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Simulation and Optimization for Crude Oil Desulfurization Using Aspen Hysys

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Dedication

With gratitude overflowing and a heart full of love,

I dedicate this humble work to those who have shaped my journey and stood by me through every challenge and triumph.

To my beloved parents whose sacrifices, prayers, and unwavering belief in me lit the path of my success. Your love is the foundation upon which this achievement rests.

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To my foreign colleagues and friends — thank you for the camaraderie, inspiration, and shared dreams.

Thank you, from the depth of my soul.

With all my heart — I dedicate this to you.

ملخص:

في إطار مشروع نهاية الدراسة، تم إجراء دراسة تهدف إلى تحسين الكفاءة التشغيلية لعملية الهدرجة (HDT) داخل وحدة إزالة الكبريت (UDS) ، باستخدام أداة المحاكاة Aspen HYSYS , تم اعتماد فهم معمّق لآليات المحاكاة إلى جانب منهجية التحسين، وذلك من أجل زيادة فعالية إزالة الكبريت من المشتقات البترولية. تم توقع سلوك النظام بدقة تحت ظروف تشغيلية مختلفة مثل درجة الحرارة، معدل التدفق، التدفق المولي، كفاءة المبادلات الحرارية، ونسبة الهواء إلى الغاز الحمضي، بهدف تحقيق إزالة فعالة للكبريت.

كلمات مفتاحية :المعالجة بالهدرجة, الكبريت, أسبن هايسيس, كسور بترولية , الغاز الحمضي, وحدة إزالة الكبريت.

Abstract:

As part of this final-year project, a study was conducted to optimize the operational efficiency of the hydrodesulfurization (HDT) process within the desulfurization unit (UDS) using the simulation tool Aspen HYSYS. A deep understanding of simulation mechanisms and a systematic optimization approach were applied to enhance the sulfur removal efficiency from petroleum fractions. The system's behavior was accurately predicted under various operating conditions, such as temperature, feed flow rate, molar flow rate, heat exchanger efficiency, and air-to-acid gas ratio achieve effective sulfur elimination.

Keywords: Hydro-treatment, Sulfur, Aspen HYSYS, Petroleum fraction, Acid-gas, Sulfur Recovery Unit,

Résumé :

Dans le cadre de ce projet de fin d'études, nous avons réalisé une étude visant à optimiser l'efficacité opérationnelle du processus d'hydrotraitement (HDT) au sein de l'unité de désulfurisation (UDS), en utilisant l'outil de simulation Aspen HYSYS. Une compréhension approfondie des mécanismes de simulation ainsi qu'une démarche systématique d'optimisation ont été mises en œuvre afin d'améliorer les rendements d'élimination du soufre présent dans les fractions pétrolières. Une modélisation précise du comportement du système a été effectuée sous différentes conditions opérationnelles telles que la température, le débit d'alimentation, le débit molaire, le rendement de l'échangeur de chaleur et le rapport air/gaz acide dans le but de maximiser l'efficacité du processus de désulfuration.

Mots clés : Hydrotraitement, Soufre, Aspen Hysys, Fraction pétrolière, Gaz-acide, Unité de désulfurisation,

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List of Symbols and Acronyms

ADA: Amine Distribution Analyzer

AG: Acid Gas

AMNU: Amine Regeneration Unit

API: American Petroleum Institute

DCS: Distributed Control Systems

EOR: Enhanced Oli Recovery

FCC: Fluid Catalytic Cracking

HDL: Hydrodearomatization

HDN: Hydrodenitrogenation

HDS: Hydrodesulfurization

K_{UOP} Factor: Kuwait University Oil Project Factor

PFD: Process Flow Diagram

SAT: Saturators

Sp Gr: Specific Gravity

SRU: Sulfur Recovery Unit

SWS: Sour Water Stripper

TGTU: Tail Gas Treatment Unit

ULSD : Ultra-Low Sulfur Diesel

VLE : Vapor-Liquid Equilibrium

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General Introduction

General introduction

Petroleum refining is a cornerstone of the global energy industry, providing essential fuels and raw materials for countless applications. However, crude oil naturally contains various impurities, among which sulfur compounds are particularly problematic due to their detrimental effects on both the environment and refinery equipment. The presence of sulfur in fuels leads to the emission of sulfur oxides (SOx) during combustion, which contribute significantly to air pollution, acid rain, and associated health hazards[1].

To address these challenges, refineries incorporate specialized processes aimed at reducing the sulfur content in petroleum products. Among these, the Sulfur Recovery Unit (SRU) plays a central role by converting toxic hydrogen sulfide (H_2S) and other sulfur-bearing compounds into elemental sulfur. This not only mitigates environmental risks but also allows for the recovery of a valuable byproduct, aligning environmental responsibility with economic benefit. The SRU thus contributes significantly to compliance with increasingly stringent environmental regulations while improving the overall efficiency and profitability of the refining process[2].

The operation of SRUs relies on a sequence of complex thermal and catalytic reactions, whose performance depends on the precise control of parameters such as temperature, pressure, gas composition, and flow rates. Moreover, the SRU must function in close synergy with other units, particularly the Acid Gas Removal (AGR) and Sour Water Stripping (SWS) systems, to ensure complete and effective treatment of sulfur compounds throughout the refining chain. This integrated approach is vital for reducing emissions and maximizing the recovery of sulfur in its elemental form[3].

From an economic standpoint, the optimization of SRU performance directly influences refinery margins by reducing operating costs, extending catalyst life, minimizing environmental penalties, and enhancing the market value of recovered sulfur. In recent years, the use of process simulation tools, especially Aspen HYSYS, has emerged as a powerful means of modeling and optimizing SRU behavior under various operating scenarios. These tools provide detailed insights into process dynamics, helping engineers improve design, operation, and control strategies[4].

This research aims to conduct a comprehensive study on the performance of sulfur recovery units through advanced simulation techniques. By identifying and analyzing the key factors influencing SRU efficiency, this work contributes to the development of more sustainable and environmentally compliant refining practices[5].

To achieve this objective, the present study is organized into four chapters. The first chapter provides an overview of crude oil characteristics, with particular emphasis on the nature and impact of sulfur-containing impurities. The second chapter explores the various methods employed for sulfur recovery, detailing their operational principles, advantages, and limitations. The third chapter is dedicated to the setup of the SRU simulation using Aspen HYSYS, outlining the adopted methodology, system configuration, and simulation parameters. Finally, the fourth chapter presents and discusses the results obtained from the simulation, highlighting potential areas for process improvement and evaluating the performance of the proposed configurations[6].

Chapter I: Overview on crude oil characteristics and associated impurities

I.1. Introduction

Crude oil, commonly known as petroleum or "black gold" is a naturally occurring, unrefined liquid composed primarily of hydrocarbons, along with varying amounts of nitrogen, sulfur, and oxygen (Figure I.1). It forms over millions of years through the decomposition of ancient marine organisms, such as algae and zooplankton, under high pressure and temperature beneath layers of sedimentary rock. This fossil fuel is extracted mainly through drilling, a process guided by geological research focused on reservoir structures, porosity, and permeability. Once extracted, crude oil undergoes refining to produce a wide range of essential products, including gasoline, kerosene, asphalt, and chemical feedstocks for plastics and pharmaceuticals. Its classification is based on three major hydrocarbon groups: paraffins, naphthene's, and aromatics, each playing a distinct role in refining and end-product applications. With global consumption reaching nearly 88 million barrels per day, crude oil remains a cornerstone of modern industry and daily life. In this chapter, we will explore the key definitions, origins, and formation processes of crude oil, as well as the main chemical correlations that determine its classification and commercial value [1].



Figure I.1. A natural oil seep.

I.2. Origin and formation of crude oil

Natural gas and oil are products of the gradual breakdown and transformation of biological materials that have been accumulated as sediments on the ocean floor over many millions of years. It is possible to find viable oil and gas reserves in a location if the source rock, reservoir rock, cap rock, and trap are all in the right places. Several thousand meters under the surface of the ocean, there is a thick layer of black clay that is the source of the majority of the gas and oil resources on the Norwegian shelf. Because it is a source rock, the black clay deposit contains agreat deal of organic matter. The clay was laid down around 150 million years ago under the surface of a sea

that encircled much of what is now northwest Europe. There was a great deal of life in the higher water levels, but the seafloor below was mostly lifeless and stagnant. Submerged in the oxygen-depleted sediments, the tiny phytoplankton eventually perished and piled up (Figure I.2). Sinking farther into the earth, they underwent a protracted chemical transformation because of bacterial decay and maturation under an ever-expanding layer of silt. As a result, hydrocarbons in both liquid and gaseous forms were produced in the rock that served as the source [7].

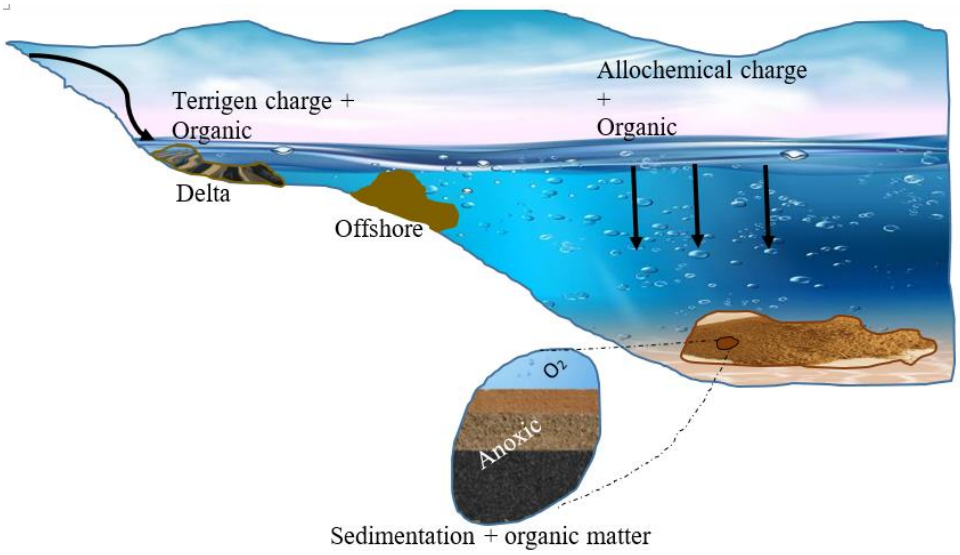


Figure I.2. Geological stages of oil formation.

Although several types of crude oil exist globally, the elemental makeup of the majority of crude oils varies within limited ranges, as seen in Table I.1 [8].

Table I.1. Elemental composition of crude Oil [8]

Element	Percent range
C	84% - 86%
H	11% -14%
S	0 - 6%
N	0 - 1%
O	0 - 2%

I.3. Composition of crude oils

Crude oil is an intricate amalgamation of organic components, mostly hydrocarbons, accompanied by contaminants that affect its characteristics and refining procedures. Crude oil has four distinct categories of hydrocarbon compounds. The proportional proportions of each component differ across oils, influencing the characteristics of each oil, as seen in Table I.2.

Table I 2. Composition by weight [4]

Hydrocarbon	Average Range
Paraffins	30% to 60%
Naphthene's	49% to 60%
Aromatics	15% to30%
Asphaltic	6%remainder

I.4. Crude oil classification

It was observed that lipids provide the principal raw material for petroleum [9]. Hydrocarbons are categorized into two primary types: aliphatic and aromatic. The primary sources were fats and oils, with the name "aliphatic" originating from the Greek word (aleiphar), meaning "fat." Petroleum may be further categorized by its density level (API*) into light, medium, and heavy oils, each fulfilling distinct functions depending on its characteristics, as shown in Figure I.3 [9].

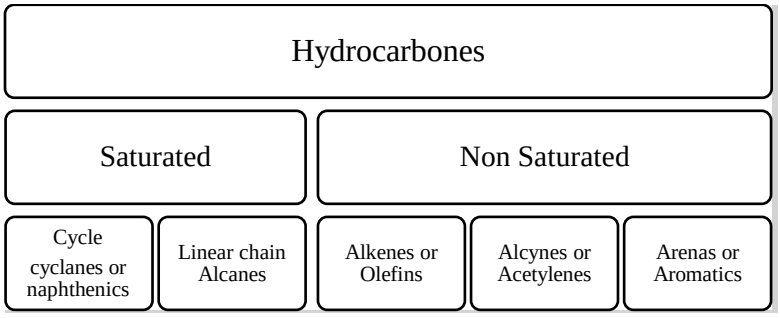


Figure I.3. Extra-light oil, light oil (Brent), medium oil, bitumen (extra-heavy oil).

Crude oil has several hundred thousand distinct molecular kinds, although only a few hundred have been accurately recognized. There are three primary groups of hydrocarbons, classified according to the nature of the carbon-carbon bonds present. The classes illustrated in Figure I.4, are as follows [10]:

- Saturated hydrocarbons consist only of single carbon-carbon bonds. They are designated as paraffins (or alkanes) if acyclic, or naphthene's (or cycloalkanes) if cyclic.
- Unsaturated hydrocarbons possess many carbon-carbon bonds, which may be double, triple, or both. They are classified as unsaturated due to having a lower number of hydrogen atoms per carbon as paraffin. These unsaturated hydrocarbons are referred to as olefins. Compounds with a double carbon-carbon bond are termed alkenes, whilst those having a triple carbon-carbon bond are referred to as alkynes.
- Aromatic hydrocarbons are a distinct category of cyclic chemicals that are structurally similar to benzene.

(a)



(b)

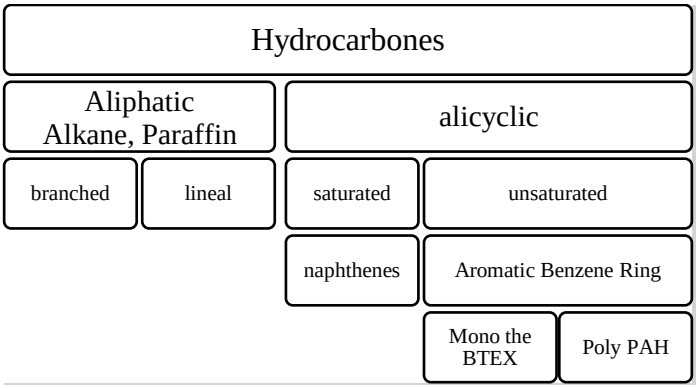


Figure I.4. Classification of hydrocarbones

I.5. Crude oil properties

Various properties of crude oil, including its API gravity (related to the H/C ratio), determine whether it is light or heavy (Figure I.5). This influences hydrocarbon composition, fuel yields, and impact economic choices related to extraction, transportation, and refining [7].

I.5.1. Density of crude oil

Density, characterized as mass per unit volume (expressed in kg/m³ or g/cm³), is a key attribute of crude oil. It varies considerably across different kinds of oil: Light oil (Brent) has low density, facilitating its refinement into high-quality fuels, while heavy crude's elevated density demands complex processing. This distinction directly impacts production costs and market value [2].

$$D_4^{15} = \frac{\rho_{(\text{curd oil } 15°\text{C})}}{\rho_{((\text{water } 4°\text{C})}} \quad \text{(I.1)}$$

$$\text{Sp. Gr}_{(60\,°\text{F}/60°\text{F})} = \frac{\rho_{(\text{curd oil } 60°\text{F})}}{\rho_{((\text{water } 60°\text{F})}} \quad \text{(I.2)}$$

Measurements of water density at various temperatures revealed that:

$$\rho_{(water\ 20°C)} = 0{,}9982.\,\rho_{\,(\text{water } 04°\text{C})} \quad \text{(I.3)}$$

Thus, we may get from the equations:

$$D_4^{15} = 0{,}99904.\,SpGr_{(60°\text{F}/60°\text{F})} \quad \text{(I.4)}$$

Density assessment with pycnometers:

$$D_{20}^{20} = \frac{\rho_{(\text{crud } 20°\text{C})}}{\rho_{((\text{water } 20°\text{C})}} \quad \text{(I.5)}$$

I.5.2. Density in degrees

Specific gravity, often represented as API gravity (formulated by the American Petroleum Institute), contrasts the density of crude oil with that of water. API gravity has an inverse relationship with density; higher API values signify lighter, more valuable oil. Light oil with an API gravity beyond 31.1° is classified as premium, whereas heavy crude with an API gravity below 22.3° is indicative of inferior quality and increased refining difficulties [11].

$$°\,\text{A. P. I} = \frac{141.5}{\text{SpGr}_{(60°\text{F}\,/60°\text{F}\,)}} - 131{,}5 \quad \text{(I.6)}$$

Avec (A.P.I): American Petroleum Institute.



Figure I.5. Heavy oil and light oil.

I.5.3. Characterization coefficient (K_{UOP})

The $K_{U.O.P}$ factor is an empirical index used in petroleum refining to characterize crude oils or petroleum fractions**.** It gives insight into the chemical nature of the hydrocarbons, whether they are more paraffinic**,** naphthenic**,** or aromatic [12].

$$K_{U.O.P} = \frac{\sqrt[3]{T°(R)}}{Sp.Gr_{(60°F\,/60°F)}} \quad \text{(I.7)}$$

$K_{u.o.\,p}$: Characterization Factor

T°(R): Boiling temperature of the crude oil in Rankine (°R)

Sp.Gr: Specific gravity at 60°F

Examples:

- $K_{U.O.P}$ = 13 ; The oil comprises normal and iso-paraffin hydrocarbons.
- $K_{U.O.P}$ = 12 ; The oil has mixed hydrocarbons, or the cycle and chain are analogous.
- $K_{U.O.P}$ = 11 ; Oil comprises low-substituted naphthenic hydrocarbons.
- $K_{U.O.P}$ = 10 ; The oil comprises pure aromatic hydrocarbons.

I.5.4. Amounts of sulfur

The sulfur concentration classifies crude oil as "sweet" (low sulfur, >0.5%) or "sour" (high sulfur, <0.5%). Sweet oil is economically advantageous owing to decreased refining expenses and fewer emissions, but sour crude necessitates costly desulfurization procedures to comply with environmental standards. The sulfur split substantially influences price and refining tactics [13].

❖ **Sweet crude oil and sour crude oil**

Crude oil is classified as **sweet** (less than 0.5% sulfur) or **sour** (higher sulfur content) (Table I.3), Sweet crude, like Brent or WTI, is easier and cheaper to refine, less corrosive, and more environmentally friendly. Sour crude, such as Arab Heavy, requires costly desulfurization and poses safety and environmental risks due to toxic hydrogen sulfide. As a result, sweet crude is more valuable and often sells at a premium [14].

Table I.3. Compared to Sweet and Sour.

Classification	Sweet oil	Sour oil
Sulfur content	<0.5**%**	> 0.5**%**
Dominant form	Inorganic(H_2S)	Organic + Inorganic
Ease of processing	Easy	Most, difficult requires advanced treatment
Environmental effect	Less polluting	More polluting

I.6. Importance of crude oil treatment in refining and pollution reduction

Oil refining is vital to modern life, converting crude oil into essential fuels and raw materials for transport, industry, and energy. Through processes like distillation and cracking, refineries maximize output from light fuels to heavy products while minimizing waste. Economically, the industry supports jobs, innovation, and national revenue, enhancing energy security. Environmentally, modern refineries produce cleaner fuels, recycle byproducts, and reduce emissions (Table I.4). They also supply key inputs for plastics, medicines, and fertilizers. Advanced technologies boost efficiency, process heavier crudes, and solve operational challenges. Balancing growth and sustainability, refining remains central to global development [14].

The treatment of crude oil is essential for safeguarding refinery equipment from corrosion induced by impurities such as sulfur and chlorides. It prolongs equipment longevity, reduces maintenance expenses, and guarantees effective refinery operations. The treatment facilitates the generation of superior petroleum products, such as gasoline, diesel, jet fuel, and lubricants, which are required to adhere to stringent quality criteria. Clean fuels boost engine performance, decrease fuel consumption, and improve energy efficiency. Furthermore, crude oil treatment assists refineries in

adhering to laws, promotes sustainable practices, and contributes to pollution reduction and climate change mitigation [15].

I.7. Types of impurities in crude oil and their impacts

Crude oil contains contaminants like sulfur, heavy metals, nitrogen compounds, and sediments, which complicate refining and harm the environment (Figure I.6). These impurities cause equipment damage, raise costs, and reduce crude value. Treatments such as hydrodesulfurization and adsorption are needed. Knowing their origins and impacts is essential for efficient and cleaner processing [16].



Figure I.6. Different types of crude oil that contain different impurities.

I.7.1. Types of sulfur in crude oil

As shown in Table I.5, sulfur in crude oil ranges from 0.05% to over 5%, classifying it as "sweet" (low sulfur) or "sour" (high sulfur), which affects both its value and environmental impact. Found mainly as HS, mercaptans, and thiophenes, sulfur compounds are corrosive and produce harmful SO_x emissions during combustion. Regulations like IMO 2020 have increased demand for low-sulfur fuels. Sour crude, common in regions like the Middle East and Venezuela, is cheaper but costlier to refine using energy-intensive hydrodesulfurization. Advances in desulfurization and shifts toward cleaner energy reflect global efforts to reduce sulfur's environmental harm while meeting industrial needs [17].

Table I. 3. Types of sulfur in crude oil.

Component	Name	Impact	Content
S_8	Elemental sulfur	Acid precipitation	(0.5%)
H_2S	Hydrogen sulfide	toxic, corrosive gas	Less of (1ppm)
R-SH	Mercaptans	Volatile, foul-smelling compounds.	Very tiny
C_4H_4S	Thiophenes	Poisoning catalyst	(0.1 – 0.5) %
S^{2-}	Sulfides	High toxicity	Less of (1ppm)
R−S−S−H	disulfide	Corrosion stimulation	Lees of 1%

I.7.2. Nitrogen/Oxygen compounds in crude oil

Understanding nitrogen and oxygen impurities in crude oil is crucial for enhancing product quality, refining efficiency, and environmental sustainability. These impurities stem from the degradation of organic matter over millions of years and can arise during extraction or transport. Their concentrations vary by oil field, influenced by geological and climatic conditions [4]. Nitrogen compounds in crude oil are mainly found in the form of heterocyclic compounds such as pyridines and pyrroles, which exhibit high chemical stability (Figure I.7).

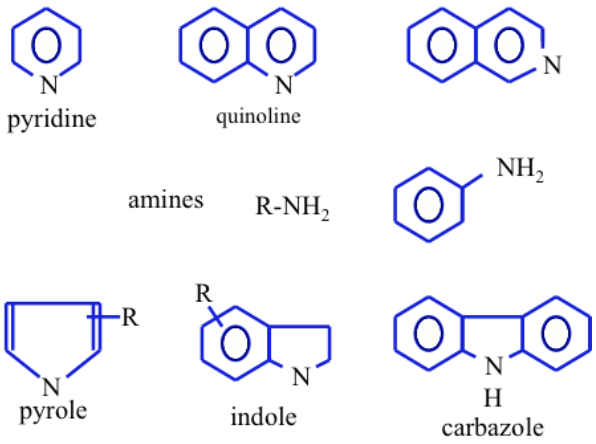


Figure I. 7. Basic and non-basic Nitrogen compounds.

Conversely, oxygen compounds often manifest as naphthenic acids, phenols, and ketones, which are linked to the corrosive properties of oil and its effects on equipment (Figure I.8).

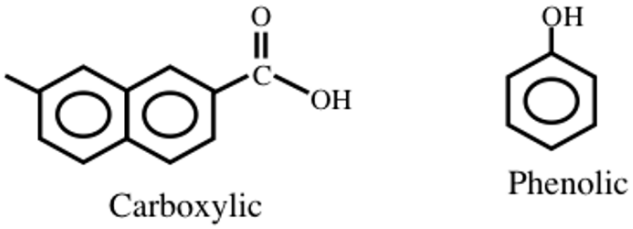


Figure I. 8. Oxygen compounds.

The impurities pose considerable technical and economic difficulties, including catalyst poisoning in refining processes (catalytic cracking and hydro processing), deposit formation during storage, and heightened oil acidity, which exacerbates pipeline and storage tank corrosion. Nitrogen and oxygen compounds emit toxic gases during oil processing or burning, including nitrogen oxides (NO_x), which are associated with acid rain and air pollution. Consequently, the elimination of these

contaminants by procedures like hydrodenitrogenation (HDN) for nitrogen elimination and deoxygenation for oxygen elimination has garnered considerable interest in the oil sector, particularly in light of the increasing stringency of worldwide environmental standards [4].

I.7.3. Heavy metals

Crude oil is a complex mixture of hydrocarbons containing impurities, particularly heavy metals like nickel (Ni) and vanadium (V), which create challenges in refining. These metals originate from the thermal decomposition of ancient microorganisms and flora, often existing as organometallic compounds like vanadyl and nickel porphyrins (Figure I.9), which dissolve in oil due to their bond with hydrocarbons [18].

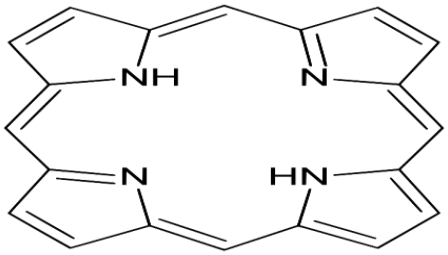


Figure I.9. The parent porphyrin.

Metal content in crude oil varies by region, with Venezuelan crude having high vanadium levels (up to 1200 ppm) compared to Arab crude oils. Nickel and vanadium pose technical and environmental challenges, causing catalyst poisoning in refining processes like fluid catalytic cracking (FCC), reducing efficiency, and increasing maintenance costs. Vanadium also forms low-melting oxides (e.g., V_2O_5), leading to corrosion in furnaces and pipelines. Environmentally, combustion of metals-contaminated fuel contributes to harmful emissions, with vanadium linked to respiratory issues and nickel being a potential carcinogen. Oil spills containing these metals contaminate ecosystems, entering the food chain and threatening marine life and human health. Detection methods such as ICP-MS, XRF, and liquid chromatography (Figure I.10) allow for precise measurement of these metals at low concentrations, aiding in monitoring and mitigation efforts [19].



Figure I.10. Spectroscopic analysis.

To limit their influence, several treatment procedures are used, including solvent extraction to eliminate metallic compounds before refining and hydrometallurgy, which employs hydrogen under high pressure to sever metal bonds. Moreover, enhancing catalysts to increase resistance to poisoning by integrating materials such as activated carbon is an essential method. Environmental restrictions significantly contribute to the reduction of these metals in petroleum products, since authorities like the EPA enforce stringent limitations on their quantities in fuels. Nickel and vanadium provide significant hurdles in the oil sector because of their technical and environmental ramifications, requiring the incorporation of modern treatment methods in adherence to environmental standards. Research continues in developing more effective techniques for eliminating toxic metals or alleviating their detrimental impacts [19].

I.7.4. Solid impurities

These contaminants originate from several sources, including reservoir formations, drilling activities, and contamination during handling and storage. Salts, mostly consisting of sodium chloride (*NaCl*), magnesium chloride ($MgCl_2$), and calcium chloride ($CaCl_2$), are often found in crude oil as dissolved or suspended particulates inside water-in-oil emulsions. If not efficiently eliminated, these salts may cause significant corrosion in pipelines, storage tanks, and refining apparatus owing to hydrolysis processes that generate hydrochloric acid (*HCl*) at elevated temperatures [20].

Salt and sand impurities in crude oil cause major operational and processing issues. Salt leads to fouling, scaling, and higher maintenance costs, while sand, introduced during extraction, causes abrasion, equipment wear, and flow blockages (Figure I.11). Both disrupt refining by damaging catalysts and reducing efficiency. To mitigate these effects, crude oil undergoes desalting (using water washing and electrostatic separation) and solid removal through filtration and sedimentation. Efficient impurity removal is essential to protect infrastructure, maintain product quality, and minimize environmental impact [20].



Figure I. 11. Corrosion of Equipment by HCl.

I.8. Conclusion

Crude oil, formed over millions of years, varies in composition and quality, affecting its classification and usability. Its processing requires techniques like enhanced recovery and pre-refining treatments to manage impurities and reduce environmental impact. Efficient refining and impurity control are essential for maximizing product quality, minimizing costs, and supporting sustainability in the global energy system.

Chapter II: Overview on Sulfur Recovery Methods

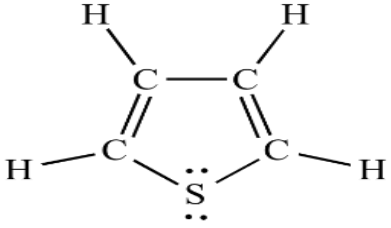
II.1. Introduction

Sulfur Recovery Units (SRUs) convert toxic H_2S from oil, gas, and chemical processing into elemental sulfur, significantly reducing emissions. Central to this process is the Claus method, combining thermal and catalytic steps to transform HS into sulfur. Modern SRUs also include tail gas treatment to meet strict environmental regulations. Recovered sulfur is reused in various industries, making SRUs vital for environmental protection and resource efficiency [21]. In this chapter, we will explore the role and functioning of Sulfur Recovery Units, with a focus on the Claus process and its extensions. We will examine how SRUs help reduce environmental impact, comply with regulations, and produce reusable sulfur. The chapter will also highlight technological advancements in sulfur recovery and their importance in aligning industrial operations with sustainability goals.

II.2. Sources of sulfur in petroleum refineries

Sulfur in crude oil (Table II.1), which varies by its geological origin, presents challenges in refining. Common sulfur compounds include mercaptans, hydrogen sulfide (H_2S), sulfides, disulfides, and thiophenes. "***Sweet***" crude oil has lower sulfur content, while "***sour***" crude contains higher amounts of H_2S and organic sulfur. Sulfur complicates refining by deactivating catalysts, causing corrosion in pipelines and equipment, and requiring additional processing to meet environmental sulfur emission standards [22].

Table II.1. Naturally occurring sulfur compounds.

Hydrogen Sulfide	H–S–H
Ethanethiol	CH_3–CH_2–SH
Disulfide Dimethyl	CH_3–S–S–CH_3
Thiophene	

II.3. Sulfur presence during petroleum processing and its emissions

During refining, sulfur compounds persist and often concentrate in heavier fractions like fuel oil and bitumen. While processes like hydrocracking can break some down, stable compounds (e.g., thiophenes) remain in fuels. Hydrodesulfurization (HDS) reduces sulfur by converting it to H_2S, though trace amounts may still exist, requiring strict quality control to meet standards like Euro 6. Refinery processes also emit H_2S and sulfur oxides (SO_x), which contribute to pollution. Technologies like the Claus process and flue gas desulfurization (FGD) are essential to recover sulfur and reduce harmful emissions, ensuring environmental and regulatory compliance [24,25].

II.3.1. Hydrodesulfurization processes (HDS)

HDS, a crucial refining procedure used to eliminate sulfur from petroleum products (diesel, gasoline), produces hydrogen sulfide (H_2S). Hydrocarbon streams and hydrogen gas are combined in HDS units, and the mixture is then run over a catalyst (cobalt-molybdenum or nickel-based catalysts) at high pressures (30-130 bar) and temperatures (300-400°C). When hydrogen reacts with sulfur-containing substances such as thiophenes, mercaptans, and sulfides, the resultant product is H_2S. For instance:

$$\textit{Organic sulfur compound} + H_2 \rightarrow \textit{Desulfurized hydrocarbon} + H_2S$$

Following separation, the resultant H_2S is sent to sulfur recovery facilities (Claus process) for elemental sulfur conversion (Figure II.1). A purposeful and regulated source of H_2S, HDS is closely related to complying with environmental standards for low-sulfur fuels [26].

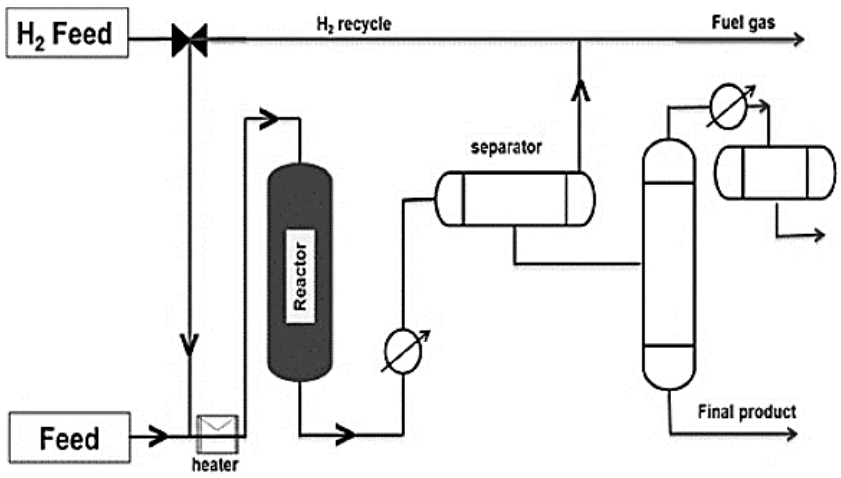


Figure II.1. Hydrodesulphurization unit [26].

II.3.2. Catalytic cracking processes

Another significant source of H_2S is catalytic cracking equipment, particularly fluid catalytic crackers (FCC). These units operate at high temperatures (typically 500-550 °C) and use a zeolite-based catalyst to break down heavy hydrocarbon molecules into lighter fractions such as gasoline and LPG (Liquefied Petroleum Gas). During this process, sulfur-containing compounds present in the heavy feedstocks are converted into hydrogen sulfide (H_2S) and other byproducts. The reaction can be summarized as:

Heavy sulfur-rich hydrocarbons → Lighter hydrocarbons + H_2S + other byproducts usually

The hydrogen sulfide (H_2S) produced in FCC unit (Figure II.2) is typically carried along with the gaseous products, known as off-gas. This H_2S must be treated downstream using sulfur recovery units or amine scrubbers. Unlike hydrodesulfurization (HDS), where sulfur removal is the main objective, H_2S formation in catalytic cracking is an unintended byproduct of the cracking reactions. As such, additional mitigation measures are required to control H_2S emissions and comply with environmental regulations [27].

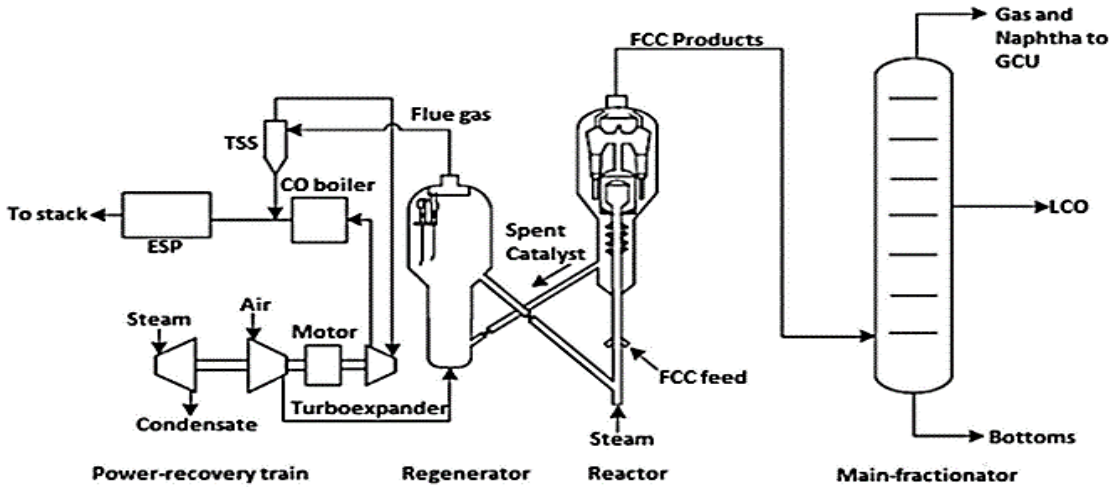


Figure II. 2. FCC Unit [27]

II.4. Sulfur recovery complex

Refineries utilize a device called the Sulphur Recovery Complex (SRC) to extract H_2S (gas) and transform it into elemental sulfur (S, solid), which may be sold or disposed of safely. Because H_2S is extremely harmful and corrosive, it must be removed; therefore, lowering sulfur emissions is necessary to comply with environmental requirements. Numerous businesses, including those

that manufacture fertilizers and sulfuric acid, can use the recovered sulfur. There are four primary units in this Complex [28].

II.4.1. Amine regeneration unit

The Amine Regeneration Unit (ARU) restores amine solutions used to absorb acid gases (CO_2 and H_2S) by heating and distilling the rich amine, then recycling the purified lean amine for continuous acid gas removal [29]. Figure II.3 illustrates an amine regeneration unit.

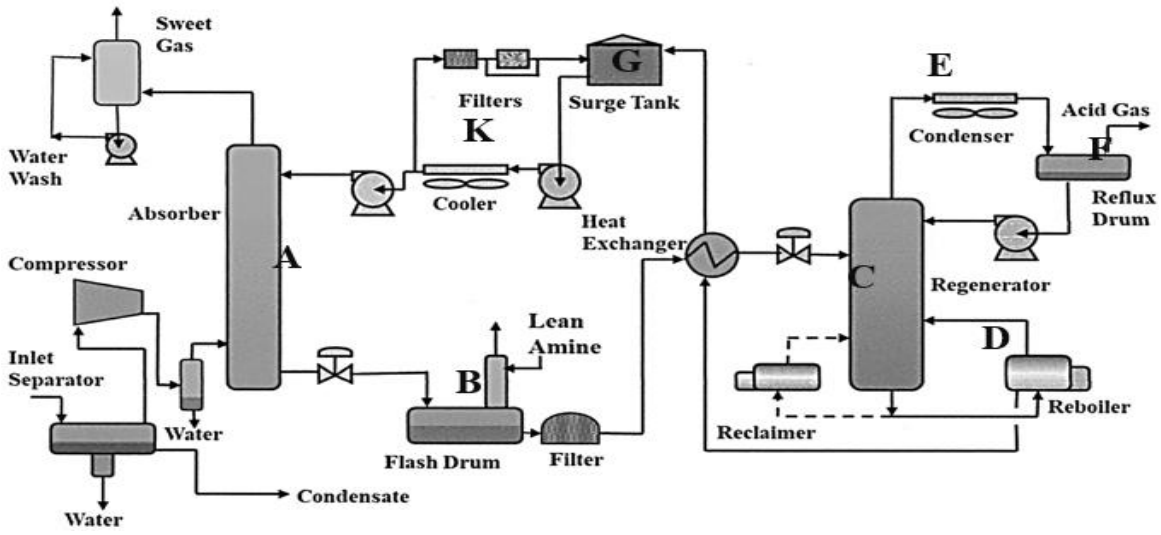


Figure II. 3. Amine regeneration unit [29]

- **Flow of operations within the ARU**

As shown in Figure II.4, the acid gas saturated with amine starts from the absorption unit and enters the A-Amine Flash Drum to separate the light gas. B- The amine solution then proceeds to the C- Amine Regenerator (Stripping Column), where it is heated by the D-Reboiler to release H_2S gas from the solution. The H_2S and steam rise to the top of the column and are condensed in the E- Overhead Condenser, where the liquid is separated in the F-Overhead Receiver. The H_2S-rich gas is sent to the SWS unit (Sour Water Stripper/Sulfur Recovery Unit), while the regenerated amine is returned to the storage tank via the G- Lean Amine Cooler and K- Lean Amine Pump to be reused in the absorption process [21].

II.4.2. Sour water stripper

To extract and eliminate acid gases like H_2S and NH_3 from sour water (contaminated water) produced by different refinery units, such as distillation and hydrotreating units, the Sour water stripper (SWS) unit is used (Figure II.5). Thermal distillation, also known as steam stripping, is used to do this, allowing the treated water to be securely

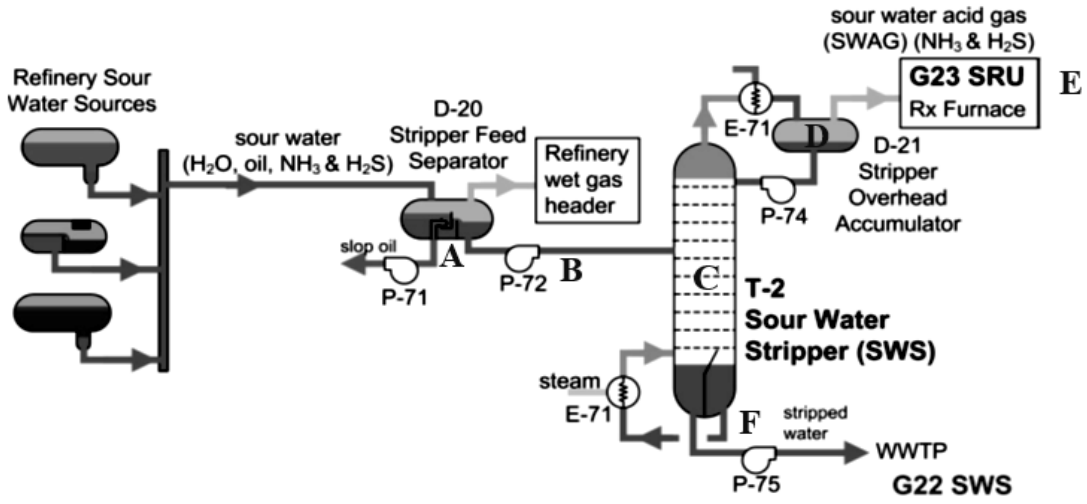


Figure II. 6. Sour Water Stripper [30]

- **Flow of operations within the SWS unit**

The process begins, as shown in Figure the by feeding sour water containing (H_2S and NH_3) into the **A**- Sour Water Feed Tank, which is then pumped to the B- Sour Water Stripper Column. Inside the column, the water is heated using the C-Reboiler to release acidic gases (H_2S and NH_3) to the top of the column. The rising vapors pass through the D-Overhead Condenser, where they are partially condensed, and then separated in the F-Overhead Receiver into gas and liquid phases. **E**- The H_2S-rich gas is sent to the Sulfur Recovery Unit (SRU), while the treated water exits from the bottom of the column to a discharge tank or is reused [22].

II.4.3. Sulphur recovery unit

The SRU plays a vital role in treating H_2S-rich gases from the Amine Regeneration Unit and Sour Water Stripping Unit (Figure II.5). Using the Claus process, a thermal and catalytic reaction, the SRU converts H_2S into elemental sulfur by precisely controlling the air-to-gas ratio. The process

involves a thermal reactor followed by catalytic converters, after which the sulfur is cooled and collected. Remaining sulfur compounds in the tail gas are further treated in the Tail Gas Treatment Unit (TGTU) to meet environmental regulations [31].

- **Reaction Principles**

The Claus Process, a mix of thermal and catalytic processes intended to transform H_2S into elemental sulfur, is the basis of the SRU. There are two primary steps to the process (Figure II. 7): the catalytic stage, which includes a number of catalytic reactors, and the thermal stage, which takes place within the Claus furnace [32].

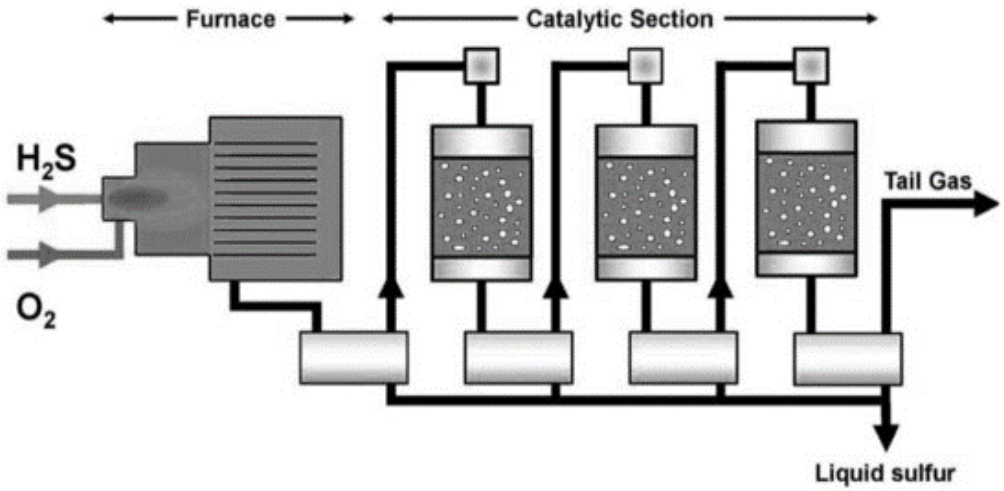


Figure II. 8. Reaction principles [32].

In the thermal stage, approximately one-third of the incoming H_2S is combusted with a controlled amount of air in the Claus furnace (Figure II. 9), generating sulfur dioxide (SO_2) and water vapor. Equation Claus furnace:

$$2H_2S + 3O_2 \xrightarrow{\text{Heating}} 2SO_2 + 2H_2O$$

High temperatures (1000-1300°C) are required for this extremely exothermic process to occur. After that, the hot gas stream is cooled in a waste heat boiler, which allows for partial sulfur condensation and energy recovery [32].

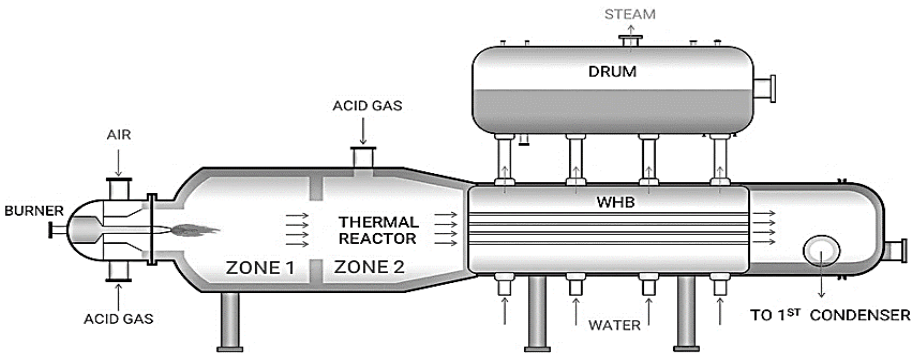


Figure II. 10. Furnace apparatus [14]

The process begins in the burner with fuel-air combustion that initiates H_2S to SO_2 conversion. The gas passes through thermal Zones 1 and 2 for further reactions and temperature stabilization, then enters the Waste Heat Boiler (WHB), which recovers heat, cools the gas, and enhances overall process efficiency[33].

In the catalytic stage, the remaining two-thirds of H_2S reacts with SO_2 produced earlier over an activated alumina or titanium dioxide catalyst, according to the Claus reaction:

Equation Claus Catalytic:

$$2H_2S + SO_2 \xrightarrow{\text{Catalyst}} 3S + 2H_2O$$

One or more Claus converters (catalytic reactors), often run in series, are where this reaction occurs. Before reheating and moving on to the following step, the gas stream is cooled in sulfur condensers between each reactor to collect the elemental sulfur [34].

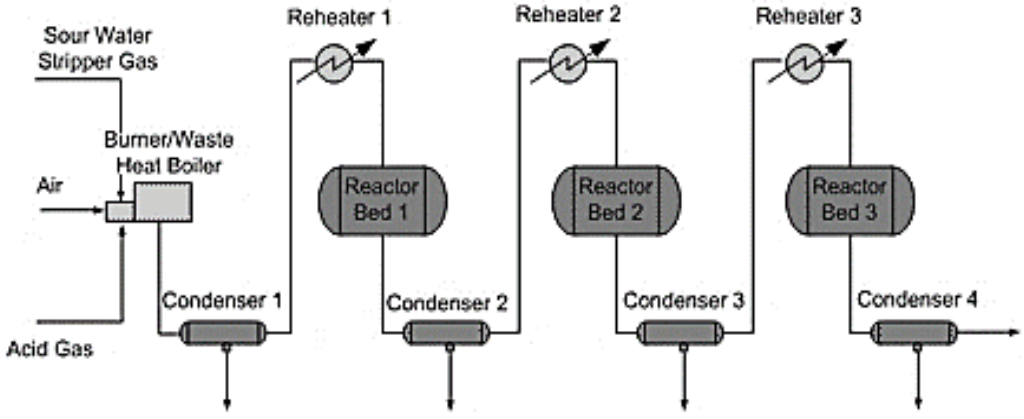


Figure II.11. Catalytic reactors [14].

The hot gas stream is sent to the sulfur condenser after leaving the furnace, as seen in Figure II.12, where it is partially cooled and elemental sulfur is separated into liquid form. After that, the residual gas moves on to the catalytic step, where it passes through reactors that contain a catalyst that encourages the continuous transformation of compounds containing sulfur into elemental sulfur. To maintain ideal reaction conditions and increase the effectiveness of sulfur recovery, the gas is cooled once again in between catalytic reactors [34].

The combined thermal and catalytic reactions can achieve sulfur recovery efficiencies of up to 95-97%, depending on the number of catalytic stages and the operating conditions.

- **Flow of operations within the unit**

The SRU process begins with acid gas feed entering the Claus Furnace, where part of the H_2S is combusted with air from the Air Blower, producing SO_2 and hot gases. These gases pass through a Waste Heat Boiler for heat recovery and then into the First Sulfur Condenser, where elemental sulfur is condensed and collected via a Sulfur Seal Pot.

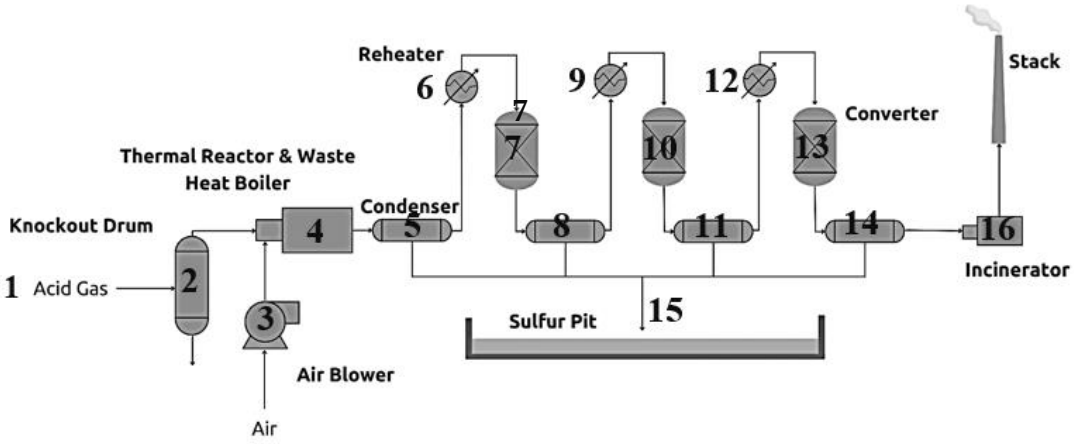


Figure II. 13. Sulfur recovery unit [35].

The remaining gas, still containing H_2S and SO_2, undergoes further reaction in the First Catalytic Reactor, followed by additional sulfur condensation in the Second Sulfur Condenser. A Reheater then restores the temperature before the gas enters the Second Catalytic Reactor. This process may continue through a Third Stage for enhanced recovery. Finally, the treated gas, now low in sulfur, is sent either to the Tail Gas Treating Unit or the Incinerator, depending on plant design. All recovered sulfur is directed to the Sulfur Storage Tank for handling [5].

II.4.4. Tail Gas Unit (TGTU)

To achieve sulfur recovery efficiencies above 99.9%, residual gases from the Claus unit, still containing sulfur compounds such as H_2S, SO_2, COS, CS_2, and S_x, are processed in the Tail Gas Treatment Unit (TGTU). While highly effective, the Claus process alone cannot fully convert all sulfur in acid gas to elemental sulfur, leaving harmful residues in the tail gas. The TGTU addresses this by converting remaining sulfur species into H_2S, which can be recycled back to the Claus unit or safely managed, ensuring compliance with stringent environmental regulations [36].

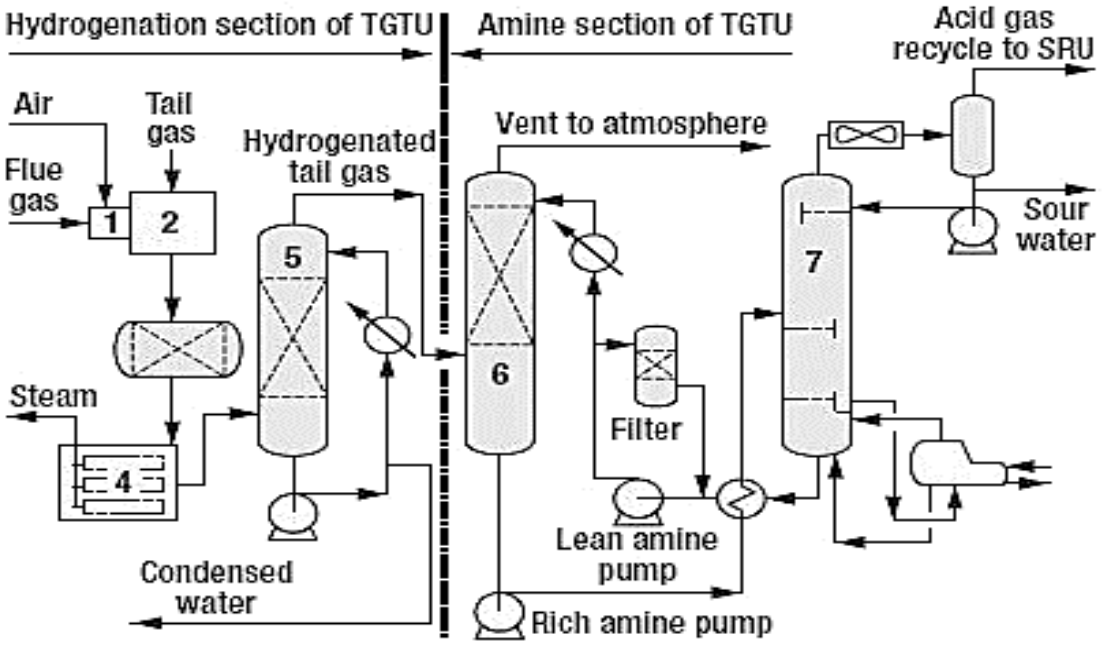


Figure II.14. Tail Gas Unit (TGTU) [36].

As shown in Figure II.9, Claus tail gas containing H_2S, SO_2, COS, and CS_2 is treated to enhance sulfur recovery. COS and CS_2 are first hydrolyzed to H_2S using steam and a catalyst. In the Hydrogenation Reactor, SO2 and elemental sulfur are reduced to H_2S using hydrogen and a cobalt-molybdenum catalyst. The gas is then cooled and sent to the Amine Absorber, where H_2S is captured by an amine solution (e.g., MDEA). The H_2S-rich amine is flashed to remove light hydrocarbons, and then stripped in the amine regeneration unit. The recovered H_2S is recycled back to the Claus unit for further sulfur recovery [23].

I.5. Conclusion

This chapter presents an in-depth analysis of the SRU, emphasizing its crucial role in modern refining operations as both an environmental safeguard and a driver of operational efficiency. It begins by outlining the economic and environmental imperatives of sulfur recovery, particularly the removal of sulfur compounds derived from crude oil to meet regulatory and quality standards. The chapter then details the key structural components of the Sulfur Recovery Complex-including the TGTU, ARU, SWS, and SRU-highlighting the SRU as the core element. Utilizing both thermal and catalytic processes, the SRU achieves high sulfur conversion rates. Attention is given to the environmental impact of the SRU, with a comprehensive discussion on its equipment and operational sequence. Ultimately, the SRU is framed as a strategic element of sustainable refining, serving not just as a technical unit, but also as a critical barrier against emissions and a key contributor to aligning industrial efficiency with environmental stewardship.

Chapter III: Setup for SRU simulation

III.1. Introduction

Control systems are essential for maintaining process efficiency, product quality, and environmental sustainability in industrial operations. Modern advancements such as Distributed Control Systems (DCS), Programmable Logic Controllers (PLC), and Supervisory Control and Data Acquisition (SCADA) have significantly improved the accuracy, safety, and reliability of process control and monitoring. This chapter introduces the setup and simulation of a SRU in Aspen HYSYS, demonstrating how these control principles are applied to optimize sulfur recovery processes. All the process steps and simulation methodology are presented in this chapter.

III.2. Insight into Aspen HYSYS

Aspen HYSYS is a powerful process simulation tool widely used in the petroleum and chemical industries for designing, analyzing, and optimizing industrial units. It supports both steady-state and dynamic simulations, enabling accurate modeling of heat transfer, chemical reactions, and separation processes without costly field trials. Its extensive equipment library includes distillation columns, reactors, compressors, heat exchangers, and pipelines, all accessible through an intuitive user interface. What sets Aspen HYSYS apart is its competitive advantage in modeling complex systems such as the SRU. With advanced thermodynamic models and integrated control features, engineers can simulate critical reactions, like those in the Claus process, and evaluate the performance of control strategies in real-time. This capability makes HYSYS an essential tool for maximizing sulfur recovery efficiency (Table III.1).

Table III.1. Comparison between Aspen Hysys and Aspen plus.

Feature	Aspen HYSYS	Aspen Plus
Primary Use	Oil & gas, gas processing, refinery operations.	Chemical processes, solid handling, specialty chemicals
Thermodynamic Models	Strong in vapor-liquid equilibrium (VLE) and gas processing	Strong in solid, liquid, and multiphase equilibrium
Interface	Intuitive, flowsheet-based, dynamic simulation support	More complex, detailed unit operations, static simulation focus
Reactor Simulation	Ideal for gas-phase reactors like Claus reactors in SRU	Better for complex reaction kinetics and batch reactors
Dynamic Simulation	Strong support with control system integration (DCS, PID controllers)	Limited support, primarily steady-state

III.3. Integration of Aspen Hysys with SRU simulation

By combining these components, Aspen HYSYS allows customers to assess process stability in various situations, evaluate sulfur recovery efficiency, and improve operating parameters all without the need for physical testing. In refineries and gas treatment plants, this makes it an effective tool for design, troubleshooting, and environmental compliance (Figure III.1).

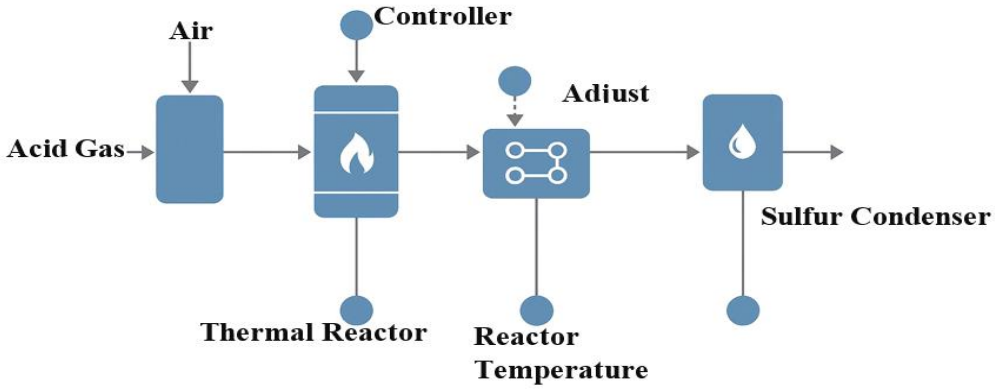


Figure III.1. Process Flow.

A simplified flow diagram for utilizing Aspen HYSYS to simulate an SRU is shown in Figure III. 2. It describes the main steps of the process, which include the sulfur condenser, the thermal reactor, the catalytic converter, and the acid gas input. Additionally, the graphic shows control points that show how dynamic simulation and process control systems are integrated, enabling performance evaluation under various operating situations and sulfur recovery efficiency optimization.

III.3.1. Model development

In order to duplicate the Claus process and assess the sulfur recovery efficiency, a simulation model of the SRU was created in this part using Aspen HYSYS. The model was constructed using the standard SRU process flow, which consists of a thermal reactor, heat exchangers, sulfur condensers, and catalytic stages. To provide realistic working circumstances, the input feed stream was set up to match the SWS unit's output composition. Important process components, including splitters, heat exchangers, and reactors were chosen and set up with care to mimic the behavior of the actual plant. The finished model offered useful insights into how operating factors affect sulfur recovery and enabled precise

process performance prediction. Below are screenshots of the stream findings and the generated process flow diagram (PFD), along with thorough descriptions of each simulation stage.

III.3.2. Using the sulfur recovery module integrated in Hysys V14

The chosen elements in this simulation stand in for the common chemical species found in sulfur recovery operations and the Claus process. H_2S, SO_2, H_2O, N_2, CH_4, and elemental sulfur (S) are the principal constituents. These elements were selected in accordance with the anticipated makeup of the acid gas supply that leaves the SWS unit. Modeling the chemical processes and phase dynamics that take place in the SRU requires precise component selection. Figure III.3 displays a list of every component utilized in the HYSYS simulation.

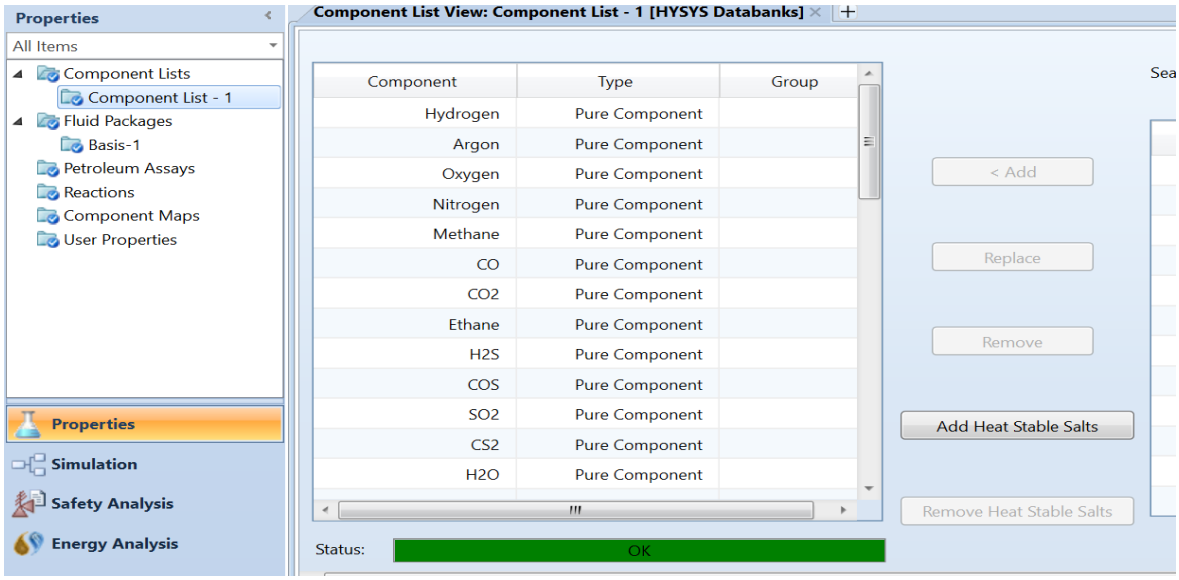


Figure III. 4. List of components used in the simulation.

III.3.2.1. Fluid packages

The Amine package was chosen as the Aspen HYSYS fluid property package for this simulation. This package is frequently used to model gas treatment and sulfur recovery operations, and it is appropriate for systems that involve acid gases like CO_2 and H_2S. The Amine package offers precise thermodynamic models that explain the solubility and phase behavior of acid gas constituents under various process circumstances. It is perfect for simulating the SRU since it also

allows response modeling, which is necessary for the Claus process. The chosen fluid package in the simulation is displayed in Figure III.5.

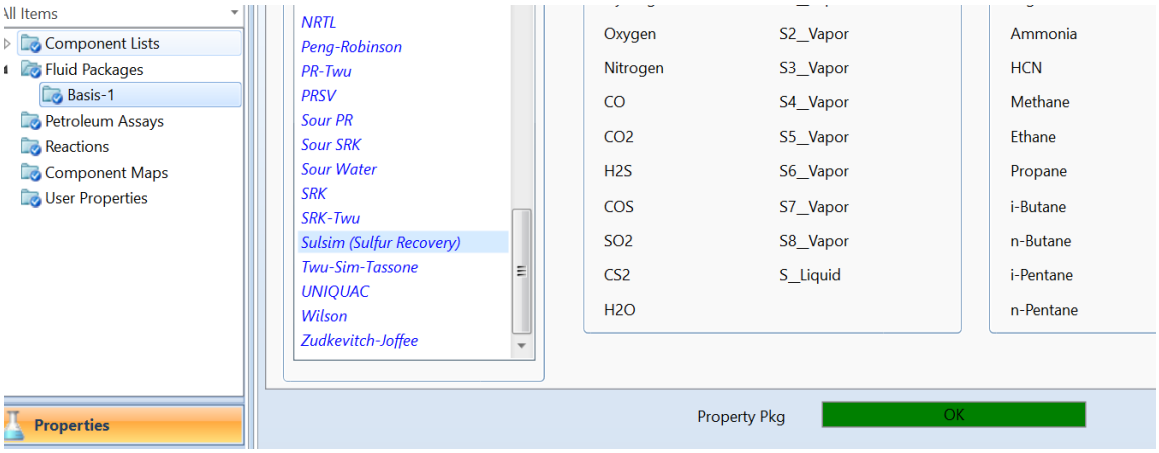


Figure III.6. Package of physical properties used in the simulation.

III.3.2.2. SRU Sub-Flowsheet initialization

The SRU sub-flowsheet was introduced to HYSYS following the selection of the fluid package and components. A setup window with the choices to start from scratch or utilize a template showed up. To manually construct the process in this instance, "Start with a Blank Flowsheet" was selected. The SRU initialization window in HYSYS is illustrated in Figure III.4.

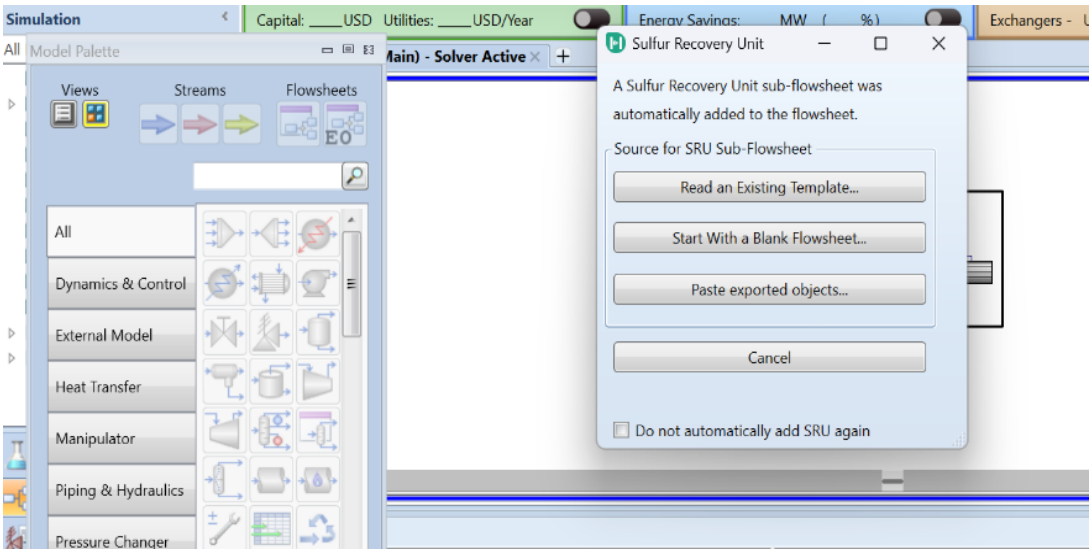


Figure III.7. SRU setup window in HYSYS.

III.3.2.3. Pre-treatment of acid gas and air in the SRU

The pre-treatment phase of the SRU process is depicted in Figure III.5, with particular attention paid to conditioning the air and acid gas streams before introducing them into the thermal reaction zone. This step improves process control and supports favorable reaction conditions downstream by humidifying the dry acid gas and dry air with steam in saturators (SAT-100 and SAT-101). After humidification, heat exchangers (E-100 and E-101) warm both streams to around 280°C for the acid gas and 350°C for the air. In order to start the partial combustion of hydrogen sulfide (H_2S) in the thermal reactor and maintain the ideal temperature and moisture content for effective sulfur recovery, thermal conditioning is necessary.

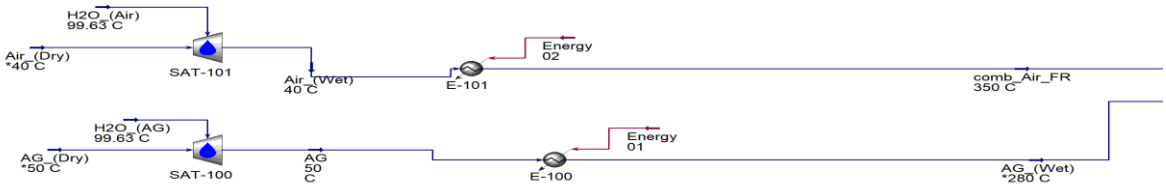


Figure III. 8. Pre-treatment and heating stage in the (SRU).

III.3.2.4. Thermal reaction section

A third of the H_2S is converted to SO_2 by the Claus thermal reaction, which takes place at high temperatures in the thermal reactor (FUR-100) once the warmed acid gas and combustion air enter. A waste heat exchanger (WHE-100) is then used to recover heat from the heated reaction gases. After cooling, the gases go via a sulfur condenser (COND-100), which condenses and extracts elemental sulfur (streams LS1 and LS2). The catalytic steps are reached by the residual gas. The thermal portion of the SRU process is depicted in Figure III.6.

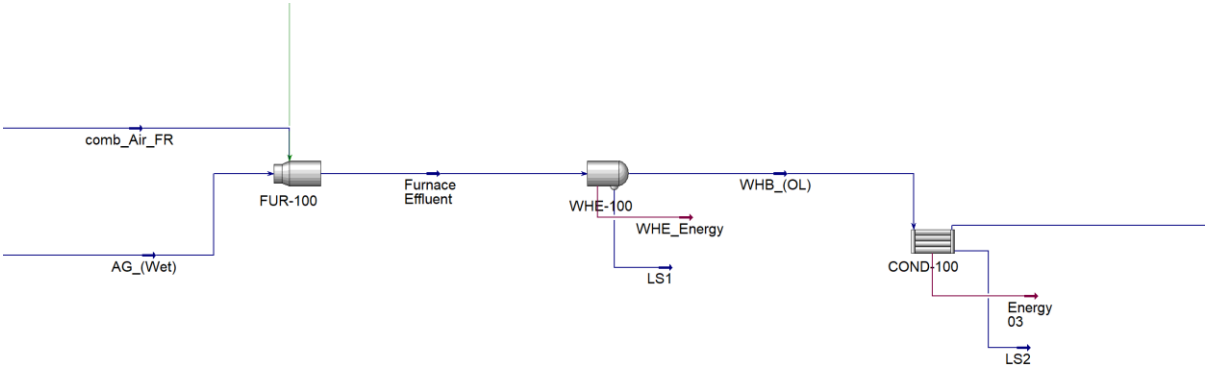


Figure III.9. Thermal reaction section of the SRU.

III.3.2.5. Catalytic reaction section

The catalytic portion of the SRU is shown in Figure III.7. Heat exchangers (E-102, E-103) are used to reheat the process gas at this step before it enters the catalytic converters (CONV-100, CONV-101), where elemental sulfur is created when hydrogen sulfide (H_2S) combines with SO_2. Condensers (COND-101, COND-102) are used to condense and separate the generated sulfur. At a temperature of around 130 °C, the residual gases escape as tail gas.

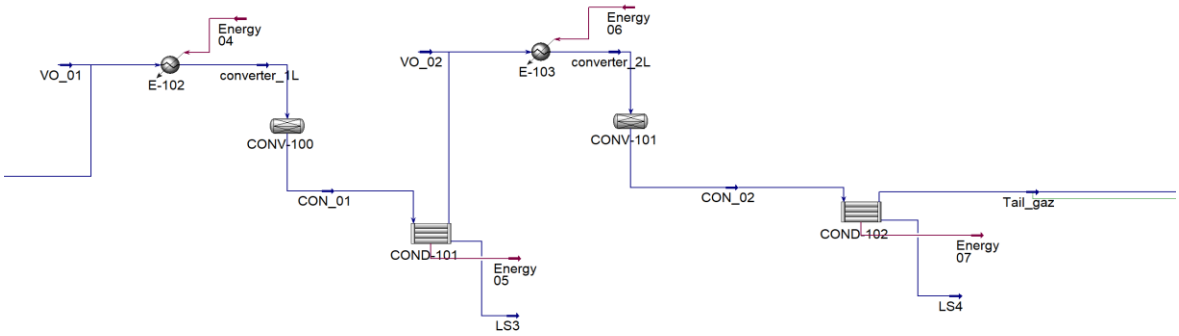


Figure III.10. Catalytic reaction section of the SRU.

III.3.2.6. Tail Gas Treatment Section

To reduce hazardous emissions, the residual tail gas is treated in the last step of the SRU process. At about 130 °C, the gas leaves the catalytic section and is sent to an incinerator (INC-100), where it is combined with fuel gas and humidified air to guarantee full combustion. This process aids in transforming any residual sulfur compounds into less dangerous ones. This process flow is shown in detail in Figure III.8.

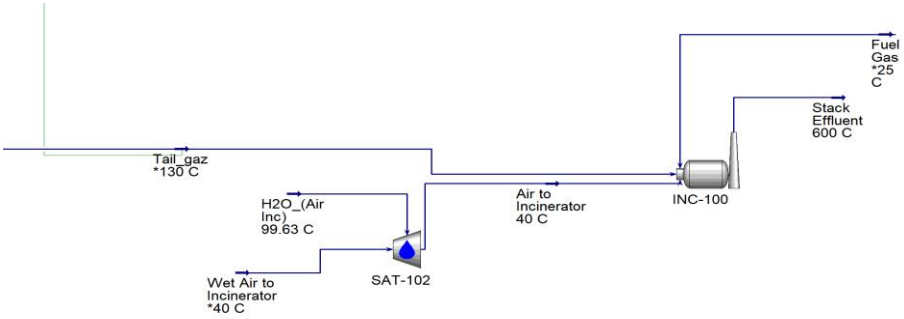


Figure III. 11. Tail gas treatment.

III.4. Input feed streams properties and operating conditions

The SRU performance and efficiency are largely determined by the input feed streams. Acid Gas (AG), which contains H_2S, and combustion air are the two main feed components. Both streams are conditioned to satisfy the necessary temperature and humidity requirements before entering the thermal reaction zone. The initial operating conditions and the input feeds' process flow as they enter the system are described in this section.

III.4.1. Pre-Startup Status

The process units are specified but not in use at the first stage (highlighted in yellow). The absence of flow data and energy exchange suggests that the system has not yet been activated. Stream conditions (temperature, composition) are not yet defined, and all lines are displayed as placeholders (Figure III.9).

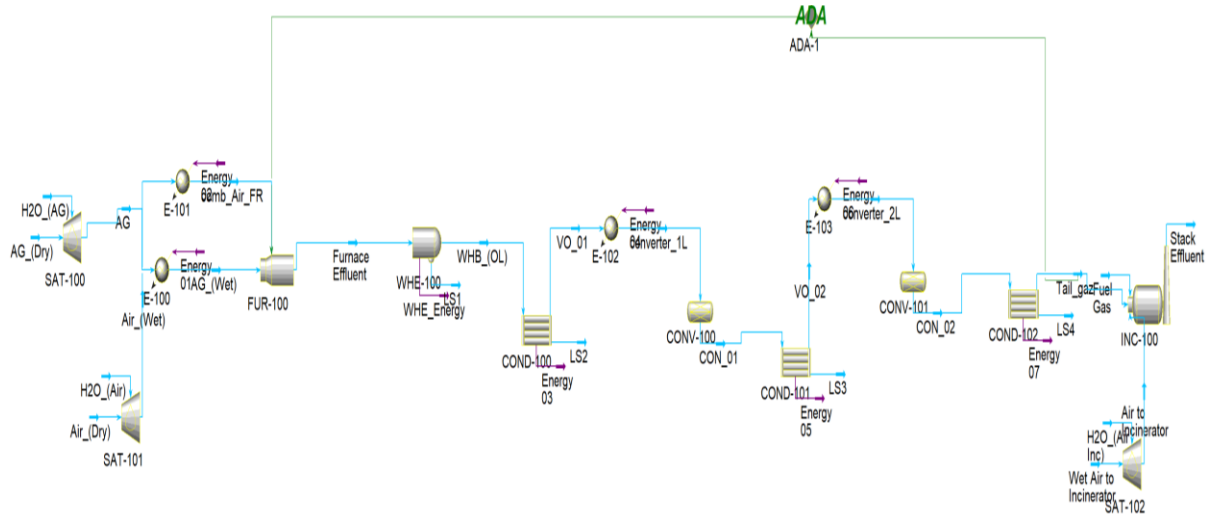


Figure III.12. Analysis of the process flow diagram.

III.4.2. Post-startup results

All streams become active, and the system starts to function efficiently when the simulation's operational settings are changed. This step symbolizes the unit's real starting phase. The Aspen Design Assistant (ADA) in HYSYS is a key tool used in this procedure. To ensure optimal gas treatment performance, the ADA tool helps track and analyze the distribution of amines throughout

the system. It is essential for preserving process stability and raising system efficiency as a whole. The system in use following variable adjustment and ADA activation is depicted in Figure III.10.

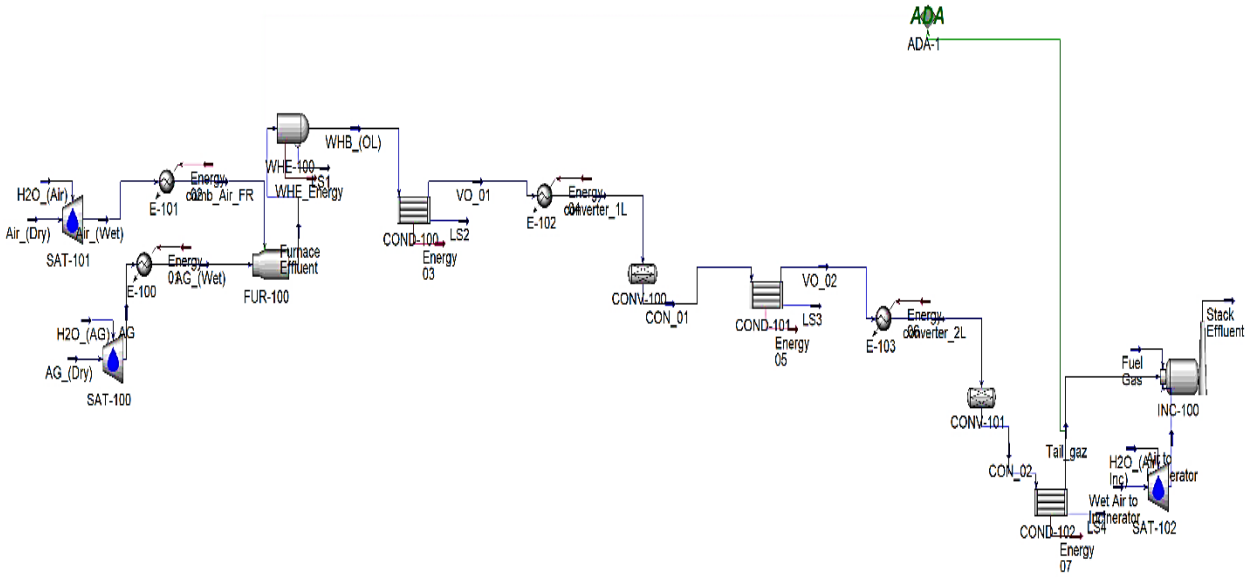


Figure III. 13. Simulation flow diagram after startup and ADA activation.

III.5. Conclusion

This study demonstrates the effectiveness of Aspen HYSYS in SRU, highlighting its intuitive interface, customizable modules, and specialized sulfur recovery features. A complete SRU model was developed, including detailed process flows and dynamic operating conditions. The integration of the Aspen Design Assistant (ADA) notably enhanced model optimization by detecting inconsistencies and guiding convergence, improving both speed and accuracy. These findings affirm HYSYS's strength in simulating real-world chemical processes with precision and efficiency, making it a vital tool in modern process engineering.

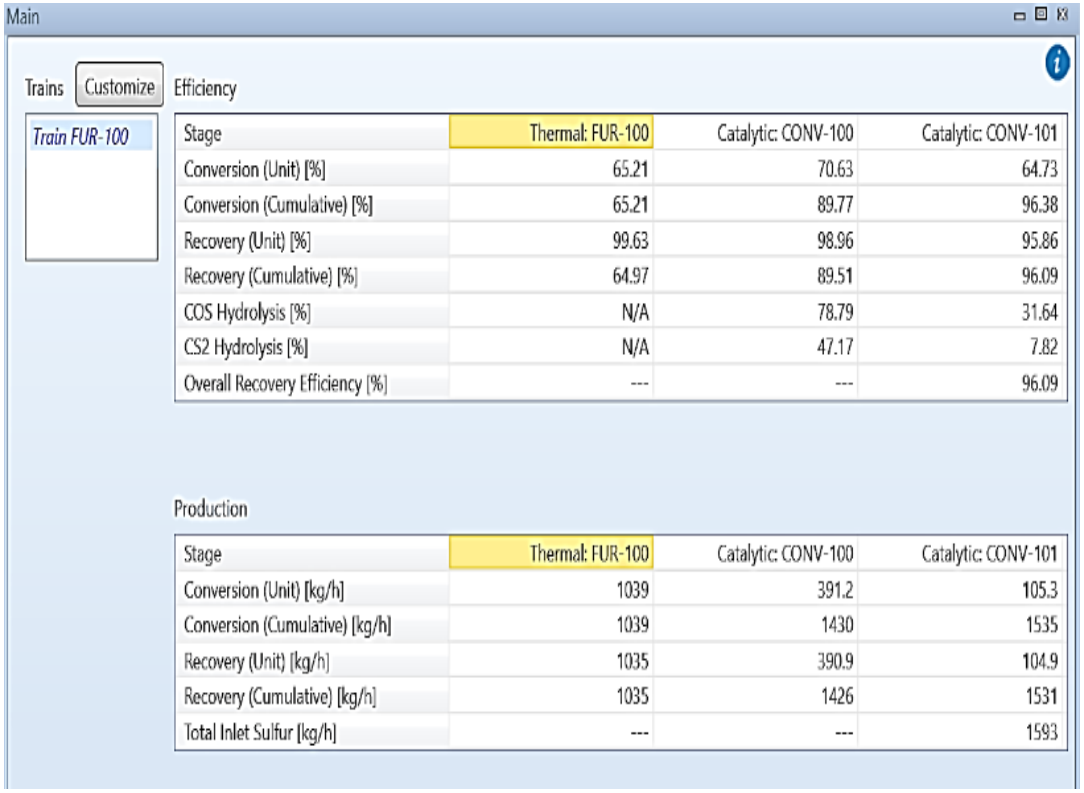
Chapter IV: Results and discussions

IV.1. Introduction

In this chapter, we present the results obtained from the simulation of the H_2S recovery unit, carried out using the Aspen HYSYS software. The unit studied is a predefined model available in the software library, on which we made some modifications, notably by adding or removing certain components. Subsequently, an optimization study was conducted to maximize the amount of sulfur removed from the fluid effluents. This optimization was based on the analysis of several physical parameters, such as temperature, molar flow rate, heat exchanger efficiency, and air-to-acid gas ration.

IV.2. Baseline performance of the sulfur recovery unit

Before conducting the parametric analysis, the SRU was simulated under standard operating conditions to establish a performance baseline. The Performance Summary tool in Aspen HYSYS was utilized to generate a detailed overview of the unit's efficiency and production metrics. The obtained results are summurized in Figure IV.1.



Stage	Thermal: FUR-100	Catalytic: CONV-100	Catalytic: CONV-101
Conversion (Unit) [%]	65.21	70.63	64.73
Conversion (Cumulative) [%]	65.21	89.77	96.38
Recovery (Unit) [%]	99.63	98.96	95.86
Recovery (Cumulative) [%]	64.97	89.51	96.09
COS Hydrolysis [%]	N/A	78.79	31.64
CS2 Hydrolysis [%]	N/A	47.17	7.82
Overall Recovery Efficiency [%]	---	---	96.09

Stage	Thermal: FUR-100	Catalytic: CONV-100	Catalytic: CONV-101
Conversion (Unit) [kg/h]	1039	391.2	105.3
Conversion (Cumulative) [kg/h]	1039	1430	1535
Recovery (Unit) [kg/h]	1035	390.9	104.9
Recovery (Cumulative) [kg/h]	1035	1426	1531
Total Inlet Sulfur [kg/h]	---	---	1593

Figure IV.1. Performance summary from Aspen HYSYS.

As illustrated in Figure IV.1, the overall sulfur recovery efficiency reached **96.09%,** with individual recovery efficiencies of **99.63%, 98.96%,** and **96.09%** for the thermal stage (FUR-100) and the two catalytic stages (CONV-100 and CONV-101), respectively. The cumulative

recovery also followed a consistent improvement through the process, indicating good performance of both thermal and catalytic sections. In terms of production, the total inlet sulfur was measured at **1593 kg/h**, with a final cumulative recovery of **1531 kg/h**. The thermal stage showed the highest single-stage recovery (**1035 kg/h**), highlighting its central role in the Claus reaction. These values serve as the reference case against which the impact of varying key parameters such as reaction temperature, air-to-acid gas ratio (Air/acid gas), feed composition, and heat exchanger efficiency will be evaluated in the upcoming case studies.

IV.3. Factor effects on the performances of SRU

This section explores how key operating parameters affect the performance of the SRU. By varying factors such as reaction temperature, air-to-acid gas ratio, H_2S concentration in the feed, and heat exchanger efficiency, the study evaluates their impact on Claus process efficiency and sulfur recovery. Each parameter was analysed independently to assess process sensitivity and identify optimization opportunities.

IV.3.1. Case study 1: Effect of inlet temperature on key SRU performance indicators

In the first case study, the focus was on evaluating how the temperature of the AG-(Dry) stream, representing the dry acid gas feed, affects various performance indicators within the SRU. The temperature was selected as the independent variable, and it was systematically varied in the simulation to observe its influence on several critical dependent variables (Figure IV.2).

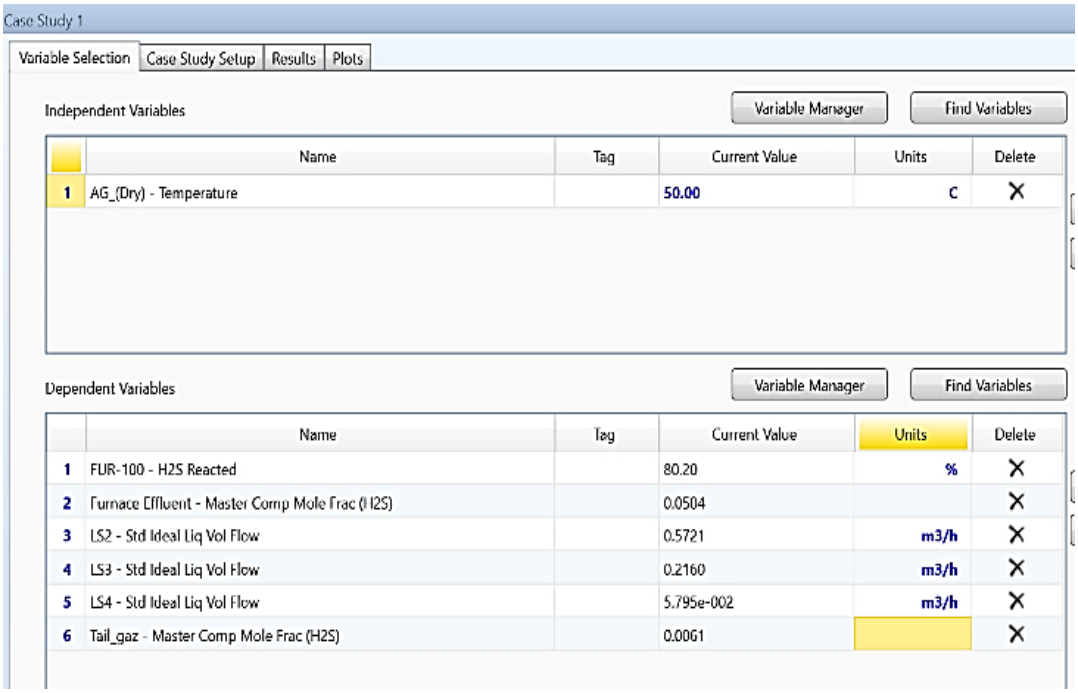


Figure IV.2. HYSYS setup case study one.

These variables were monitored using the case study tool in Aspen HYSYS, with output values recorded at different temperature set-points of the AG-(Dry) stream. This methodology enables the identification of the most favorable operating temperature range that maximizes sulfur recovery while minimizing H_2S slip and emissions.

The data in Table IV.1, and corresponding charts of Figure IV.3, illustrate the effects of varying the AG-(Dry) inlet temperature from 30 °C to 60 °C on several key output parameters in the SRU unit. These parameters include the mole fraction of H_2S in the Furnace effluent, the sulfur flow rates in LS_2, LS_3, and LS_4 streams, and the remaining H_2S content in the Tail gas. The x-axis represents the AG-(Dry) inlet temperature, while the y-axis shows the response of each dependent variable to this temperature variation.

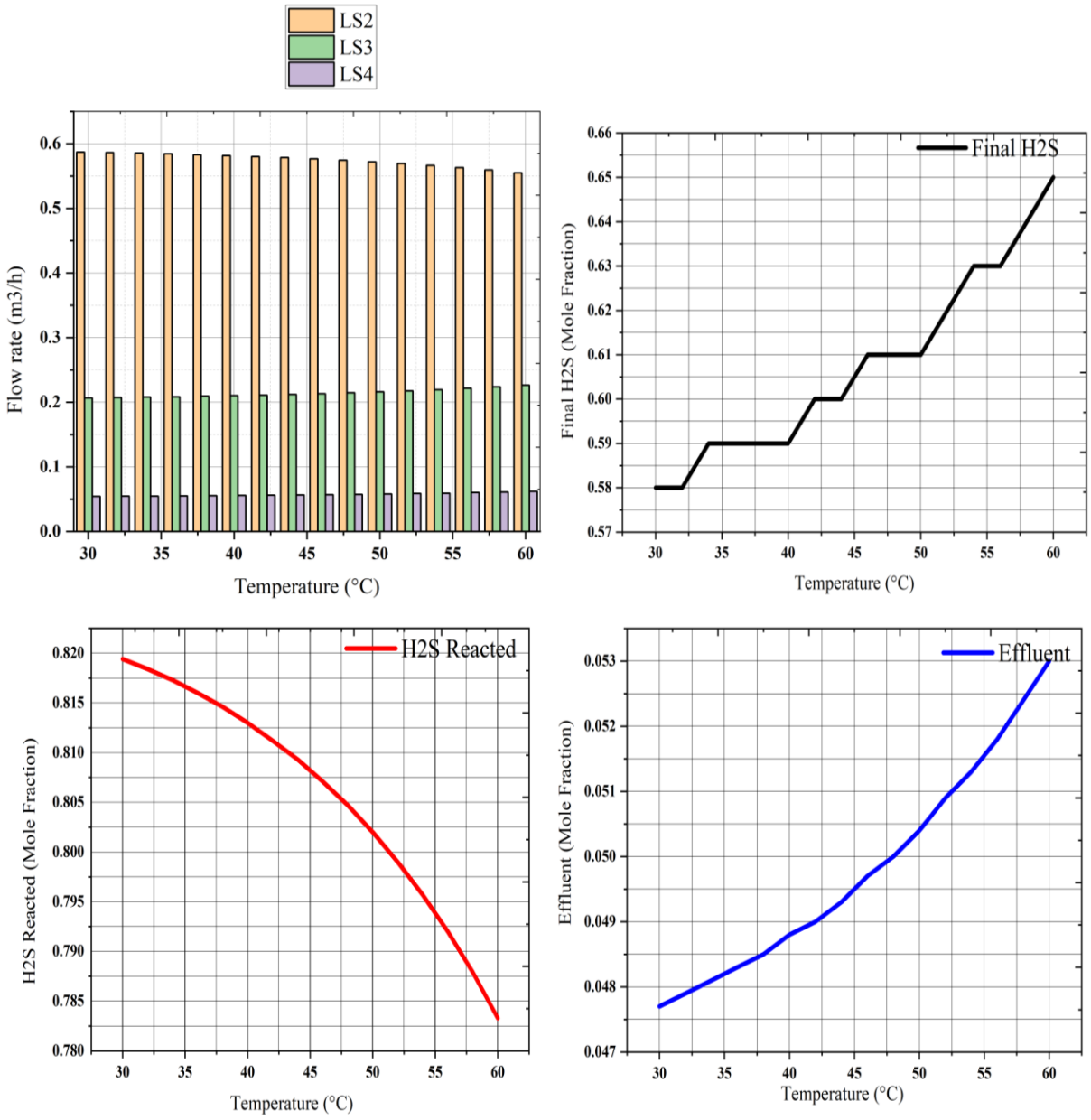


Figure IV.3. Effect of Inlet Temperature of AG (Dry) Steam.

Table IV.1 provides the exact numerical values for each case to support the graphical trends, documenting the temperature change and its direct effect on the dependent variables.

From this Table, we observe that as AG-(Dry) temperature increases:

- The H_2S mole fraction in the Furnace effluent rises steadily from 0.0477 at 30 °C to 0.053 at 60 °C
- The liquid sulfur flow rates also show an increase, with LS_3 rising from 0.2067 m³/h to 0.2264 m³/h, and LS_4 from 0.05441 m³/h to 0.06187 m³/h, suggesting improved sulfur formation
- The Tail gas H_2S slightly increases from 0.0058 to 0.0065, which might reflect a limitation in complete conversion at higher temperatures.

This simple numerical breakdown confirms the trend seen in Figure IV.3 and provides a clear quantitative understanding of how temperature influences process efficiency in the SRU.

Table IV.1. Summary of case study 1

	Thermal stage			Catalytic stage		
Temperature (°C)	H2S Reacted (%)	Effluent (%)	LS2 (m^3/h)	LS3 (m^3/h)	LS4 (m^3/h)	Final H2S (%)
30	**0.8194**	**0.0477**	**0.5872**	**0.2067**	**0.05441**	**0.58**
32	0.8184	0.0479	0.5863	0.2073	0.05462	0.58
34	0.8173	0.0481	0.5854	0.2079	0.05485	0.59
36	0.816	0.0483	0.5843	0.2085	0.05511	0.59
38	0.8146	0.0485	0.583	0.2093	0.05539	0.59
40	0.813	0.0488	0.5817	0.2101	0.05571	0.59
42	0.8112	0.049	0.5802	0.2111	0.05607	0.6
44	0.8093	0.0493	0.5785	0.2121	0.05646	0.6
46	0.8071	0.0497	0.5766	0.2133	0.0569	0.61
48	0.8047	0.05	0.5744	0.2146	0.0574	0.61
50	0.802	0.0504	0.5721	0.216	0.05795	0.61
52	0.799	0.0509	0.5694	0.2176	0.05856	0.62
54	0.7957	0.0513	0.5665	0.2195	0.05925	0.63
56	0.792	0.0518	0.5631	0.2215	0.06002	0.63
58	0.7879	0.0524	0.5594	0.2238	0.06089	0.64
60	**0.7833**	**0.053**	**0.5551**	**0.2264**	**0.06187**	**0.65**

IV.3.2. Case Study 2: Effect of inlet temperature on key SRU performance indicators

In this case, the impact of the wet acid gas (AG-Wet) inlet temperature on the performance of the SRU was analysed using the case studies tool in Aspen HYSYS. The AG-(Wet) temperature was defined as the independent variable, and several critical output parameters were monitored as dependent variables.

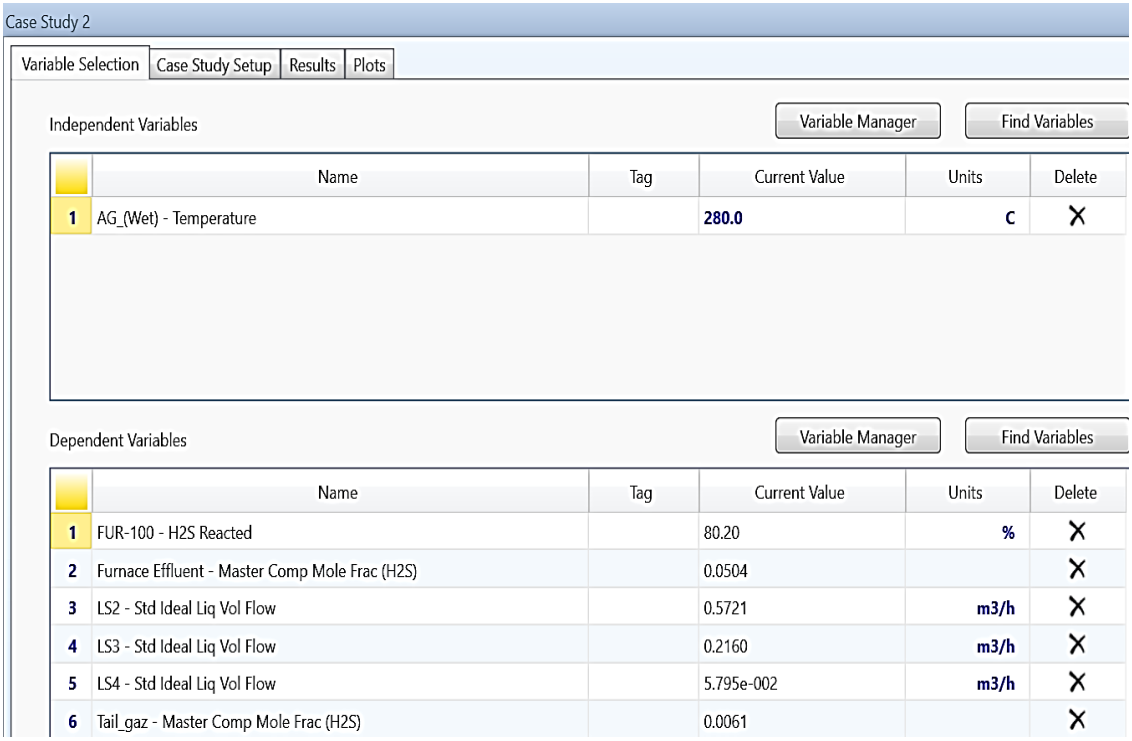


Figure IV. 4. HYSYS setup case study 2

The graphs presented in Figure IV.5 illustrate the impact of varying the AG-(Wet) inlet temperature from 240 °C to 320 °C on several performance indicators within the SRU. These include the H_2S mole fraction in the Furnace effluent and Tail gas, as well as sulfur flow rates in LS_2, LS_3, and LS_4. The horizontal axis represents the AG-(Wet) temperatures for each case, while the vertical axis reflects the resulting values of the selected output variables.

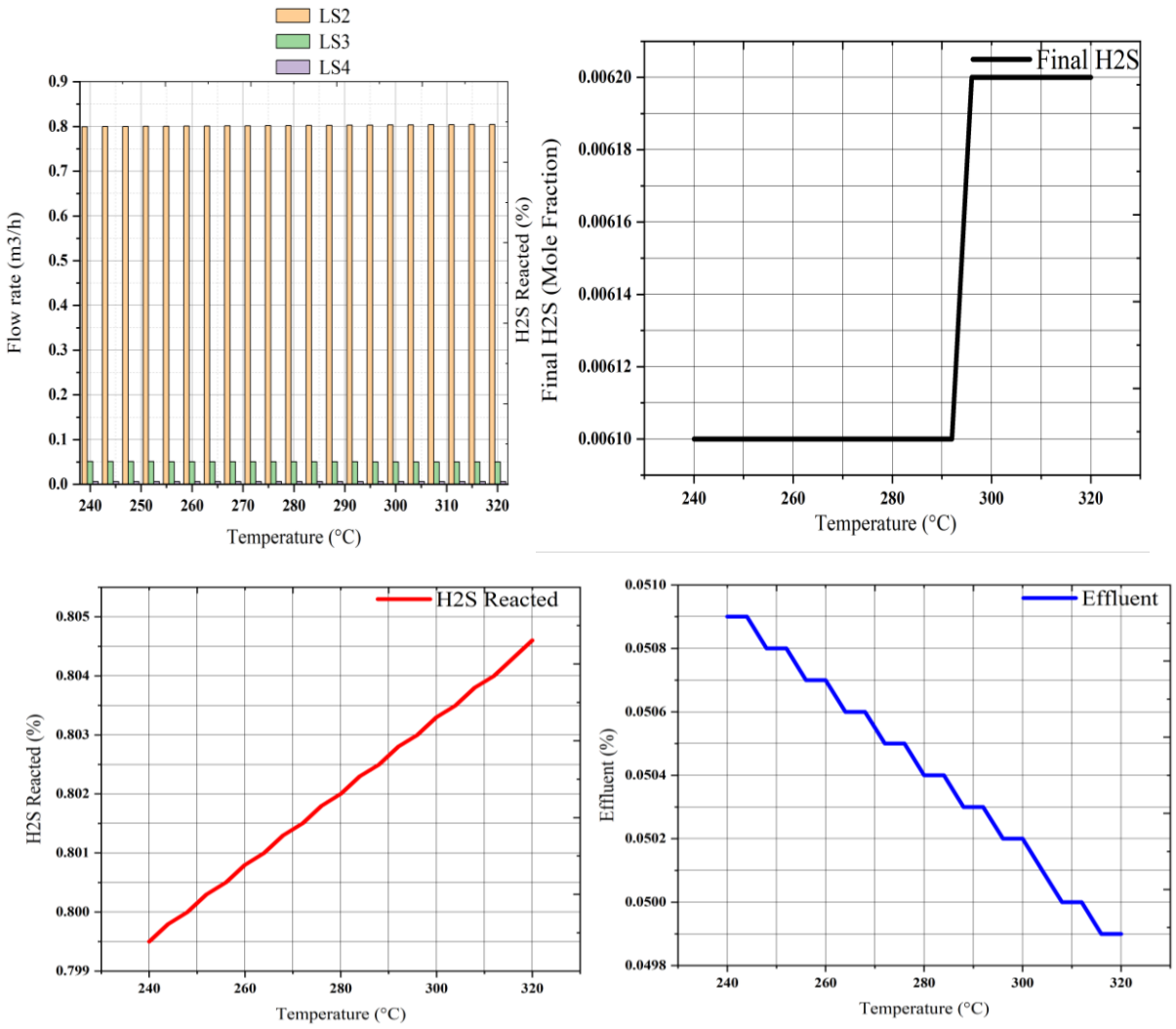


Figure IV.5. Effect of inlet temperature of AG (Wet) stream.

From Figure IV.5, it was observed that all dependent variables exhibit slight and stable trends, with a relatively small variation across the tested temperature range, indicating the system's resistance to major fluctuations in this specific operating window.

Table IV.2 presents the detailed numerical results for each case. It shows that as AG-(Wet) temperature increases from 240 °C to 320 °C.

Table IV.2. Summary of case study (2)

	Thermal stage			Catalytic stage		
Temperature (°C)	H2S Reacted (%)	Effluent (%)	LS2 (m^3/h)	LS3 (m^3/h)	LS4 (m^3/h)	Final H2S (%)
240	**0.7995**	**0.0509**	**0.5723**	**0.2162**	**0.05768**	**0.0061**
244	0.7998	0.0509	0.5723	0.2162	0.0577	0.0061
248	0.8	0.0508	0.5723	0.2162	0.05773	0.0061
252	0.8003	0.0508	0.5723	0.2162	0.05775	0.0061
256	0.8005	0.0507	0.5722	0.2161	0.05778	0.0061
260	0.8008	0.0507	0.5722	0.2161	0.0578	0.0061
264	0.801	0.0506	0.5722	0.2161	0.05783	0.0061
268	0.8013	0.0506	0.5722	0.2161	0.05786	0.0061
272	0.8015	0.0505	0.5721	0.2161	0.05789	0.0061
276	0.8018	0.0505	0.5721	0.216	0.05792	0.0061
280	0.802	0.0504	0.5721	0.216	0.05795	0.0061
284	0.8023	0.0504	0.572	0.216	0.05797	0.0061
288	0.8025	0.0503	0.572	0.216	0.058	0.0061
292	0.8028	0.0503	0.572	0.216	0.05804	0.0061
296	0.803	0.0502	0.5719	0.216	0.05807	0.0062
300	0.8033	0.0502	0.5719	0.216	0.0581	0.0062
304	0.8035	0.0501	0.5719	0.216	0.05813	0.0062
308	0.8038	0.05	0.5718	0.2159	0.05816	0.0062
312	0.804	0.05	0.5718	0.2159	0.0582	0.0062
316	0.8043	0.0499	0.5717	0.2159	0.05823	0.0062
320	**0.8046**	**0.0499**	**0.5717**	**0.2159**	**0.05826**	**0.0062**

- The Furnace effluent H_2S mole fraction changes slightly between 0.0499 and 0.0509.
- The LS2 sulfur stream fluctuates within a narrow range, peaking at 0.5732 m^3/h.
- LS3 and LS4 flow rates also show gradual variations, suggesting a mild sensitivity to inlet temperature.
- The Tail gas H_2S content remains relatively constant, with a small increase from 0.0061 to 0.0064, which may indicate limited additional H2S slippage at higher temperatures.

These results confirm that the AG-(Wet) temperature has limited but measurable influence on the sulfur recovery performance, which can be useful for fine-tuning the operating conditions.

IV.3.3. Case study 3: Effect of inlet flow molar on key SRU performance indicators

This case study investigates the effect of varying the molar flow rate of combustion air (Comb-Air-FR) entering the SRU system, ranging from 108 to 109 kmol/h. The HYSYS setup highlights the selected independent variable (Comb-Air-FR) as well as the dependent variables representing key SRU performance indicators such as Furnace Effluent, LS2, LS3, and Tail Gas. The simulation aims to evaluate how small variations in air feed impact sulfur recovery efficiency and gas composition.

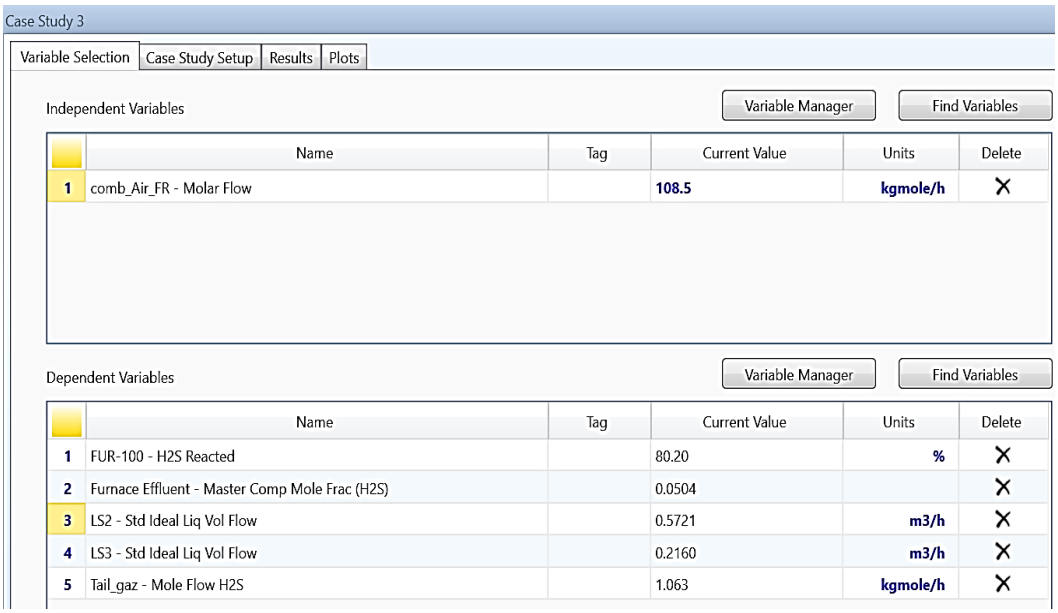


Figure IV.6. HYSYS setup case study 3

The graphs illustrated in Figure IV.7 show what happens when the combustion airflow (Comb_Air_FR) increases slightly from 108 to 109 kmol/h. Most values like LS2, LS3, and Furnace effluent stay almost the same, which means the unit is stable. However, the Tail gas value goes down a little, which is a good sign because it means less H_2S is leaving the unit. So, even a small increase in air flow helps make the process work a bit better.

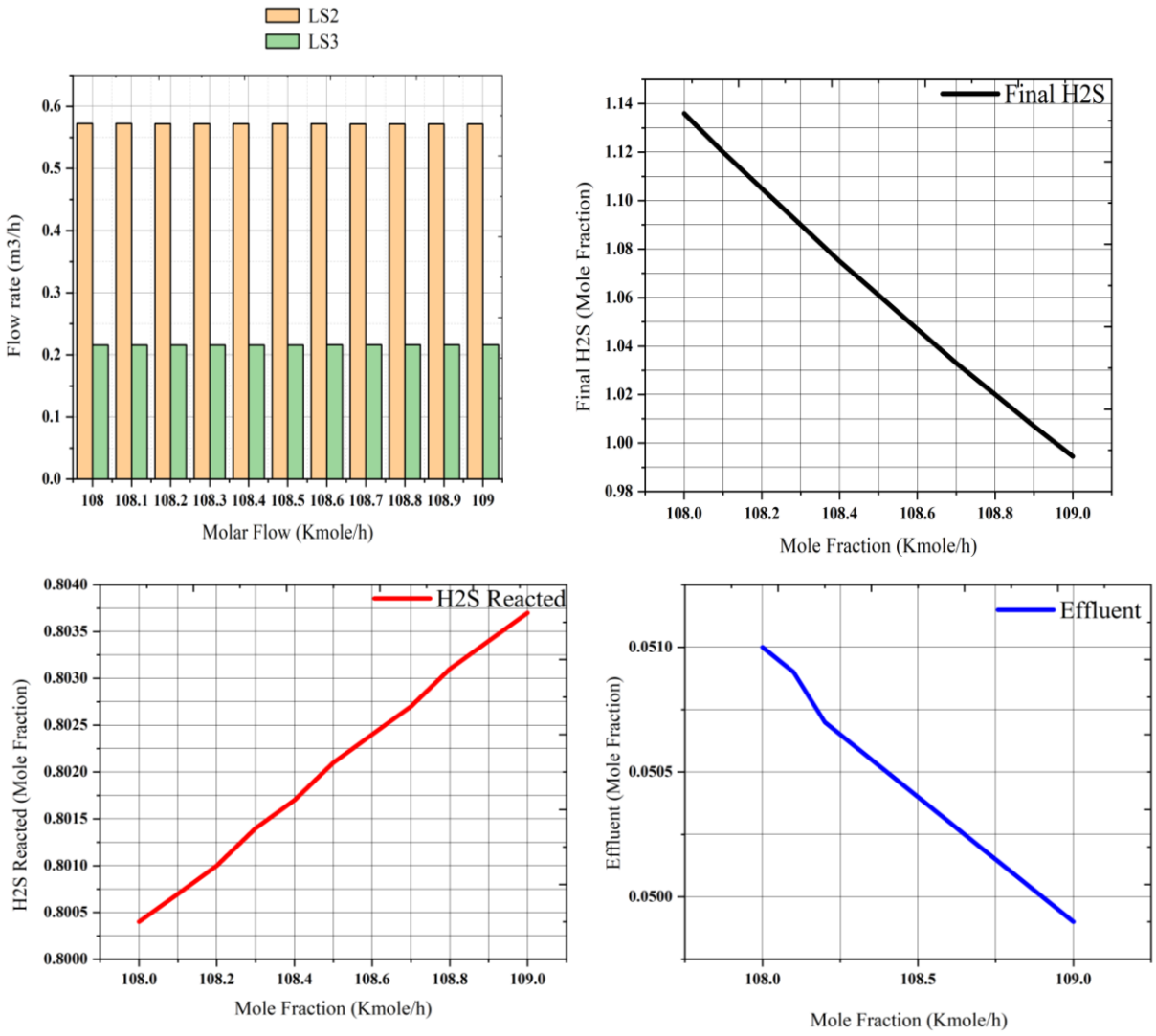


Figure IV.7. Effect of Inlet Molar Flow of Comb Air Steam.

Overall, the data in the table matches the graph results. The unit remains stable, but a small increase in air flow slightly improves performance.

Table IV.3. Summary of Case Study (3)

	Thermal stag			Catalytic stag	
Molar Flow (Kmole/h)	H2S Reacted (%)	Effluent (%)	LS2 (m^3/h)	LS3 (m^3/h)	Final H2S (%)
108	**0.8004**	**0.051**	**0.5724**	**0.2159**	**1.136**
108.1	0.8007	0.0509	0.5723	0.2159	1.12
108.2	0.801	0.0507	0.5722	0.2159	1.105
108.3	0.8014	0.0506	0.5722	0.216	1.09
108.4	0.8017	0.0505	0.5721	0.216	1.075
108.5	0.8021	0.0504	0.5721	0.216	1.061
108.6	0.8024	0.0503	0.572	0.2161	1.047
108.7	0.8027	0.0502	0.5719	0.2161	1.033
108.8	0.8031	0.0501	0.5719	0.2161	1.02
108.9	0.8034	0.05	0.5718	0.2161	1.007
109	**0.8037**	**0.0499**	**0.5718**	**0.2162**	**0.9945**

From the results obtained, we can conclude that:

- The Furnace effluent values are very close (from 0.051 to 0.0499), showing that the change in air flow has a very small effect on this stream
- The LS2 and LS3 values are nearly fixed (around 0.572 and 0.216), which confirms that sulfur production remains steady
- The Tail gas shows a small decrease (from 1.136 to 0.9945), which means a slight improvement in removing H_2S from the system.

IV.3.4. Case Study 4: Effect of inlet temperature on key SRU Performance indicators

The following case study investigates the effect of the inlet temperature to Converter-1L on the performance of the SRU. The temperature of Converter-1L was varied across a range of 200 °C to 260 °C in order to observe its impact on three critical indicators:

- LS_3: Std ideal liquid volume flow
- LS_4: Std ideal liquid volume flow
- Tail Gas : Master Composition mole fraction (H_2S)

Figure IV.8 presents the HYSYS configuration used to perform this analysis.

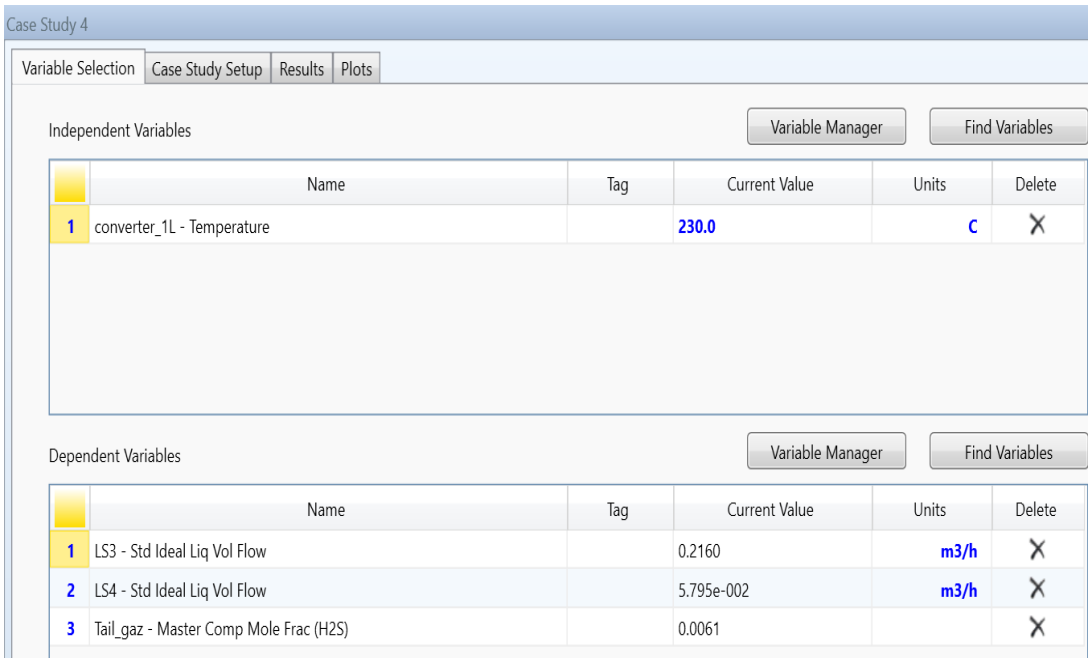


Figure IV.8. HYSYS setup case study 4

The plots illustrated in Figure IV.9 show the variation in LS3, LS4, and Tail gas values as a function of the Converter-1L inlet temperature.

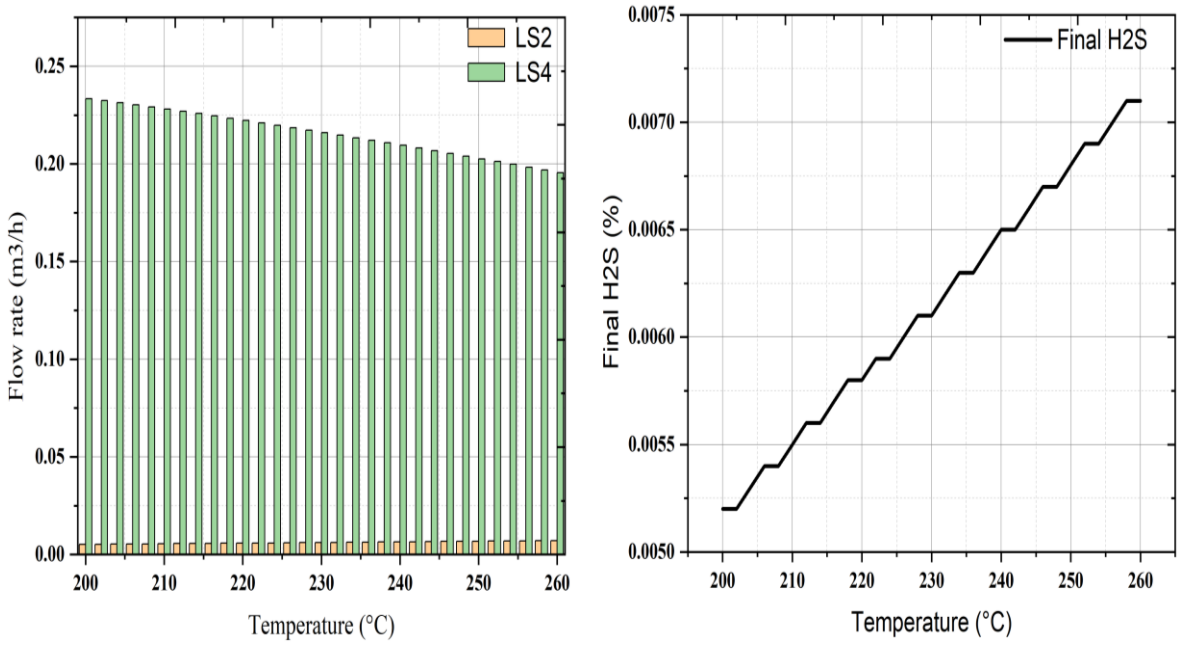


Figure IV. 9. Effect of Inlet Temperature of Converter (L_1) Stream

Key observations from these graphs are as follows:

- LS3: Exhibits a decreasing trend as the inlet temperature increases. This suggests a decline in the liquid sulfur output at the third stage of condensation.
- LS4: Shows a steady increase with temperature, indicating improved sulfur condensation in the fourth stage as higher temperatures favor the conversion reactions.
- Tail Gas (H_2S): Experiences a slight but consistent increase, which could imply incomplete conversion efficiency at higher temperatures.

The tabulated data (Table IV.4) clearly show that the inlet temperature to Converter-1L has a notable effect on SRU performance. As the temperature increased from 200 °C to 260 °C, the liquid sulfur flow from the third condenser (LS3) decreased from 0.2334 to 0.1955 m^3/h, indicating a reduction in sulfur condensation at this stage. On the other hand, the liquid sulfur flow from the fourth condenser (LS_4) increased significantly from 0.04118 to 0.0764 m^3/h, suggesting that higher temperatures enhance conversion efficiency in the later stage. Additionally, the mole fraction of H_2S in the tail gas rose slightly from 0.0052 to 0.0071, which may indicate a small decline in overall sulfur recovery at elevated temperatures.

Table IV.4. Summary of case study 4

	Thermal stage	Catalytic stage	
Temperature (°C)	LS2 (m^3/h)	LS4 (m^3/h)	Final H_2S (%)
200	0.2334	0.04118	0.0052
202	0.2324	0.04223	0.0052
204	0.2313	0.0433	0.0053
206	0.2302	0.04437	0.0054
208	0.2291	0.04545	0.0054
210	0.228	0.04655	0.0055
212	0.2269	0.04765	0.0056
214	0.2258	0.04876	0.0056
216	0.2246	0.04988	0.0057
218	0.2234	0.051	0.0058
220	0.2222	0.05214	0.0058
222	0.221	0.05329	0.0059
224	0.2198	0.05444	0.0059
226	0.2185	0.0556	0.006
228	0.2173	0.05677	0.0061
230	0.216	0.05795	0.0061

232	0.2147	0.05913	0.0062
234	0.2134	0.06032	0.0063
236	0.2121	0.06152	0.0063
238	0.2108	0.06272	0.0064
240	0.2095	0.06394	0.0065
242	0.2081	0.06516	0.0065
244	0.2068	0.06638	0.0066
246	0.2054	0.06761	0.0067
248	0.204	0.06885	0.0067
250	0.2026	0.07009	0.0068
252	0.2012	0.07134	0.0069
254	0.1998	0.0726	0.0069
256	0.1983	0.07386	0.007
258	0.1969	0.07512	0.0071
260	0.1955	0.0764	0.0071

IV.2.5. Case study 5: Effect of inlet temperature on key SRU performance indicators

In this case, the effect of the inlet temperature to the second catalytic converter (Converter_2L) was investigated to assess its impact on two critical performance parameters in the Sulfur Recovery Unit (SRU): the liquid sulfur flow rate at LS4 and the concentration of H_2S in the tail gas. The converter's role in completing the Claus reaction through catalytic conversion makes its inlet temperature a sensitive and influential operating variable. The study aims to determine how temperature adjustments can enhance sulfur recovery efficiency and minimize residual H_2S emissions. The HYSYS configuration used to perform this analysis is presented in Figure IV.10.

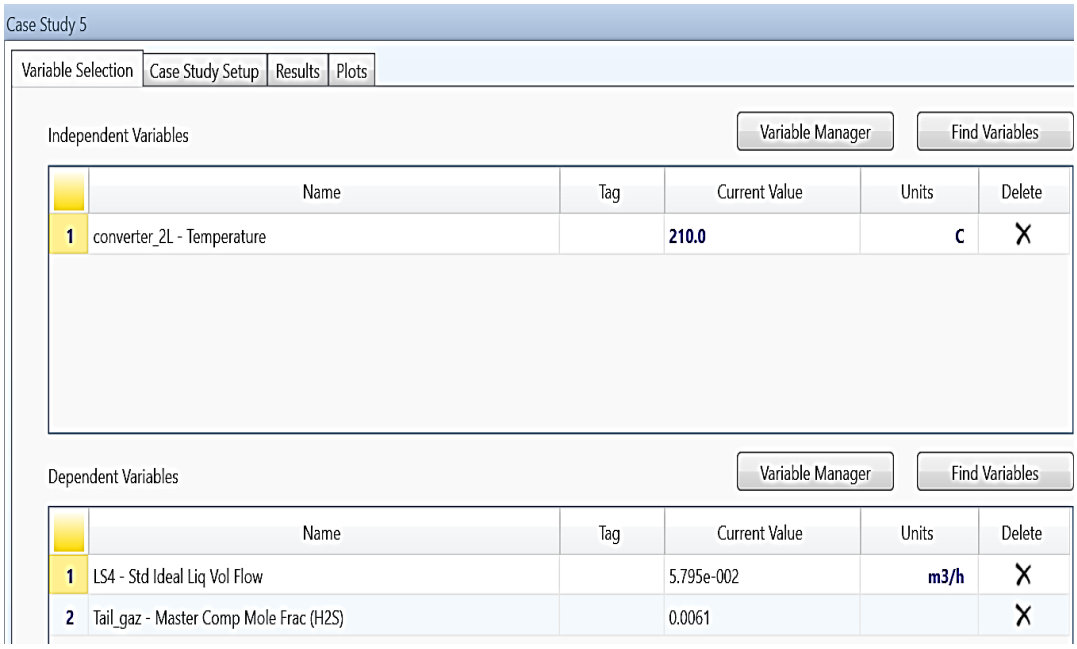


Figure IV.10. HYSYS setup case study 5

The graphical outputs shown in Figure IV.11 demonstrate the impact of the increasing of the inlet temperature from 180 °C to 240 °C on both LS4 and the tail gas H_2S fraction.

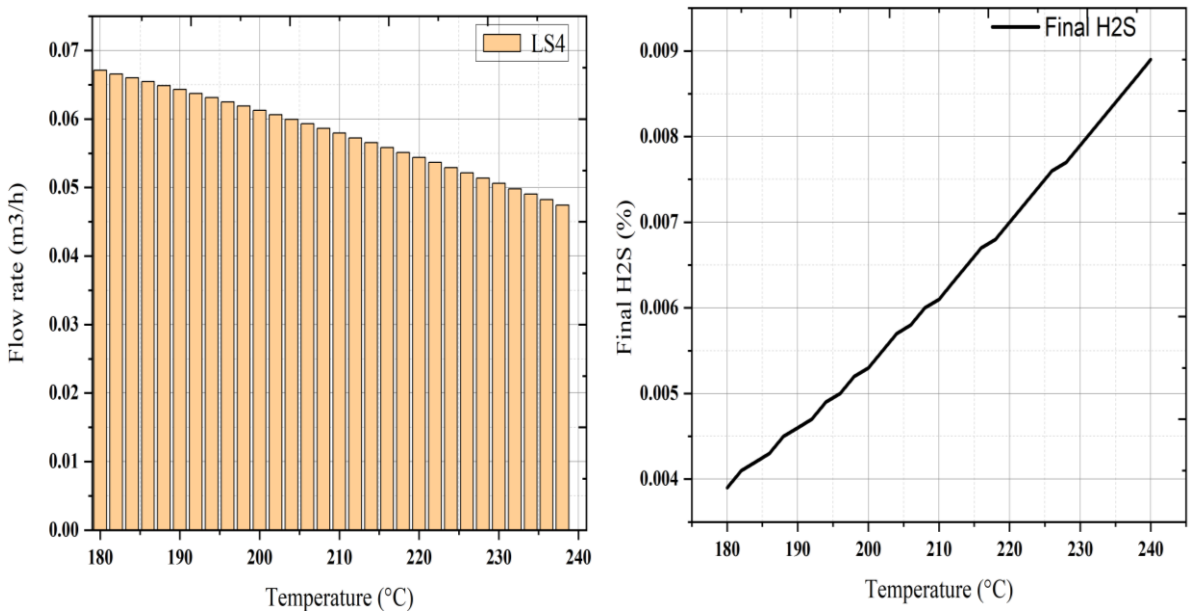


Figure IV. 11. Effect of Inlet Temperature of Converter (L2) Stream

From the chart, it is observed that as the inlet temperature increases:

- The flow of liquid sulfur at LS_4 decreases continuously, suggesting reduced sulfur production efficiency at elevated temperatures.
- Conversely, the mole fraction of H_2S in the tail gas increases, indicating less complete conversion of H_2S to elemental sulfur at higher temperatures.

This inverse relationship highlights the importance of optimizing the inlet temperature to maximize sulfur recovery while minimizing emissions. Table IV.5 summarizes the numerical results for each temperature interval tested during the simulation.

Table IV.5. Summary of case study 5

	Catalytic stage	
Temperature (°C)	LS4 (m^3/h)	Final H_2S (%)
180	**0.0671**	**0.0039**
182	0.06656	0.0041
184	0.06601	0.0042
186	0.06546	0.0043
188	0.06489	0.0045
190	0.06431	0.0046
192	0.06372	0.0047

194	0.06312	0.0049
196	0.0625	0.005
198	0.06188	0.0052
200	0.06125	0.0053
202	0.06061	0.0055
204	0.05996	0.0057
206	0.0593	0.0058
208	0.05863	0.006
210	0.05795	0.0061
212	0.05725	0.0063
214	0.05655	0.0065
216	0.05584	0.0067
218	0.05512	0.0068
220	0.05439	0.007
222	0.05366	0.0072
224	0.05291	0.0074
226	0.05215	0.0076
228	0.05138	0.0077
230	0.05061	0.0079
232	0.04982	0.0081
234	0.04903	0.0083
236	0.04823	0.0085
238	0.04742	0.0087
240	**0**	**0.0089**

Also, it was observed from Table IV.5 that LS_4 decreased from 0.0671 m^3/h at 180°C to zero at 240°C, while the H_2S content nearly doubled over the same range. This indicates that operating the converter at excessively high inlet temperatures may be detrimental to the overall sulfur recovery process.

With an emphasis on the design, modelling, and performance analysis of the Sulfur Recovery Unit (SRU) using Aspen HYSYS, this study has offered a comprehensive and in-depth investigation of the sulfur recovery process in petroleum refineries. In Chapter One, the research began with an examination of the properties of crude oil and focused on the crucial role that sulfur compounds play in the environment and in processing. Although these substances are naturally found in crude oil, they must be effectively eliminated to meet environmental regulations and guarantee the durability and safety of refinery machinery. The SRC, which consists of the core SRU, the ARU, the SWS, and the TGTU, was described in Chapter Two along with its composition and operations. As the central component of the complex, the SRU is in charge of using the Claus process to transform H_2S into elemental sulfur. The efficiency of the unit has a direct impact on the refinery's overall sulfur handling capacity and environmental performance.

The modelling process in Aspen HYSYS was described in Chapter III, which also demonstrated how each unit operation was connected, represented, and calibrated to match performance in the actual world. Performance summaries that assessed important parameters including sulfur production output and recovery efficiency were used to verify the simulated SRU model. Using HYSYS's Case Studies tool, in-depth case studies were carried out in Chapter IV to investigate the ways in which different operational characteristics impact the SRU's overall effectiveness. Reaction temperature was the main factor examined for both dry and wet acid gas streams. The investigations concentrated on the effects of these temperatures on important streams, including tail gas emissions, sulfur condensers, and furnace effluents. Trends using simulation data showed that even small changes in input conditions might significantly influence sulfur conversion rates and emissions. A quantifiable improvement in recovery efficiency and emission control Can be Achieved by Optimizing Certain parameters, according to the examination of graphical and numerical findings.

Additionally, the methodical approach taken to examine every variable offers a trustworthy foundation for engineers and operators to improve SRU performance in practical situations. This study underscores the importance of integrating advanced simulation tools like Aspen HYSYS with thorough theoretical understanding to enhance operational efficiency. Moreover, the findings contribute significantly towards sustainable refining practices by aiding in the reduction of sulfur emissions and promoting environmental compliance.

Future work is recommended to explore catalyst regeneration techniques, alternative reactor configurations, and the incorporation of real-time monitoring and control systems to further optimize SRU performance. While this study provides a solid foundation, continued research is necessary to address evolving industrial challenges and to adapt to stricter environmental regulations.

In conclusion, this research serves as both a practical guide for refinery engineers aiming to maximize sulfur recovery while adhering to environmental standards and an academic reference advancing the field of environmental engineering and petroleum processing.

Recommendations

1.Optimization of Catalyst Life and Performance:

Investigate advanced catalyst formulations and regeneration techniques to enhance catalyst longevity and activity. Incorporating nano-structured catalysts or alternative materials could substantially improve the catalytic conversion efficiency and reduce operational downtime.

2.Implementation of Real-Time Monitoring and Control Systems:

Develop and integrate sophisticated real-time process monitoring tools using IoT sensors and advanced analytics. This approach enables dynamic optimization of SRU operating parameters, enhances safety, and minimizes environmental emissions.

3.Exploration of Alternative Reactor Designs:

Evaluate novel reactor configurations, such as microchannel reactors or membrane-assisted reactors, to improve mass transfer and reaction kinetics. Such innovations could lead to higher sulfur recovery efficiencies with reduced energy consumption.

4.Integration with Upstream and Downstream Processes:

Foster seamless integration between the SRU and associated units like Acid Gas Sweetening (ARU) and Tail Gas Treating Units (TGTU). Process intensification and heat integration strategies should be employed to maximize energy efficiency and minimize overall operational costs.

5.Application of Machine Learning and Predictive Modelling:

Utilize machine learning algorithms and predictive models to analyze historical and real-time data. This can enhance fault detection, predictive maintenance, and process optimization, thereby improving overall unit reliability and performance.

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Annexes

aspentech	Dr. Najran MALFI Skikda	Case Name: Mohammad Sawalhi Unit Set: EuroSI Date/Time: Tue Jun 3 15:33:25 2025

Sulfur Condenser: COND-100

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation
WHB_(OL)	Waste Heat Exchanger (Single Pass): WHE-100

Outlet Stream

Stream Name	To Unit Operation
VO_01	Heater: E-102
LS2	

Energy Stream

Stream Name	To Unit Operation
Energy 03	

PARAMETERS

Outlet T:							130.0 C
Delta P:	3.447e-002 bar	Delta T:	-170.0 C *	Percent Entrainment:	0.00 %	Mass Entrainment:	0.0000

CONDITIONS

Name		WHB_(OL)	VO_01	LS2	Energy 03
Vapour		1.0000	1.0000	0.0000	---
Temperature	(C)	299.9654	129.9654	129.9654	---
Pressure	(bar)	0.9211	0.8866	0.8866	---
Molar Flow	(kgmole/h)	182.7612	178.2274	32.2819	---
Mass Flow	(kg/h)	6028.7995	4993.6965	1035.1030	---
Std Ideal Liq Vol Flow	(m3/h)	6.4217	5.8496	0.5721	---
Molar Enthalpy	(kcal/kgmole)	-2.776e+004	-3.075e+004	1117	---
Molar Entropy	(kJ/kgmole-C)	236.6	216.6	44.79	---
Heat Flow	(kcal/h)	-5.0737e+06	-5.4807e+06	3.6063e+04	3.7089e+05

SULFUR RECOVERY

Sulfur Recovery as S1 (Mass):	1035 kg/h	Duty:	-3.709e+005 kcal/h
Sulfur Recovery as S1 (Molar):	32.27 kgmole/h	Predicted Total H2S + H2Sx Dissolved in Liquid S:	278.0 ppmwt
Sulfur Recovery Efficiency:	99.63 %	Predicted H2S Dissolved in Liquid S:	171.1 ppmwt
Sulfur Recovery Enthalpy:	3.606e+004 kcal/h	Predicted H2Sx Dissolved in Liquid S:	106.9 ppmwt
Calculated Mass Entrainment:	0.0000	Predicted Liquid S Viscosity:	9.345 cP

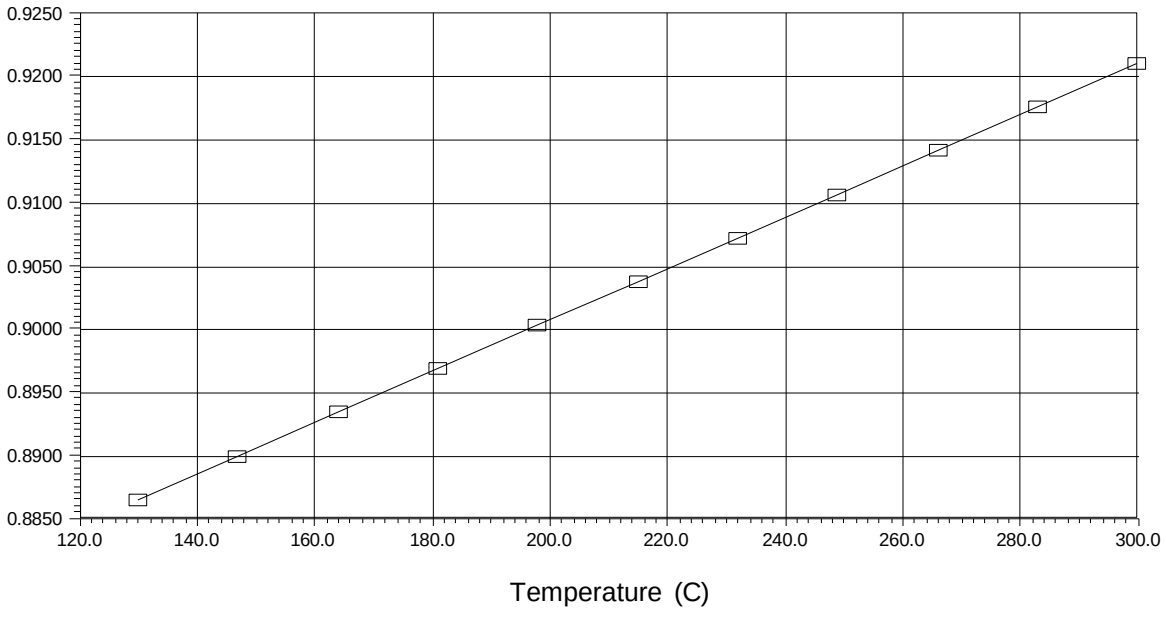
PERFORMANCE PLOT

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Dr. Najran
MALFI Skikda

Case Name:	Mohammad Sawalhi
Unit Set:	EuroSI
Date/Time:	Tue Jun 3 15:33:25 2025

Sulfur Condenser: COND-100 (continued)



Sulfur Condenser: COND-101

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation	
CON_01	Catalytic Converter:	CONV-100

Outlet Stream

Stream Name	To Unit Operation
VO_02	Heater: E-103
LS3	

Energy Stream

Stream Name	To Unit Operation
Energy 05	

PARAMETERS

Outlet T:							130.0 C *
Delta P:	3.447e-002 bar	Delta T:	-168.7 C	Percent Entrainment:	0.00 %	Mass Entrainment:	0.0000

CONDITIONS

Name		CON_01	VO_02	LS3	Energy 05
Vapour		1.0000	1.0000	0.0000	---
Temperature	(C)	298.7174	130.0000 *	130.0000	---
Pressure	(bar)	0.8421	0.8076	0.8076	---
Molar Flow	(kgmole/h)	175.9076	174.1603	12.1943	---
Mass Flow	(kg/h)	4993.6936	4602.6933	391.0003	---
Std Ideal Liq Vol Flow	(m3/h)	5.6947	5.4786	0.2160	---

Pressure (bar)

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Case Name: Mohammad Sawalhi
Unit Set: EuroSI
Date/Time: Tue Jun 3 15:33:25 2025

Sulfur Condenser: COND-101 (continued)

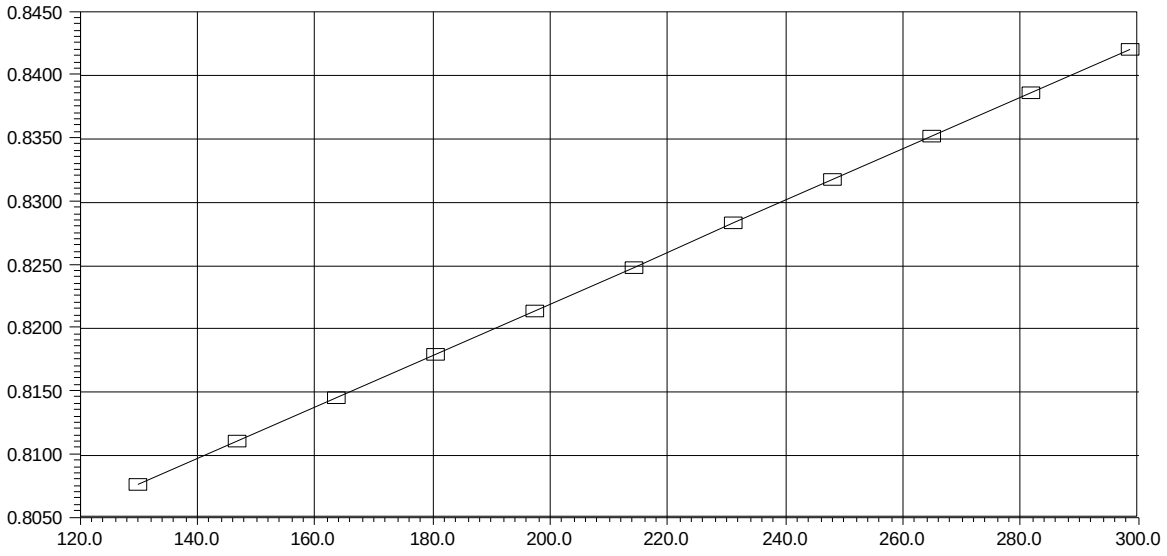
CONDITIONS

Molar Enthalpy	(kcal/kgmole)	-3.034e+004	-3.236e+004	1118	---
Molar Entropy	(kJ/kgmole-C)	228.1	213.1	44.75	---
Heat Flow	(kcal/h)	-5.3372e+06	-5.6350e+06	1.3638e+04	2.8425e+05

SULFUR RECOVERY

Sulfur Recovery as S1 (Mass):	391.0 kg/h	Duty:	-2.842e+005 kcal/h
Sulfur Recovery as S1 (Molar):	12.19 kgmole/h	Predicted Total H2S + H2Sx Dissolved in Liquid S:	65.33 ppmwt
Sulfur Recovery Efficiency:	98.96 %	Predicted H2S Dissolved in Liquid S:	41.05 ppmwt
Sulfur Recovery Enthalpy:	1.364e+004 kcal/h	Predicted H2Sx Dissolved in Liquid S:	24.28 ppmwt
Calculated Mass Entrainment:	0.0000	Predicted Liquid S Viscosity:	9.362 cP

PERFORMANCE PLOT



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Temperature (C)

Sulfur Condenser: COND-102

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation	
CON_02	Catalytic Converter:	CONV-101

Outlet Stream

Stream Name	To Unit Operation	
Tail_gaz	Incinerator:	INC-100
LS4		

Energy Stream

Stream Name	To Unit Operation
Energy 07	

aspentech Dr. Najran MALFI Skikda

Case Name: Mohammad Sawalhi
Unit Set: EuroSI
Date/Time: Tue Jun 3 15:33:25 2025

Sulfur Condenser: COND-102 (continued)

Pressure

PARAMETERS

Outlet T:							130.0 C *
Delta P:	3.447e-002 bar	Delta T:	-99.01 C	Percent Entrainment:	0.00 %	Mass Entrainment:	0.0000

CONDITIONS

Name		CON_02	Tail_gaz	LS4	Energy 07
Vapour		1.0000	1.0000	0.0000	---
Temperature	(C)	229.0075	130.0000 *	130.0000	---
Pressure	(bar)	0.7632	0.7287	0.7287	---
Molar Flow	(kgmole/h)	173.5196	173.0678	3.2698	---
Mass Flow	(kg/h)	4602.6918	4497.8502	104.8416	---
Std Ideal Liq Vol Flow	(m3/h)	5.4332	5.3753	0.0579	---
Molar Enthalpy	(kcal/kgmole)	-3.184e+004	-3.279e+004	1119	---
Molar Entropy	(kJ/kgmole-C)	220.1	212.0	44.73	---
Heat Flow	(kcal/h)	-5.5244e+06	-5.6751e+06	3.6577e+03	1.4709e+05

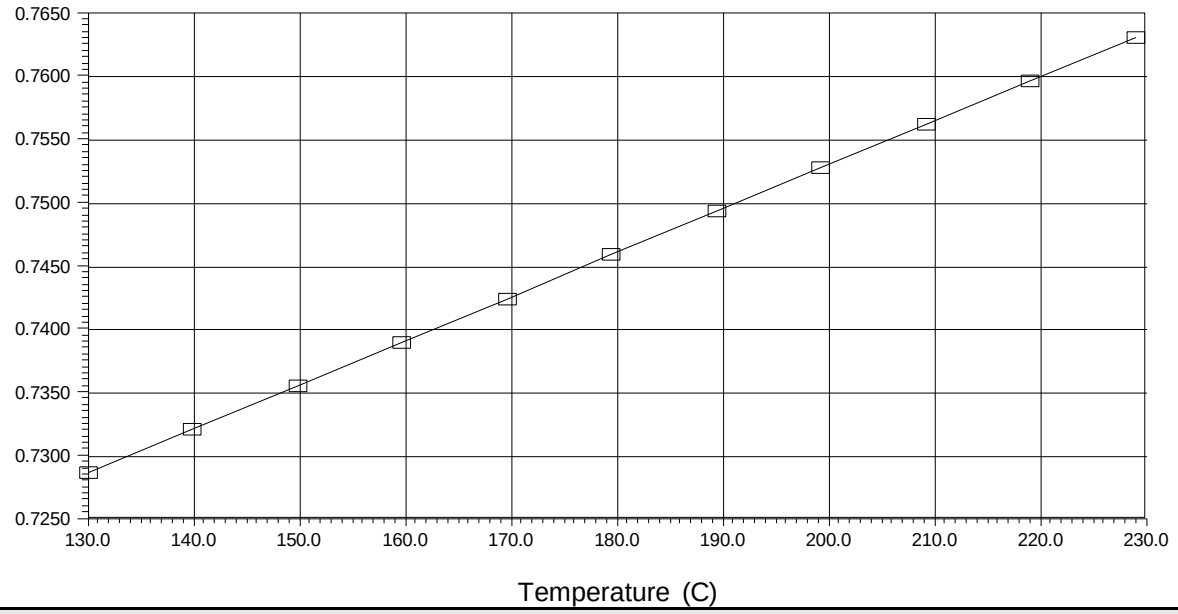
SULFUR RECOVERY

Sulfur Recovery as S1 (Mass):	104.8 kg/h	Duty:	-1.471e+005 kcal/h
Sulfur Recovery as S1 (Molar):	3.270 kgmole/h	Predicted Total H2S + H2Sx Dissolved in Liquid S:	14.44 ppmwt
Sulfur Recovery Efficiency:	95.85 %	Predicted H2S Dissolved in Liquid S:	9.285 ppmwt
Sulfur Recovery Enthalpy:	3658 kcal/h	Predicted H2Sx Dissolved in Liquid S:	5.159 ppmwt
Calculated Mass Entrainment:	0.0000	Predicted Liquid S Viscosity:	9.367 cP

PERFORMANCE PLOT

Licensed to: Company Name Not Available

* Specified by user.



Reaction Furnace (Single Chamber): FUR-100

CONNECTIONS

Dr. Najran
MALFI Skikda

Case Name:	Mohammad Sawalhi
Unit Set:	EuroSI
Date/Time:	Tue Jun 3 15:33:25 2025

Reaction Furnace (Single Chamber): FUR-100 (continued)

Inlet Stream

Stream Name	From Unit Operation	
AG_(Wet)	Heater:	E-100
comb_Air_FR	Heater:	E-101

Outlet Stream

Stream Name	To Unit Operation	
Furnace Effluent	Waste Heat Exchanger (Single Pass):	WHE-100

PARAMETERS

Furnace Model:	Thermodynamic	Delta P:	3.447e-002 bar
Air Stream to Inlet Gas Molar Flow Rate Ratio:			1.274

PERFORMANCE

Air Demand:	-3.12 %	H2 at Outlet:	2.457e+004 ppmmol
Sulfur Conversion:	33.78 kgmole/h	CO at Outlet:	1.981e+004 ppmmol
Sulfur Conv. Efficiency:	68.00 %	COS+CS2+H2S at Outlet:	5.231e+004 ppmmol
H2S Reacted:	80.20 %	HHV at Complete Burn:	6.549e+006 kcal/h
NH3 Reacted:	---	LHV at Complete Burn:	6.027e+006 kcal/h
COS at Outlet:	1879 ppmmol	HHV at Burner Stoichiometry:	1.751e+006 kcal/h
CS2 at Outlet:	3.818 ppmmol	LHV at Burner Stoichiometry:	1.382e+006 kcal/h

CONDITIONS

Name	AG_(Wet)	comb_Air_FR	Furnace Effluent	
Pressure (bar)				

Licensed to: Company Name Not Available

* Specified by user.

35	Vapour		1.0000	1.0000	1.0000	
36	Temperature	(C)	280.0000 *	350.0000	1099.8654	
37	Pressure	(bar)	0.9900	0.9900	0.9555	
38	Molar Flow	(kgmole/h)	85.1436	108.4840 *	195.0548	
39	Mass Flow	(kg/h)	2985.8077	3043.0659	6028.8039	
40	Std Ideal Liq Vol Flow	(m3/h)	3.6748	3.4956	6.4169	
41	Molar Enthalpy	(kcal/kgmole)	-3.530e+004	-1922	-1.648e+004	
42	Molar Entropy	(kJ/kgmole-C)	236.8	222.2	266.1	
43	Heat Flow	(kcal/h)	-3.0057e+06	-2.0852e+05	-3.2142e+06	

Heater: E-100

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION	
AG	Stream Saturator	SAT-100

Outlet Stream

STREAM NAME	TO UNIT OPERATION	
AG_(Wet)	Reaction Furnace (Single Chamber)	FUR-100

Energy Stream

STREAM NAME	FROM UNIT OPERATION
Energy 01	

Heater: E-100 (continued)

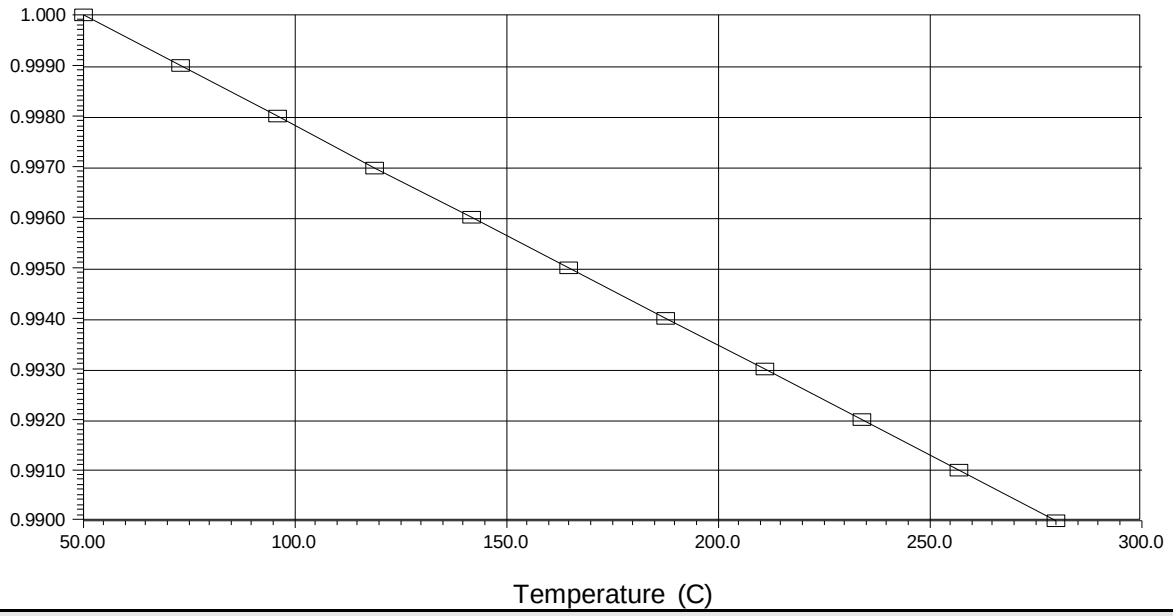
PARAMETERS

Pressure Drop:	1.000e-002 bar *	Duty:	1.775e+005 kcal/h	Volume:	0.1000 m3
Function:	Not Selected	Zones:	1		

CONDITIONS

Name		AG	AG_(Wet)	Energy 01	
Vapour		1.0000	1.0000	---	
Temperature	(C)	50.0000	280.0000 *	---	
Pressure	(bar)	1.0000	0.9900	---	
Molar Flow	(kgmole/h)	85.1436	85.1436	---	
Mass Flow	(kg/h)	2985.8077	2985.8077	---	
Std Ideal Liq Vol Flow	(m3/h)	3.6748	3.6748	---	
Molar Enthalpy	(kcal/kgmole)	-3.739e+004	-3.530e+004	---	
Molar Entropy	(kJ/kgmole-C)	216.6	236.8	---	
Heat Flow	(kcal/h)	-3.1832e+06	-3.0057e+06	1.7750e+05	

PERFORMANCE PLOT



Heater: E-101

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION	
Air_(Wet)	Stream Saturator	SAT-101

Outlet Stream

STREAM NAME	TO UNIT OPERATION	
comb_Air_FR	Reaction Furnace (Single Chamber)	FUR-100

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MALFI Skikda

Case Name:	Mohammad Sawalhi
Unit Set:	EuroSI
Date/Time:	Tue Jun 3 15:33:25 2025

Heater: E-101 (continued)

CONNECTIONS

Energy Stream

STREAM NAME	FROM UNIT OPERATION
Energy 02	

PARAMETERS

Pressure Drop:	1.000e-002 bar *	Duty:	2.426e+005 kcal/h	Volume:	0.1000 m3
Function:	Not Selected	Zones:	1		

CONDITIONS

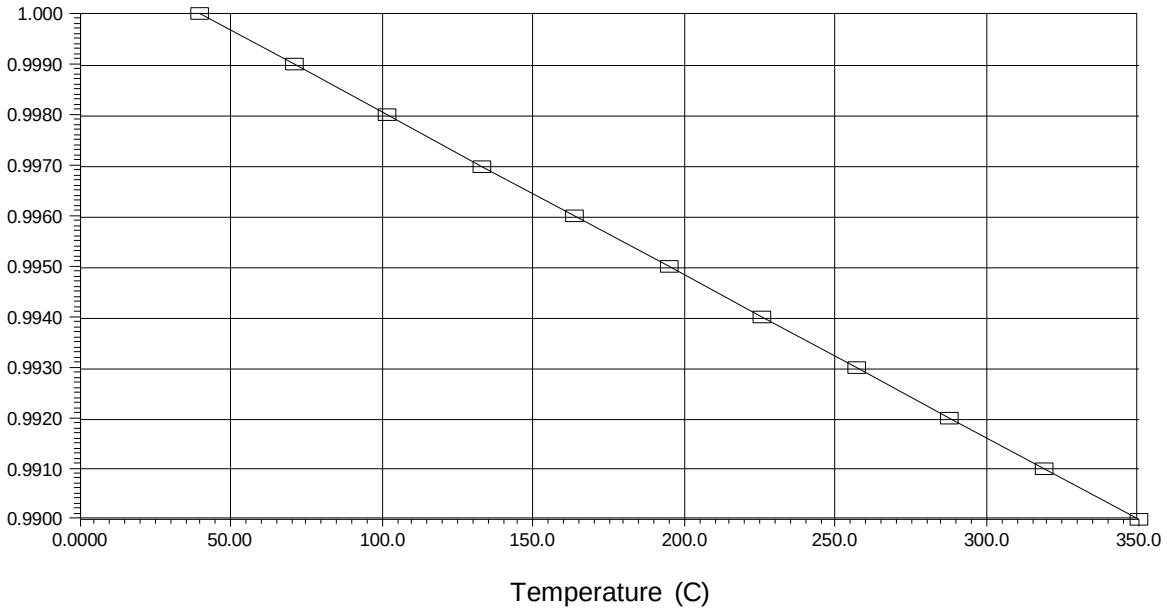
Name		Air_(Wet)	comb_Air_FR	Energy 02	
Vapour		1.0000	1.0000	---	
Temperature	(C)	40.0000	350.0000	---	
Pressure	(bar)	1.0000	0.9900	---	
Molar Flow	(kgmole/h)	108.4840	108.4840 *	---	
Mass Flow	(kg/h)	3043.0659	3043.0659	---	

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* Specified by user.

27	Std Ideal Liq Vol Flow	(m3/h)	3.4956	3.4956	---	
28	Molar Enthalpy	(kcal/kgmole)	-4158	-1922	---	
29	Molar Entropy	(kJ/kgmole-C)	201.5	222.2	---	
30	Heat Flow	(kcal/h)	-4.5112e+05	-2.0852e+05	2.4260e+05	

PERFORMANCE PLOT



Heater: E-102

CONNECTIONS

Inlet Stream

Heater: E-102 (continued)

CONNECTIONS

STREAM NAME	FROM UNIT OPERATION	
VO_01	Sulfur Condenser	COND-100

Outlet Stream

STREAM NAME	TO UNIT OPERATION	
converter_1L	Catalytic Converter	CONV-100

Energy Stream

STREAM NAME	FROM UNIT OPERATION
Energy 04	

PARAMETERS

Pressure Drop:	1.000e-002 bar *	Duty:	1.435e+005 kcal/h	Volume:	0.1000 m3
Function:	Not Selected	Zones:	1		

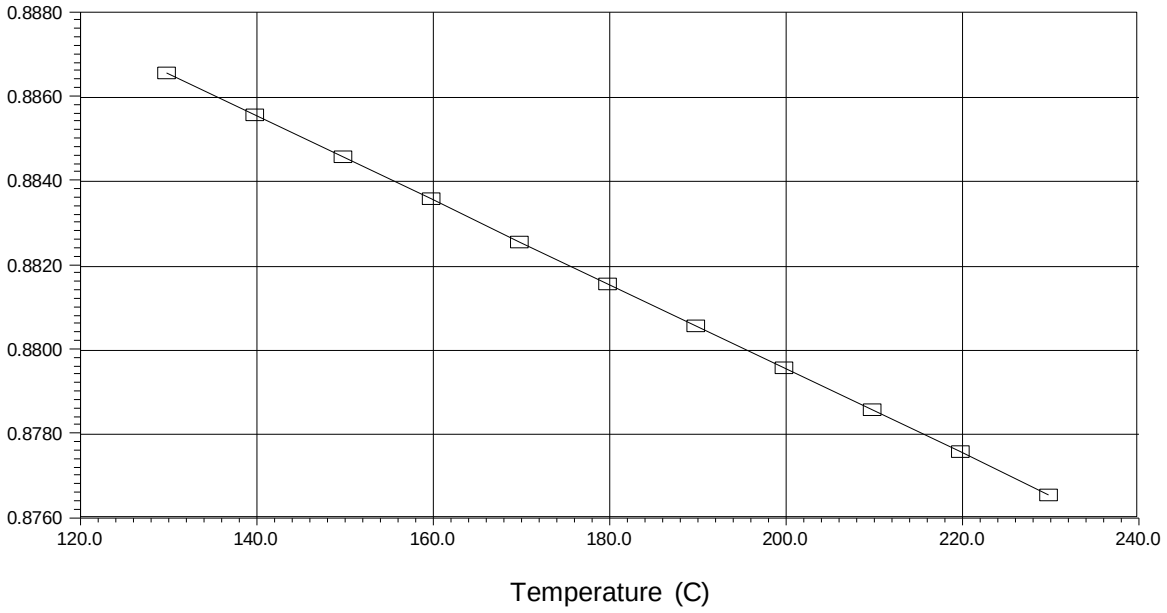
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* Specified by user.

CONDITIONS

Name		VO_01	converter_1L	Energy 04	
Vapour		1.0000	1.0000	---	
Temperature	(C)	129.9654	229.9654	---	
Pressure	(bar)	0.8866	0.8766	---	
Molar Flow	(kgmole/h)	178.2274	178.2293	---	
Mass Flow	(kg/h)	4993.6965	4993.6982	---	
Std Ideal Liq Vol Flow	(m3/h)	5.8496	5.8496	---	
Molar Enthalpy	(kcal/kgmole)	-3.075e+004	-2.995e+004	---	
Molar Entropy	(kJ/kgmole-C)	216.6	224.1	---	
Heat Flow	(kcal/h)	-5.4807e+06	-5.3372e+06	1.4350e+05	

PERFORMANCE PLOT



Dr. Najran
MALFI Skikda

Case Name: Mohammad Sawalhi
Unit Set: EuroSI
Date/Time: Tue Jun 3 15:33:25 2025

Heater: E-103

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION	
VO_02	Sulfur Condenser	COND-101

Outlet Stream

STREAM NAME	TO UNIT OPERATION	
converter_2L	Catalytic Converter	CONV-101

Energy Stream

STREAM NAME	FROM UNIT OPERATION
Energy 06	

PARAMETERS

Licensed to: Company Name Not Available

* Specified by user.

Pressure Drop:	1.000e-002 bar *	Duty:	1.106e+005 kcal/h	Volume:	0.1000 m3	
Function:	Not Selected	Zones:	1			

CONDITIONS

Name		VO_02	converter_2L	Energy 06	
Vapour		1.0000	1.0000	---	
Temperature	(C)	130.0000 *	210.0000 *	---	
Pressure	(bar)	0.8076	0.7976	---	
Molar Flow	(kgmole/h)	174.1603	174.1618	---	
Mass Flow	(kg/h)	4602.6933	4602.6941	---	
Std Ideal Liq Vol Flow	(m3/h)	5.4786	5.4786	---	
Molar Enthalpy	(kcal/kgmole)	-3.236e+004	-3.172e+004	---	
Molar Entropy	(kJ/kgmole-C)	213.1	219.1	---	
Heat Flow	(kcal/h)	-5.6350e+06	-5.5244e+06	1.1064e+05	

PERFORMANCE PLOT

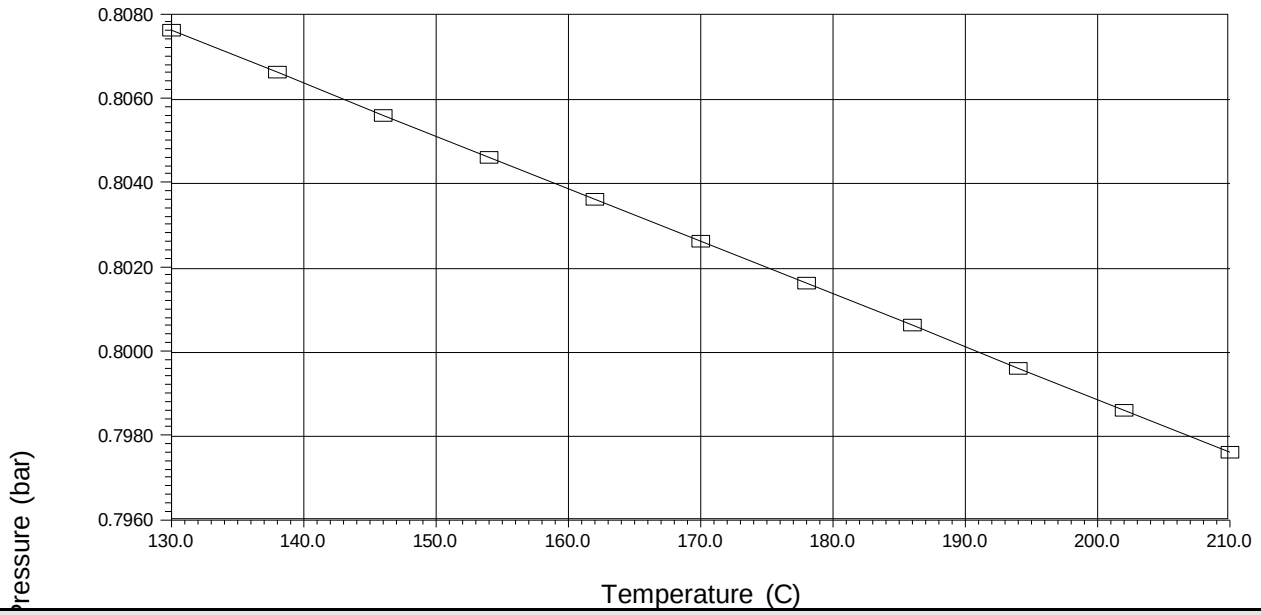
Dr. Najran
MALFI Skikda

Case Name:	Mohammad Sawalhi
Unit Set:	EuroSI
Date/Time:	Tue Jun 3 15:33:25 2025

Heater: E-103 (continued)

Licensed to: Company Name Not Available

* Specified by user.



Incinerator: INC-100

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation
Tail_gaz	Sulfur Condenser: COND-102

Outlet Stream

Stream Name	To Unit Operation
Stack Effluent	

Fuel Stream

Stream Name	From Unit Operation
Fuel Gas	

Air Stream

Stream Name	From Unit Operation
Air to Incinerator	Stream Saturator: SAT-102

CONDITIONS

Name		Tail_gaz	Air to Incinerator	Fuel Gas	Stack Effluent
Vapour		1.0000	1.0000	1.0000	1.0000
Temperature	(C)	130.0000 *	40.0000	25.0000 *	600.0000
Pressure	(bar)	0.7287	1.0000	1.6000 *	0.6597
Molar Flow	(kgmole/h)	173.0678	85.9184	4.5882	263.1205
Mass Flow	(kg/h)	4497.8502	2410.0843	77.4693	6985.3871
Std Ideal Liq Vol Flow	(m3/h)	5.3753	2.7685	0.2531	8.2819
Molar Enthalpy	(kcal/kgmole)	-3.279e+004	-4158	-1.805e+004	-2.324e+004

Incinerator: INC-100 (continued)

Licensed to: Company Name Not Available

* Specified by user.

	CONDITIONS					
Molar Entropy	(kJ/kgmole-C)	212.0	201.5	190.6	238.2	
Heat Flow	(kcal/h)	-5.6751e+06	-3.5728e+05	-8.2824e+04	-6.1153e+06	

Stream Saturator: SAT-100

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation
AG_(Dry)	
H2O_(AG)	

Outlet Stream

Stream Name	To Unit Operation
AG	Heater: E-100

CONDITIONS

Name		AG_(Dry)	H2O_(AG)	AG	
Vapour		1.0000	0.9439	1.0000	
Temperature	(C)	50.0000 *	99.6296	50.0000	
Pressure	(bar)	1.0000 *	1.0000	1.0000	
Molar Flow	(kgmole/h)	74.8296	10.3140	85.1436	
Mass Flow	(kg/h)	2800.0000 *	185.8077	2985.8077	
Std Ideal Liq Vol Flow	(m3/h)	3.4886	0.1862	3.6748	
Molar Enthalpy	(kcal/kgmole)	-3.460e+004	-5.759e+004	-3.739e+004	
Molar Entropy	(kJ/kgmole-C)	216.5	126.5	216.6	
Heat Flow	(kcal/h)	-2.5891e+06	-5.9403e+05	-3.1832e+06	

Stream Saturator: SAT-101

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation
Air_(Dry)	
H2O_(Air)	

Outlet Stream

Stream Name	To Unit Operation
Air_(Wet)	Heater: E-101

CONDITIONS

Name		Air_(Dry)	H2O_(Air)	Air_(Wet)	
Vapour		1.0000	0.9356	1.0000	
Temperature	(C)	40.0000 *	99.6332	40.0000	
Pressure	(bar)	1.0000 *	1.0000	1.0000	
Molar Flow	(kgmole/h)	100.4799	8.0041	108.4840	
Mass Flow	(kg/h)	2898.8716	144.1943	3043.0659	
Std Ideal Liq Vol Flow	(m3/h)	3.3511	0.1445	3.4956	
Molar Enthalpy	(kcal/kgmole)	104.6	-5.767e+004	-4158	

Dr. Najran
MALFI Skikda

Case Name: Mohammad Sawalhi
Unit Set: EuroSI
Date/Time: Tue Jun 3 15:33:25 2025

Licensed to: Company Name Not Available

* Specified by user.

Stream Saturator: SAT-101 (continued)

CONDITIONS

Molar Entropy	(kJ/kgmole-C)	200.0	125.6	201.5	
Heat Flow	(kcal/h)	1.0514e+04	-4.6163e+05	-4.5112e+05	

Stream Saturator: SAT-102

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation
Wet Air to Incinerator	
H2O_(Air Inc)	

Outlet Stream

Stream Name	To Unit Operation
Air to Incinerator	Incinerator: INC-100

CONDITIONS

Name		Wet Air to Incinerator	H2O_(Air Inc)	Air to Incinerator	
Vapour		1.0000	0.9356	1.0000	
Temperature	(C)	40.0000 *	99.6332	40.0000	
Pressure	(bar)	1.0000 *	1.0000	1.0000	
Molar Flow	(kgmole/h)	79.5793	6.3392	85.9184	
Mass Flow	(kg/h)	2295.8835	114.2008	2410.0843	
Std Ideal Liq Vol Flow	(m3/h)	2.6540	0.1144	2.7685	
Molar Enthalpy	(kcal/kgmole)	104.6	-5.767e+004	-4158	
Molar Entropy	(kJ/kgmole-C)	200.0	125.6	201.5	
Heat Flow	(kcal/h)	8.3269e+03	-3.6561e+05	-3.5728e+05	

Waste Heat Exchanger (Single Pass): WHE-100

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation
Furnace Effluent	Reaction Furnace (Single Chamber): FUR-100

Outlet Stream

Stream Name	To Unit Operation
WHB_(OL)	Sulfur Condenser: COND-100
LS1	

Energy Stream

Stream Name	To Unit Operation
WHE_Energy	

PARAMETERS

Outlet T:							300.0 C
Delta P:	3.447e-002 bar	Delta T:	-799.9 C *	Percent Entrainment:	0.00 %	Mass Entrainment:	0.0000

Reactions Permitted

Licensed to: Company Name Not Available

* Specified by user.

aspentech	Dr. Najran MALFI Skikda	Case Name:	Mohammad Sawalhi
		Unit Set:	EuroSI
		Date/Time:	Tue Jun 3 15:33:25 2025

Waste Heat Exchanger (Single Pass): WHE-100 (continued)

CONDITIONS

Name		Furnace Effluent	WHB_(OL)	LS1	WHE_Energy
Vapour		1.0000	1.0000	0.0000	---
Temperature	(C)	1099.8654	299.9654	299.9654	---
Pressure	(bar)	0.9555	0.9211	0.9211	---
Molar Flow	(kgmole/h)	195.0548	182.7612	0.0000	---
Mass Flow	(kg/h)	6028.8039	6028.7995	0.0000	---
Std Ideal Liq Vol Flow	(m3/h)	6.4169	6.4217	0.0000	---
Molar Enthalpy	(kcal/kgmole)	-1.648e+004	-2.776e+004	2684	---
Molar Entropy	(kJ/kgmole-C)	266.1	236.6	58.34	---
Heat Flow	(kcal/h)	-3.2142e+06	-5.0737e+06	0.0000e-01	1.8595e+06

PERFORMANCE

Sulfur Recovery as S1 (Mass):	0.0000 kg/h	Duty:	-1.860e+006 kcal/h
Sulfur Recovery as S1 (Molar):	0.0000 kgmole/h	Predicted Total H2S + H2Sx Dissolved in Liquid S:	503.0 ppmwt
Sulfur Recovery Efficiency:	0.00 %	Predicted H2S Dissolved in Liquid S:	274.4 ppmwt
Sulfur Recovery Enthalpy:	0.0000 kcal/h	Predicted H2Sx Dissolved in Liquid S:	228.6 ppmwt
Calculated Mass Entrainment:	0.0000	Predicted Liquid S Viscosity:	2712 cP
Back Reaction as S1:			1.386 kgmole/h