grid system which can impact to the financial business to the company. Consequently, an evaluation of boiler parameters between the ideal performance and actual performance of the boiler was made and the problems were identified and analysed. Recommendations will then be made for further improvement on handling the boiler operation.

1.3 Objective

Analysing of the boiler operation performance, boiler efficiency and energy losses which was accomplished during the combustion process which uses sub-bituminous coal as the main fuel. In order to resolve the problem statement, the research aim has been established. Objectives of this study had been develop and which related to meet the research proposal.

Listed below are the research objectives to be achieved:

1. To determine the boiler efficiency with different types of sub-bituminous coal.
2. To identify the effect of boiler parameters with different types of sub-bituminous coal.
3. To identify the effect of plant performance through energy audit with different types of sub-bituminous coal.

1.4 Scope and Limitation

The study was conducted at a coal power plant located in Manjung Perak with maximum load generation, 700 megawatt net capacity and connected to the Perak substation which supplies to the Grid System, Malaysia. The plant was commissioned in 2003. It was designed with sub-critical boiler, installed with reheats process. It is considered for continuous operation at 105% TMCR over 48.5 Hz to 51 Hz frequency range.

For the purpose of objective, only one boiler will be used during the study. Looking forward to the boiler design main characteristics, the boiler tube specification indicates the operational regime of the thermal plant. For this study, detail of the boiler capability such as boiler arrangement for main-steam piping and capability, the boiler cold reheat steam piping measurement and hot reheat steam piping measurement was discussed in Chapter 3. The boiler operational mechanism concepts are two-pass type boiler. This power plant was installed with boiler drum with Boiler Circulation Pump (BCP) for the purpose of control circulation. In facts, the entire component of the boiler was designed following the ASTM specification (ASTM, 1998).

For the types of fuel, the plant was designed to fire with sub-bituminous coal. Only one type of sub-bituminous coal was commissioned and tuned during the design stage (Alstom O&M Training Note, 2010). In fact, the coal in use was limited to sub-bituminous coal which is achieve the minimum coal specification requirement stated in the Power Plant Agreement (PPA) of the power plant. For this study the four types sub-bituminous coal have been used. The properties of the coal were referred to the coal certification delivery from the coal supplier. The lab test had been done to verify the coal specification to meet the coal specification mentioned in the certification.

Furthermore, the numerical data collection was triggered and recorded through the PI Process Book system. The data collected was transferred to Microsoft Excel and analyzed through the selected method. To ensure no interruption during the plant operation, the period of research study and data collection was in accordance with the power plant operation instruction by National Load Dispatch Centre (NLDC).

1.5 Significance of Study

This study contributed to significant savings to the country in terms of boiler performance and cost savings on sub-bituminous coal supply. In addition, the developed checklist allows top management and technicians to handle situations in having new type of coal.

This study gives an advantage to the industry whereby the thermal power plant can predict the boiler performance. Thus, the life cycle of the power plant should be considered as well. The assessment, experiment, testing and research carried out will improve the existing system for a better future.

1.6 Thesis Outline

There were five chapters in this thesis. Chapter 1 explains the general introduction of the study, significance of the research work, problem statement, research objectives, scope and limitation of the study and this sub chapter; thesis outline. Literature review related to the thesis was covered in Chapter 2. This chapter delivers the general knowledge and research that has been done before. Important key words in this research; thermal power plant process, boiler, sub-bituminous coal, boiler parameters, and boiler efficiency are highlighted as well. The related theories and findings from previous literature was used as a guide and reference while conducting the study. Chapter 3 briefly gives the methodologies involved in order to achieve the objectives of this thesis. The method used was thoroughly discussed in Chapter 3 which involves experimental research. The materials specifications and equipment specifications related to this study was also mentioned.

Next, the results and discussions carried out in Chapter 4 provides detailed explanations to the phenomena. The researcher discusses the results from the data collected for each of the research objectives. The data collected, results and observations during the study was discussed and presented in table and graphical chart form in Chapter 4. Finally, Chapter 5 discourses about the general conclusion and highlights the potential for future research.

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