Analysis of Boiler Engine Efficiency Unit 2 PT. PJB UP Paiton

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Abstract. The boiler machine is a component that initiates energy changes. The boiler engine in the PLTU is a closed vessel that can convert water into steam at high temperature and high pressure by utilizing heat from coal combustion. Steam flows out of the boiler engine into the steam turbine. In this turbine, there is a conversion of kinetic energy from steam into mechanical energy to drive the turbine blades. The rotation of the turbine shaft is coupled with the generator to produce electrical energy from the conversion of the magnetic field coil in the generator. The purpose of this study is to determine the efficiency of a boiler engine and to find out the best method for calculating the efficiency of a boiler engine. There are two methods used to calculate the efficiency of boiler machine, namely the direct method and the indirect method or losses method. In the direct method uses a comparison between the output (steam) and heat input (fuel) for efficiency evaluation. Meanwhile, the indirect method is done by reducing the heat generated when burning coal with losses that occur during and after the combustion process. Based on the data analyzed to determine the efficiency of the boiler machine by direct method, it can be seen that the efficiency is 87.20%. Meanwhile, based on the indirect method, the efficiency is 81.22%. These results are appropriate after being compared with boiler commissioning data in 1994 that efficiency of the boiler machine at PT. PJB UP Paiton reaches 80% - 90%.

1. Introduction

Utilization of electrical energy has been used in various sectors of necessity, for example household, commercial, government agencies, where electrical energy has become a basic in society because the majority of technology used by the community depends on electrical energy. Electrical energy is one of the important components that drive a country's economic growth. Boiler,condenser, feedwater and steam turbine are important equipments in Power plants [1]

In effort to provide reliable and efficient electrical energy, PT PJB unit 2 is a power plant company that uses engines with steam and coal-fired power systems with a capacity of 2 x 400 MW. PLTU is a steam power generation company whose working principle is to heat water to high temperature steam by utilizing the heat from coal combustion that occurs in the boiler engine and then the hot steam which has high pressure is flowed to rotate the turbine blades which will be forwarded to the generator, thus generating electricity. In the PLTU system, the boiler machine is a component that initiates energy changes. The definition of a boiler engine in a PLTU is a closed vessel that can convert water into steam or steam at high temperature and pressure by utilizing the heat from the combustion of coal. Then, steam flows out of the boiler engine into the steam turbine. In this turbine, there is a conversion of kinetic energy from steam into mechanical energy to move the turbine blades. The turbine shaft rotation is then coupled with the generator to produce electrical energy from the conversion of the magnetic field coil in the generator. Combustion is a fast chemical reaction between oxygen and combustible material which produces heat. At the flue gas temperature in 150^{0}C, when the air excess coefficient was increased by 10% the total heat loss was increased by 8% due to the flue gas heat, and when the air excess coefficient was increased by 50%, it was increased by 28% with investigated the effects of the coal composition on the power plant performance is focused on the coal grinding and flue gas cleaning process [2]. Bhatt had investigated that three effect of air intake on energy efficiency that the combustion zone, in the post combustion zone and the air preheaters of coal-fired thermal power plants. It is stated that the optimum amount of oxygen is 3% for combustion in the pulverized coal-fired systems [3]. Energy, energy losses, exergy efficiency and destruction for a boiler to reduce boiler energy consumption. Controlling excess air, enhancing heat transfer rate have improving combustion efficiency, use environmentally friendly fuel recovering condensate, recovering waste heat, decrease boiler energy consumption [4]. Huang had researched that coal content effect on power plants have fluidized bed boiler. It developed an equation helps to decide efficiency of coal-fired thermal power plant used for effect of ash content, sulfur content, moisture content, and coal heating value on the power plant efficiency [5]. Boiler operation more efficiently in thermal power plant with indirect method which is the best way to explain all of boiler losses. It is noted that the flue gas loss in a boiler is more important than other losses. For decreasing flue gas loss, a coal having low moisture content, higher calorific value and low ash content should be used [6]. Various parameters to the boiler system which helps to increase boiler performance calculated boiler efficiency with indirect method and investigated effect of Gross Calorific Value (GVC) of coal. It simulated with various value of fuel, when they used higher GVC of coal, the efficiency of boiler increased [7].

1.1 Basic Operating System for PLTU Paiton Units 2

Basically, the electricity operation at PLTU UP Paiton uses a heating system of water to steam to drive a turbine. Furthermore, the turbine will rotate the generator and generate electric power. Meanwhile, the exhaust steam from the turbine is turned into water again by a condensation process. This is done continuously so as to form a closed cycle. Broadly speaking, the basic operating system of the PLTU can be grouped into several systems, namely: Coal Handling System, Water Treatment Plant, Ash Handling System, Steam Production System, Combustion system. In general, the flow of these processes can be seen in the following figure:

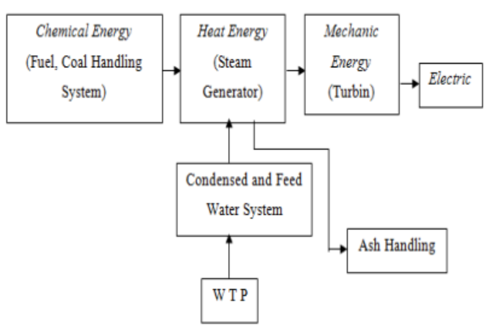

Figure 1. Block Diagram of Electricity Production at PLTU Paiton Unit 2

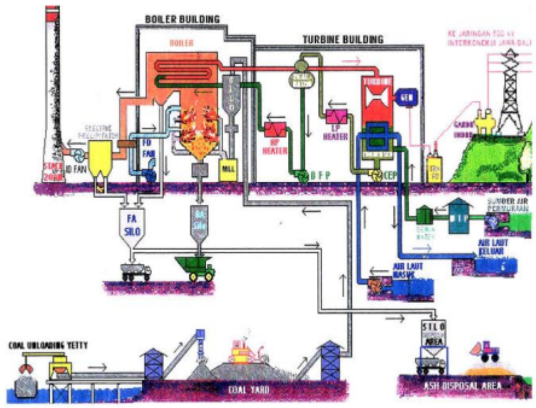

Figure 2. Flow of Electricity Production Process for PLTU Paiton Unit 2

The steam production process occurs in the boiler and the process of changing the phase from water to steam occurs precisely in the water wall/water tube/evaporator, condensate water turns into steam after previously going through a series of processes in LPH (Low Pressure Heater), Deaerator, HPH (High Pressure) Heater), Economizer, the steam formed in the water wall will then flow to the steam drum to then flow to the Super heater to be heated again to a temperature of 538 ° C and a pressure of 16 kg / cm^2. This steam is used to rotate the blades of the coupled steam turbine with a generator so that the generator will rotate and produce electric power. The generator at PLTU Paiton Units 1 and 2 is operated at 3000 rpm with an output power rating of 473 MVA, a frequency of 50 Hz and a voltage of 18 kV. The resulting electrical power is then increased by the Transformer Generator (GT) 18/500 kV, 473 MVA to be streamed via 500 kV transmission to GI Krian and via 150 kV transmission to GI Probolinggo and Situbondo.

Table 1. Boiler Specifications

BOILER	
Type	*Vertical Balance Draft, Drum Unit, Control Cyrculation*
Factory	*Combustion Engineering*, USA
capacity	Pressure185 Kg/cm^2, Temperature 538 °C, Flow 1330 ton/hour
Fuel	coal (main), HSD (start up s/d 30% load)

1.2 Boiler Machine

A boiler engine is a device consisting of pipes containing water which functions to convert water into superheated steam at high temperatures and pressures by utilizing conduction heat, radiation, and convection from burning coal fuel in the furnace.

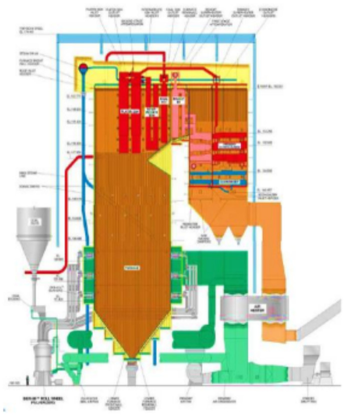

Figure 3. *Corner burner for mill type of boiler*

Boiler Parts

1. Water wall

   Water wall is a part of the boiler which consists of pipes installed in a row to form the furnace wall. Water wall is installed vertically for a vertical boiler type whose bottom is connected to the lower header, while for the upper pipe it is connected to the upper header, which is connected to the steam drum. The heat energy from the coal burning process in the combustion room is mostly absorbed by the water wall. Water wall functions to change the liquid phase into saturated vapor.

2. Steam Drum

   The function of the steam drum is as follows: as a reservoir for feed water and to accommodate the steam produced by the boiler and as a separator between water and steam to be channeled to the super heater. The steam that has been separated from the water is flowed into the super heater, while the water that enters the steam drum is placed near the down comer where the temperature is lower.

3. Super heater

   Super heater is a row of pipes used to convert the saturated steam phase to superheated steam. Where the steam from the steam drum enters the Low Temperature Super heater (LTSH) which is located above the economizer, then it enters the Header Primary Super heater. The primary super heater is located at the top of the combustion chamber. The steam that comes out of the premary super heater is collected in the header, which has a steam temperature controller (De super heater). The steam coming out of the secondary super heater (final super heater) is a quality dry steam (superheat) which has high energy needed to move the turbine blades with a pressure of 169 kg / cm^2 and a temperature of 540 ° C. The steam capacity that comes out of the super heater reaches 1330 tons/h.

4. Re heater

   It is used to heat the steam coming out of the high pressure turbine to reach 538°C and a pressure of 43 kg/cm^2. By reheating the steam from the output of the high pressure turbine so that the enthalpy value of steam increases which is used to drive the next turbine (Intermediate pressure turbine). So that a higher efficiency is obtained. The re heater has three parts, namely: The vertical speed re heater which is located above the surface, wall front radial re heater located behind the furnace, and Radial wall side re heater located on the inner wall of the furnace.

5. Economizer

   The economizer is a device used for preheating water before entering the steam drum. The economizer heat is obtained from the exhaust gas heat from the furnace. The initial goal of an economizer is to avoid thermal shock to the pipes that can cause damage. The location of the economizer is under the low temperature super heater (LTSH). In a modern boiler, the economizer plays a very important role because it has several advantages, namely: Lower maintenance costs because it can avoid thermal shock in the boiler pipe.

6. Furnace

The furnace is a combustion chamber located at the bottom of the boiler which is used to increase the temperature of the fluid in the boiler. There are two designs for the boiler combustion room, namely: Positive combustion room, which is a combustion room design that is not equipped with an induced draft fan. The negative combustion chamber is a combustion chamber design that uses an induced draft fan to keep the combustion chamber pressure negative (the pressure in the combustion chamber is less than the ambient temperature).

7. Boiler Circulating Water Pump

Used to control the flow of water through the water wall system. The water that has been separated by the steam drum is pumped and flowed into the water wall system below the furnace to the top so that the evaporation process occurs. The steam returns to the steam drum to undergo a water content cleaning process. Each boiler is equipped with 3 circulation pumps, each of which is capable of operating 50% of the unit load to keep the unit stable if one of the pumps is interrupted.

2. Methods

2.1 Boiler Efficiency

The factors that can affect the efficiency of a boiler machine:

2.1.1 Moisture loss (moisture)

a. Coal quality.
b. Pipe leaks.
c. Air has high moisture.

2.1.2 Loss of Dry Gas

a. Air leak in boiler casing

Leaks in the boiler casing can be seen when there is a decrease in the temperature of the furnace exit (before economizer), a decrease in the temperature of the boiler exit (after economizer), the mass of combustion air flow and O2 when leaving the boiler.

b. Air preheater leak

The leakage of the preheater can be seen when the average cold end temperature decreases, the water heater increases, and O2 when exiting the boiler

c. Mismatch in the ratio between fuel and air

This error is caused by the high O2 when exiting the boiler.

d. The heat transfer surface is not clean

The displacement surface which is usually dirty occurs in the following parts:

a) Boiler wall

There is an increase in the temperature of the main steam and an increase in the flow of the super heater spray.

b) Super heater

There is a decrease in the main steam temperature and a decrease in the flow of the super heater spray.

c) Re heater

There is a decrease in hot reheat temperature and an increase in the burner tilt.

d) Air preheater

Low air outlet temperature, unchanged gas intake temperature, and increased ΔP in the air heater (erosion) as well as furnace pressure instability.

e) Economizer

There is a decrease in the exit temperature, an increase in the temperature of the main steam, and an increase in the flow of the super heater spray.

2.1.3 Incomplete combustion

a. Coal quality.
b. Burner tip clogging.
c. Decreased refinement of fuel at the mill.
d. Burner damper adjustment.
e. Incompatibility of the ratio of fuel to air mixture

2.1.4 Losses due to heat transfer

This loss is caused by the boiler skin temperature being 50 ° F higher than the air temperature.

2.2 Boiler Efficiency Calculations

Direct method

The direct method of boiler efficiency analysis is to compare the energy obtained from the working fluid (water and steam) with the energy contained in boiler fuel. This methodology is also known as the 'input-output' method due to the fact that it only requires output (steam) and heat input (fuel) for efficiency evaluation. Direct method can be formulated as follows:

$$\text{Efficiency } (\eta): \frac{[Qs\ x\ (hms - hf)] + (Qhr\ x\ hhr) - (Qcr\ x\ hcr)}{Q\ coal\ x\ GCV}\ x\ 100\% \quad (1)$$

Keterangan:
Q *steam* (Qs) = main steam flow rate (kg/h)
Q *hot reheat* (Qhr) = reheat hot steam flow rate (kg/h)
Q *cold reheat* (Qcr) = reheat cold steam flow rate (kg/h)
h *main steam* (hms) = Enthalpy of main steam (kJ/kg)
h *feedwater* (hf) = Enthalpy of feed water (kJ/kg)
h *hot reheat* (hhr) = Enthalpy of hot reheat (kJ/kg)
h *cold reheat* (hcr) = Enthalpy of cold reheat (kJ/kg)
GCV = Energy contained in coal (kJ/kg)

Indirect Method

In calculating the efficiency of the boiler machine, the direct method is less accurate, especially when measuring fuel flow (coal per hour, or also other measurements). The flow of steam, the amount of coal burned, and the amount of heat of coal released are difficult to measure accurately, so the result is a rough ratio. Coal from the coal wagons is unloaded in the coal handling plant. This Coal is transported up to the raw coal bunkers with the help of belt conveyors [8].

a. *Loss due to dry fue gas (sensible heat)*

Losses that occur because the heat of the exhaust gas is still quite high after passing through the air heater (heating the air entering the boiler engine). This high temperature carries a high enough energy, but cannot be used by the boiler engine anymore.

$$Losses = \frac{m\ flue\ gas\ mass\ x\ cp\ flue\ gas\ x\ (Tfg - Ta)}{GCV\ fuel}\ x\ 100\% \quad (2)$$

$m_{fuel\ gas}$ = *flue gas mass* (kg/kg fuel)
$cp_{flue\ gas}$ = *specific heat flue gas* (kJ/kg.K)
T_{fg} = *flue gas temperature* (˚C)
T_a = *ambient air temperature* (˚C)
GCV_{fuel} = energy contained in fuel (kcal/kg)

b. Loss due to hydrogen in fuel

This loss is caused by the element hydrogen (H) in the fuel which when burned will react with oxygen from the air and form water vapor (H_2O) .

$$Losses = \frac{\frac{9\,x\,\%H}{100}\,x\,[584 + cp\;superheat\;x\,(Tfg - Ta)]}{GCV\;fuel}\;x\;100\% \quad (3)$$

%H = ultimate analysis hydrogen in coal (kg/kg coal)
$cp_{super\ heat}$ = *specific heat super heat steam* (kJ/kg.K)
T_{fg} = *flue gas temperature* (°C)
T_a = *ambient air temperature* (˚C)
GCV_{fuel} = energy contained in fuel (kcal/kg)

c. *Loss due to moisture in fuel*
This losses caused by *moisture* in fuel.

$$Losses = \frac{\frac{Total\;Moisture}{100}\,x\,[584 + cp\;superheat\;x\,(Tfg - Ta)]}{GCV\;fuel}\;x\;100\% \quad (4)$$

Total Moisture = amount of wet vapor in the coal (kg/kg coal)
$cp_{super\ heat}$ = *specific heat super heat steam* (kJ/kg.K)
T_{fg} = *flue gas temperature* (˚C)
T_a = *ambient air temperature* (˚C)
GCV fuel = energy contained in fuel (kcal/kg)

d. *Loss due to moisture in air*
This is because the air that enters the combustion chamber is not dry and still contains water, resulting in incomplete combustion.

$$Losses = \frac{m\;actual\;air\;x\;humidity\;ratio + cp\;superheat\;x\,(Tfg - Ta)}{GCV\;fuel}\;x\;100\% \quad (5)$$

$M_{actual\ air}$ = actual air requirements (kg/kg fuel)
humidity ratio = amount of moisture in dry air (kg/kg dry air)
$cp_{super\ heat}$ = *specific heat super heat steam* (kJ/kg.K)
T_{fg} = *flue gas temperature* (˚C)
T_a = *ambient air temperature* (˚C)
GCV fuel = energy contained in fuel (kcal/kg)

e. *Loss due to carbon monoxide*

$$Losses = \frac{\frac{\%CO\;x\;\%C}{100}}{\%CO + \%vol\;CO2}\;x\;\frac{5744}{GCV\;fuel}\;x\;100\% \quad (6)$$

% CO = percent carbon monoxide *flue gas*
% C = carbon ultimate analysis in coal (kg/kg coal)
% vol. CO_2 = dry volume percentage CO_2
GCV fuel = energy contained in fuel (kcal/kg)

f. Unburn carbon losses in fly ash

$$Losses = \frac{\%Ash\!:\!(GCV\;fly\;ash\;x\;100)}{GCV\;fuel}\;x\;100\% \quad (7)$$

% Ash = percent of ash from combustion
GCV fly ash = energy contained in *fly ash* (kcal/kg)
GCV fuel = energy contained in fuel (kcal/kg)

g. Unburn carbon losses in bottom ash

$$Losses = \frac{\%Ash:(GCV\ bottom\ ash\ x\ 100)}{GCV\ fuel}\ x\ 100\% \quad (8)$$

% Ash = percent of ash from combustion
GCV buttom ash = energy contained in *fly ash* (kcal/kg)
GCV fuel = energy contained in fuel (kcal/kg)

h. Loss due to surface radiation, convection, and other uncounted
Percentage losses that occurs due to heat transfer by radiation and convection on the surface.

$$Losses = \frac{\left(\frac{Ts+273}{55,55}\right)^4 - \left(\frac{Ta+273}{55,55}\right)^4 + 1,975\ x\ (Ts-Ta)^{1,25}\ x\ \left(\frac{196,85\ x\ Vm+68,9}{68,9}\right)^{0,5}}{GCV\ fuel} \quad (9)$$

Ts = *surface temperature* (°C)
Ta = *ambient air temperature* (°C)
Vm = *furnace volume* (m^3)
GCV fuel = energy contained in fuel (kcal/kg)

i. *Boiler engine efficiency*

(η) = 100% - total losses (a, b, c, d, e, f, g, h) % (10)

3. Results and Discussion

3.1 *Direct Method*

The direct method of boiler efficiency analysis is to compare the energy obtained from the working fluid (water and steam) with the energy contained in boiler fuel. This methodology is also known as the 'input-output' method due to the fact that it only requires output (steam) and heat input (fuel) for efficiency evaluation. Boiler Efficiency Analysis Unit 2 PT. PJB UP Paiton by Direct Method.

Table 2. *Performance Test* Boiler Machine

Parameter	Result	unit
Main Steam Pressure	165.398959	bar
Main Steam Temperature	546.86	°C
Main Steam Enthalpy	3433.81	kJ/kg
Main Steam flow rate	1097275.927	kg/h
Feedwater flow rate	1053183.47	kg/h
Feedwater Pressure	178	bar
Feedwater Temperature	174.72	°C
Feedwater enthalpy	750.1284	kJ/kg
Cold Reheat vapor flow rate	989122.667	kg/h
Cold Reheat vapor enthalpy	3116.778	kJ/kg
Hot Reheat vapor flow rate	1036297.37	kg/h
Hot Reheat vapor enthalpy	3550.722	kJ/kg
Coal flow rate	217923	kg/h
GCV of coal	18635.4	kj/kg

$$\eta: \frac{[1097275.927\ x\ (3433.81 - 750.1284)] + (1036297.37\ x\ 3550.722) - (989122.667\ x\ 3116.778)}{217923\ x\ 18635.4}\ x\ 100\%$$

$$\eta: \frac{[2944739215.4] + (3679603870.2) - (3082875767.8)}{4061082274.2}\ x\ 100\%$$

η: 87.20%

Based on the data analysed to determine the efficiency of the boiler machine by direct method, it can be seen that the efficiency is 87.20%. This result are appropriate after being compared with boiler commissioning data in 1994 that the boiler efficiency at PT. PJB UP Paiton reaches 80%-90%. The results of this data are success in boiler machine, because based on the numbers obtained, it does not pay attention to the losses that occur in the boiler machine.

Indirect Method

In the calculation of boiler machine efficiency, the direct method is less accurate, especially when measuring fuel flow (coal per hour or also other measurements) [9]. Steam flow, the amount of coal burned and the amount of heat in coal released are difficult to measure accurately, so the results are rough comparisons.

Table 3. *Ultimate Analysis (Ar)*

Parameter	Result
Carbon (C)	47,112 %
Hydrogen (H)	3,732 %
Oxygen (O)	14,206 %
Nitrogen (N)	0,656 %
Sulfur (S)	0,148 %
Ash	7,618 %
TM	32,092 %
Total	105,564 %

Table 4. *Volumetric Composition of Flue Gas*

Product	%volume, dry	%volume, wet
CO_2	11,91	11,27
SO_2	0,01	0,01
O_2	7,91	7,48
N_2	80,17	75,88
H_2O	-	5,36

Table 5. *Operational Condition*

Parameter	Result
%CO in flue gas	0,05255 %
Coal flow	217,923 ton/h
Excess air	59 %
Actual air requirements	9,65083 kg/kg fuel
Flue gas temperature (Tfg)	143,15 °C
Ambient air temperature (Ta)	33 °C
Surface temperature (Ts)	65 °C
GCV fuel (GCVf)	4437 kkal/kg
GCV fly ash (GCVfa)	1700 kkal/kg
GCV bottom ash (GCVba)	145,897 kkal/kg
cp superheat steam (cpsh)	0,48
cp flue gas (cpfg)	0,243
Massa flue gas (m)	9,97 kg/kg fuel
Furnace volume (Vm)	800 m^3

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Humidity ratio	0,041 kg/kg dry air

Table 6. *Losses in Boiler*

Parameter	Results
Loss due to dry flue gas	6.01 %
Loss due to hydrogen in fuel	4.82 %
Loss due to moisture in fuel	4.61 %
Loss due to moisture in air	1,20 %
Loss due to carbon monoxide	0.27 %
Unburn carbon losses in fly ash	0,01 %
Unburn carbon losses in bottom ash	0,18 %
Loss due to surface radiation, convection, and other uncounted	1,68 %
Total	18,78 %
Boiler Efficiency = (100 – 18.78)%	81,22 %

Data is obtained from the performance of the boiler engine control test on the monitor screen in the CCR (Central Control Room). The data include flue gas temperature, ambient gas temperature, surface temperature, and GCV values for fuel, fly ash, and bottom ash. The result of the efficiency of the indirect method boiler is 100% - the total percentage of losses that occur in the boiler.

Based on this analysis, the results of boiler efficiency were 81.22%. This result is more accurate than the direct method method and is in accordance with the results of the commissioning test in 1994. The efficiency value of the boiler machine by indirect method is smaller than the efficiency value of the boiler machine using the direct method. This difference occurs because of different calculation methods. In the direct method (input-output method) uses the ratio between the output (steam) and heat input (fuel) for efficiency evaluation. Meanwhile, the indirect method (heat losses method) is done by reducing the heat generated during coal combustion with the losses that occur during and after the combustion process.

According to Baldi *et al* [10], Boilers that utilize exhaust gas for reheat the incoming feed water the boiler can increase efficiency by 10-12%, while according to Barma *et al* [11], maintenance is carried out schedule on the boiler and gas utilization exhaust can increase thermal efficiency. Factors affecting boiler engine efficiency are factor of the rate of clean air supplied throug the air heater, burner factor, combuctions air temperature, fouling, blowdown, condensate utilization [12].

The factors that can influence the thermal efficiency of the boiler is the temperature of the gas exhaust and fuel volatile ratio [13], meanwhile Patro [14] stated system control operations on boilers online against feed fuel, the combustion process includes the ratio of fuel and gas combustion can increase thermal efficiency. Fuel that does not burned complately at the bottom the combustion chamber which causes the descent boiler thermal efficiency [15,16]. Calculation of boiler efficiency is major factor affecting thermal power plant performance. There are two methods to determine boiler efficiency: direct method and indirect method., the efficiency of a fluidized bed boiler having a steam production capacity of 462000 kg/h and 17.2 bar pressure was calculated by using indirect method. In other Boilers in India, a Thermal power plant are to be operated efficiently to achieve higher plant efficiency in the present day market economy. Many of the boilers operating today are performing at efficiencies that are less than 60 percent [7].

4. Conclusions

Based on this analysis, the results of boiler efficiency were 81.22%. This result is more accurate than the direct method and is in accordance with the results of the commissioning test in 1994. The efficiency value of the boiler engine is indirectly smaller in assessing the efficiency value of the boiler engine directly because the Indirect Method reduces the heat generated during coal combustion with losses that occur during and after the combustion process.

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References

[1] Oktay Z 2009 *Appl. Therm. Eng.* **29** 550.
[2] Oman J, Senegačnik A, and Dejanovič B 2001 *Energy Convers. Manag.* **42** 251.
[3] Bhatt S M 2007 *Energy Convers. Manag.* **48** 2150.
[4] Huang J T, McMullan B C, and Williams 2000 *Fuel.* **79** 1595.
[5] Saidur R., Saidurn J U, Ahamed H H, and Masjuki 2010 *Energy Policy* **38** 2188.
[6] Chetan T Patel, Dr Bhavesh K Patel, and Vijay K Patel 2013 *Int. J. Innov. Res. Sci. Eng. Technol.* **2** 1518.
[7] Ashokkumar A 2012 *Middle-East J. Sci. Res.* **12** 1675.
[8] Samir A, Vikash K, and Arindam G 2014 *Int. J. Adv. Mech. Eng.* **4** 1.
[9] Yohana E and Askhabulyamin 2012 *J. ROTASI.* **14** 7.
[10] Baldi, S, Quang T Le, Holub O, and Endel P 2017 *J. Energy Convers. Manag.* **136** 329.
[11] Barma M C, Saidur R., Rahman S M A, Allouhi A, Akash B A, and Sait S M 2017. *Renew. Sustain. Energy Rev.* **79** 970.
[12] Gao X, Qi L, Lyu W, Chen T, and Huang D 2017 *J. Fuel.* **205** 272.
[13] Kitto J B, and Stultz S C 2015 *Steam* (USA: The Babecock and Wilcox Company Barbeton.)
[14] Patro B 2016 *J. Alex. Eng.* **55** 193.
[15] Spisak M, Cehlar V, Jakao Z, Jurkasova M, and Paskova 2012 *Acta Metallurgica Slovaca.* **18.** 133.
[16] Celen P and Erdem H H 2017 *Int. Conf. Adv. Mech. Eng. Istanbul* **3** 1.

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