Thermal and Physical Exergy Efficiency on 2 Units 7 MW Boiler at PLTU Tanjung Balai Karimun Kepulauan Riau

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Abstract

Boiler as an important device in steam power plant has a big role in producing power. The study of thermal efficiency and physical exergy efficiency had been done on boiler at PLTU Tanjung Balai Karimun Kepulauan Riau. This study used three variations of operation load. The analysis of thermal efficiency on boiler used indirect method. From the evaluation that has analysed, the boiler has decrease trend line along with the load of operation which 100% load of operation has 82.453% , 75% load of operation has 80.055% and 50% load of operation has 79.5% as output. Loss due to heat in dry flue gas, moisture in combustion air and carbon monoxide increase as the decrease of load operation. Major losses which more than 0.5% are loss due to heat in dry flue gas, moisture in as fired fuel and moisture from burning hydrogen. Minor losses which less than or equal to 0.5% are moisture in combustion air, carbon monoxide, radiation and convection, unburned carbon in ash, sensible heat in bottom ash, sensible heat in fly ash and unaccountable loss. Exergy as a method to evaluate the boiler as following 2nd law of thermodynamic. Exergy method, especially physical exergy was evaluated boiler based on the environment which called dead. The analysis of physical exergy efficiency shows 28.8% from 100% load of operation, 27.3% from 75% load of operation and 26.28% from 50% load of operation.

Keyword: **Efficiency, Boiler, Heat Loss, Exergy**

Introduction

In this era of globalization, the rapid development of technology impacts competition among countries, especially in industrial sector. That also impacts fulfillment of energy requirement that will be grows over time, where industrial sector is one of the most energy consumer [1]. The growth of industrial sector, must be coupled with the availability of sufficient energy, which called electricity. Therefore required a variety of power plants that are adapted to local conditions and natural factors [1]. Thermal power plants, using heat engine that transforms thermal energy from combustion into rotational energy to be mechanical power. On this case, steam power plant are widely used due to its high efficiency, economical cost, and produced great power [2].

One of the main component of steam power plant is boiler. One of its function, boiler can increase the thermal efficiency of rankine cycle by increasing boiler pressure [3]. Factor of efficiency is related closely to the cost. Time, age, bad maintenance are examples of many reasons why boiler efficiency decreases.

By the 1st law of thermodynamic, heat loss is a main factor which have an effect on thermal efficiency identify at boiler. This method analyze various type of losses that can be influence to the performance of boiler. By the 2nd law of thermodynamic, exergy is a method to evaluate the efficiency correctly. Therefore, by the description above hence the indirect method analyze and physical exergy are needs to know the efficiency by 1st and 2nd law of thermodynamic, which will be useful to evaluate to increase the efficiency and thrift of operational cost.

Theoritical

Boiler. Boiler is a combination between systems and devices which used to transform chemical energy from fossil fuel to be thermal fuel, and transfer that thermal energy produced to working fluid, usually water, to be worn on the process of elevated temperatures until it becomes heated or steam to a partial change into mechanical energy in a turbine [4] .

Efficiency of Boiler. Efficiency is the work value ability of a device to process materials from input to be output. Efficiency of boiler is defined as the percentage of heat input that is effectively utilized to generate steam.

Indirect Method. On indirect method, efficiency is 100 substrate by heat loss fractions as showed in figure 2.1.

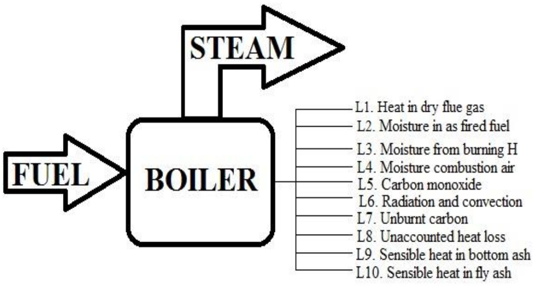

Figure 1 Indirect Method Evaluation

Heat Losses and Efficiency of Boiler Formula

A. Loss due to heat in dry flue gas (L_g)

$$\frac{WG'15 \times CpG' \times (tG15 - ta8)}{HHV} \times 100 \quad (1)$$

B. Heat loss due to moisture in as fired fuel (L_{mf})

$$\frac{mf \times (h15 - hw)}{HHV} \times 100 \quad (2)$$

C. Heat loss due to moisture from burning hydrogen (L_h)

$$\frac{8.936 \times H \times (h15 - hw)}{HHV} \times 100 \quad (3)$$

D. Heat loss due to moisture in combustion air (L_{ma})

$$\frac{WmA' \times [WA']15 \times (h15 - hRv)}{HHV} \times 100 \quad (4)$$

E. Heat loss due to carbon monoxide (L_{co})

$$\frac{\frac{28680.8 \times [CO]15 \times Cb}{[CO_2]15} + [CO]15}{HHV} \times 100 \quad (5)$$

F. Heat loss due to radiation and convection (L_r)

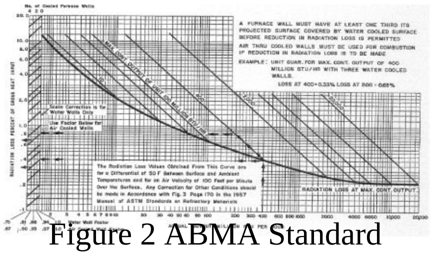

Figure 2 ABMA Standard Radiation Loss Chart

G. Heat loss due to unburned carbon (L_{uc})

$$\frac{33728.86 \times W_{d'p'} \times Uc}{HHV} \times 100 \quad (6)$$

H. Unaccounted heat loss (L_{un})
Set as 1

I. Heat loss due to sensible heat in bottom ash ($L_{p'}$)

$$\frac{0.1 \times W_{d'p'} \times C_{pp'} \times (t_{p'87} - t_{Ra})}{HHV} \times 100 \quad (7)$$

J. Heat loss due to sensible heat in fly ash ($L_{d'}$)

$$\frac{0.9 \times W_{d'p'} \times C_{d''15} \times (t_{15} - t_{Ra})}{HHV} \times 100 \quad (8)$$

K. Boiler thermal efficiency

a. $\sum L$ = Total Heat Loss

$$\sum L = L_g + L_{mf} + L_h + L_{ma} + L_{co} + L_r + L_{uc} + L_{un} + L_{p'} + L_{d'} \quad (9)$$

b. $$\eta_{bh} = (100 - L) \quad (10)$$

Exergy. Exergy is the work potential of energy. The amount of energy that can extract as useful work. In an exergy analysis, the initial state is specified. The system must be in the dead state at the end of the process to maximize the work output.

Energy = Exergy + Anergy

In the process of fuel combustion, the necessary quantity of oxygen for combustion is bringing the right amount of air. The air for temperature and pressure, possesses certain exergy, or its exergy is assumed zero if its state is in equilibrium with the environment. Dead state is when it is in thermodynamic equilibrium with the environment.

At the dead state, a system is at the temperature and pressure of its environment. The properties of a system at the dead state are denoted by subscript zero.

Physical Exergy Formula.

General physical exergy equation:

$$E = (H - H_0) - T_0 (S - S_0) \quad (11)$$

A. Incoming Flows

a. Feed Water

$$E = (H_{fw} - H_0) - T_0 (S_{fw} - S_0) \quad (12)$$

b. Fuel

$$E = (H_f - H_0) - T_0 (S_f - S_0) \quad (13)$$

B. Outgoing Flows

a. Flue Gas

$$E = (H_{fg} - H_0) - T_0 (S_{fg} - S_0) \quad (14)$$

b. Main Steam

$$E = (H_{ms} - H_0) - T_0 (S_{ms} - S_0) \quad (15)$$

c. Ash

$$E = (H_{ash} - H_0) - T_0 (S_{ash} - S_0) \quad (16)$$

C. Physical Exergy Efficiency

$$\eta_e = \frac{\sum E_{outgoing\ flows}}{\sum E_{incoming\ flows}} \text{ X } 100 \quad (15)$$

Result

1. Thermal Efficiency

A. Heat Loss Due To Heat in Dry Flue Gas

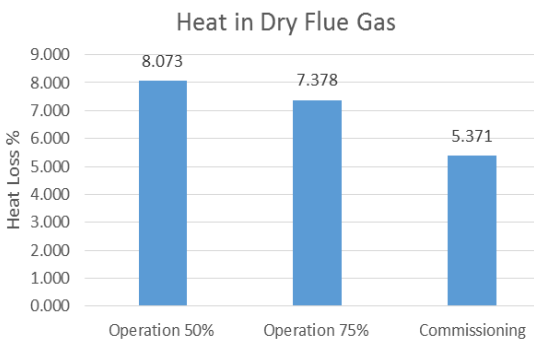

Figure 3 Percentage Comparison Heat Loss Due To Heat In Dry Flue Gas

The number of heat loss due to heat in dry flue gas decreases as the increase of operation load. This heat loss has the largest number than other losses. This heat loss can be categorized as combustion factor which the burners ability to burn fuel measured by unburned fuel and excess air in the exhaust. This percentage can be occurs by content of fix carbon, volatile matter, moisture and ash in the coal as a fuel. Excess air also occurs the combustion which the perfect combustion has its own ingredients content between fuel and air. Thus, this heat loss is depends on its coal and combustion process.

B. Heat Loss Due To Moisture in as Fired Fuel

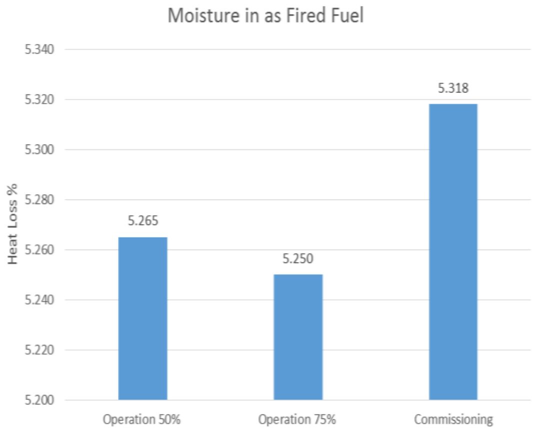

Figure 4 Percentage Comparison Heat Loss Due To Moisture In As Fired Fuel

The number of heat loss due to heat in moisture in as fired fuel depends with the load of operation. This heat loss depends at the moisture content of coal and enthalpy of vapor at gas temperature leaves chimney.

The measurement of moisture also the reason why this heat loss depends on the load of operation. This heat loss can be categorized as combustion loss which the burners ability to burn fuel measured by unburned fuel and excess air in the exhaust.

C. Heat Loss Due To Moisture from Burning Hydrogen

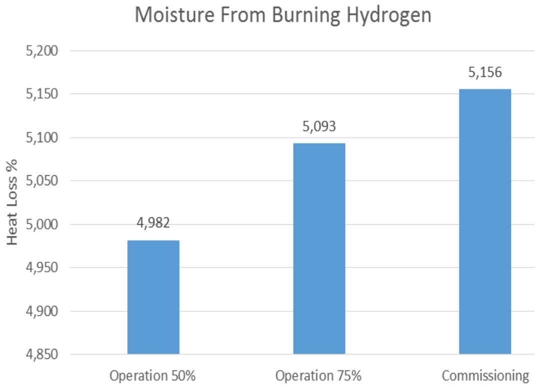

Figure 5 Percentage Comparison Heat Loss Due To Moisture from Burning Hydrogen

The number of heat loss due to moisture from burning hydrogen decreases along with the load of operation. This heat loss can be categorized as combustion loss which the burners ability to burn fuel measured by unburned fuel and thermal loss which indicates the heat exchangers effectiveness to transfer heat from the combustion process to the water or steam in the boiler. The content of hydrogen from coal, the enthalpy subtract h_{RW} by h_{15} and the excess air also are the reasons of why this loss decreases along with the load of operation. The excess air effects if less excess air means incomplete combustion and too much excess air means large heat dissipated to the chimney.

D. Heat Loss Due To Moisture in Combustion Air

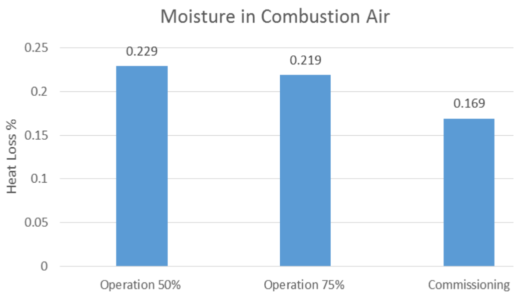

Figure 6 Percentage Comparison Heat Loss Due To Moisture In Combustion Air

The number of heat loss due to moisture in combustion air decreases as the increase of operation load. The absolute humidity, relative humidity, dry air per kg as fired coal burned, substraction of enthalpy of saturated vapor at reference temperature by enthalpy of gas exit and excess air are the factors of from combustion ability. Less excess air means incomplete combustion and too much excess air means large heat dissipated to the chimney.

E. Heat Loss Due To Carbon Monoxide

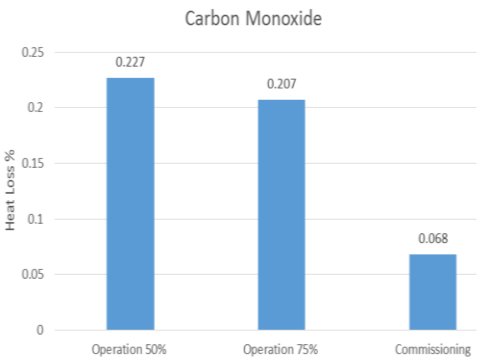

Figure 7 Percentage Comparison Heat Loss Due To Carbon Monoxide

The number of heat loss due to moisture from burning hydrogen are decrease as the increase of operation load. When too little air is supplied to the burner, there is not enough oxygen to completely form CO_2 with all the carbon in the fuel. Instead, some oxygen combines with carbon to form carbon monoxide (CO). CO is a highly toxic gas associated with incomplete combustion and efforts must be made to minimize its formation.

F. Heat Loss Due To Radiation and Convection

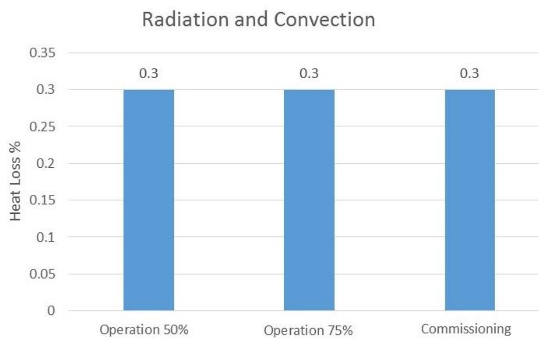

Figure 8 Percentage Comparison Heat Loss Due To Radiation and Convection

The number of heat loss due to radiation and convection are same in every operation. In every condition where 50%, 75% and 100% load of operation has 0.3% heat loss. This heat loss is depends on the design of furnace wall which must have at least one third its projected surface covered by water cooled surface before reduction in radiation loss is permitted. Air through cooled walls must be used for combustion if reduction in radiation loss is to be made. Because the furnace produce maximum continuous output of 400 million btu/hr, thus the number of heat loss percentage is 0.3%.

G. Heat Loss Due To Unburned Carbon in Ash

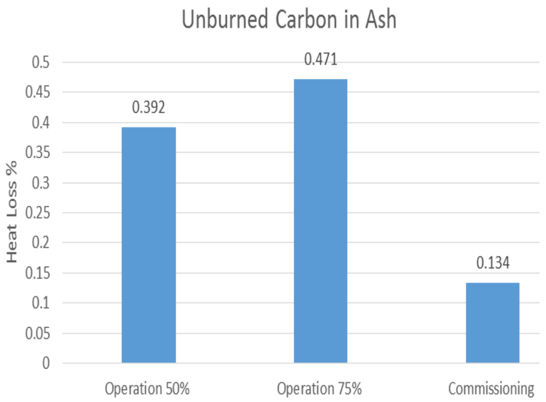

Figure 9 Percentage Comparison Heat Loss Due To Unburned Carbon In Ash

The number of heat loss due to unburned carbon in ash are depends on every condition. The factors of this heat loss are from coal content and combustion factor which called as burner ability. The difference condition of coal in different condition of load operation and the decreases of excess air along with the load of operation are factors why this heat loss percentage can be depends on the condition of load operation.

H. Unacountable Loss

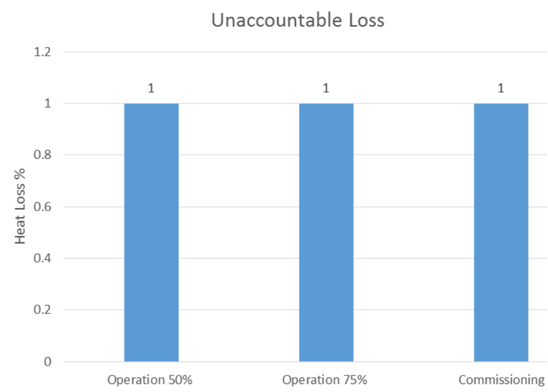

Figure 10 Percentage Comparison of Unaccountable Loss

The number of unaccountable loss are same on every condition. In condition 50%, 75% and 100% operation condition has 1% from ASME PTC 4. This loss comprise usually due to heat loss in ash, effects of sulfation, and calcination reactions in FBC boiler, unstated instrument tolerances and errors and any other immeasured losses.

I. Heat Loss Due To Sensible Heat in Bottom Ash

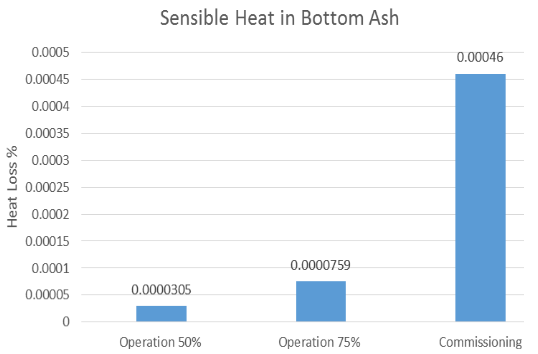

Figure 11 Percentage Comparison Heat Loss Due To Sensible Heat In Bottom Ash

The number of heat loss due to sensible heat in bottom ash are depends with the load of operation. Sensible heat is dry heat affect to change in temperature, not in the moisture content. This heat loss is occurs due to coal content and the burner ability to burn the coal. The excess air has a role how to increase the loss to the load of operation. Because excess air is part of combustion formula to burn the fuel.

J. Heat Loss Due To Sensible Heat in Fly Ash

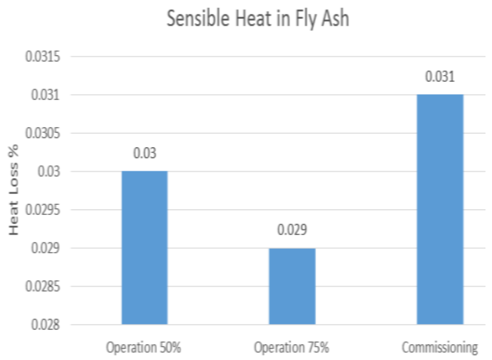

Figure 12 Percentage Comparison Heat Loss Due To Sensible Heat In Fly Ash

The number of heat loss due to sensible heat in fly ash are depends on the load of operation. This heat loss is occurs due to coal content and combustion factor. The heat value is responsible of this heat loss. The gas temperature also takes a role why this heat loss number depends on the load of operation.

K. Total Heat Loss

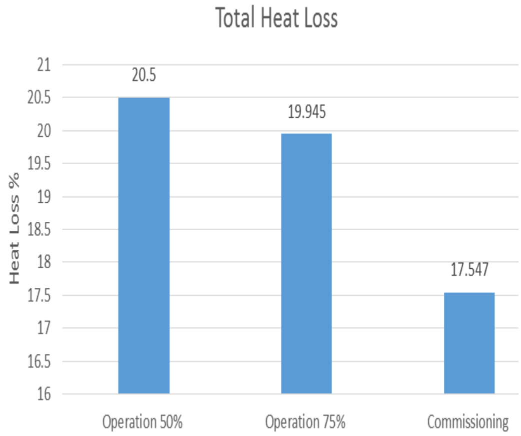

Figure 13 Percentage Comparison of Total Heat Loss

The number of total heat loss are decrease as the increase with the load of operation.

L. Boiler Thermal Efficiency

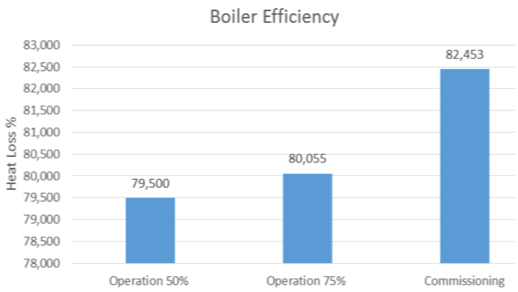

Figure 14 Percentage Comparison of Boiler Efficiency

The number of boiler efficiency are increases along with the load of operation. According to the journal reference [2] Analisis Teknis Evaluasi Kinerja Boiler Type IHI FW SR Single Drum Akibat Kehilangan Panas di PLTU PT PJB Unit Pembangkitan Gresik, there are 7 same heat losses to the observation. There are heat in dry flue gas, moisture in fuel, moisture from burning hydrogen, moisture in the combustion air, carbon monoxide, radiation and unaccounted loss. This is the table comparison analysis of fuel content from commissioning condition between journal reference PLTU PT PJB Unit Pembangkitan Gresik [1] and the observation from PLTU Tanjung Balai Karimun Kepulauan Riau.

Table 1 Comparison Heat Losses of Commisioning Condition from Power Plants

No.	**Heat Loss**	**Commissioning**		**Unit**
		PLTU PT PJB Unit Pembangkitan Gresik	**PLTU Tanjung Balai Karimun**	
1	Heat in Dry Flue Gas	3.16	5.371	%
2	Moisture in Fuel	0.0106	5.318	%
3	Moisture from Burning Hydrogen	6.36	5.15	%
4	Moisture in Combustion Air	0.11	0.169	%
5	Carbon Monoxide	0	0.068	%
6	Radiation	0.2	-	
7	Radiation and Convection	-	0.3	%
8	Unburned Carbon in Ash	-	0.134	%
9	Unaccountable Loss	1	1	%
10	Sensible Heat in Bottom Ash	-	0.0005	%
11	Sensible Heat in Fly Ash	-	0.03	%
12	Atomizing Steam	0.196	-	%
13	Total Heat Loss	11.03	17.547	%
14	Efficiency of Boiler	88.96	82.453	%

2. Physical Exergy

Table 2 Boiler Efficiency and Heat Losses List By The Condition

No.	**Load of Operation**	**Incoming Flows**		**Outgoing Flows**			**η_e**
		Fuel	**Feed Water**	**Flue Gas**	**Main Steam**	**Ash**	
1	50%	7275.3 kJ/kg	190.01 kJ/kg	743.94 kJ/kg	1217.99 kJ/kg	0.078	26.28%
2	75%	7280.61 kJ/kg	81.381 kJ/kg	757.65 kJ/kg	1251.97 kJ/kg	0.384 kJ/kg	27.3%

3	100%	7270.04 kJ/kg	118.1 kJ/kg	825.94 kJ/kg	1289.1 kJ/kg	13.1 kJ/kg	28.8%

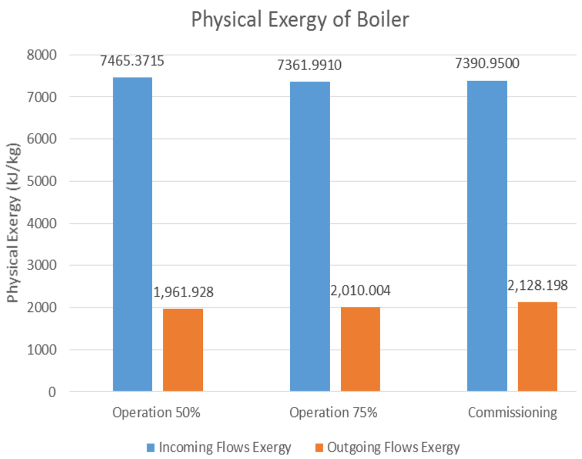

Figure 15 Comparison Physical Exergy Incoming and Outgoing Exergy

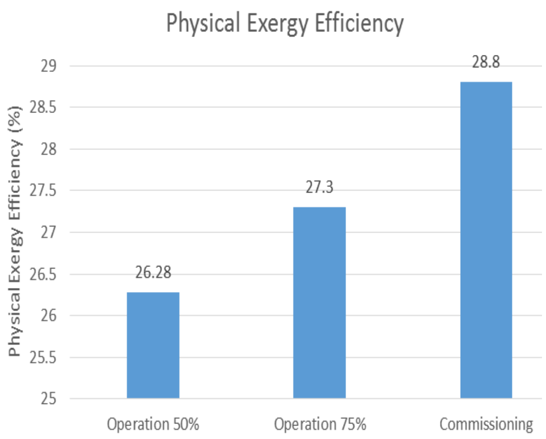

Table 2 is the table of physical exergy according to the calculation from equation 11 and physical exergy efficiency of boiler according to the calculation from equation 12 as its load of operation. From the figure 15, the big role of the incoming flows is fuel. The number of incoming flows from figure 15 is depends as its load of operation. Outgoing flows has several factors as explained in table 2.

In figure 16, the biggest number of exergy is at commissioning which is 100% load of operation. From the figure 16, the physical exergy efficiency is depends on the load of operation. This kind of efficiency is depends with the nature temperature and pressure that has been set by the engineer at the plant. Figure 15 and table 2 the outgoing flows exergy is explained as the exergy that cannot be recovery, while in figure 15 and table 2 the incoming flows exergy is explained as the exergy that need to the process input. Then, the table 2 the physical efficiency of exergy is explained as the energy which used to be work that known as exergy.

Table 3 Comparison Between Journal Reference and Observation

No.	**Thermal Plant "Technical Faculties" in Nis**		**PLTU Tanjung Balai Karimun Kepulauan Riau**
1	Theory Specification		
	Capacity	8.7 MW	8.1 MW
	Thermal efficiency	91%	± 80%
	Fuel	Natural Gas	Coal
2	Counted		
	Efficiency Thermal	89.9%	82.453%
	Efficiency Exergy	57.27%	28.8%

Comparison between journal reference Application of Energy and Exergy Analysis To Increase Efficiency of A Hot Water Gas Fired Boiler [10] took Thermal Plant "Technical Faculties" in Nis and PLTU Tanjung Balai Karimun as an object observation, as shown as table 4.20. On journal reference [5] , the specification of the boiler that took as an object shown if boiler at Thermal Plant "Technical Faculties" in Nis has larger capacity than the boiler at PLTU Tanjung

Balai Karimun Kepulauan Riau. Also, from the comparison of exergy efficiency, the boiler at PLTU Tanjung Balai Karimun Kepulauan Riau has lower number than the Thermal Plant "Technical Faculties" in Nis because of different fuel, production capacity, distinction of temperature reference and relation between system – environment from both of boiler.

Conclusion

1. The analysis of heat losses and efficiency due to its load of operation has 10 variation of heat loss. Loss due to heat in dry flue gas, moisture in combustion air and carbon monoxide decrease of the increase load operation. Major losses which more than 0.5% are loss due to heat in dry flue gas, moisture in as fired fuel and moisture from burning hydrogen. Minor losses which less than or equal to 0.5% are moisture in combustion air, carbon monoxide, radiation and convection, unburned carbon in ash, sensible heat in bottom ash, sensible heat in fly ash and unaccountable loss. The efficiency of boiler increase along with the load of operation which combustion is the main factor of why the efficiency decrease
2. The analysis of physical exergy efficiency due to its load of operation proof if the physical exergy efficiency increase along with the load of operation. The combustion, temperature, pressure, types of coal, maintenance of the devices can be the reasons why the energy that can be work as potential energy. The analysis shows 26.28% of 50% load of operation, 27.3% of 75% load of operation and 28.8% of 100% load of operation.

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