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Performance Analysis and Techno Economy of Post Overhaul Circulating Fluidized Bed Boiler PLTU

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Abstract---*All countries in the world have a high dependence on energy. Predictions of energy demand continue to increase in all countries, so savings measures are needed. One of the saving measures in the power generation industry is an overhaul. An overhaul is a maintenance activity that must be carried out periodically to maintain the NPHR performance of the power plant as it was when the initial conditions were built. This study aims to (1) determine the performance of the power plant before and after overhaul, (2) determine how the PLTU performs at 50%, 75%, and 100% load, and (3) analyze the techno-economics of overhaul activities with a serious type inspection. The results of this study explain that the three treatments of the post-overhaul loading pattern have a good impact on the PLTU, namely in the form of a decrease in the NPHR after the overhaul work. The impact of the reduced post-overhaul NPHR value at this PLTU is that it can save fuel costs of 17.5 billion rupiahs per year. The cost for this overhaul work is 14.9 billion rupiah so in 1 year it can save around 2.6 billion rupiah.*
Keywords---*air heater, circulating fluidized bed boiler, NPHR, overhaul, PLTU, savings*.

Introduction

The need for energy in the world is currently increasing along with the increase in population and industry (Santika et al., 2020), therefore the construction of power plants in the world is always increasing every year (Ritchie & Roser, 2014). In Indonesia, the need for electrical energy also increases every year (Jeremy, 2021). Researchers predict that Indonesia's energy needs for decades to come will increase significantly along with the many developments in the industrial sector so that the construction of power plants will continue to increase

PLTU is a coal-fired steam power plant (Drbal et al., 1996). Inside the PLTU there are several main pieces of equipment such as turbines, boilers, boiler feed pumps, and condensers (Energy Education, 2018). A boiler is a place where the change in the fluid phase from liquid to vapor occurs (Nurfitria et al., 2019). In general, PLTU is divided into 3 types of boilers namely Pulverized, Circulating Fluidized Bed (CFB), and chain grate (Komarudin & Wahuningsih, 2020). CFB boilers are the most efficient and environmentally friendly boilers among these three types (Wang & Zhu, 2018). CFB boilers are environmentally friendly because they produce the least amount of SOx and NOx. This CBF boiler only requires low-rank coal (Ibrahim et al., 2011).

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The water heater in the CFB boiler is divided into two, namely the primary air heater and the secondary air heater. The primary air heater supplies air to the wind box for the particle bed (fluidizing) bubbling process, while the secondary air heater supplies combustion air in the lower furnace area (Suwarno et al., 2021).The air heater is in the backpass area and undergoes a heat transfer process through the wall of the air heater tube. The calculation of the heat transfer rate in the tube air heater is based on the tube material, the dimensions and thickness of the material, and the temperature difference (Basu, 2015).

Air Heater is a heat exchanger in a power plant that functions to heat the combustion air, both primary and secondary air so that the coal combustion process in the boiler occurs optimally (Davis & Caldeira, 2010). The heating media of this air heater comes from the combustion exhaust gas. The working principle of the 25 MW PLTU air heater, the combustion air to be heated is passed through the tube while the heating medium, namely flue gas, flows through the outside of the tube arrangement (tube banks) (Aied, 2020). Since 2017 until now the air heater tube has been leaking. So this results in an increase in the NPHR value which causes operational costs to increase. This tube air heater leak can cause power plant shutdown so this problem must be resolved immediately otherwise it will cause very large losses. To prevent the NPHR value from increasing, it is necessary to replace the tube air heater so that the reliability and efficiency of the unit can be maintained (Zala, 2017).

The specifications for the 25 MW PLTU air heater tube are GB3087 Grade A with a thickness of 1.6 mm. When an overhaul is to be carried out, 365 tubes will be replaced with the equivalent material, namely ASTM A53-type tubes with a thickness of 3.2 mm. The performance of the power generation unit can be determined based on a value called the Net Plant Heat Rate (NPHR). The amount of energy used to produce electrical energy by a generator is a value that indicates the Net plant heat rate (NPHR) of a power plant unit. The greater the value of the Net Plant heat rate produced, the worse the performance of the power generation unit can be. This can be caused by the greater amount of energy used but the electrical energy produced remains the same or gets smaller. This happens because there are very large losses in a generator system so it is necessary to carry out an energy audit so that production costs do not increase (Wang & Zhu, 2018).

The 25 MW PLTU is a power plant located in North Sulawesi. Overhaul activities with this type of serious inspection will be carried out at this PLTU. Serious Inspection will be carried out when the PLTU's operating hours have reached 32,000 hours of operation. One of the works that will be carried out in this overhaul activity is retubing the air heater tubes with a total of 365 tubes.

To find out whether the overhaul activity is on target or not, it is necessary to carry out an energy audit before and after the overhaul. This overhaul activity is expected to be successful because the budget value for this activity is very expensive and requires quite a long time of work. One of the parameters for the success of the overhaul is the improvement in the NPHR value before and after the overhaul is carried out. The aims of this study were (1) to analyze the differences in NPHR values before and after the overhaul, (2) to analyze the performance of PLTU at 50%, 75%, and 100% load, (3) to provide recommendations for improving energy efficiency performance, and (4) to analyze the techno-economics of overhaul activities with a serious type inspection (Basu, 1999; Basu & Nag, 1996; Chen & Lu, 2007; Leckner & Gómez-Barea, 2014).

Method

Research step

Data collection for this study began before the overhaul began by briefly calculating the NPHR before the overhaul using the direct method. The NPHR value during the performance test at 100% load is a reference point as the basis for this research and is a parameter for calculating savings after overhauling. The next step is to compare the performance when the load variations are 50%, 75% and 100% before and after the overhaul. The performance being compared is the Net positive heat rate (NPHR). After the results of the post-overhaul are known, then a techno-economic analysis is carried out. This analysis is a calculation of how much savings can be obtained before and after the overhaul and what is the profit margin obtained after this overhaul work. And the last step is to provide recommendations for improvements for the next overhaul.

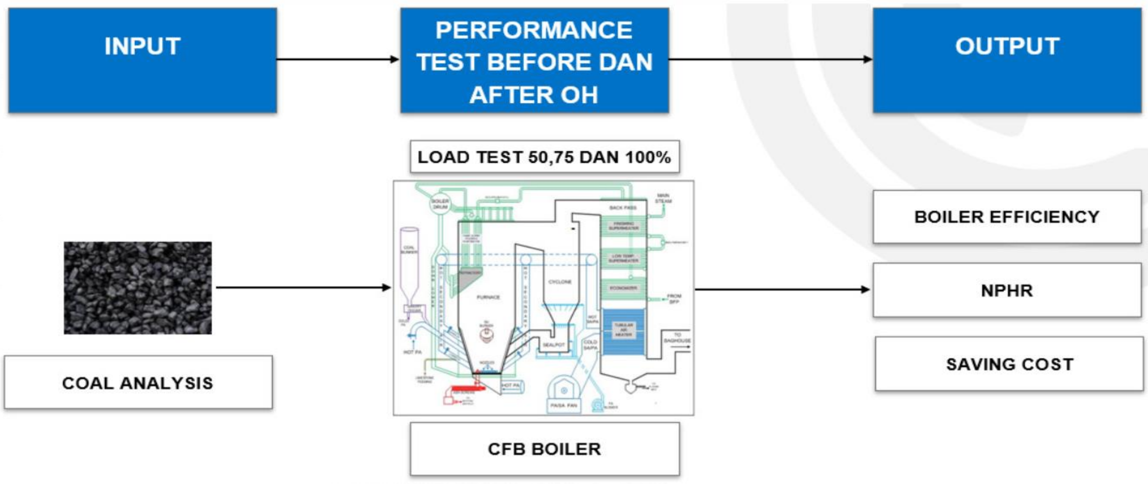

Figure 1. Research Steps

CFB Boilers

A CFB boiler is a device for generating steam by burning fossil fuels in a furnace operated under special hydrodynamic conditions in which fine fuel is transported through the furnace at a velocity exceeding the average particle terminal velocity, but there is sufficient solids reflux rate to ensure uniformity of temperature in the furnace. The furnace or combustion chamber of a CFB boiler holds large supplies of non-combustible solids which are lifted and carried by the high-velocity combustion gases passing through the furnace. The primary fraction of solids exits the furnace and is captured by the gas-solid separator and is recirculated near the bottom of the furnace at a rate high enough to cause a minimum level of solids reflux in the furnace. Figure 2.1 shows a typical schematic of a CFB boiler. Combustion of fuel in solid suspension of solids kept under special hydrodynamic conditions in the furnace. A small portion of the combustion heat is absorbed by the water/steam-cooled surface located within, and the remainder is absorbed in a convective section located further downstream of the furnace known as the back lane. The creation of special hydrodynamic conditions, known as Fast bed, is key to the operation of CFB boilers. The special combination of gas speed, and solid recirculation known as the Fast bed, is the key to the operation of a CFB boiler. The special combination of gas speed, and solid recirculation known as the Fast bed, is the key to the operation of a CFB boiler. The special combination of gas speed, solid recirculation (Do et al., 2014; Gürtürk & Oztop, 2016; Gámez et al., 2016; Pérez et al., 2016).

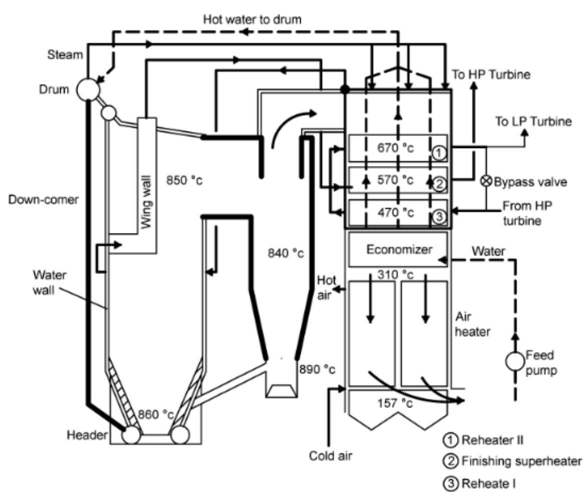

Figure 2. Circulating fluidized bed boilers
Source : (https://www.linkedin.com/posts/miswar-alamsyah-lubis-1b8841125_economizer-cfbboiler-activity-6869178646935015424-N2vJ?trk=public_profile_like_view, 2023)

Boiler efficiency calculation

Calculation of efficiency with indirect methods can be defined, as efficiency is the difference between the energy lost and energy input. In the indirect efficiency calculation method, efficiency can be measured easily by measuring all the losses that occur in the boiler using the principles of heat loss balance. Boiler efficiency can be obtained by subtracting the percentage of heat loss from 100%. An important advantage of this method is that errors in measurement do not make a significant change in efficiency.

$$n(\%) = 100 - (L1+L2+L3+L4+L5+L6+L7+L8 \qquad (1)$$

1) heat loss in dry flue gas such as sensible heat (L1).
2) heat loss due to the presence of water content in coal (L2).
3) heat loss due to the presence of hydrogen content in coal (L3).
4) heat loss due to the presence of water content in the combustion air (L4).
5) heat loss due to the presence of unburned carbon (L5).
6) heat loss due to sensible heat in bottom ash (L6).
7) heat loss due to sensible heat in fly ash (L7).
8) heat loss due to radiation and boiler surface conventions, the value has been set by the boiler manufacturer (L8)

Plant heat rate analysis

The energy requirement to produce 1 kWh of electrical energy is the meaning of the Plant heat rate. This value is one of the main parameters of how efficient a power plant unit is. If the value of the plant heat rate is higher then the unit is increasingly inefficient. In addition, the value of the plant heat rate can reflect the health of a power plant unit. There are 2 methods for calculating plant heat rate, namely by using gross power and net power data. The energy requirement to produce 1 kWh of gross electricity is the meaning of GPHR, while the energy requirement to produce 1 kWh of net electricity is the definition of NPHR. Calculation of plant heat rate uses 2 methods, namely the input-output method and the energy balance method (Suwarno et al., 2021).

$$\text{NPHR (kCal/kWh)} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)\frac{\boldsymbol{NTHR}}{\text{Boiler efficiency with heat loss method}}$$

Increase in fuel costs due to increase in heat rate

An increase in the NPHR value at a power plant will result in an increase in the value of the raw materials to produce the same net amount of electrical power. The value of the increase in fuel costs is strongly influenced by the NPHR value, the rupiah price of coal, the calorific value of coal and net power at the power plant as well as the value of the generator capacity factor (CF). The calculation of the increase in the cost of fuel at a power plant for 1 year uses equation 3, while the calculation of the increase in fuel costs due to an increase in the NPHR value for one year uses equation 4.

$$\text{Fuel costs} = \text{x NPHR x DN x CF x } 8760\frac{Coal\ price}{HHV\ calorific\ value\ of\ coal} \qquad (3)$$

$$\boldsymbol{\Delta}\text{Fuel costs} = \text{x } \Delta\text{NPHR x DN x CF x } 8760\frac{HCoal\ price}{HHV\ calorific\ value\ of\ coal} \qquad (4)$$

With:

Coal costs	: cost of coal fuel (Rp/year)
ΔCoal costs	: cost of coal fuel (Rp/year)
NPHR	: Net plant heat rate (kcal/kwh)
ΔNPHR	: the difference in the value of Net plant heat rate (kcal / kwh)
Coal price	: coal price (Rp/kg)
Coal HHV	: high heating value of coal (RP/kg)
DN	: net power generation (MW)
Cf	: CAPACITY FACTOR (%).

Results and Discussion

Coal test results

The coal to be used in the performance test for the steam power plant with the 25 MW CFB Boiler type is subject to laboratory testing with ultimate and proximate testing. The test results by the indicated laboratory are shown in Table 1 on a received (AR) basis

Table 1
Ultimate and proximate analysis results for coal after overhaul

Analysis		Units	50% LOADS	LOADS 75%	LOAD 100%
Proximate Analysis	Moisture in analysis	%wt	33.97	32.88	34,39
	Ash content	%wt	3.76	4.38	4.05
	volatile matter	%wt	34,30	34,23	33,37
	Fixed carbon	%wt	28.97	28.51	28,19
	total sulfur	%wt	0.41	0.49	0.45
	Gross calorific value	kCal/kg	4.137	4.143	4.106
Ultimate analysis	Carbons	%wt	44,44	44.01	43,42
	Nitrogen	%wt	0.71	0.70	0.69
	oxygen	%wt	16,10	15.80	15,49
	Hydrogen	%wt	1.61	1.74	1.51

Laboratory test results of coal used for the performance test of a steam power plant with a CFB type boiler in the form of ultimate and proximate analysis are then used as a data source for calculating the efficiency value of a steam power plant using the heat loss method.

NPHR value before and after overhaul

Calculation of the value of the net plant heat rate using the heat loss method can be obtained after several parameters are known for calculating the value of boiler efficiency and turbine heat rate are known in advance. The value of the plant heat rate can be determined by using the analysis of the net and gross power of the power plant. The results of the measurement and calculation of the value of the net plant heat rate (NPHR) can be seen in Tables 2, 3, and 4.

Table 2
Net plant heat rate calculation results before and after 50% load

Parameter	Units	Before OH	After OH
Net Turbine Heat Rate	kcal/kwh	4,110.05	3,116.50
Boiler Efficiency	%	85.45%	83.33%
Net Plant Heat Rate	kcal/kwh	4,810.14	3,740.12
Net Plant Efficiency	%	17.88%	22.99%

Based on the calculation of the net plant heat rate at 50% load presented in table 3.2, it is obtained that the value of the net plant heat rate (NPHR) before overhaul was 4810.14 kcal/kwh and after overhaul was 3740.12 kcal/kwh. Meanwhile, the value of net plant efficiency before the overhaul was 17.88% and after the overhaul was 22.99%. So there are differences in the NPHR and plant efficiency before and after the overhaul, this indicates that there is a significant impact between before and after the overhaul on this steam power plant (Yolnasdi, 2021).

Table 3
Net plant heat rate calculation results before and after 75% load

Parameter	Units	Before OH	After OH
Net Turbine Heat Rate	kcal/kwh	3,208.27	2,996.58
Boiler Efficiency	%	85.74%	83.81%

Net Plant Heat Rate	kcal/kwh	3741.973932	3,575.24
Net Plant Efficiency	%	22.98%	24.05%

Based on the calculation of the net plant heat rate at 75% load presented in table 3.3, it is obtained that the value of the net plant heat rate (NPHR) before overhaul was 3741.97 kcal/kwh and after overhaul was 3575.24 kcal/kwh. Meanwhile, the value of net plant efficiency before the overhaul was 22.98% and after the overhaul was 24.05%. So there are differences in the NPHR and plant efficiency before and after the overhaul, this indicates that there is a significant impact between before and after the overhaul on this steam power plant.

Table 4
Net plant heat rate calculation results before and after 100% load

Parameter	Units	Before OH	After OH
Net Turbine Heat Rate	kcal/kwh	2,955.46	2,895.96
Boiler Efficiency	%	83.22%	85.02%
Net Plant Heat Rate	kcal/kwh	3551.55285	3,406.24
Net Plant Efficiency	%	24.21%	25.25%

Based on the calculation of the net plant heat rate at 100% load presented in Table 3.4, it is obtained that the value of the net plant heat rate (NPHR) before overhaul is 3551.55 kcal/kwh and after overhaul is 3406.24 kcal/kwh. Meanwhile, the value of net plant efficiency before the overhaul was 24.21% and after the overhaul was 25.25%. So there are differences in the NPHR and plant efficiency before and after the overhaul, this indicates that there is a significant impact between before and after the overhaul on this steam power plant (Wang et al., 2003; Gu et al., 2020; Kim et al., 2007; Shun et al., 2021).

Savings

The calculated savings are calculated by calculating the difference between the rupiah losses before and after the overhaul using equation 4 and then compared with the costs of the overhaul activities.

$$\mathbf{\Delta}\text{Fuel costs} = \text{x } \Delta\text{NPHR x DN x CF x } 8760\frac{Harga\ batubara}{nilai\ kalor\ HHV\ batubara}$$

If

Coal price : IDR 800/kg
Capacity factor : 80%
Coal HHV value : 4106 kcal/kwh
Net capable power : 22.5 MW
NPHR post OH : 3404 kcal / kwh
NPHR before OH : 3982 kcal/wkh

$\mathbf{\Delta}$Fuel costs = x (3982-3404) x 22.5 x 80% x 8760$\frac{800}{4106}$

$\mathbf{\Delta}$Fuel costs = x (578) x 22.5 x 80% x 8760$\frac{800}{4106}$

$\mathbf{\Delta}$Fuel costs = Rp. 17,513,990,000.34

While the cost of this overhaul work is Rp. 14,900,030,128.00 so that in 1 year this can save Rp. 2,613,961,104.34.

Conclusion

After the overhaul is carried out, there is an improvement in the NPHR value between before and after the overhaul, which is 578 kcal/kwh and can reduce coal consumption in one year by Rp. 17,513,990,000.34 The cost of this overhaul work is Rp. 14,900,030,128.00 so that in 1 year this can save Rp. 2,613,961,104.34.

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