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Assessment of Thermal Oxidizer (Tox) Performance Efficiency

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ABSTRACT: The use of a Thermal Oxidizer (TOX) aims to treat industrial waste gases by oxidizing harmful gases, such as sulphur dioxide (SO_2) and hydrogen sulphide (H_2S), at high temperatures. This study aims to evaluate the TOX operating conditions and analyze its efficiency in reducing harmful emissions released to the environment. Operating data is based on temperature, pressure, gas flow rate, and SO_2 concentration measurements from the Thermal Oxidizer (TOX). The measurement results show that the SO_2 emissions meet the government's standard setting below the maximum limit of 2,600 mg/Nm³. However, the actual TOX performance efficiency of 45.61% decreased compared to the initial design efficiency of 63.27%. This decrease was due to several factors, including reducing the hot oil flow rate and leakage in the chamber.

Keywords: Thermal Oxidizer, Emissions, Operation, Efficiency

INTRODUCTION

Flue gas emissions from industry are one of the most pressing environmental issues. Harmful gases such as sulphur dioxide (SO_2), hydrogen sulphide (H_2S) and carbon dioxide (CO_2) are generated from industrial processes, with SO_2 emissions in Indonesia reaching 1.5 million tonnes per year, contributing to the formation of acid rain and respiratory health problems(Hidup, 2021). Hydrogen sulphide, although less commonly generated, is highly toxic even at low concentrations (W.H.O., 2020). CO_2, as a greenhouse gas, accounts for about 40% of total national CO_2 emissions (Kehutanan, 2021).

One promising solution to the flue gas emissions problem is the use of flue gas treatment technologies, particularly Thermal Oxidizers. These Devices work by destroying volatile organic compounds (VOCs) and other harmful gases through high-temperature combustion, thereby significantly reducing harmful emissions and converting them into CO_2 and water vapour. Research has shown that Thermal Oxidizers can reduce VOC emissions by up to 98%, making them a highly efficient and effective solution (Y., 2019).

The analysis of the Thermal Oxidizer at Company X aims to describe the operational process and measure the SO2 emission content of the exhaust gas(Truong & Huynh, 2023). The Company must consider these emissions because they become waste gases that are toxic to health and environmental sustainability. In addition, it aims to analyse and compare the efficiency of the Thermal Oxidizer through the calculation results with the expected values or standards that have been set. A case study at a chemical plant showed that by optimising the temperature and gas residence time, the treatment efficiency can increase up to 15% (Doe, 2021).

Recent studies confirm the critical role of Thermal oxidizers in reducing harmful gas emissions, such as SO2 and H2S. This research shows that the oxidation process of these compounds is very effective in reducing the negative impact on the environment (Muhammad et al., 2023). In addition, there is research showing that optimizing the structure and airflow distribution of the Regenerative Thermal Oxidizer (RTO) system can increase the VOC removal efficiency to more than 99%(Niu et al., 2024). Using specialized heat storage media, RTO can achieve significant heat recovery efficiency, which contributes to the overall reduction of energy consumption and greenhouse gas emissions (Wang et al., 2020). These findings are also supported by research that emphasizes the importance of proper operating settings, such as inlet temperature and valve switching time, in achieving optimal efficiency in RTOs(A. & Jones, 2020).

Flue gas emissions from industry require effective control to minimise their negative impact. In addition to Thermal Oxidizer, other studies from the Environmental Protection Agency (EPA) show that this technology has been proven to reduce emissions of volatile organic compounds (VOCs) significantly and is safe for the environment (*Environmental Protection Agency, "Thermal Oxidizers: A Review of Technology*, 2018). Reports from the International Energy Agency (IEA) also reveal that the industrial sector accounts for the majority of global CO_2 emissions, making it a significant contributor to climate change (*International Energy Agency, "Global CO2 Emissions in the Industrial Sector*, 2020). Performance evaluation of Thermal Oxidizer by Lee and Kim mentioned that factors such as temperature, residence time, and gas flow velocity significantly affect its efficiency in treating flue gas (C. & D., 2020).

International standards, such as those developed by the Greenhouse Gas Protocol, provide technical guidance used by industry in calculating direct emissions (Scope 1), which include emissions from combustion processes such as Thermal Oxidizers (Protocol, 2021). In addition, reports from the United Nations Environment Programme (UNEP) highlight the close relationship between air pollution from industry and its impact on global public health, confirming the importance of greener solutions (UNE, 2020).

The fuels used in thermal oxidizers vary, ranging from natural gas and propane to liquid fuels. The use of this fuel dramatically affects the efficiency and operational costs of the thermal oxidizer itself. For example, using natural gas as fuel can reduce carbon dioxide (CO2) emissions compared to using liquid fuels(Ren et al., 2024; Yoon et al., 2022). In addition, the heat generated from this combustion process is used to maintain the operating temperature of the thermal oxidizer to remain stable and effective in treating flue gas(Bekhouche et al., 2023; Chen et al., 2023).

Temperature, pressure, and flow rate are important parameters that affect the performance of the thermal oxidizer. Temperatures that are too low can cause incomplete combustion, resulting in higher pollutant emissions. On the other hand, temperatures that are too high can cause damage to the thermal oxidizer components. The optimal operating pressure ranges from 1 to 3 bar, where the flue gas flow rate can be well controlled at this pressure, thereby increasing combustion efficiency (Johnson & Wang, 2020).

However, the operation of the thermal oxidizer is not without obstacles. Some of the challenges that are often faced include fluctuations in the flue gas flow rate, changes in gas composition, and difficult temperature control(Han et al., 2023; Shi et al., 2022; Zhang et al., 2024). Fluctuations in the gas flow rate can cause drastic temperature changes, which can disrupt the combustion process. In addition, changes in flue gas composition due to variations in the production process can also affect the efficiency of the thermal oxidizer. Therefore, it is important for companies to carry out strict monitoring and control of the thermal oxidizer operating conditions (Brown, 2021).

METHOD

This research methodology combines two main approaches: literature studies and direct data collection in the field. Literature studies were conducted to collect information related to the basic theory of thermal oxidizers, working principles, formulas, how to calculate the efficiency of thermal oxidizers, and emission limits applicable in the oil and gas industry. The sources used include relevant scientific journals, books, and previous research reports. Direct data collection was carried out at PT.X, where measurements were made of important variables, such as operating temperature, pressure, gas flow rate, and gas emissions. The temperature of the Thermal Oxidizer, which ideally ranges from 1,400°F to 1,700°F, is measured to ensure the oxidation process is efficient. The pressure and gas flow rate are also monitored to maintain the stability and capacity of the device. Gas emissions, such as CO_2, H_2S, and SO_2, are measured using a gas analyser to ensure that the emissions produced comply with the standards set by the government.

The data obtained from the literature studies and direct data collection is then used to calculate the actual Thermal Oxidizer heat efficiency, which is then compared with the initial design efficiency. The calculation process can be broken down into several stages. First, we compare the incoming acid gas data with the outgoing acid gas from the Thermal Oxidizer. Then, we compare the outgoing acid gas with the emission quality standards. Next, we calculate the total heat out of the Thermal Oxidizer, which includes the heat absorbed by the Hot Oil system and the heat wasted with flue gas through the stack. Finally, we calculate the total heat entering the Thermal Oxidizer unit, which includes the sensible heat of fuel gas, the heat of gas combustion, the sensible heat of acid gas, and the sensible heat of combustion air.

This comparison is a crucial step in the research, as it aims to assess the performance of the Thermal Oxidizer and identify factors that affect the difference between actual efficiency and initial design. These factors, such as equipment age, gas quality, equipment capacity, and operational and maintenance conditions, are key in guiding future improvements to the operational efficiency of the Thermal Oxidizer.

RESULT AND DISCUSSION

Thermal Oxidizer is a series of equipment that burns waste gas produced by PT.X. The goal is to oxidize the waste gas into a relatively safe gas before being discharged into the surrounding environment. Using the Thermal Oxidizer, the gases will be oxidized efficiently before being discharged into the atmosphere. This helps maintain the environment's safety around PT.X by reducing the negative impact of waste gases generated by various units.

The Thermal Oxidizer at PT.X is divided into three main parts: a radiant section or retention chamber where combustion occurs, a WHRU (Waste Heat Recovery Unit) as a circulation of heated Hot Oil, and a stack or chimney as a channel for exhaust emissions. The following is an explanation of the components contained in the Thermal Oxidizer, including:

1. Radiant section or retention chamber

The radiant section or chamber is the most essential part of the thermal oxidizer. In the chamber, there is a mixture of Fuel gas as fuel, air as a source of oxygen, and acid gas from the BSRU absorber and bioreactor. Combustion in the chamber is at a high temperature in the range of 1400ºF to 1500ºF. Combustion in the chamber is intended to oxidize hazardous materials before being discharged into the environment to make it relatively safer and by regulations set by the government.To support the operation process at high temperatures, the chamber is equipped with refractory walls with heat insulation in the form of firebricks resistant to high heat.

2. Waste Heat Recovery Unit (WHRU)

Waste Heat Recovery Unit, or WHRU, is where heat exchange occurs between flue gas and Hot Oil, which will later be used as an auxiliary heating medium. Heat exchange in WHRU occurs when Hot Oil enters the tube and receives heat from the flue gas. The incoming Hot Oil has a temperature of approximately 290ºF, while the Hot Oil output from the WHRU is around 340ºF.

3. Stack

A stack or chimney is a disposal path for emission or residual gas produced by the Thermal Oxidizer. The residual gas released from the stack has a temperature above 750ºF because the heat has been reused to heat the Hot Oil in the WHRU. In the stack section, an SO2 analyzer is used to analyze the amount of SO2 in the residual gas. The amount of SO2 wasted should not exceed 2,600 mg/Nm3 because, in Kep/MenLH/129/2003, the government limits the amount of SO2 emissions discharged into the environment.

The process that occurs in the Thermal Oxidizer is that acid gas from process areas, such as treated gas from the Biological Sulphur Recovery Unit (BSRU), mixed hydrocarbon gas from the Gas Separation Unit (GSU), Condensate Handling Unit (CHU), and Produced Water Unit (PWU); acid gas from the Acid Gas Removal Unit (AGRU); and vent gas from the Dehydration Unit (DHU), enter the Thermal Oxidizer from the bottom. Fuel gas is supplied from the bottom to the burner. Combustion air from the surrounding environment uses an air intake fan K-0403 A/B. The elements (acid gas, fuel gas, and air) mix at the bottom of the Thermal Oxidizer. The burner will burn the mixture of the three gases at a high temperature above 1500°F to ensure all harmful gases are burned and oxidized completely.

The combustion exhaust gas will go up to the convective section, where the WHRU will absorb its heat energy to heat the Hot Oil. After passing through the WHRU, the temperature of these flue gases drops to around 400°F. The flue gas is then discharged to the environment through the chimney as emission gas that has met the environmental requirements set by the government.

In addition to using fuel gas, the Thermal Oxidizer can also use diesel oil as fuel, but this diesel oil is only used in the start-up process. Under normal operating conditions, the Thermal Oxidizer uses fuel gas as its primary fuel.

The main variables in the operation of the Thermal Oxidizer are temperature, pressure, and flow rate. All three influence the thermal oxidiser process, so they must be maintained and controlled at specific predetermined values. Changes to any of these variables can disrupt the process and cause operational problems. The following are the actual data of the three main variables obtained:

a. Temperature

Table 1. Temperature in Thermal Oxidizer

Date	Time	Temperature (ºF)			
		Chamber	***Stack***	***Hot Oil Inlet***	***Hot Oil Outlet***
30/10/2024	15:00	1434.14	757.23	294.23	339.48
29/10/2024	15:00	1434.53	759.37	293.73	339.13
28/10/2024	15:00	1429.63	756.43	293.18	338.29
27/10/2024	15:00	1434.53	759.63	294.41	339.82
26/10/2024	15:00	1450.13	767.9	293.36	339.87

Temperature plays a crucial role in the Thermal Oxidizer (TOX) process, as temperature variables directly affect its operational efficiency and safety. Temperature control is achieved by regulating the flow rates of fuel gas and air and monitoring four key temperature measurement points: chamber temperature, stack temperature, hot oil inlet temperature, and hot oil outlet temperature. The temperature in the chamber must be kept above 1,400°F to ensure complete oxidation of the acid gases, with the set point ideally at 1,700°F. A drop in temperature below 400°F can lead to condensation of sulphur vapour, which risks damaging the stack. Meanwhile, the stack temperature should be below 800°F to avoid damage to the hot oil and reheat unit (WHRU). Temperature regulation also applies to the Hot Oil system, with inlet temperatures required to remain above 280°F and outlet temperatures around 350°F. This temperature control involves precision and care, as uncontrolled temperature changes can make resetting difficult and destabilize the process.

b. Pressure

Table 2. Pressure in Thermal Oxidizer

Date	Time	Pressure	
		Fuel gas **(psig)**	***Air*** **(inch H_2O)**
30/10/2024	15:00	6.22	3.82
29/10/2024	15:00	6.23	3.86
28/10/2024	15:00	6.16	3.83
27/10/2024	15:00	6.26	3.83
26/10/2024	15:00	6.29	3.83

In the thermal oxidizer process, the two main pressure variables that are controlled are fuel gas pressure and combustion air pressure. Measurement and monitoring of these pressures provide essential information regarding the volume of fuel gas and combustion air supplied to the chamber, which directly affects the efficiency of the oxidation process. Under normal operating conditions, the fuel gas pressure entering the pilot is around ten psig, while the fuel gas pressure supplied to the burner is generally at 35 psig. Fuel gas pressure downstream must be kept from falling below one psig because the pressure drop can cause damage to the burner and disrupt the continuity of the combustion process.

c. Flow Rate

Table 3. Flow Rate in Thermal Oxidizer

Date	Time	Flow Rate	
		Fuel gas **(SCFH)**	***Hot Oil*** **(BPD)**
30/10/2024	15:00	68,136.59	175,250
29/10/2024	15:00	70,782.56	181,820
28/10/2024	15:00	70,782.56	182,558
27/10/2024	15:00	75,139.07	183,125
26/10/2024	15:00	74,226.74	175,321

In the Thermal Oxidizer process, two controlled flow rate variables, namely the flow rate of fuel gas and the flow rate of hot oil entering the Waste Heat Recovery Unit (WHRU), significantly influence system performance. Fuel gas flow rate directly affects the combustion intensity in the Thermal Oxidizer chamber. Then, an increase in the fuel gas flow rate will increase the fuel gas supply, produce a larger flame, and increase the temperature in the chamber. Conversely, a reduction in the Fuel gas flow rate will reduce the flame and temperature in the system. The Fuel gas flow rate is generally set in the range of 70,000 Standard Cubic Feet per Hour (SCFH) to maintain the stability of the combustion process. In addition, the flow rate of Hot Oil also plays an important role in influencing the temperature increase in Hot Oil. To maintain heating efficiency, the Hot Oil flow rate should be at least 120,000 Barrels per Day (BPD), because a decrease in the flow rate can hinder the optimal heat recovery process in the WHRU system.

d. Emission SO_2

Table 4. Emission SO_2 in Thermal Oxidizer

Date	Time	Concentration SO_2 (mg/Nm^3)
30/10/2022	15:00	1,602
29/10/2022	15:00	1,588
28/10/2022	15:00	1,503
27/10/2022	15:00	1,487
26/10/2022	15:00	1,401

Another critical aspect of the thermal oxidizer process is emission control, especially for SO2 gas from H2S oxidation. Based on government regulations (KEP/MENLH/13/2009), the maximum limit of SO2 emissions is 2,600 mg/Nm^3. Therefore, SO2 emissions from the Thermal Oxidizer to the environment must be maintained to not exceed this limit. From the table, PT.X has met the standards set by the government because the SO2 emissions do not reach 2,600 mg/Nm3.

Next, there is actual feed composition data and Thermal Oxidizer stack and design data as follows:

Table 5. Thermal Oxidizer Feed and Stack Composition Data

Feed Composition Data				
Parameter	**Current**			**Desain**
	08/09/2024	**09/09/2024**	**10/09/2024**	
Flow Rate	181385 BPD	180124 BPD	181125 BPD	247267 BPD
Suhu *Inlet*	293.38°F	295.09°F	294.89°F	297.5°F
Suhu Outlet	342.99°F	345.13°F	345.54°F	350°F
ΔT	49.61°F	50.04°F	50.65°F	52.5°F
Data *Stack Thermal Oxidizer*				
Temperature Stack	750.04°F	755.35°F	754.4°F	500°F
Excess air	15%	15%	15%	10%

(Source: DCS PT.X 2024, Manual Book PT.X)

The following are the stages required in calculating combustion efficiency and evaluating the performance of the Thermal Oxidizer, including:

1. Comparing incoming acid gas with outgoing acid gas
   This stage involves comparing the composition and amount of acid gas entering the Thermal Oxidizer with the acid gas leaving the unit. Acid gas analysis data is required to perform this comparison.
2. Comparing the outgoing acid gas with the gas emission quality standard
   In this stage, a comparison is made between the composition and amount of acid gas leaving the Thermal Oxidizer and the gas emission quality limits set by applicable regulations or standards. This aims to evaluate whether gas emissions from the Thermal Oxidizer meet the environmental requirements that have been set.
3. Calculating the heat absorbed by the Hot Oil system
   In this stage, the heat absorbed by the Hot Oil system is calculated. The required data includes the input temperature and output temperature of the Hot Oil, the mass flow of Hot Oil, and the thermal properties of the fluid used.
4. Calculating the total heat entering the Thermal Oxidiser Unit
   This stage involves collecting and summarising all the heat entering the Thermal Oxidizer. This includes heat from the combustion of fuel gas and acid gas. Required data includes mass flow and composition of the fuel gas, acid gas analysis, and information on the operating conditions of the Thermal Oxidizer.

The author can proceed with further calculations and evaluations regarding combustion efficiency and Thermal Oxidizer performance by performing the above steps.

There is acid gas (waste gas) entering the Thermal Oxidizer, which is the result of absorber processing and bioreactor output gas at BSRU, whose data can be seen in the following table:

Table 6. Waste Gas Data Enters The Thermal Oxidizer

Data *Waste gas* in		
Component	**Unit**	**Value**
SO_2	Ppm	94264,2
CO_2	% mol	21,5492

The acid gas treated at the BSRU will be combusted in the Thermal Oxidizer to reduce the waste gas concentration before it is released into the environment. In addition, the heat from the combustion process is also utilised to heat the Hot Oil. The concentration of acid gas or waste gas after combustion can be seen in the following table:

Table 7. Data Waste gas Out Thermal Oxidizer

Data *Waste gas* Out	
SO_2	Ppm ≤ 5
CO_2	% mol 0

At the output of the Thermal Oxidizer, the SO2 acid gas concentration has been reduced to less than or equal to 5 ppm, while the CO2 concentration is 0% mol after combustion. The following is a table of Hot Oil specification data used in this process using the 1510 Seriola type:

Table 8. Data Specification Hot Oil Seriola 1510

Typical Characteristic	Unit	*Value*	
		Min	*Max*
Density at 60°C	Kg/m^3	870	
Viscosity 40°C	Cst	30.6	
Viscosity 100°C	Cst	5.2	
Flash Point	°C	210	230
Pour Point	°C	-12	
Conradson Carbon Residue	%*weight*	0.03	

Furthermore, there is fuel gas data and composition used to calculate the heat capacity or Cp as follows:

Table 9. Gas Fuel Data

Operating Conditions	Unit	Temperature (°F)			Average
		08/09/2024	09/09/2024	10/09/2024	
Flowrate	m^3/jam	3216.31	3203.89	3241.14	3220.447
Temperature	°C	41	40.9	42.83	42
Tekanan	Psig	110	110	110	110

(Source: DCS PT.X Tahun 2024)

Table 10. Gas Fuel Component Analysis

Composition (%mol)										
C_1	C_2	C_3	iC_4	nC_4	iC_5	nC_5	C_6	N_2	CO_2	Total
93.8	3.3	1.4	0.22	0.11	0.07	0.3	0.3	0.48	0	100

From the calculation of each composition, data on the total content of C, H, N, O, and S in acid gas is obtained as follows:

Table 11. Weight of Components C, H, N, O, S Acid gas from BSRU

Composition	Time	Concentration SO_2 (mg/Nm^3)	Total Weight (lb/jam)
C	25.72305249	41165.46	10589.01249
H	0.227447417	41165.46	93.62977199
N	0.023507627	41165.46	9.677022461
O	35.84599407	41165.46	14756.1678
S	3.71370454	41165.46	1528.763499

The Thermal Oxidizer unit cannot fully absorb all incoming heat. Some of the obstacles and problems that interfere with the thermal oxidizer operational process include:

1. Difficulty in purging during start-up on the pilot.
   This is likely due to the improper composition of fuel and air and the spark generated by the spark plug on the pilot, which is not strong enough to ignite the fire. The solution proposed by the operator is to modify the pilot by expanding the distance between the spark plugs and replacing them with larger spark plugs to create a more vital spark.
2. The temperature on the stack is too high or too low.
   The temperature limitation on the stack is that it must be greater than 400°F and less than 800°F. Temperatures that are too low can cause condensation of the sulfur still present in the flue gas, damaging the stack. On the other hand, temperatures that are too high can damage the hot oil and tubes in the WHRU (Waste Heat Recovery Unit).
3. Flame instability is caused by an imbalance between the fuel and air combination, which may cause the UV scanner to detect that the flame has gone out.
   Suppose the UV scanner detects that there is no flame. In that case, the system will automatically signal to activate the SDV (Shut Down Valve) as an equipment and operation safety measure. Therefore, two UV scanners are installed on the burner so that if neither of them detects the flame, the safety system will not activate the SDV.
4. One part of the plant that requires Hot Oil in addition to the amine reboiler is the MSPP Unit. MSPP requires a significant amount of Hot Oil. Not paying attention to the opening of the valve for Hot Oil in the MSPP can cause a drastic decrease in Hot Oil flow in the WHRU. This decrease in flow will cause an increase in temperature on the stack. If the temperature is not

maintained and exceeds 800°F, the TOX will trip. A drastic decrease in Hot Oil flow can also cause the TOX to trip.
5. Fuel gas pressure must be maintained above one psig. If the Fuel gas pressure drops below this value, the flame will die, allowing the TOX to trip.
6. If the thermal oxidizer (TOX) operates normally, special attention must be paid to temperature as it is a sensitive variable. If the temperature in the TOX does not match the operational conditions, the SDV system will be activated as a safety measure. Some of the temperatures that need to be maintained include:
   a) The temperature in the chamber must be higher than 1400 °F.
   b) The temperature at the Hot Oil inlet must be higher than 280 °F.
   c) The temperature in the stack must be within the range of 400 - 800 °F. If the above requirements are not met, the acid and waste gas valves will automatically close.
7. Incomplete combustion can be indicated by smoke from the TOX stack. If the smoke is black, it suggests the combustion in the chamber lacks combustion air. If the smoke is white, it indicates an excess of combustion air in the chamber. This lack or excess of combustion air will reduce the effectiveness of the fuel in the TOX.
8. The occurrence of leaks in the convective section of the thermal oxidizer is caused by corrosion, which causes cracks in the flue gas from the section. This reduces the effectiveness and performance of the WHRU. The recommended solution to overcome this problem is to increase the heat supply to the radiant section so that the Hot Oil output temperature remains within the 350 °F range. This heat addition is done temporarily until the refinery's TA (Turn Around) time.

Therefore, the Thermal Oxidizer has a performance efficiency, the ratio between the heat absorbed and the total heat entering. The actual performance efficiency of the Thermal Oxidizer is 45.61%. At the same time, the efficiency of the initial design data was 63.27%. From these results, the efficiency has decreased by 17.66%; this can be caused by several factors, including:
1. Decrease in Hot Oil flow rate so that the heat generated by the Thermal Oxidizer is wasted to the environment inefficiently.
2. We have identified leaks in the north and south of the chamber, a critical issue that is resulting in excess heat loss. These leaks not only reduce the heat efficiency of the system but also increase the demand for Hot Oil, leading to a significant impact on our operations.
3. Leaks in the chamber can also cause a drop in temperature when it rains, potentially leading to a shutdown. This is a serious issue that needs to be addressed promptly to avoid any disruptions in our operations.
4. The absence of combustion air usage controls and indicators, such as oxygen analysers in the stack, makes it difficult to calculate excess air. Excessive use of excess air leads to increased inefficient heat dissipation.

There are recommendations for improvements that can be made to the Thermal Oxidizer at PT.X, namely by applying Regenerative Thermal Oxidizer (RTO) technology. RTO is an efficient technology for reducing harmful exhaust emissions while optimising heat recovery from combustion. According to studies, RTO can achieve higher heat recovery efficiency than conventional thermal oxidiser systems because it uses regenerative media that stores and releases heat during the operational cycle. This technology allows the flue gas to pass through the regenerative media before being discharged into the atmosphere, improving heat utilisation and reducing additional energy consumption for heating.

In addition, RTO is also effective in reducing Volatile Organic Compounds (VOC) emissions, which is relevant for PT.X. Research shows that the RTO system with three canisters has an excellent ability to capture and oxidise VOCs up to 99% efficiency, so harmful flue gas emissions such as SO_2 and NOx can be minimised. RTO also allows better control of the backflushing flow, ensuring that no unoxidised flue gas remains in the regenerative media, thus improving system performance (Pu et al., 2021).

With the implementation of RTO, the heat recovery efficiency at PT.X can be significantly improved. According to research, using RTO with honeycomb regenerative media and optimised packing can increase heat recovery efficiency by more than 75%. This allows more heat from the flue gas for hot oil heating, reduces fuel consumption, and lowers the temperature of the flue gas released to the environment. In addition, proper regulation of valve switching time can reduce heat leakage during phase transition and improve combustion stability and overall operational efficiency.

By implementing RTO, PT.X can improve energy efficiency and Thermal Oxidizer performance and meet environmental regulations related to emission control more effectively. These improvements are expected to provide significant benefits in hazardous gas emission reduction and energy recovery efficiency in the future.

CONCLUSION

Based on the results of research using the literature study method and direct data collection in the field, it can be concluded that the Thermal Oxidizer at PT.X has functioned properly in burning hazardous gas waste into emissions that are safer for the environment. This research uses data from the main variables, such as temperature, pressure, and flow rate, as well as data on the composition of the Thermal Oxidizer feed and stack. The results showed that the actual Thermal Oxidizer performance efficiency only reached 45.61%, a decrease of 17.66% from the initial design efficiency of 63.27%. The decrease in the efficiency of heat utilization of the thermal oxidizer due to the reduction in hot oil flow rate of 830,745.95 lb/hour resulted in the heat generated by the thermal oxidizer being wasted on the environment for free.

The Thermal oxidizer's acid gas combustion efficiency is a standout feature, reaching an impressive 99.99%. This high efficiency instils confidence in the system's performance. The system has also successfully met the environmental emission standards set by the Ministry of Environment, with SO2 gas emissions below 2600 mg / nm^3. The actual acid gas flowrate is lower than the design acid gas flowrate (84.45%), and the actual fuel consumption was lower than the design fuel consumption, further demonstrating the system's efficiency.

Several factors, such as a decrease in Hot Oil flow rate, leakage in the chamber, and lack of control of combustion air usage, can cause a decrease in efficiency. Therefore, improvements and optimization are needed to increase the efficiency of the thermal oxidizer again and to achieve its initial design value. Thus, the thermal oxidizer can operate optimally and effectively in reducing harmful gas emissions to the environment, which can help reduce negative impacts on public health and the environment.

As a recommendation to improve the performance of the Thermal Oxidizer at PT.X, several more specific optimization steps can be taken based on literature studies and field observation results. One of the main recommendations is to apply regenerative thermal oxidizer (RTO) technology. Using RTO can improve heat recovery efficiency by optimizing regenerative media so that energy utilization efficiency can increase to more than 75% through heat capture from flue gases and reducing additional fuel consumption.

In addition, improved regenerative media design and more optimised valve switching time settings are recommended. These measures aim to minimise heat leakage during the transition phase and ensure maximum heat utilisation. These improvements will help overcome the efficiency drop caused by heat loss through leakage and temperature imbalance in the system.

Another recommendation is to add an oxygen analyser to the chimney to monitor the use of excess air in real time. Proper control of combustion air usage can improve combustion efficiency and reduce energy waste due to excess air.

The implementation of these improvement measures is expected to restore the efficiency of PT.X's Thermal Oxidizer to the initial design level of 63.27%. With such optimisation, PT.X not only can meet but also has the potential to exceed the set environmental emission standards. This will also lead to a significant reduction in energy consumption and environmental impacts.

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