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Analysis of combustion quality on auxiliary boiler performance using heat loss method

Elli Prastyo[1*], Tegar Regi Setiawan2[1], Dian Farkhatus Solikha[1]
[1] Department of Chemical Engineering, Faculty of Engineering, Institut Teknologi Petroleum Balongan, Indramayu, Indonesia, 45216
*Corresponding author: elli.prastyo@gmail.com

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ABSTRACT

Boiler is one type of vessel that is closed and has the main function as a means of converting energy from water into steam / steam. A good combustion process is able to produce a minimal amount of flue gas and is able to increase thermal efficiency. The value of efficiency is important because it can save operating costs and increase product productivity in auxiliary boilers. This report is based on direct observations to the company PT Trans-Pacific Petrochemical Indotama. Data collection is carried out through interviews and boiler operational logsheet data collection. The research activities will be carried out on January 2 – February 28, 2023. The purpose of this study is to determine the performance of auxiliary boilers in terms of thermal efficiency and combustion reactions that occur using the heat loss method. The variables used in this study are fuel gas flow rate, theoretical air requirements, O2 excess value, flue gas temperature, and efficiency in auxiliary boilers at PT TPPI. The results of actual data and calculations per six days in one month in January 2023 obtained an average value of fuel gas of 4544.34 m3 / hr, theoretical air of 140658.02 m3 / hr, flue gas of 54964.83 m3 / hr, and the average value of thermal efficiency in auxiliary boilers is 63.44%. The results showed that the thermal efficiency value of PT TPPI's auxiliary boiler was still suitable for use with an efficiency value standard set above 60%.

Keywords: boiler, efficiency, flue gas, fuel gas, furnace

1. INTRODUCTION

The petrochemical industry is an industrial sector that continues to grow every year due to increasing demand. Over time, the petrochemical industry has experienced very rapid development, both from technological developments and from consumer demand that continues to increase [1]. Increasing demand certainly requires industry to increase production capacity which has an impact on energy needs [2].

After the first energy supply shocks in the early 1970s, the issue of energy consumption was considered by policymakers and industry players. Therefore, currently the indicator of energy consumption efficiency in several countries is a mandatory assessment [3]. The petrochemical industry's need for energy is an important factor that must be a concern. The importance of energy efficiency requires us to study productive factors, especially energy demand in the petrochemical industry [4]. One of the interesting issues in the discussion of energy is the quality of energy produced from the combustion reaction that occurs. A good combustion reaction will result in increased energy efficiency due to the use of fuel and oxygen in the combustion reaction [5]. A good combustion reaction can certainly produce minimal flue gas and have an impact on the energy lost due to the combustion process [6]. Therefore, petrochemical companies continue to optimize boilers that function as a source of combustion and produce steam.

PT TPPI is a petrochemical company that processes condensate and naphtha. The production process in the Feed & Platforming unit and the Aromatic unit at PT TPPI requires steam to support the process. Steam is useful as energy for heating processes and for generating electricity. Energy demand continues to increase, especially in the petrochemical industry sector in line with the increase in production. Good management of energy resources is one of the parameters to increase boiler efficiency in producing energy.

The efficiency value of this boiler is influenced by several parameters, including the value of temperature flue gas and O2 excess [7]. In the operation of the boiler, it needs to be maintained and evaluated periodically so that the boiler efficiency value remains in a good value [8]. The importance of maintaining boiler efficiency will benefit from total costs [9]. The greater the efficiency in the equipment, the smaller the total cost used, and the company will also experience cost savings [5].

Research on boiler performance evaluation in terms of efficiency has been carried out by several previous studies. The furnace performance in unit I (HVU I) at Pertamina Refinery Unit (RU) IV Cilacap shows boiler efficiency results of 73.6085%. The efficiency value obtained has a lower value than the standard set referring to design efficiency, which is 79%. Equipment condition factors and operating processes are some of the things that cause low furnace efficiency values. The evaluation process is needed to determine the factors that most affect the value of furnace efficiency [10].

Performance tests of the steam power plant in Paiton (unit IX) were carried out based on heat rate data obtained with 100% furnace loading had been carried out. The highest boiler efficiency value was obtained at 85.689% which occurred on November 26, 2014, while the lowest boiler efficiency value occurred on March 12, 2015 at 83.280%. The best boiler performance in terms of heat rate value occurred on January 13, 2015 of 2,500,811 kcal / kWh. The lowest boiler performance in terms of heat rate value occurred on December 11, 2014 of 2,658.098 kcal / kWh [11].

The direct heat losses method is used to analyze boiler losses in sugar mills. This study aims to make the Company focus on analyzing the kinerja of boilers due to work losses that occur. Research shows that heat loss in dry flue gases from boilers is one source of work loss, which is 12.82%. Furthermore, the water content is the largest aspect in work losses that occur in boilers by 14.40%. Ash content is the next and last factor is due to fuel that does not burn completely (unburn carbon). The boiler performance value in terms of thermal efficiency was obtained by 59% using the direct heat loss method [12].

The current review aims collectively to present an evaluation of boiler performance at PT Trans Pacific Petrochemical Indotama. The novelty of this study is the use of auxiliary type boilers which are reviewed based on combustion quality seen from the value of flue gas produced.

2. MATERIALS AND METHODS

This research is a field study conducted at PT Trans Pacifik Petrochemical Indotama located in Tuban Regency, East Java. A quantitative approach is taken to determine the performance of the boiler used. This research has several stages as follows:

1. Field Observation
   Field observations are carried out to determine the condition of the research location, especially regarding tool specifications, tool performance, logsheet data history, and historical reports on the maintenance process that has been carried out
2. Data Collection
   Data collection was carried out on auxiliary boilers located in the utility unit of PT TPPI Tuban. Data collection is carried out directly to the field from existing daily and weekly logsheet data. The study uses primary and secondary data in carrying out the process of processing and analyzing data. The primary data taken is in the form of boiler inlet air temperature, fuel gas flow rate, heating value fuel gas, flue gas temperature, boiler operating pressure, and boiler temperature. The secondary data used are average humidity data in the PT TPPI plant area based on BMKG data and properties of material taken from appendix table data and chemicalogic steam tab companion.
3. Data Processing and Analysis
   The data obtained is processed using the heat-loss method in determining the thermal efficiency of the boiler. The heat loss method is used based on fuel gas consumption with the same thermal load supported by the Sankey diagram.
   The concept of thermal efficiency is a measure of how much effectiveness the heat content in the fuel can be utilized during the combustion process. The thermal efficiency of any furnace system is defined as the useful energy derived from the system relative to energy input [13]. Thermal efficiency is formulated as follows.

$$\eta = \frac{useful\ heat}{total\ heat}.100\% \quad (1)$$

$$\eta = \frac{(Q_a+Q_f+Q_{fs})-(Q_r+Q_s)}{(Q_a+Q_f+Q_{fs})}.100\ \% \quad (2)$$

Heat of sensible air:

$$Q_1 = cp.\Delta T.\frac{m_a}{m_f} \quad (3)$$

$$m_a = \frac{(28{,}85.\%O_2).\left(\frac{N_2}{28}+\frac{CO_2}{44}+\frac{H2O}{18}\right)}{20{,}95-\%O_2.\left[\left(1{,}6028.\frac{kg\ H2O}{air\ required}\right)+1\right]} \quad (4)$$

$$mf\left(\frac{kg\ wet\ air}{kg\ fuel}\right) = \frac{air\ required}{1-\frac{kg\ moisture}{kg\ air}} \quad (5)$$

Heat combustion of fuel gas

$$Q_f = m.HHV \quad (6)$$

Heat sensible of fuel gas

$$Q_{fs} = m.cp.\Delta T \quad (7)$$

Heat of Radiation

$$Q_r = Q_3.\%radiation \quad (8)$$

Heat of stack

$$Q_s = m_{component}.H_{component} \quad (9)$$

Table 1. Operation condition of furnace

Time (Jan-2023)	Air (^{O}C)	Fuel		Flue gas (^{O}C)
		Temperature (^{O}C)	Flow (m^3/jam)	
1-6	33,94	31,31	4913,44	135,34
7-12	34,22	32,36	4639,00	134,70
13-18	34,64	31,17	4582,72	134,17
19-24	34,58	32,28	4436,28	133,47
25-30	33,86	29,31	4150,24	132,9

Table 3 demonstrates that the air and fuel gas entering the furnace are at ambient temperature, while the combustion gas reaches a temperature range of 132–139°C. The flow rate of the gas fuel exhibits considerable fluctuations.

3. RESULTS AND DISCUSSION

This research was carried out at PT TPPI Tuban on January 1, 2023 – January 30, 2023. The research was conducted through taking operation data directly on the auxiliary boiler to carry out the analysis process on the performance of the auxiliary boiler. Data on operating conditions for 1 month such as temperature, and flow rate are calculated on average in one week. In calculating the performation of aulixilary boilers, researchers use a standard temperature of 20oC referring to NIST, while for excess air 10% is used based on the operating conditions of the tool. The fuel used for PT TPPI auxiliary boiler is butane with a complete combustion reaction, where the reaction is:

$$C_4H_{10\,(g)} + 6\frac{1}{2}O_{2(g)} \rightarrow 4CO_{2(g)} + 5H_2O_{(l)}$$

Butane flow is obtained from actual data on January 1-6, 2023 (4913.44 m^3/hr) and is used for calculation examples assuming air contains 79% nitrogen and 21% oxygen. The following is the calculation of the results of the combustion reaction:

$$O_2 = \frac{4913{,}44\ m^3/hr}{1}.6{,}5\ = 31937{,}39\ m^3/hr$$

$$N_2 = \frac{79}{21}.4913{,}44\ m^3/hr = 120145{,}42\ m^3/$$

$$CO_2 = \frac{4913{,}44\ m^3/hr}{1}.4 = 19653{,}78\ m^3/hr$$

$$H_2O = \frac{4913{,}44\ m^3/hr}{1}.5 = 24567{,}22\ m^3/hr$$

$$Excess\ Air = (O_2 + N_2).10\% = 15208{,}28\ m^3/hr$$

$$N_2\ excess = EA.79\% = 12014{,}54\ m^3/hr$$

$$O_2\ excess = EA.21\% = 3193{,}74\ m^3/hr$$

$$Total\ air\ = (O_2 + N_2 + Excess\ Air) = 167291{,}08\ m^3/hr$$

Table 2 show the calculation results of O2, N2,

CO_2, H_2O, O_2 excess, and N_2 excess, from the combustion reaction of the fuel used (m^3) in January 2023 with an average per 6 days.

Table 2. Combustion Reaction Calculation Results

Information	1-6	7-12	13-18	19-24	25-30
O_2 (m^3/hr)	31937,39	30153,50	29787,69	28835,81	26976,53
N_2 (m^3/hr)	120145,42	113434,60	112058,47	108477,55	101483,15
CO_2 (m^3/hr)	19653,78	18556,00	18330,89	17745,11	16600,94
H_2O (m^3/hr)	24567,22	23195,00	22913,61	22181,39	20751,18
Excess Air (m^3/hr)	15208,28	14358,81	14184,62	13731,34	12845,97
Excess N_2 (m^3/hr)	12014,54	11343,46	11205,85	10847,76	10148,32
Excess O_2 (m^3/hr)	3193,74	3015,35	2978,77	2883,58	2697,65
Total air (m^3/hr)	**167291,08**	**157946,90**	**156030,78**	**151044,70**	**141305,66**

Based on the results of combustion reaction calculations, theoretical air requirements for auxiliary boilers tend to decrease every week for one month. This decrease is correlated with the flow of fuel gas presented in table 1. The increase or decrease in fuel gas demand in boilers will correlate with air demand [14]. Fuel gas requires O_2 in the air to carry out the combustion reaction, the higher the O_2 flow rate that is not balanced with the fuel flow rate will adversely affect the performance of the combustion chamber [8].

3.1. Thermal Efficiency

The heat content contained in the fuel and can be utilized in the combustion process is an understanding of the thermal efficiency of a heat exchanger. The thermal efficiency of any furnace system is defined as the useful energy derived from the system relative to the energy input [13]. Thermal efficiency can be formulated as follows.

$$\eta = \frac{(Qa+Qf+Qfs)-(Qr+Qs)}{Qa+Qf+Qfs}\,.100$$

$$Qa = 0{,}62\ kj/hr$$

$$Qf = 611890945{,}04\ kj/hr$$

$$Qfs = 7999146{,}4\ kj/hr$$

$$Qr = 2202807{,}402\ kj/hr$$

$$Qs = 226746415{,}29 kj/hr$$

$$\eta = 63{,}07\%$$

The data used as an example calculation is taken from actual data on January 1-6, 2023. After calculating thermal efficiency, thermal efficiency in auxiliary boilers in January 2023 with an average per 6 days will be tabulated in table 3.

Date	η (%)
1 - 6 January 2023	63,07
7 - 12 January 2023	63,18
13 - 18 January 2023	63,39
19 - 24 January 2023	63,60
25 - 30 January 2023	63,97
Average	63,44

Table 3. Thermal Efficiency Calculation Data

The Effect of Flow Fuel Gas and Theoretical Air Requirements on Flue Gas

Table 4 shows that theoretical air demand correlates with the amount of fuel gas entering the furnace, the higher the fuel discharge, the air demand increases. The rise or fall of theoretical air is caused by a combustion reaction, if the amount of fuel gas used is high, then the theoretical air demand will also be high, which has an impact on the amount of flue gas produced will also increase. This is proven in table 4 which shows that the values of fuel gas, theoretical air, and flue gas correlate with each other. The amount of each component in flue gas (CO_2, H_2O, N_2, and O_2) produced depends on the amount of fuel gas used.

Where theoretical air needs (N_2 and O_2) affect the amount of air heat and stack heat [14]. Theoretical air demand always decreases every 6 days because the flow rate of incoming fuel gas also decreases, this affects the amount of flue gas produced.

Table 4. Flow Fuel gas, Theoretical Air, and Thermal Efficiency Data

Date (Januari 2023)	*Fuel Gas* (m^3/hr)	Theoritical Air (m^3/hr)	*Flue gas* (m^3/hr)
1-6	4913,44	152082,80	59429,28
7-12	4639,00	143588,09	56109,81
13-18	4582,72	141846,16	55429,12
19-24	4436,28	137313,36	53657,84
25-30	4150,24	128459,67	50198,09

Effect of Excess O_2 on Thermal Efficiency

Based on the calculation data, it can be seen the comparison between O2 excess and thermal efficiency shown in the following Figure 2.

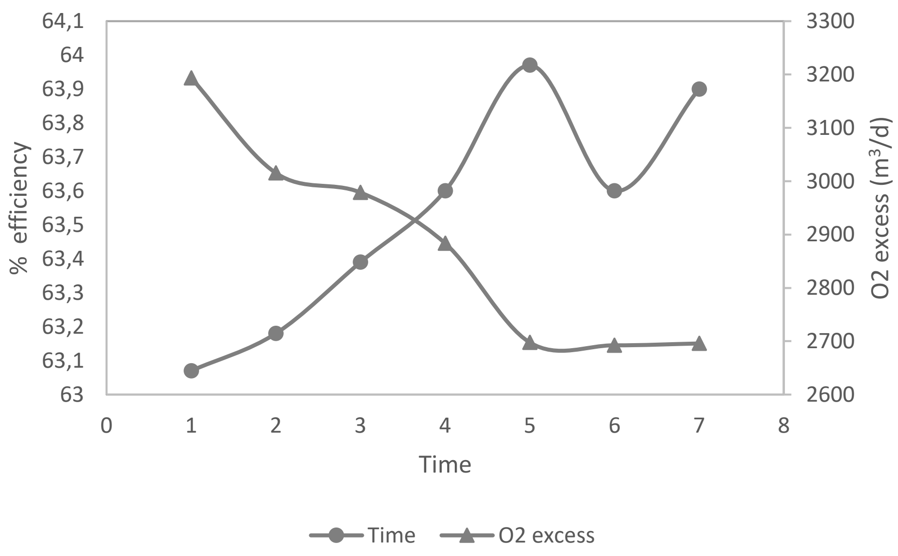

Figure 2. The relationship of excess O_2 to thermal efficiency

In Figure 2 it can be seen that the smaller the O_2 excess value, the higher the thermal efficiency value of the auxiliary boiler. From the six-day data, it can be seen that there is a slight fluctuation caused by the value of fuel gas flow in different six-day data, which results in a slightly fluctuating value which has an impact on the value of O_2 excess is also different.

Excess air (O_2% in the exhaust gas) is able to affect the boiler performance value [15]. High excess air value has an impact on boiler efficiency which is decreasing. Boiler efficiency can increase when the air supply provided to the combustion chamber is close to equilibrium, so that the excess air value is minimal [16]. The reduction in air supply in the combustion chamber has an impact on the pressure in the combustion chamber, so that the residence time of the hot fluid can increase in the combustion chamber and the temperature flue gas that comes out through the stack can be lowered. The reduction in air supply which has an impact on decreasing the value of excess air also makes fuel use more efficient [17]. This opinion is also reinforced by [18] who states that to achieve a combustion reaction that is close to ideal, a certain amount of O_2 volume is needed which is offset by the addition of some excess air into the combustion chamber. However, when the excess air value given is too high, it can create high heat loss and can reduce the thermal efficiency value of the boiler [19].

3.2. The Effect of Flue Gas Temperature on Thermal Efficiency

Based on the calculation data, it can be seen the comparison between Flue Gas Temperature and Thermal Efficiency shown in the following figure 3.

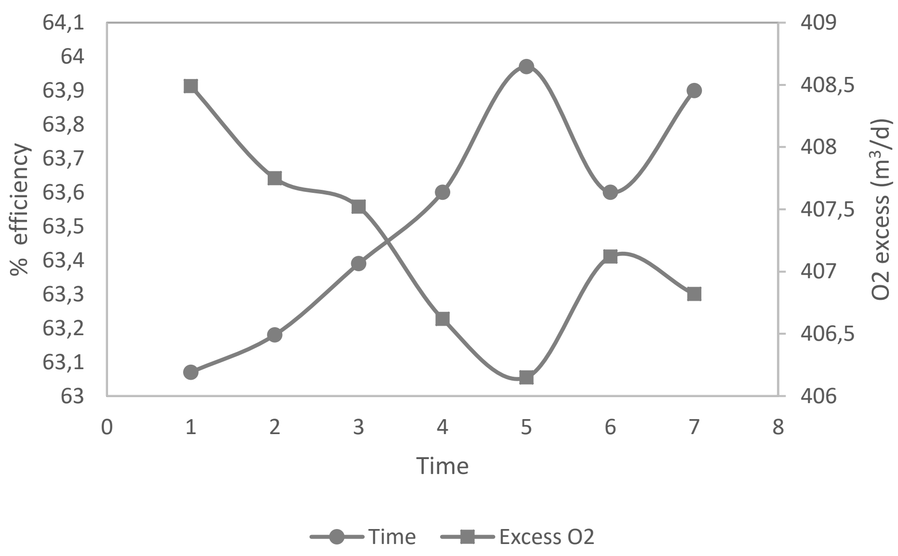

Figure 3. Gas flue temperature to thermal efficiency effect

In Figure 3 it can be seen that the higher the temperature of the flue gas, the smaller the thermal efficiency value. This is because the increase in temperature will affect the more heat produced by flue gas where the Qloss stack produced will also be greater and have an impact on decreasing the value of thermal efficiency [8]. The Qloss value of the stack is influenced by the enthalpy and flow of each component of the flue gas [20]. The enthalpy obtained is greater when the temperature of the flue gas is higher and the flow of each component in the flue gas is also greater when the flow from the fuel gas is greater. The average thermal efficiency value in January 2023 is 63.44%.

Temperature flue gas is an indicator used in this study which represents a number of heat absorption during the heat transfer process that occurs in the boiler. The value of heat transfer that is not good can be represented by the temperature value of flue gas measured on the stack [21]. The cross section of the stack that has a certain area becomes the trajectory traversed by flue gas. When the air flow rate entering through the EA is getting bigger, it has an impact on the volume of flue gas which is higher than the volume in the EA which has a small cross-sectional area [22]. The situation that occurs where the volume of flue gas is higher than the air supplied by EA has an impact on heat absorption to be less good, so that the temperature of flue gas becomes high [23], [24]. Higher flue gas temperatures can reduce boiler thermal efficiency because of the higher Qloss value [25].

3. CONCLUSION

The flow rate and temperature flue of the combustion reaction have a significant effect on boiler performance. The highest thermal efficiency value on January 25-30, 2023 was 63.97%, when the gas flue temperature reached 406.03 K, and the lowest thermal efficiency value on January 1-6, 2023 was 63.07%, when the gas flue temperature reached 408.49 K. The highest O2 Excess value was detected on January 1-6, 2023 at 3193.74 m3/hr with a thermal efficiency value of 63.07% and the lowest on January 25-30, 2023 at 2697.65 m3/hr with a thermal efficiency value of 63.97%. The furnace is expected to reduce the excess O_2 flow rate in order to improve efficiency. The use of an economizer is recommended to lower the flue gas temperature, thereby contributing to the enhancement of furnace efficiency.

CONFLICT OF INTEREST

No potential conflict of interest was reported by the author(s).

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work, including its accuracy and integrity.

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