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Analysis of Sulfur Recovery Unit (SRU) Refinery as Sulfur Emission Control Unit at PT X, Indonesia

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Abstract

PT X is an Indonesian oil and gas processing industry. Recognizing the potential harm posed by gas emissions from oil and natural gas processing, PT X is actively working to control air pollution. One of their initiatives involves the construction of a Sulfur Recovery Unit (SRU) refinery to reduce sulfur gas emissions, particularly from H_2S, by converting them into liquid sulfur products. The SRU refinery effectively processes approximately 73% of the H_2S gas emitted during production. In January 2023, air quality measurements were conducted on stack 94-F-403 SRU, revealing the following results: the average concentration of SO_2 emissions was 14.69 mg/m^3, and the average concentration of NO_2 emissions was 3.04 mg/m^3. These measurements indicate that both parameters fall below the quality standards set by the Indonesian Minister of Environment Regulation No. 13 of 2009, which defines acceptable emission limits for the oil and gas industry. Based on these findings, it can be concluded that the emissions from stack 94-F-403 SRU are classified as non-polluting, adhering to the Indonesian government's quality standards. PT X's commitment to environmental responsibility is evident through their implementation of the SRU refinery, which significantly reduces gas emissions and ensures compliance with regulatory requirements.

Keywords: Oil Gas Refinery; Sulfur; Recovery; Emission control

1. Introduction

Air pollution is a pressing environmental issue that continues to escalate in tandem with human activities, particularly the rapid advancements of the industrial revolution. Industrial activities, characterized by factories equipped with chimneys, release various gases as pollutants into the air. These pollutants can travel through the air, settling and descending back to the Earth's surface or lower areas. According to data from the Central Bureau of Statistics, the industrial sector in Indonesia emitted a total of 259 million tons of CO2 as greenhouse gases in 2021. PT X is one of the seven refineries in Indonesia with the highest capacity, capable of processing 348,000 barrels per day of crude oil into fuel oil, non-fuel oil, and petrochemicals. The processing refineries encompass the Fuel Oil Complex I, FOC II, Lube Oil Complex I, LOC II, Utility Complex I, Paraxylene, Sulfur Recovery Unit, and Residual Fluid Catalytic Cracking refineries.

PT X conducts air quality monitoring using two methods: a semi-annual manual method and the Continuous Emission Measurement System. Additionally, the company employs an air pollution control system that consists of a flare system, which burns gas emissions generated from oil and gas processing units, and a Sulfur Recovery Unit system. Due to the presence of sulfur in crude oil, hydrogen sulfide (H2S) is commonly found in raw natural gas streams and in byproduct gases emanating from processing units in oil industries [1]. The Sulfur Recovery Unit system processes H2S gas emissions into liquid sulfur and other by-products, aiding in the reduction of harmful gas emissions. The process of

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turning acid gas into elemental sulfur is known as sulfur recovery from acid gas stream (mostly H2S and CO2) [2]. Typically, the SRU is divided into a thermal section and a multi-stage (2–4) catalytic unit assembly [3].

By implementing these monitoring and control measures, PT X strives to mitigate air pollution and promote environmental sustainability in its operations.

2. Material and methods

2.1. Data Collection

The data collection process incorporates multiple methods to ensure a comprehensive assessment of sulfur emission control practices in the oil and gas industry.

2.1.1. Environmental Observations

Detailed observations are conducted in the workplace environment to gather data on sulfur emission sources, control systems, and their effectiveness. This involves monitoring emissions from chimneys, equipment, and processing units.

2.1.2. Stakeholder Interviews

Interviews are conducted with key stakeholders, including industry experts, environmental regulators, and company personnel responsible for sulfur emission control. These interviews provide valuable insights into current practices, challenges, and potential solutions.

2.1.3. Literature Studies

Extensive literature reviews are conducted to gather information on best practices, technological advancements, regulatory frameworks, and case studies related to sulfur emission control in the oil and gas industry. This helps establish a comprehensive understanding of the subject matter.

2.2. Data Analysis

The collected data is analyzed using qualitative and comparative descriptive analysis methods to evaluate the effectiveness of sulfur emission control practices.

2.2.1. Quantitative Analysis

The qualitative analysis involves interpreting and categorizing the collected data to identify patterns, trends, and key findings. It provides insights into the strengths, weaknesses, and gaps in sulfur emission control practices.

2.2.2. Comparative Descriptive Analysis

Comparative analysis is conducted to compare different sulfur emission control strategies, technologies, or implementations within the oil and gas industry. This allows for benchmarking and identifying best practices for effective control measures. The quantitative analysis involves interpreting and categorizing the collected data to identify patterns, trends, and key findings. It provides insights into the strengths, weaknesses, and gaps in sulfur emission control practices.

3. Results and discussion

3.1. Emission monitoring

PT X employs two distinct methods for air pollution monitoring. Firstly, the manual method is carried out every 6 months by the Center for Standardization and Industrial Pollution Prevention Services (BBSPJPPI). Secondly, the continuous method utilizes the Continuous Emission Monitoring System (CEMS). These monitoring methods adhere to the regulations specified in the Law -Invite No. 22 of 2021, which governs the implementation of environmental management protection, as well as the Minister of Environment Regulation No. 13 of 2009, which sets emission quality standards for the oil and gas industry.

The specific focus of this discussion is the monitoring of exhaust emissions originating from stack 94-F-403 within the SRU unit. The current conditions and selection of the sampling point location on stack 94-F-403 comply with the requirements outlined in SNI 19.7117.13-2009. The test sampling point is positioned at a height of 8.84 meters from the ground surface, and it encompasses a total of 4 sampling points to ensure accurate measurement.

The parameters monitored during the assessment include $\mathbf{SO_2}$, NO2, CO, CO2, particulate matter, opacity, and O2. These parameters are essential for assessing the air quality and evaluating the effectiveness of the pollution control measures implemented by PT X. By monitoring and analyzing these parameters, the company can gain valuable insights into the emission levels and take necessary actions to mitigate any adverse environmental impact.

The utilization of both manual and continuous monitoring methods, along with adherence to relevant regulations and standards, ensures a comprehensive evaluation of air pollution at PT X. The inclusion of multiple parameters in the monitoring process allows for a detailed assessment of the emissions and aids in maintaining compliance with environmental regulations. Figure 1 shows the location of emission sampling point.

Figure 1 Existing condition and sample point location of the stack

A continuous monitoring tool called the Continuous Emission Monitoring System (CEMS) has been installed in stack 94-F-403 at PT X. The CEMS employs a stack dilution extractive sampling method to monitor the parameters of $\mathbf{SO_2}$, NO2, and O2. In addition to these three parameters, CEMS also measures temperature, gas flow, and speed. The selection of the dilution extractive method is based on the suitability for the variables being monitored, the instruments used, and the stack conditions.

Measurement results at PT X are reported through two different channels. Manual measurements conducted by a contractor are reported every 6 months, while continuous measurements using CEMS are reported every 3 months. These reports are submitted to multiple stakeholders, including the local government, the Ministry of Environment and Forestry, the Ministry of Energy and Mineral Resources, and the headquarters.

By utilizing CEMS and implementing regular reporting intervals, PT X demonstrates a commitment to accurate and timely monitoring of emissions. This proactive approach enables effective environmental management and ensures compliance with regulatory requirements. The combination of manual and continuous monitoring methods, along with comprehensive reporting, allows PT X to maintain transparency and provide valuable data to relevant authorities for environmental assessment and decision-making.

3.2. Emission pollution control

PT X employs air pollution control units to mitigate emission air pollution. These units consist of two systems: the flare system and the sulfur recovery system located at the SRU Refinery. The flare system serves as a method to control air pollution gas emissions by utilizing combustion. It effectively manages the discharge of hydrocarbon vapors that may arise from various upset operating conditions such as surging, blocked discharge, or compressor shutdown.

On the other hand, the sulfur recovery system is specifically designed to control air pollution emissions, particularly sulfur gas. It accomplishes this by processing H2S derived from the production process feed gas and converting it into liquid sulfur. This process aids in reducing the concentration of $\mathbf{SO_2}$ emissions released through stack 94-F-403.

For the purpose of this practical work journal, the analysis and discussion will primarily focus on the Sulfur Recovery system within PT X's Sulfur Recovery Unit (SRU) Refinery. By narrowing the scope to this particular unit, a more detailed examination of the sulfur emission control methods and their effectiveness can be conducted.

By implementing these air pollution control systems, PT X demonstrates a proactive approach in addressing emission air pollution. The combination of the flare system and sulfur recovery system contributes to the reduction of harmful pollutants, ensuring compliance with environmental regulations.

3.3. Sulfur Emission Treatment Process at Sulfur Recovery Unit (SRU) Refinery

The SRU refinery at PT X comprises of five interconnected processing units and a common facilities unit. These units play a crucial role in the overall operation of the refinery and facilitate the production of various valuable products. In the furnace chamber, almost one-third of hydrogen sulfide is burned by the process of oxidation, which results in the formation of sulfur dioxide and water [4]. Then, at temperatures above 1000 C, the residual portion of hydrogen sulfide interacts with sulfur dioxide to form sulfur and water in accordance with the overall equilibrium Claus reaction [4]. The first processing unit is unit 91, known as the Gas Treating Unit, which focuses on the treatment and purification of natural gas. The second unit, unit 92, is the LPG Recovery Unit responsible for the recovery and extraction of Liquefied Petroleum Gas (LPG). Unit 93, the Sulfur Recovery Unit, is the third processing unit that plays a pivotal role in reducing sulfur gas emissions by processing H2S gas from the production process into liquid sulfur products. Unit 94, known as the Tail Gas Unit, serves to further enhance the sulfur recovery process by treating the tail gas from the sulfur recovery unit. Finally, unit 95, the Refrigeration Unit, is responsible for the cooling and condensation of various process streams.

3.3.1. Gas Treating Unit (Unit 91)

The Gas Treating Unit at PT X is specifically designed to effectively reduce the levels of H2S (hydrogen sulfide) to a maximum of 10 parts per million by volume (ppmv). Within this unit, the H2S gas is treated by absorption using a solution of methyldethanolamine, an amine derivative.

Unit 91 receives off gases from a total of 9 different sources. Out of these sources, 8 of them initially have low pressure, necessitating the equalization of pressure through the employment of Low Pressure Amine Treating. Once the 9 feed gases are brought to the same pressure level, they are ready for H2S absorption using the amine solution.

The H2S that has been successfully separated from the feed gas within Unit 91 is then directed to Unit 93. Unit 93, known as the Sulfur Recovery Unit, plays a crucial role in further processing the H2S and converting it into liquid sulfur products.

This systematic process in the Gas Treating Unit ensures that the H2S content in the feed gas is efficiently absorbed and removed, ultimately contributing to the reduction of harmful emissions. The subsequent transfer of separated H2S to Unit 93 facilitates the subsequent stages of the sulfur recovery process, promoting environmental sustainability and compliance with regulatory standards.

3.3.2. Sulfur Recovery Unit (Unit 93)

The Sulfur Recovery Unit (SRU) is a crucial facility responsible for converting the H2S gas produced by the amine regenerator into liquid sulfur through a process known as the Claus reaction. This conversion process occurs in two distinct stages: the thermal stage and the catalytic stage.

During the thermal stage, the acid gas derived from Unit 91 is introduced into the Reaction Furnace Burner. Within this furnace, approximately one-third of the H2S gas is combusted in the presence of fuel gas, resulting in the production of $\mathbf{SO_2}$ (sulfur dioxide) through Equation 3. It is important to note that the reaction taking place within the reaction furnace can only convert around 60-70% of the H2S gas into $\mathbf{SO_2}$, and this process occurs under high-temperature conditions.

Furthermore, it is worth mentioning that the acid gas entering the reaction furnace may also contain hydrocarbons, which are subsequently oxidized and destroyed at the elevated temperatures present in the furnace.

The thermal stage of the sulfur recovery process is a critical step in the overall conversion of H2S gas to liquid sulfur. It facilitates the initial transformation of H2S into **SO_2** , setting the foundation for subsequent stages, including the catalytic stage [5]. This process ensures efficient and effective removal of H2S from the gas stream while simultaneously addressing any accompanying hydrocarbons.

$$H_2S + 3/2\ O_2 \rightarrow \mathbf{SO_2} + H_2O \quad (1)$$
$$2H_2S + \mathbf{SO_2} \rightarrow S_2 + 2H_2O + \quad (2)$$
$$3H_2S + 3/2\ O_2 \rightarrow S_2 + 3H_2O \quad (3)$$

The heat generated through combustion in the Reaction Furnace is directed to the Waste Heat Exchanger, where it undergoes a cooling process to reduce its temperature to approximately 310°C. This intentional cooling is essential as it enables the condensation of sulfur vapor that has been formed during the reaction (as depicted in Equations 4 and 5).

By subjecting the heat to the cooling process within the Waste Heat Exchanger, the temperature is lowered to a point where the sulfur vapor present in the gas undergoes a phase change and transitions into a liquid state. This phase transition is vital for the subsequent collection and extraction of liquid sulfur from the gas stream.

The cooling process in the Waste Heat Exchanger plays a critical role in ensuring efficient sulfur recovery within the Sulfur Recovery Unit (SRU). By effectively reducing the temperature of the gas, it facilitates the condensation of sulfur vapor, allowing for the separation and collection of liquid sulfur, a valuable end product of the sulfur recovery process.

$$3S_2 \rightarrow S_6 + \text{Heat} \quad (4)$$
$$4S_2 \rightarrow S_8 + \text{Heat} \quad (5)$$

After passing through the Waste Heat Exchanger, the exhaust gas proceeds to the condenser where the crucial process of condensation takes place. Within the condenser, the vapor and liquid components of the gas are separated. The liquid component, in the form of liquid sulfur, is then directed to the sulfur pit for storage and further use.

Meanwhile, the gas formed during the condensation process undergoes reheating, raising its temperature to approximately 234°C. This reheating step is necessary to optimize the gas's properties and ensure it meets specific requirements for subsequent processes or discharge.

The separation of vapor and liquid within the condenser is a vital stage in the overall sulfur recovery process. By efficiently condensing the vapor component, valuable liquid sulfur is obtained, which can be stored or utilized for various purposes. Simultaneously, the reheating of the gas helps to maintain optimal operating conditions and prepares it for subsequent steps in the overall system.

3.3.3. Tail Gas Unit (Unit 94)

The Tail Gas Unit plays a crucial role in the sulfur recovery process by effectively reducing the sulfur content in the Claus SRU Tail Gas to an environmentally acceptable level. The Claus SRU Tail Gas initially contains approximately 4-5% sulfur, which originates from the acid gas inlet of the SRU.

The tail gas from the Claus SRU is directed to the Hydrogenation Reactor Preheater, where it undergoes heating to reach a temperature of 288°C. Additionally, hydrogen gas is introduced into the gas stream. This heated gas mixture, along with the added hydrogen, then enters the Hydrogenation Reactor.

Within the Hydrogenation Reactor, a cobalt-molybdenum catalyst facilitates the hydrogenation process, converting all the sulfur present into H2S. This transformation occurs through a series of chemical reactions represented by equations 6-10.

$$\mathbf{SO_2} + 3H_2 \rightarrow H_2S + 2H_2O \quad (6)$$
$$Sn + nH_2O \rightarrow nH_2S \quad (7)$$

COS and CS2 are converted to H2S through hydrolysis reactions.

$$COS + H_2O \rightarrow H_2S + CO_2 \quad (8)$$
$$CS_2 + 2H_2O \rightarrow 2H_2S + CO_2 \quad (9)$$

CO is converted by the 'Water Shift' reaction

$$CO + H_2O \rightarrow CO_2 + H_2 \quad (10)$$

The gas stream generated by the Hydrogenation Reactor, which has a temperature of 329°C, undergoes a cooling process to 177°C. This cooling is necessary to facilitate the absorption of water content by the reflux liquid, which is composed of H2O. The cooled gas is then directed to the absorber, where further separation of the remaining H2S gas takes place. The Claus furnace, on the other hand, has a significantly lower running cost due to the utilization of fuel gas during startup and shutdown, purging operations, and the upkeep of flame scanners [6].

Simultaneously, the bottom product from the absorber is subjected to cooling using a Quench Water Cooler. The gas stream from the Quench Column enters the absorber, which is designed as a tray column. Within the absorber, the inlet gas is brought into contact with cooled lean amine. The lean amine, which has been cooled by the TGU Lean Amine Trim Cooler, enters trays 10, 12, and 14, enabling the separation of H2S gas from the gas mixture.

The gas exiting the top of the Tail Gas Unit, along with water from the Sulfur Pit Ejector, undergoes further treatment. It is introduced into a Thermal Oxidizer, where it is oxidized by burning with oxygen. This process converts the remaining sulfur into **SO_2** at a high temperature of 1750°C. The tail gas from the top of the absorber is mixed into this combustion process within the Thermal Oxidizer Chamber. Subsequently, the resulting gas is discharged into the atmosphere through a natural draft in the Stack Thermal Oxidizer, which operates at a normal temperature of 650°C. Claus reaction is unique in that the slope of equilibrium conversion changes from negative to positive as the temperature increases [7]. The furnace's thermal reaction is endothermic, whereas Claus catalytic reactions exhibit exothermic behavior [7].

3.4. Analysis of the Effectiveness of the Sulfur Recovery Unit (SRU) Refinery in Processing Sulfur Emissions

The SRU (Sulfur Recovery Unit) refinery plays a critical role in air pollution control at PT Pertamina Internasional RU IV Cilacap refinery. Its primary function is to recover sulfur from the existing process units while simultaneously producing additional LPG gas. The feed gas, also known as sour gas, originates from the FOC I, FOC II, and LOC III refineries. All of this feed gas is directed to the SRU unit, where it undergoes processing to produce new products, including LPG and liquid sulfur. It is important to note that the feed gas or sour gas entering the SRU unit has a consistent composition.

The SRU unit significantly contributes to reducing greenhouse gas emissions by converting these emissions, which would otherwise be released into the atmosphere, into new and more valuable products. Upon entering the SRU unit, the feed gas is separated and processed by unit 91, resulting in the production of HC (hydrocarbons) and H2S (hydrogen sulfide). The HC flows into unit 92, known as the LPG Recovery unit, while the H2S is directed to unit 93. It is worth mentioning that the size of the incoming feed has an impact on the amount of H2S that will be processed within unit 93.

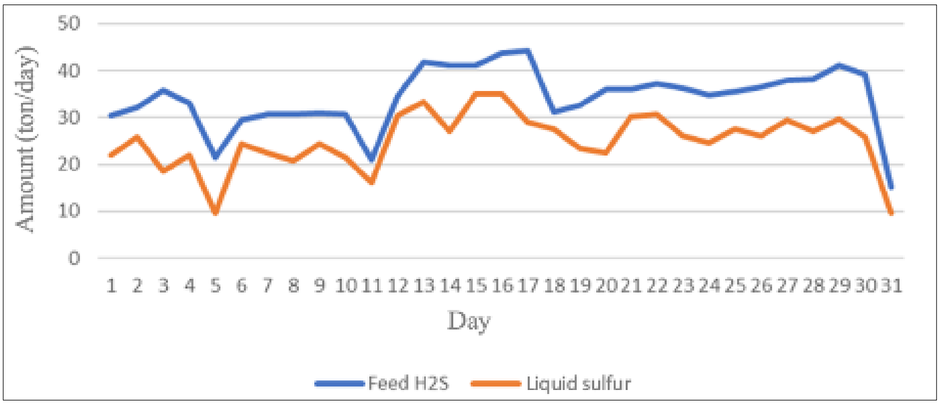

Figure 2 Flow H2S and liquid sulfur production at Unit 93 in January 2023

Based on Figure 3.6, it can be deduced that the average daily H2S feed entering unit 93 in January 2023 was approximately 34.21 tonnes. The maximum feed occurred on January 17, reaching 44.25 tonnes, while the minimum feed was recorded on January 31, amounting to 15.14 tonnes (Figure 2). The data presented in Figure 3.6 also indicates that approximately 73% of the H2S feed entering unit 93 is successfully converted into liquid sulfur. However, it is important to note that not all of the processed H2S in unit 93 can be completely transformed into liquid sulfur. A small portion of it still escapes in the form of gas.

The sulfur gas that is not converted into liquid sulfur will be directed to unit 94, also known as the TGU (Tail Gas Unit), for further processing. In unit 94, the sulfur gas is reprocessed and transformed back into H2S, which is then returned to unit 93. The remaining portion of the sulfur gas is sent to the Thermal Oxidizer, where it undergoes combustion to generate emissions. These missions are subsequently released through the LPG and SRU refinery flares. The information provided by Figure 3.6 highlights the efficiency of the sulfur recovery process in unit 93 and the subsequent treatment of sulfur gas in unit 94 and the Thermal Oxidizer.

3.5. Analysis of the Emission Characteristis of Stack 94-F-403

The gases that cannot be converted into liquid sulfur undergo a combustion process in the thermal oxidizer. In the thermal oxidizer, these gases are burned using excess air and fuel gas, generating a high temperature of 1750°C. The purpose of adding excess air to the thermal oxidizer is to ensure the complete combustion of sulfur and other components present in the gases. After the combustion process, the resulting gas is discharged into the atmosphere through the thermal oxidizer stack (91-F-403). The stack operates at a lower temperature of 650°C, ensuring the safe release of the burnt gases into the air.

Based on the data presented in Figure 3.7, it is evident that the overall emission output for the **SO_2** parameter in stack 94-F-403 during January 2023 remains below the quality standard specified in Minister of Environment Regulation No. 13 of 2009 Appendix 1c. This conclusion is drawn from the average 4-hourly measurements of **SO_2** emissions obtained through the Continuous Emission Monitoring System (CEMS).

Examining Figure 3.7 reveals that the highest concentration of the **SO_2** parameter was recorded on January 14, 2023, reaching 16.37 mg/m3. Conversely, the lowest concentration occurred on January 1, 2023, measuring 12.08 mg/m3. These variations in concentration levels reflect the dynamic nature of emissions throughout the monitoring period.

Figure 3.9 provides insightful data on the emissions of **SO_2** at stack 94-F-403 over different semesters. The highest recorded **SO_2** emissions occurred in the first semester of 2021, reaching 895 mg/Nm3. However, it is important to note that this value is still considered non-polluting, as it remains significantly below the **SO_2** quality standard outlined in PerMen LH No. 13 of 2009 Appendix 2b, which is set at 2600 mg/Nm3.

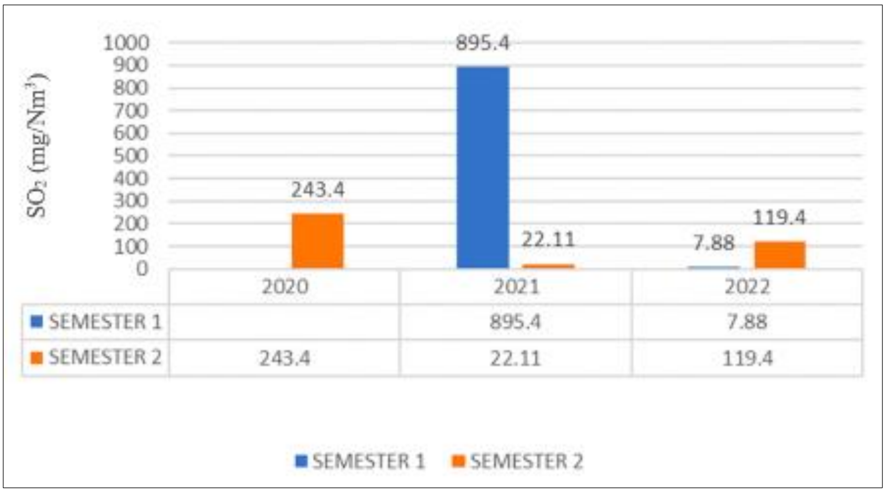

Figure 3 SO_2 emission monitoring from 2020 to 2022

Throughout subsequent semesters, a notable decrease in **SO_2** oncentrations can be observed. In the second semester of 2021, the concentration dropped to 22.11 mg/Nm3, further decreasing to 7.88 mg/Nm3 in the first semester of 2022. However, it is worth noting that there was a subsequent increase in **SO_2** concentration to 199.4 mg/Nm3, as shown in Figure 3.

These findings highlight the effectiveness of the sulfur recovery system in reducing the concentration of sulfur contaminants in the air, which can contribute to environmental pollution and acid rain effect. Comparatively, if the feed gas containing high levels of sulfur were directly burned using the flare system without undergoing the sulfur recovery process, it would result in significant pollution of the ambient air, posing environmental risks. Sulfur gas, when present in excessive concentrations, can be hazardous to the environment. Hydrogen sulfide is a hazardous pollutant due to its toxic, corrosive and acidic nature [8].

4. Conclusions

In conclusion, the SRU refinery at PT X serves as an important air pollution control unit that plays a vital role in the recovery of sulfur generated by the refinery's process units. This recovery process not only helps in mitigating environmental pollution but also results in the production of additional LPG gas. The average daily incoming feed of H2S gas to the SRU unit is approximately 34.21 tons/day.

Within the SRU unit, an impressive 73% of the incoming feed gas undergoes processing, leading to the production of liquid sulfur. On average, this process yields a liquid sulfur product amounting to 25.08% of the initial feed gas volume. These figures highlight the effectiveness of the SRU refinery in efficiently converting H2S gas into a valuable byproduct, while significantly reducing the release of sulfur emissions into the environment.

By implementing the SRU refinery and optimizing the recovery process, PT X demonstrates its commitment to sustainable practices, reducing air pollution, and maximizing resource utilization. The successful operation of the SRU unit not only aids in complying with environmental regulations but also contributes to the overall environmental well-being and sustainability goals of the company.

Compliance with ethical standards

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Disclosure of Conflict of interest

All authors declare no conflict of interest affecting the findings of this study.

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