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Analysis of Furnace Performance Efficiency 201-H-001 Prefractionation Unit PT Trans-Pacific Petrochemical Indotama Tuban-East Java

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Abstract
Petroleum processing generally begins with a heating process, so equipment is needed to heat the crude oil before entering the fractionation column. This heating is closely related to the separation of fractions based on differences in boiling points. Heating at a fairly high temperature is used by a furnace, where the heat source comes from gas fuel. Based on the discussion above, furnace efficiency is fascinating to calculate as an indication of whether or not the furnace is operational. This efficiency calculation is also a reference for PT. Trans-Pacific Petrochemical Indotama to shut down and repair equipment, especially furnaces. This research aims to understand the furnace's working principles, determine the parameters that influence furnace performance, and calculate the efficiency of Furnace 201-H-001 in the Prefractionation unit. The results obtained in this research are that there are variables used to calculate thermal furnace efficiency. These variables are air temperature, fuel gas temperature, fuel gas flow, flue gas temperature, theoretical air requirements, and excess air in terms of efficiency and combustion reactions. The results of the furnace efficiency calculations were 78.03%, 77.34%, and 77.75% respectively. The minimum thermal efficiency value ranges from 75 - 80%, so it can be said that the furnace in this research is still suitable for use.
Keywords: Furnace, efficiency value, fuel, combustion reactions

1. Introduction

The development of the oil and gas industry towards fuel production needs is increasing every year. The petroleum processing industry requires equipment to heat crude oil before being fed to the fractionation column. This heating is closely related to the separation of fractions based on their boiling point trajectories (Aliyah Shahab & Achmad Faisal F, 2023; Yuliani, 2011). One of the equipment that requires quite a lot of energy in industry is a heat exchanger, for heating at quite high temperatures a furnace is used whose heat source comes from fuel. Heat transfer in a furnace occurs between the heated fluid and the heat produced by burning the fuel (Kurniawan & Suharti, 2023).

Most industries have heat exchangers in their production processes. PT Trans-Pacific Petrochemical Indonesia (TPPI). PT TPPI is a factory engaged in the petroleum refining industry and chemical industry. One of the unit operations at PT TPPI that involves a heat transfer is the prefractionation process. Prefractionation is the main unit of platforming. Fractionation is the main method in the processing industry, a separation technique widely used to separate components in mixtures with different boiling points. The degree of separation of multi-component systems depends on the nature of the feed mixture, operating conditions, and other limitations (Saputri, 2022).

Furnaces are one of the tools that contribute the most to energy processing units in petroleum refining and the petrochemical industry. Furnace thermal efficiency plays an important role in factory energy savings. So, it is very important to maximize the heat value transferred to the crude oil processing process and minimize the heat lost from the furnace (Satria et al., 2019).

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From the results of the research conducted (Rizal et al., 2016) on furnaces that have been made, it was found that the heat produced by the furnace was obtained from the conversion of electrical energy into heat energy. The furnace turns on or works when the temperature in the cabin has not yet reached the setting temperature, whereas the furnace is turned off when the temperature in the cabin slightly exceeds the setting temperature.

Furnace efficiency is very important in measuring the performance of a furnace. Furnace efficiency calculations must be carried out periodically in order to determine the performance of the furnace so as to avoid long-term damage that can cause maintenance and thus affect production and refinery costs. If the feed that enters the furnace does not comply with specifications, it can burden the performance (duty) of the furnace, this will be more serious if the efficiency of the furnace itself is low (Aliyah Shahab & Achmad Faisal F, 2023). Therefore, an evaluation of the furnace performance was carried out to determine the feasibility of operating the furnace used by PT TPPI. Evaluation of furnace performance is carried out by calculating the heat efficiency of the furnace.

2. Method

Data Collection

This research applies a quantitative approach by collecting primary data from furnace log sheets, including parameters such as air temperature, fuel gas temperature, fuel gas flow, flue gas temperature, theoretical air requirements, and excess air. In addition, secondary data such as combustion reaction calculations and thermodynamic properties are also used. Next, the data was processed using Microsoft Excel to calculate the thermal efficiency of furnace.

Analysis Data

Thermal efficiency is a dimensionless measure that shows the performance of thermal equipment such as internal combustion engines. Thermal efficiency can be formulated as follows:

$$\eta = \frac{(Q_a + Q_f + Q_{fs}) - (Q_r + Q_s)}{Q_a + Q_f + Q_{fs}} \cdot 100$$

a. Calculating the sensible heat of air (Qa)

$$Q_a = Cp_a \times (T_a - T_d) \times \frac{m_a}{m_f}$$

Where, Cp_a = specific heat of air (kJ/kg.K), T_a = inlet air temperature (K; C), T_d = standard temperature (K; C), m_a = excess air/kg fuel, m_f = kg wet air/kg fuel

b. Calculating the heat of combustion of fuel gas (Qf)

$$Q_f = m \times GHV$$

Where, m = flow rate (m^3/h; kg/hr; mol/hr), GHV = gross heating value (kJ/kg)

c. Calculating sensible gas fuel (Qfs)

$$Q_{fs} = m \times C_p \times \Delta t$$

Where, m = flow rate (m^3/h; kg/hr; mol/hr), C_p = heat capacity (kJ/kg.K), T_a = inlet air temperature (K; C), T_d = standard temperature (K; C)

d. Calculating Radiant Loss (Qr)

$$Q_r = Q_f \times \%Radiasi$$

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Where, Q_f = heat of combustion of fuel gas

e. Calculating heat loss (Qs)

$$Q_s = m \times H$$

Where, m = flow rate (m^3/h; kg/hr; mol/hr), H = enthalpy (kJ/kg)

3. Results and Discussion

Working Principle Of Furnaces

In the oil and gas industry, a furnace is a tool designed as a main heating place for crude oil which is equipped with a burner. The purpose of heating in a furnace is to evaporate the light fractions contained in crude oil. The furnace's heat source comes from the combustion process of fuel oil, fuel gas, or a combination of both. The crude oil will enter the furnace through the tube at the top at a temperature of 110°C and then continue to the bottom, this is done to avoid damage to the crude oil due to sudden heating, causing cracking or fracturing. The light fractions in the form of steam leave the heavy fraction as crude oil, then exit the furnace at a temperature of 340°C.

Research Data

Primary data is used as material for calculating the thermal efficiency of the Furnace 201-H-001 prefractionation unit obtained from logsheet data at PT. Trans-Pacific Petrochemical Indotama. Data was taken during the periods on January 1, 9, and 18 2024:

Table 1.
Primary data

Furnace operating conditions 201-H-101 PT. TPPI				
Date (January 2024)	air	fuel		Flue
	Temp (°C)	Temp (°C)	Flow (m^3)	Temp (°C)
1	35	45	1.424794	291.274
9	35	45	1.662920	300.290
18	35	45	1.283492	294.990

Table 2.
Secondary data

Furnace operating conditions 201-H-101 PT. TPPI				
Date (January 2024)	Excess air (%)	T reference (°C)	Radiasi (%)	O_2 (%)
1	15	20	2.5	8.27
9	15	20	2.5	6.56
18	15	20	2.5	9.16

Secondary data collection used as calculation material in the evaluation analysis of Furnace 201-H-001 in the Prefractionation Unit was obtained from field and literature data. Field study data was obtained by looking at the Furnace operating conditions on the DCS (distributed control system) daily report with the required data in the form of operating condition data and furnace data design. In the Literature study, the data obtained were the Furnace calculation steps, graphs, and tables referring to literature (Kern, 1965).

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Combustion Reaction

The fuel used in the combustion reaction is fuel gas, including LPG (liquefied petroleum gas), while the fuel components are hydrogen, methane, ethane, and propane. Each fuel component undergoes a complete and perfect combustion reaction, as written in the following equation:

$H_2 + ½ O_2 \rightarrow H_2O$

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$C_2H_6 + 3{,}5O_2 \rightarrow 2CO_2 + 3H_2O$

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

The following are the results of the calculation of O_2, N_2, CO_2, H_2O, excess air, and air from the combustion reaction of fuel used (kg/hr) on January 1, 9, and 18 2024:

Table 3.
Component Combustion Reaction Results

Date (January 2023)	**1**	**9**	**18**
O_2 (kg/hr)	40.2389	46.9641	36.2483
N_2 (kg/hr)	151.3751	176.6745	136.3627
CO_2 (kg/hr)	20.5596	23.9957	18.5206
H_2O (kg/hr)	39.3586	45.9366	35.4553
Total Air (kg/hr)	220.3563	257.1844	198.5027
Excess Air (kg/hr)	28.7421	33.5458	25.8916

Thermal Efficiency Calculations

Furnace efficiency is the performance of a furnace to provide heat produced by burning a certain amount of fuel to the fluid heated in the furnace tube. To find out the efficiency of the furnace, first determine the heat balance.

Table 4.
Heat balance

No	**Hot type**	**Heat in (kJ/hr)**	**Heat out (kJ/hr)**
1	Sensible heat of air (Qa)	0.258957776	-
2	Heat of combustion of fuel (Qf)	10894252.72	-
3	Fuel sensible heat (Qfs)	111130,3571	-
4	Radiation heat (Qr)	-	272356,3179
5	Heat stack (Qs)	-	2144948.126
6	Heat lost	-	8588078.887
	Total	11005383.33	11005383.33

After calculating the thermal efficiency, the thermal efficiency of Furnace 201-H-001 on January 1, 9, and 18 2024 is obtained as follows:

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Table 5.
Thermal efficiency of Furnace

No	Date	Efficiency (%)
1	1 January 2024	78.03
2	9 January 2024	77.34
3	18 January 2024	77.75
	Average	77.71

To maintain furnace performance, the crude oil capacity must be maintained following the furnace design specifications. If crude oil enters at a capacity below specification, it can result in uneven heat distribution, potentially compromising tube integrity. Flue gas outlet temperature also affects efficiency; Too high a temperature can result in a waste of heat through flue gas (I Wayan Sugita et al., 2022).

Several design and operational parameters on furnace efficiency also influence energy savings and the study found a positive trend. These parameters include flue gas temperature, combustion air inlet temperature, thickness, and emissivity of the refractory wall. Reducing the flue gas temperature increases the furnace efficiency by up to 73%, increasing the air inlet temperature increases the furnace efficiency by up to 61%, and increasing the thickness of the refractory walls increases the furnace efficiency (Ajah et al., 2023). Carrying out regular maintenance is also very important in improving furnace performance (Satria et al., 2019).

Based on the furnace efficiency calculations that have been carried out, the efficiency of Furnace 201-H-001 PT TPPI on January 1, 9, and 18 2024 is 78.03%, 77.34%, and 77.75% respectively. According to (Kern, 1965), the current minimum thermal efficiency value ranges from 75% to 80%, it can be concluded that the furnace in this study is suitable for operation. Furnace efficiency can be maintained because the equipment is always cleaned and maintained regularly so that the amount of excess water that enters it is minimal. This reduces the amount of heat lost through the flue gas. The heat lost to the environment is also low because the furnace walls remain in good condition and do not experience leaks.

Effect of Percent O_2 on Reducing Furnace Performance Efficiency

Furnace performance efficiency refers to how efficiently the energy is used to achieve the heating or combustion goal in the process. Good furnace performance efficiency means that less energy is wasted, so it is more efficient in heating or burning the required materials. When oxygen is involved in the combustion process in a furnace, it acts as an oxidizing agent. This oxygen plays a role in chemical reactions that cause fuel to burn and produce the heat needed to reach the desired temperature (Aswan et al., 2017).

When oxygen is involved in the combustion process in a furnace, it acts as an oxidizing agent. This oxygen plays a role in chemical reactions that cause fuel to burn and produce the heat needed to reach the desired temperature. However, if the oxygen percentage in the furnace does not match the needs of the combustion process, various problems can arise, including reducing the efficiency of the furnace's performance. A certain amount of O_2 is required for complete combustion along with an additional amount of residual air required to ensure complete combustion. However, too much excess air causes heat loss and lower efficiency (Ningsih et al., 2021).

Parameters that influence furnace performance

The parameter that is used as a reference for furnace performance is its thermal efficiency. Thermal efficiency is a description of the use of heat produced by burning fuel to heat the process fluid. Factors that can influence the effectiveness of furnace performance are as follows (Samosir & Safaruddin, 2022):

1. Oxygen (O_2)
   If the percentage of oxygen in the furnace does not match the needs of the combustion process, various problems can arise, including a decrease in furnace efficiency.
2. Excess air
   To avoid incomplete combustion during combustion in the furnace, excess air is introduced from the theoretical air requirement. A little excess air will cause incomplete combustion (formation of CO_2) thereby reducing efficiency. However, too much excess air is also inefficient because it will create a large volume of exhaust gas and the combustion will be absorbed, causing the air temperature to increase.
3. Heat loss
   Heat loss will reduce the effective value. The following are things that can cause heat loss:
   a. Heat is lost through the furnace walls.
   b. Incomplete combustion of gas fuel results in components that do not burn or burn incompletely, compared to high flue gas temperatures resulting in heat being wasted in the flue gas.
4. Isolation
   The quality of the insulation in the furnace is very important. Poor insulation can cause heat leaks resulting in wasted energy and reduced efficiency.
5. Fuel
   The type of fuel used in the furnace will affect efficiency. Poor quality fuel or fuel that does not match the furnace design can cause incomplete combustion and reduce efficiency.
6. Maintenance and cleaning
   Furnaces that are not well maintained and dirty tend to have lower efficiency due to less than optimal combustion and disturbed airflow.

4. Conclusion

Crude oil will enter the furnace through the tube at the top at a temperature of 110°C, this is done to avoid damage to the crude oil due to sudden heating, causing cracking. The light fractions in the form of steam leave the heavy fraction as crude oil, then leave the furnace at a temperature of 340°C. Meanwhile, the function of the furnace in industrial processes is to increase the temperature of the oil fluid according to requirements to reach the evaporation point, thermal reaction point, and catalyst reaction point. Parameters that can influence the performance efficiency of the 201-H-001 furnace are oxygen, excess air, heat loss, insulation, fuel, maintenance, and cleaning. From the results of the calculations that have been carried out, it was found that the optimum performance efficiency value for the 201-H-001 furnace on January 1 2024 was 78.03%, this shows that the condition of the furnace is still said to be suitable for use.

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