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Investigation of Gaseous Emissions from Sulfur Recovery Unit at Mellitah Gas Plant

A research proposal submitted to the department in partial fulfillment of the requirements of M.Sc. degree in Chemical Engineering

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ
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Abstract

The global use of natural gas is growing rapidly. This is primarily attributed to the environmental advantages it enjoys over other fossil fuels such as oil and coal. There is worldwide drive towards increasing the utilization of natural gas and the need to minimize energy consumption and increase profit associated with the process. So, the raw gas should be treated in order to meet the international specifications and eliminate or at least minimize the emission of toxic and/or pollutant gases to the surrounding area. Mellitah gas plant applies the latest technology in order to meet the international market requirements for natural gas specifications and prevent the emission of H_2S but the other exiting emissions from this plant are not conforming with the international standards allowable limitations and environment standards.

According to this a simulation model of Sulfur Recovery Unit (SRU) that used in Mellitah Gas Plant was done by using Aspen HYSYS V7.3. This simulation investigate the amount and concentration of pollutant gaseous emission from SRU depending on the known of field operating conditions. Simulation results (mass and temperature of streams) are verified and agreed with field data. The main units simulated throughout thesis are MDEA absorption unit that consist of (Absorber and Regenerator) leads to reducing amount of CO_2 up to 79.66% (vol.) and increasing quantity of H_2S up to 13.88% (vol.); while treated stream sent to regenerator to separating MDEA then recycled to reuse in absorption process (Lean MDEA), and treated stream sent to SRU. Sulfur Recovery Unit (SRU) consist of thermal reactor, burning of H_2S to converts into SO_2 with traces of C_2S and COS then sent to the catalytic convertors that consist of two convertors, and three condensers to produce sulfur from H_2S and SO_2 . The amount of sulfur recovered reaches 97.79%. Tail produces gases from this unit sent to Tail Gas Treatment Unit (TGTU) followed by incinerator combustion chamber to reach 99.21% of H_2S as a recovered sulfur.

Results data reveal that, the main composition of emission produced from SRU stacks are CO_2 , N_2 , O_2 , SO_2 , & H_2O with small amount of H_2 . Generally, results indicate SO_2 concentration emitted with high concentration (reaches 1307.94 mg/m^3) it have great deviation more the allowable international standard limits, and there is very huge quantity of CO_2 emitted to atmosphere from the incinerator stack (Equivalent to 160.4 ton/hr). While there is no NO_x emitted from this unit. Also results of dispersion of air pollutants concentrations show that atmospheric air of Mellitah Gas Plant neighboring regions (for distances more than 10 km from the point source) suffers from the presence of SO_2 contaminant greatly affect the health of the population. But there no effect on the air quality inside the complex.

الملخص

تشير الدراسات العلمية حول العالم إلى أن الانبعاثات الناجمة عن عملية إحتراق الوقود بنوعيه الثقيل و الخفيف والغاز الطبيعي تتسبب في تأثيرات سلبية على الصحة العامة وتؤدي إلى تدني مستوى البيئة المحيطة. لذا يعالج الغاز الطبيعي الخام بمحطات تحلية الغاز الطبيعي بهدف إزالة الشوائب الكبريتية قبل إستخدامه. وعلى هذا الصعيد فإن مجمع مليته للغاز/ليبيا هي إحدى المجمعات التي تطبق أحدث التقنيات الصناعية المستخدمة في هذا المجال وذلك من أجل تلبية المتطلبات الدولية للحصول على الغاز الطبيعي نقياً من خلال إزالة مركب ثاني كبريتيد الهيدروجين (H_2S) وتحويله إلى صورة كبريت عنصري حر، ويصاحب هذه العملية تصاعد العديد من الانبعاثات الغازية الأخرى مثل ثاني أكسيد الكبريت من مدخنة المعمل والتي لها يكون لها أثار سلبية على البيئة المحيطة في حال تجاوز تركيزها المعايير البيئية الدولية المسموح بها.

ووفقاً لهذا تم عمل نموذج محاكاة لوحدة إسترجاع الكبريت (SRU) المستخدمة في "معمل مليته للغاز الطبيعي" باستخدام برنامج الهايسيس (HYSYS V7.3) للتحقق من كمية وتركيز انبعاثات الملوثات الغازية الناجمة عن هذه الوحدة كونها الوحدة الأساسية بالمعمل التي يتم فيها معالجة الغازات الكبريتية، وتم إجراء المحاكاة إستناداً إلى الظروف التشغيلية والتصميمية للوحدات التشغيلية بوحدة إسترجاع الكبريت. كما تم التحقق من نتائج عملية المحاكاة وذلك بمقارنة (الكميات ودرجات الحرارة) مع بيانات القراءات الحقلية. يتكون معمل معالجة الغاز الطبيعي من وحدة الإمتصاص بالأمين والتي تتكون من عمودي (إمتصاص وإسترجاع الأمين)، حيث يعمل عمود الإمتصاص بشكل أساسي على التقليل من كمية غاز ثاني أكسيد الكربون (CO_2) في مجرى التغذية بنسبة 79.66% (حجماً)، كما تعمل على زيادة نسبة غاز ثاني كبريتيد الهيدروجين (H_2S) بمجرى التغذية إلى نسبة 13.88% (حجماً)؛ ويتم إرسال مجرى التغذية المعالج إلى وحدة إسترجاع الأمين لفصله ثم إعادة تدويره لإعادة إستخدامه، بينما المجري المعالج الناتج يُرسل إلى وحدة إسترجاع الكبريت (SRU). تتكون وحدة إسترجاع الكبريت من المفاعلات الحرارية والتي تعمل على حرق (H_2S) و تحويله إلى غاز ثاني أكسيد الكبريت (SO_2) كمنتج أساسي وغازات جانبية كبريتية أخرى وهي (CO_2 و COS) ويتم إرسال هذه المنتجات إلى عدد إثنين من المحولات المحفزة وعدد ثلاثة مكثفات وذلك ليتم إنتاج الكبريت. تصل كمية الكبريت المسترجعة إلى 97.79%، كما تنتج غازات كنواتج جانبية من هذه الوحدة و التي ترسل إلى وحدة معالجة الغازات الذيلية (TGTU) والتي يليها المحرقة. وبنهاية عملية الإحتراق فإن كمية الكبريت المسترجعة تصل إلى 99.21%.

تُظهر النتائج، بأن المكونات الرئيسية للانبعاثات الغازية الناتجة من مداخن وحدة إستخلاص الكبريت تتكون أساساً من H_2O ، و SO_2 ، O_2 ، CO_2 ، N_2 مع كمية صغيرة من H_2 . وبصفة عامة، تشير النتائج إلى أن تركيز غاز SO_2 المنبعث هي تراكيز عالية (تصل إلى 1307.94 مغم/م³) وهذه القيمة تتجاوز جميع الحدود القياسية الدولية المسموح بها، كما أن الوحدة تنتج كمية كبيرة جداً من غاز CO_2 والتي يتم طرحها أيضاً للغلاف الجوي بشكل مباشر (بما يعادل 160.4 طن/ساعة). بينما لا يوجد هناك أي انبعاثات ناتجة لأكاسيد النيتروجين من هذه الوحدة. كما تشير نتائج محاكاة الإلتشار لغاز ثاني أكسيد الكبريت الناتجة من مدخنة المحرقة بإستخدام برنامج (Disper) بأن المدن المجاورة للمجمع والتي تقع في نطاق نصف قطره أكثر من 10 كم حول مصدر الانبعاث تعاني من مشاكل التلوث وإرتفاع تركيز غاز ثاني أكسيد الكبريت بالهواء الجوي الذي قد يكون له تأثير سلبي على صحة السكان على المدى القصير والطويل. كما أنه لا يوجد أي تأثير سلبي على جودة الهواء داخل المجمع.

1.1. Introduction & Motivation

Natural gas is used primarily as a fuel and as a raw material in chemical industry. It is used in home furnaces, water heaters, and cooking stoves. As an industrial fuel, it is used in brick, cement, and ceramic-tile kilns; in glass making; for generating steam in water boilers; and as a clean heat source for sterilizing instruments and foods processing. As a raw material in petrochemical manufacturing, natural gas is used to produce hydrogen, sulfur, carbon black, and ammonia. The ammonia is used in a range of fertilizers and as a secondary feedstock for manufacturing other chemicals, including nitric acid and urea. Ethylene, an important petrochemical, is also produced from natural gas [1].

The global use of natural gas is growing rapidly due to it is considered as an environmentally friendly clean fuel, offering important environmental benefits when compared to other fossil fuels. The superior environmental qualities over coal or crude oil are that emissions of sulfur dioxide are negligible or that the levels of nitrous oxide and carbon dioxide emissions are lower. This helps to reduce problems of acid rain, ozone layer, or greenhouse gases. Natural gas is also a very safe source of energy when transported, stored, and used [1, 2].

There is worldwide drive towards increasing the utilization of natural gas and the need to minimize energy consumption and increase profit associated with the process [2]. Due to the increase of energy consumption, natural gas energy is becoming one of the most important sources to fulfill the world energy demand. But normally the available raw natural gas is mixed with some heavy components such as C_3^+ and/or some impurities such as CO_2 , N_2 & sulfur compounds (H_2S & RSH). The raw gas should be treated in order to meet the international specifications and eliminate or at least minimize the emission of toxic and/or pollutant gases to the surrounding area [3].

So, due to the worldwide pressure to reduce emissions in general led the Libyan authorities to use a suitable treatment for raw natural gas from Baher Elsalam platform. Mellitah complex is one of the advanced worldwide energy supply project. This Western Libya gas project comprises three locations: Wafa field, Baher Elsalam field and Mellitah plant. Mellitah plant, which is the focus of this investigation from the emission point view, consists of the facilities for crude oil

stabilization produced from Wafa desert, condensate stabilization and the main plant treating the raw gas produced from Baher Elsalam in the gas plant and sulfur recovery units.

Normally Wafa desert raw gas contains no H_2S and it is subjected to physical separation in order to control the gas composition and obtain CO_2 content within the required specification. Then the produced gas is compressed and sent to Mellitah site (to Green Stream for compression and export to Italy through subsea pipe line).

Since the raw gas from Baher Elsalam field is containing considerable amount of H_2S hence it is subjected to normal treatment in order to obtain a clean gas completely similar to the gas produced from the gas plant at Wafa Desert and exported together through export line. The other products from gas plant are LPG which sent to Wafa coastal plant (LPG splitter) for further separation process and the Acid gas which contain mainly CO_2 and H_2S is sent to sulfur recovery units in which these units recover the associated sulfur element up to 99.8%wt [4]. The use of this process is increasing in the world for the purpose of air pollution control. The recovered sulfur from this process is solidified in past elating unit and exported as a solid phase with high quality [5].

Different processes at Mellitah site are working to produce a clean natural gas for export and recover of associated sulfur compound with the raw gas and /or acid gas. The recovered sulfur is produced in liquid phase then dried for storage in solid phase. The solid sulfur is exported to international market. Elemental sulfur is of great importance. More than 85% of the total world production of elemental sulfur is converted to sulfuric acid. More than 50% is used for the production of fertilizer [6]. In elemental form sulfur has the following uses [7];

- as a fertilizer
- used in cements and insulators
- gun powder
- In the production of Sulfuric acid
- In manufacturing of wood pulp (Sulfite process)
- In insecticides
- as bleaching agent
- In detergents and dyes

- In plant and soil treatment
- In sulfur alkali batteries
- petroleum catalyst

The raw gas should be treated in order to meet the international specifications and eliminate or at least minimize the emission of toxic and/or pollutant gases to the surrounding area.

1.2. Objective of the work

This study present a simulation by Aspen HYSYS V7.3. The purposes of this simulation are;

- Simulation of (Sulfur Recovery Unit) SRU, at Mellitah plant, because it's the main source of emissions of pollutant gaseous (due to treating an acid gas).
- Comparison of simulation results with data sheet (material & Energy balances of SRU) to verification of the simulation process and assumptions.
- Comparison of gas emissions within international standard limits of emission gaseous to investigate the existing emissions from this plant are within the standards or not.
- The results obtained followed by an investigation of the main pollutants emitted from the plant by using DISPER V4.0 simulator to study the dispersion of SO_2 over the surrounding area of the Mellitah Gas Complex.

1.3. Methodology

The main steps to reach the objective are;

- Collection of operating conditions for the operating units of SRU.
- Simulation of SRU by using HYSYS simulator V7.3 then verify of the results with real data.
- Comparison of data with International standard limits of emission gaseous.
- Suggest some of economic solutions (depending on nature of the results) leading to satisfy energy requirements without emissions of gaseous to protection of the environment.

- Simulation the dispersion of SO_2 emitted from Mellitah Gas Plant over the neighboring area using DISPER V4.0, then verify of the results with WHO regulations for Air quality.

1.4. Construction of Thesis

Generally, the main construction of thesis present as follow;

Chapter 1 gives a general definition and description of the study problems.

Chapter 2 give a general background on Mellitah Gas Complex then a details description of SRU. Also, a literature review for the previous studies concern on pollution of emission gaseous and the main international standard limits are present.

Chapter 3 describes a methodology and used tools. Description of the operating conditions and field data used throughout a simulation process, and explain the main parameters of the study.

Chapter 4 explains the estimated results of the simulation process for all these processes, and gave comparison with real field data and discussion enhanced with references.

Finally, main conclusions and recommendations present in chapter 5.

2.1. Introduction about the Western Libyan Gas Project.

Mellitah gas is the operator of Western Libya Gas Project (WLGP) as shown in Figure (2.1), which entails the development of two reservoirs; Wafa field located in the south west part of Libya, adjacent to the Libyan-Algerian border. Approximately 500 km from the Mediterranean coast, BaherEssalam field located offshore and covering an area distant between 30 and 350 km from the Libyan coast in water depth ranging from 70 to 350 m [4].



Figure (2.1): Western Libyan gas project [4]

Western Libya Gas Project comprises three locations: Wafa field, BaherElsalam field and Mellitah complex. The main locations and stream pipelines are shown in Figure (2.2). The main target of the project is to annually produce about $1 \times 10^{12} \text{ m}^3$ of sales gases for international and local markets.

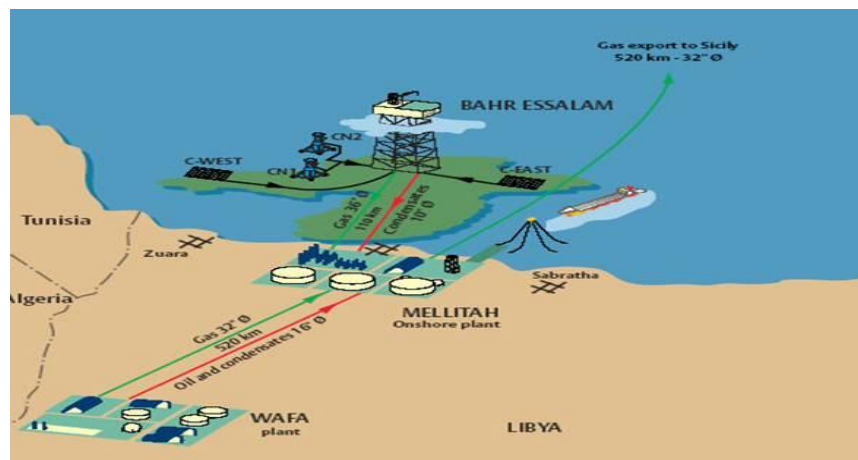


Figure (2.2): Components of Western Libyan gas project [4]

2.1.1. Mellitah Complex

Comprise of Wafa coastal plant, Mellitah plants and Marine export facilities as shown in Figure (2.2).

Mellitah plant consists of the facilities for crude oil stabilization produced from Wafadesert, condensate stabilization and the main plant treating the raw gas produced from BaherElsalam in the gas plant and sulfur recovery units.

2.1.1.1 Gas plant (Sweetening Plant)

The gas received from the platform is treated in Mellitah gas plant and combined with treated gas from Wafa coastal plant, the total gas is delivered through fiscal metering to Mellitah gas compressor station (MGCS) for final export to Italy.

2.1.1.2 Sulfur Recovery Units (SRU)

Sulfur recovery units are designed to convert the H_2S removed from the raw gas to elemental sulfur in a liquid form, which then sent to pastillation unit for solidification and stored as solid sulfur.

2.1.2. Products

The main products from Mellitah complex are [4]:

- Natural sales gas.
- Crude oil.
- Condensate C_5^+ .
- Liquefied petroleum Gas (LPG).
- Solid sulfur.

2.2. Mellitah Gas Plant

Mellitah gas plant, which is the focus of this investigation from the emission point view, in which the main plant treating the raw gas produced from BaherElsalam in the gas plant and sulfur recovery units. It is subjected to complete treatment in which all the containments such as CO_2 , H_2S ...etc (acid gas) are separated at the first stage of the process by absorption utilizing MDEA as a solvent and sent to SRU trains as shown in Figure (2.3) [4].

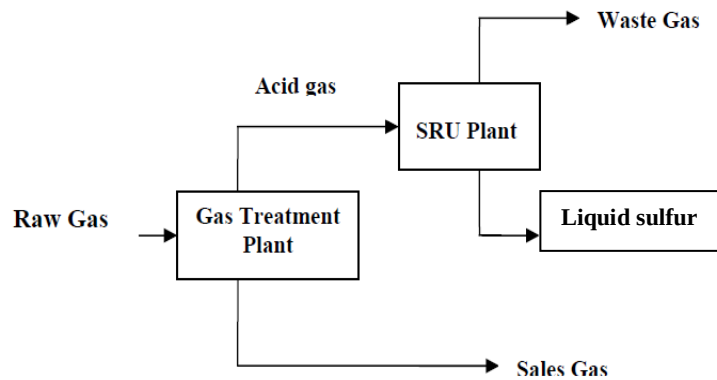


Figure (2.3): Mellitah Gas Plant Flow Diagram [4]

The clean gas (sweet gas) is physically separated into [3, 4]:

- **Sales gas (dry gas)** which is subjected to dehydration process in order to control HC dew point specification and then sent to export gas header.
- **Heavy hydrocarbons (C_3^+)** sent first to de-ethanizer in order to separate at the top ethane and lighter products and then the gas is sent to fuel gas system. The bottom product is sent to De-butanizer in order to separate at the bottom C_5^+ as condensate which is sent to condensate stabilization plant and the top product from Debutanizer is mainly LPG and sent to LPG splitter at Wafa coastal plant.

The acid gas produced from gas plant is sent to Sulfur Recovery Unit (SRU) plant which includes the following stages as shown in Figure (2.4):

- Low pressure absorber to separate CO_2 from the acid gas in order to reduce the hydraulic load on upstream Claus process and maximize H_2S concentration of the main feed to thermal reactor as Amine Acid Gas.
- Claus process which contains thermal reactor and catalytic converters at SRU plant. In which H_2S convert to SO_2 then converts to sulfur through 3 stages connect in series. In this process the recovery is reached to 97.5 %.
- Tail Gas Treatment unit in which the waste gas from Claus process is sent to TGT in order to increase the overall sulfur recovery up to 99.8% and reduces the emission to minimum and acceptable level environmentally.

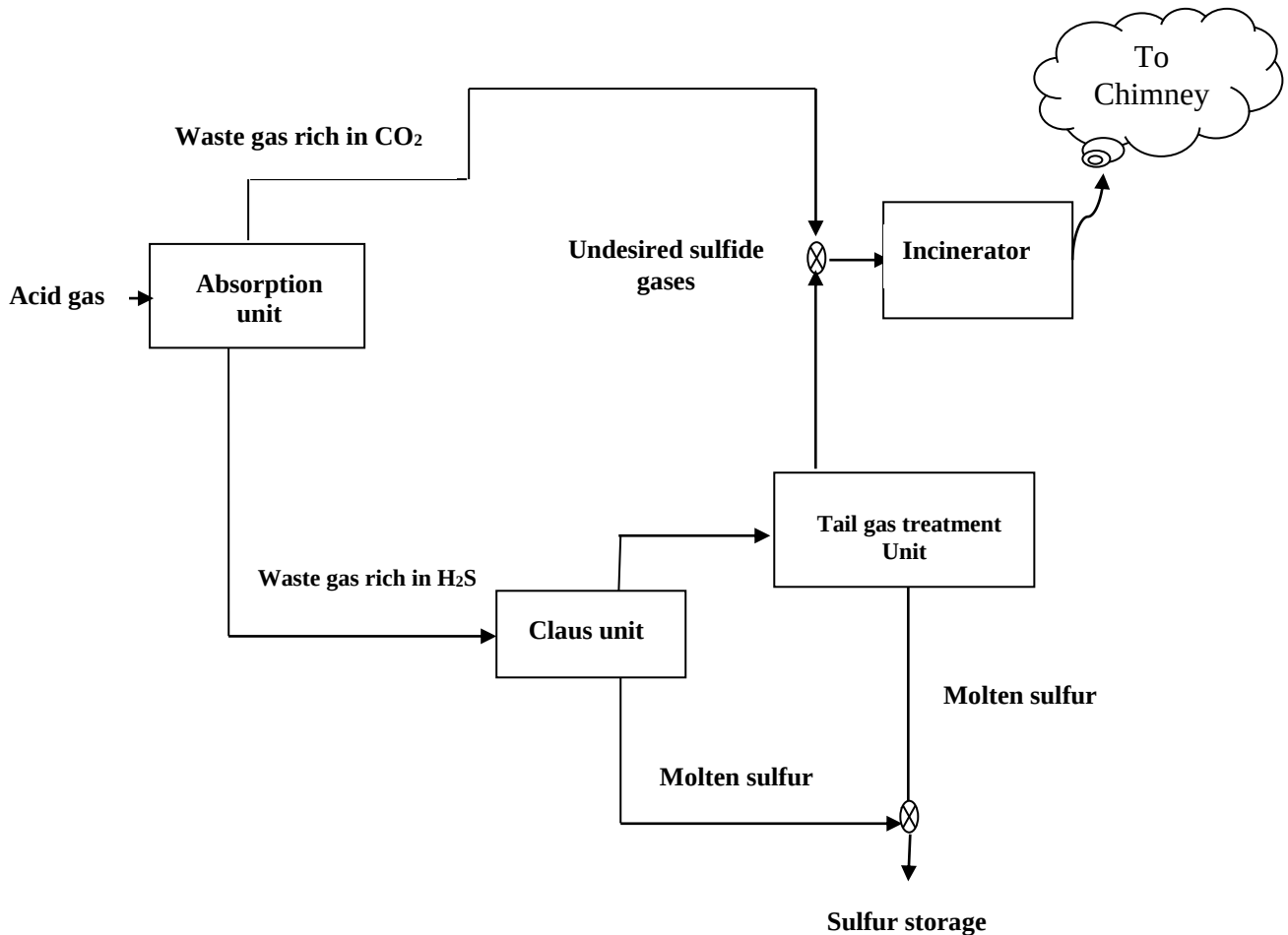


Figure (2.4): Sulfur recovery unit flow diagram

- Incinerator in which all undesired composition (COS , CS_2 and H_2S) of the flows from previous units are burned and converted to outputs less harmful to the environment and health, such as (CO_2 , CO , SO_3 , SO_2 , H_2O and N_2).

2.3. Description of Sulfur Recovery Units process (SRU)

The acid gas feed coming from gas sweetening units shall be treated in MDEA unit to increase the H_2S concentration for Claus unit feed. The Sulfur Recovery Unit (SRU) shall be implemented in a two reactors Claus section followed by a Tail Gas Treating Unit (HCR) [3, 4].

Sulfur degassing section has been designed to treat total sulfur produced by Claus unit at design capacity. The Tail gas leaving the HCR unit, along with all the other Off Gases shall be thermally incinerated in the incinerator and the resulting flue gas shall be discharged to atmosphere via a stack, after waste heat recovery. So,

details description of each stage of the Sulfur Recovery Unit Plant that shown in Figure (2.4) is [8, 9];

2.3.1. MDEA AbsorptionUnit

2.3.1.1 H_2S Absorption

Process flow diagram of this section is shown in Figure (2.5), in which the acid gas coming from upstream Sweetening Unit(S_1) is fed to the MDEA absorber. The semi-lean MDEA (S_5) coming from HCR unit, is mixed with recycled MDEA(S_{13})upstream the absorber inlet. The absorption of H_2S contained in the acid gas is accomplished in the absorber by means of MDEA solution.

The rich MDEA leaving the bottom of (S_9)is sent to the MDEA regenerator. The waste gas rich in CO_2 (S_2) leaving the top of the absorber is sent to the incineration unit.

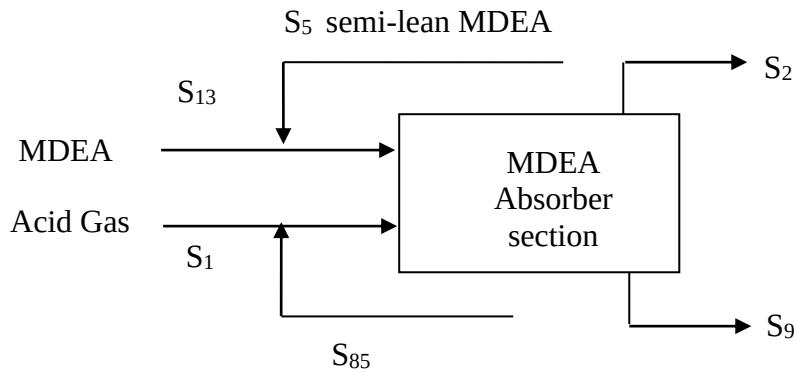


Figure (2.5): H_2S Absorption section flow diagram

2.3.1.2 MDEA Regeneration

Process flow diagram of this section is shown in Figure (2.6). The stripping of the absorbed H_2S from the rich MDEA (S_9)is achieved in the MDEA regenerator.

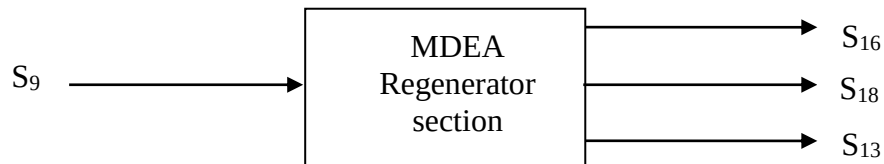


Figure (2.6): MDEA regeneratorsection flow diagram

The gas leaving the MDEA regenerator overhead system amine acid gas(S_{16}) sent to the sulfur recovery unit during normal operation or, in case the acid gas is improperly managed, to the acid flare. While the condensate from the MDEA regenerator overhead system (S_{18}) is sent to the sour water stripping unit. The regenerated lean MDEA leaving the bottom of the MDEA regenerator (Recycled Stream) is cooled and sent to the absorber section (S_{13}).

2.3.2. Claus Unit (Sulfur Recovery Unit)

2.3.2.1 Thermal Reactor Section

Process flow diagram of this section is shown in Figure (2.7), amine acid gas (S_{16}) feeding to Claus unit. Ambient air required for acid gas combustion is compressed and preheated at 250°C using HP steam, then inlet to thermal reactor (S_{30}).

Whereas(S_{16}) (Amine acid gas) is preheated at 250°C before entering into thermal reactor (S_{17}) in order to increase as much as possible the adiabatic flame temperature.

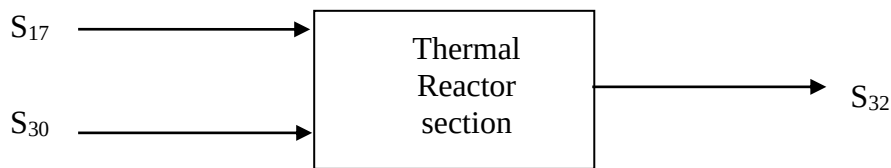


Figure (2.7): Thermal Reactor section flow diagram

On Amine gas line, on-line analyzers for H_2S and hydrocarbons have been installed to measure their content in the feed. Both measures are used to optimize the ratio between Amine acid gas and combustion air to the burner and to have proper conditions inside the combustion chamber.

-Claus Burner

The Burner and the Thermal Reactor are the most important items in the Claus unit and correct operation in that area is mandatory to assure smooth operation.

Combustion of acid gas is done under highly controlled condition, in order to assure proper air feeding and, as a result, optimum sulfur recovery. The Thermal Reactor has been designed as a two-zone reaction furnace, operating in three different modes:

- Straight run operations.

- Split flow of acid gas between the first and the second zone of the Thermal Reactor.
- Fuel gas supported run.

In straight run operation all the acid gas is fed to the thermal reactor, approximately 1/3 of the H_2S present is burnt to SO_2 and the resulting flame temperature is related to the overall fraction of H_2S in acid gas.

-Waste Heat Boiler

The combustion product leaving the reaction furnace is cooled down to about 360°C in the Waste Heat Boiler to produce high pressure steam. A major fraction of the produced steam is superheated in the steam superheater and exported while the remaining is used to heat up process streams. Note that a sulfur discharge line has been foreseen to recover the sulfur condensed inside the boiler tubes. At design condition no flow rate of sulfur is expected, at reduced flow rate a large flow is usually detected.

2.3.2.2 Catalytic Converters Section

Process flow diagram of this section is shown in Figure (2.8). Process gas leaving the waste heat boiler [stream (32)] at approx 360°C is further cooled down to about 190°C in the 1st condenser generating low pressure steam. The sulfur produced in the reaction furnace (S_{40}) is condensed and discharged by gravity to the sulfur degassing pit through its dedicated hydraulic seal. The process gas leaving the condenser passes through two series of equipment, each comprising heater, catalytic converter and sulfur condenser.

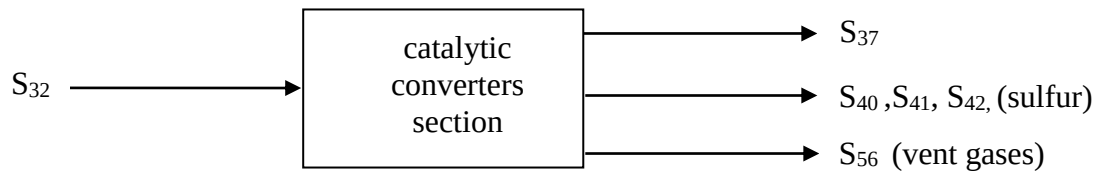


Figure (2.8): Catalytic converters section flow diagram

In the 1st and 2nd catalytic converters, the Claus reaction between H_2S and SO_2 continues until equilibrium is reached at that condition. The liquid sulfur from condensers (S_{41}, S_{42}) is discharged by gravity to the pit.

The H_2S and SO_2 ratio of the outlet process gas (upstream of the 3rd condenser), (S₃₇) is continuously analyzed for tuning the trim air flow rate to Thermal combustion for proper operating condition of HCR unit. The elemental liquid sulfur condensed in the three condensation steps and in the waste heat boiler is discharged by gravity to the liquid sulfur pit, through the dedicated hydraulic seals.

2.3.3. Tail Gas Treatment Unit

The Claus section tail gas leaving the final condenser (S₃₇) can be fed either to the HCR to achieve the required sulfur recovery efficiency or directly to the thermal incinerator in case the HCR is shut. It is not allowed to split the flow within the two units. The Tail Gas Treating Unit (TGTU) is designed for the removal of sulfur compounds (H_2S , SO_2 , COS , CS_2 , elemental sulfur) from the tail gas of Claus section. Flow diagram is shown in Figure (2.9). This is achieved by catalytic hydrogenation of mentioned components to hydrogen sulfide and the subsequent absorption of hydrogen sulfide in MDEA. Rich MDEA is sent to the MDEA absorption unit (S₅), essentially recycling the absorbed H_2S back to the Claus sections for further recovery of elemental sulfur there from.

2.3.3.1 Reducing Reactor Section

The hot process gas (S₃₇) is preheated to 280 °C and fed to the hydrogenation reactor, where all sulfur compounds are hydrolyzed and hydrogenated to H_2S . The hydrogenation reactor is filled with a catalyst.

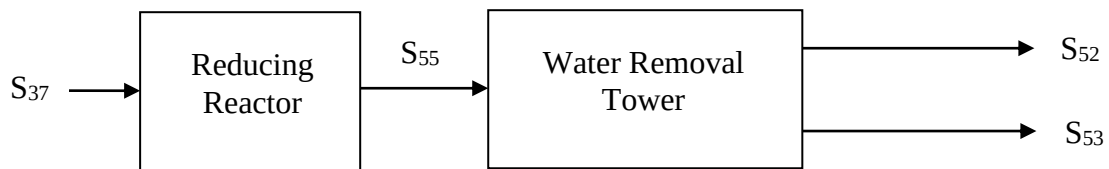


Figure (2.9): Reducing Reactor unit flow diagram.

The process gas leaving the hydrogenation reactor is cooled down and fed to the Water Removal Tower. The gas entering [stream (55)] is first water-saturated in the bottom section and then quenched to about 40°C in the top section, where most of

the steam contained in the process gas is condensed and delivered to the Sour Water Stripping Unit.

In the water removal tower the temperature decreasing and the H_2S partial pressure increasing lead in this way to a better H_2S absorption in the MDEA section, as well as the gas volume flow decreasing. Caustic soda solution injection is foreseen in case of very low pH to avoid sulfur deposition. The process gas from the top [stream (52)] is normally sent to the MDEA Absorber. In case of failure of HCR unit the gas is sent to thermal incinerator.

2.3.3.2 H_2S Absorption Section

Process flow diagram of this section is shown in Figure (2.10). The process gas leaving the water removal tower [stream (52)] at 40°C is fed to the MDEA Absorber, to remove the contained H_2S and to achieve the required sulfur recovery efficiency.

The MDEA solution (S_3') used as absorption medium, available at 37°C, is able to remove practically all the H_2S but only about the 20 % of the CO_2 contained in the gas. While, the MDEA semi lean solution [stream (4)] is sent back to MDEA absorption column. A H_2S analyzer has been provided to monitor sweet gas stream leaving the absorber (S_{54}).



Figure (2.10): H_2S Absorption Section flow diagram

2.3.4. Thermal Incinerator Unit

Process flow diagram of this section is shown in Figure (2.11). The tail gas leaving the column [stream (54)], waste gas leaving (MDEA unit) [stream (62)], vent gas from the sulfur pits [stream (65)] and sweep gas from the degassing system [stream (71)] are fed to thermal incinerator for burning the residual H_2S in order to meet the requirements on the flue gas sent to the atmosphere through the stack. In the same way, Claus tail gas coming from the SRU should be sent to the thermal incinerator in case the HCR is shut.

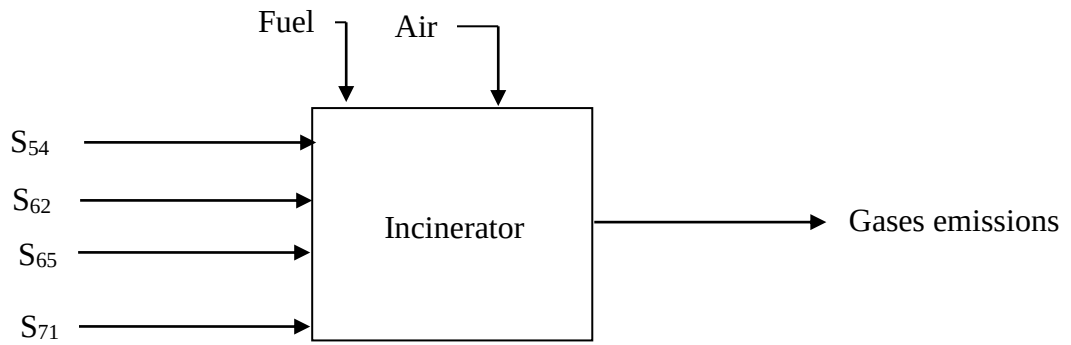


Figure (2.11): Incinerator flow diagram

Refinery fuel gas S_{fuel} is used to support combustion and to achieve temperature of 750°C. Thermal Incinerator can be divided in three zones:

- Fuel gas combustion zone.
- Tail gas combustion zone, and
- Steam superheating zone.

In the first zone support fuel gas is burnt to CO_2 and H_2O by combustion air, operating at relatively high air excess, in order to achieve optimum flame temperature.

In the second zone all tail gas and waste gas are mixed with hot flue gas, at controlled temperature, and all sulfur bearing compounds are oxidized to SO_2 . Residual H_2S content is lower than 10 ppm (vol.)

In the third zone the sensible heat of flue gas is used to heat up saturated HP steam. When the MDEA unit is bypassed Sour Gas from the overhead stripper separator is fed to the thermal incinerator.

2.4. Emitted Pollutants from the Mellitah complex of Oil and Gas

Oil and gas complexes cause number of health problems resulting from the gases emitted, which directly affect the health of the population living in the surrounding areas. According to field studies, statistics and investigations conducted on the residential areas adjacent to gas and oil refineries around the world, find that the people of these areas have suffered and continue to suffer the ravages of disease and various cancers and health problems and emotional instability due to

greenhouse gas emissions and pollutants resulting from these complexes and spills, explosions and fires caused by the pipelines for gas and oil products, and the damage and injuries that cause them.

Proved statistics and follow-up work short-term and medium-term and long-term effects on areas that fall within the scope of projects, natural gas processing and gas and petroleum liquids, which are similar with Mellitah complex, they are exposed to many pollutants which can be categorized as follows [1, 10]:

2.4.1. Gas Emissions

It is polluting emissions to air and breathby the population, and it has hazard effects on public health, which includes the areas surrounding a point of emission, and located in a range between 35 and 50 kilometers from the source point location, which is effective impact depending on the height of source point of emission from the surface of the earth. Gaseous emissions are divided into:

2.4.1.1 *Escapee emissions*

It is emission leaking from pipelines, valves, fittings, bundles, packaging lines, open cabinets surface floating, pumps and locks equipment air pressure, gas transmission systems, pressure relief valves, tanks or basins open, and operations of filling and emptying of hydrocarbons. Sources include the major pollutants of concern emissions from volatile organic compounds emitted from the storage tanks during the filling and also resulting from aeration tanks, separators closure on the surfaces in the case of storage tanks on the roofs floating, wastewater treatment units, and units of product improvement. These gases include usually methane, carbon monoxide, hydrogen, and carbon dioxide gas leaking from dialysis units and acid gas, and also resulting mainly from all combustion processes.

2.4.1.2 *Exhaust Gases*

Constitute the emissions of exhaust gases resulting from the combustion of gas or other types of hydrocarbon fuels in turbines, boilers and pressure equipment, gas pumps and other engines for power and heat generation is an important source of air emissions from rising natural gas processing facilities. It also produces

byproducts from burning in the oxidizing gas (LNG) production facilities of carbon dioxide and emissions of nitrogen oxides.

2.4.1.3 Discharge & Burning Gases

Discharge and burning is an important measure for the safety operation. It used in natural gas processing facilities to ensure the disposal of gas in a safe in an emergency or power failure or stop machinery or the occurrence of any circumstance may solve the facility. Also disposed of materials and secondary gases that did not interact through the discharge and burning. But should not dump the excess gas, but should instead use an effective system to get rid of the gas.

2.4.2. Wastewater

It is the water used in industry or any other wastewater may contain dissolved hydrocarbons or oxidizing active compounds in the wastewater treatment unit.

The steps include in the usual wastewater treatment unit are; grease traps, snowmobiles oils, flotation of dissolved air, hardware separation of oil/water and floating solids, and filtration for separating solid impurities, and the neutralization of flow and loading, and sedimentation to reduce the impurities suspended solids using filtration devices and biological treatment to reduce organic liquid material, and the removal of feeding materials and biological chemical methods to reduce the levels of nitrogen and phosphorus, and excess flow treatment with chlorine at the request of sterilization, drying and disposal of hazardous waste in landfills.

2.4.3. Hazardous Materials

The processing of natural gas treatment use large quantities of hazardous materials, including raw materials (natural gas containing sulfur pollutants), and the intermediate products (such as carbonated sulfur compounds) and final desired products (sulfur liquid and tail gases) and secondary products (such as lean-amine used in the purification processes, waste catalysis). So must be managed in the handling, storage and transportation of these materials properly to avoid or reduce environmental impacts from these hazardous materials.

2.4.4. Noise

Major sources of noise in natural gas sweetening process are the large recycling machines (such as air compressors, turbines, pumps, electric motors, air coolers, heaters that run by sparks). Also during relieve pressure in an emergency situation may occur loud noise issued during unloading high-pressure gases to burn or to release steam into the atmosphere.

2.5. Health & Environmental Impacts of emitted pollutants from the Mellitah complex of Oil and Gas

Many studies conducted in this area [11, 12] proved that, the gaseous emissions have the greatest impact on public health areas adjacent compared to the other types of risks (Noise can reduces by using insulators of sound inside the industrial site; wastewater which are treats in multiple units of treatment within the complex). Second type of pollutants has a high impact on neighboring regions is the presence of hazardous materials resulting from industrial process as by-products (such as liquid sulfur) which is converted to solid powder of sulfur, which is volatile with the atmosphere causing pollution to the surrounding areas of the complex. Currently populated areas surrounding the Mellitahcomplex suffering of this problem, in which sulfur dust can be seen with the naked eye in yellow dust accumulated on cars and plants in those areas [12].

2.5.1. Environmental Impacts on Human Health

The gases emitted from oil and natural gas facilities including (butadiene, benzene, ethyl benzene, aerosol, carbon monoxide, carbon dioxide, nitrogen oxides, sulfur oxides, hexane, volatile organic compounds, toluene, xylene, styrene, methane, pentene, and propane) effect mainly on the health of the human, directly effect on the growth system of body, reproductive system, the circulatory and endocrine disruptors, digestive system, the immune system, kidneys, nervous system, respiratory system, and skin [10-13].

2.5.2.EnvironmentalImpact on Agricultural Crops and Livestock

Previous scientific investigations proved that high levels of SO_2 in the air cause low rates of production of agricultural crops and lead to the death of some plants in the

early stages, depending on the type of plant. Effects of damage on plants at concentrations in the range of 1,850 $\mu\text{g}/\text{m}^3$ after exposure for eight hours or 40 $\mu\text{g}/\text{m}^3$ throughout the growing season [14]. Trees affected by type with different concentrations of sulfur dioxide, e.g. pine trees forests exposed to average concentrations in the range of 44 $\mu\text{g}/\text{m}^3$, and over ten years leaves the concrete damage [10].

Impacts of SO_2 on plants and trees depends on the type of soil, type of plant, weather situation, multiplicity of types of insects and other factors. Studies show that animals that, expose to NO_2 for periods ranging from several weeks to several months in concentrations in the range of 1,880 $\mu\text{g}/\text{m}^3$ has negative effects on the performance of the lungs occurs by biochemical changes. Also when the animals exposed to concentrations up to 990 $\mu\text{g}/\text{m}^3$ of NO_2 for a period of six months suffer from rupture in the wall of the alveoli and an increase in respiratory bacterial infections [10, 14-16].

Data shows that the physiological effects of NO_2 on human and animal attributable to receive doses of high concentrations during short periods of time more than the cumulative doses over long periods of time. It has the same effect on the health of human health, livestock and poultry almost the same way. Damage of the environment, plants and farms in the long term, especially because of the aerosol, which consists of incomplete combustion of oils, volatile sulfur dust, also because of the sulfur oxides that turn in the presence of moisture and fog to acids affect the trees, then contaminate in fruits.

2.5.3. Impacts on metals, buildings and humanitarian heritage

Main impacts of air pollutants on the metals are rust, corrosion, and change the electrical properties of metals. The main factors that affect the rate of corrosion of metal are humidity, rain, and temperature and pollutant type. Studies proved that, presence of sulfates increase of metals corrosion rate, where is the sulfur dioxide gas cause a corrosion of zinc layer used in galvanizing steel and protection from rust. Although the resistance of aluminum for steel in the presence of sulfur dioxide in the air as the aluminum alloys, but the practical experiments indicate that high concentrations in the range (280 ppm) can cause corrosion in aluminum at moisture

levels above 70% formed a white powder of aluminum sulfate. It also shows that the exposure of copper in the switchgear to hydrogen sulfide lead to increase the electrical resistance, then loss of electric power as it travels over copper wires [10].

Pollution impacts on the rocks within the construction materials involves corrosive of limestone and marble rocks, this causes the low level of human heritage of ancient architectural landmarks and historic stirred ancient civilizations (Sabratha archaeological). Corrosion occurs under the influence of acid gases such as sulfur dioxide, which sulfur dioxide and moisture in the air reacts with limestone (CaCO_3) to form calcium sulfate (CaSO_4) and gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). These sulfates dissolve in water, which cause corrosion in the building blocks and the mortar used in the building blocks cohesion. Calcium sulfate can permeate the pores of the limestone rock and crystallize again expands to cause more wear and weaken the rock. Carbon dioxide converts in the presence of moisture to carbonic acid, which in turn converts limestone into bicarbonate dissolve in water then drifted by the rain. These chemical processes also cause erosion of the marble statues and columns [10].

Environmentally, the CO gas is one of the greenhouse gases in global warming and has a negative impact on the environment more than CO_2 emissions, but the quantities of CO_2 emission exceed amounts of CO in millions of times, so do not real threat to the atmosphere [10].

2.6. International Standard Limits for Air Pollution.

Polluted gaseous emission from several sources natural and industrial, some of industrial emissions come from fixed sources and others come from mobile sources. The most important goal of maintaining the air quality is to maintain human health through air monitoring inhaled and limit the access of contaminants to food chain, this requires maintaining the integrity of agricultural crops, plants and the safety of other living things. In addition to the damage caused by the deterioration of the environment beings buildings corrosion and archaeological structures, in addition to low vision, requires the development of threshold values for the control of emissions rates from stationary and mobile industrial sources, there are threshold values for assessing air quality.

Standard limits for emissions of industrial facilities and standard-limits for air quality is non-uniform internationally, whereas the standard limits of developed countries more conservative than other countries, but there some of the countries in the world have no legal limit controls and regulations governing emissions and air quality. The most important laws and regulations issued own developed countries are the US and European regulations.

Limit values for emissions are changing over the years in order to provide control techniques to control emissions and the use of the finest types of fuel and the use of alternative means of energy [10].

During this study a comparison between the emissions from the combustion and standard limits of the most modern and the most stringent of: United States Environmental Protection Agency (USEPA) and the European Commission for the Environment (ECE), in addition to the threshold values used for the Arab Republic of Egypt (Egypt) and Saudi Arabia (KSA). Comparison with the US and European countries is based on the high level of cumulative experience that produced those limits, while comparing with the standard limits for some of the Arab countries can be justified by the geographical locations of those Arab countries that are located in an environment similar to the local environment of the desert character, Which loaded dust in the wind contributes a share in effect on the air quality and the similarity of the climatic conditions of the Arab countries.

Table (2.1) provides the latest standard limits allowed for each of the gaseous emissions of sulfur dioxide (SO_2 , NO_x) for electric power generation units, boilers, furnaces and incinerators.

Table (2.1): International Standard Limits allowed for electric power generation units, boilers, furnaces and incinerators. [17, 20]

Standard Emission Type	USEPA	ECE	KSA	Egypt
SO_2	0.99 lb/MW.hr	300 mg/m ³	2.3 lb/MBtu	2500 mg/m ³
NO_x	1.3 lb/MW.hr	150 NG mg/m ³	0.3 lb/MBtu	3000 mg/m ³

The standard limits listed in the Table (2.1) will be used to evaluate the emission rates of the target site in terms of their conformity with international standards.

2.7. Standards for Air Quality

Air quality standards are limits to the concentrations of air pollutants in the atmosphere and that should not be exceeded during a certain period of time, and these limits can be general maximum applied to the entire state, or limited only to some particularly sensitive air pollutants areas, there are two of these criteria: The first determines the maximum limits for pollutants in populated areas, a more stringent because of the population they are exposed for 24 hours a day throughout the year, and The second type determines the maximum limits for pollutants in industrial areas which are less stringent, and the concentrations of pollutants with the highest given that exposed for a period of 8 hours per day for a period of 5 days a week.

Clean air is a necessary to maintain human health and well-being of basic conditions, but air pollution remains a major threat to human health all over the world, and the World Health Organization designed especially air quality evidence in order to provide guidance aimed to reduce the health effects of air pollution, and put these principles for the first time in 1987[21], and updated in 1997[22], which is based on the experts of the current scientific evidence assessment and given the large number of recent studies of the health effects of air pollution, which has been published in the scientific publications since the signs of air quality for the region Europe "Air quality Guidelines for Europe", where the WHO conducted a review by the accumulated scientific data and to consider the raised regarding the WHO guidelines on air quality. This document presents the results of those actions in the form of the values of a revised function of selected pollutants from air pollutants, which are applicable in all of the WHO regions.

The purpose of these directories is to provide information for those responsible for policy planning and the statement of appropriate targets for a wide range of private management of air quality in different parts of the world political choices, and include such modern evidence on the quality of life of new information related to four of the most common air pollutants, namely: Sulfur dioxide (SO_2), and

nitrogen dioxide (NO_2), and particulate matter (PMs). Scope of this review reflects the availability of new data for these pollutants and their relative importance with respect to the current effects, and those that will occur in the future of air pollution in each of the WHO regions.

WHO guidelines on air quality are signs prepared for use at the level of destruction of the world, and the purpose of the preparation is the business aimed to achieve the air quality that helps to protect public health in various contexts support the standards for air quality, they are criteria established by each country in order to protect public health to its citizens, and are therefore an important component of risk management and environmental policy at the national level. Varying of national standards according to multiple factors, including adopted to offset the health hazards approach, the possibility of technological application, economic considerations, and various other political and social factors, which in turn depends on the National Development, and the ability to air quality management level.

Summary health impact and shortcomings in the full report, which supports the revised evidence evaluation methods, so measuring the concentrations of air pollutants should be in monitoring sites representing the population exposure to air pollutants, and air pollution levels are higher near the specific sources of air pollution such as roads and power plants and sources of fixed engines, and perhaps necessitated the protection of the population living in these areas take special measures to reduce the levels of pollution limits to declining values listed in directories.

However, of the International Health Organization guidelines WHO remains the basis, but some countries decided to adopt the lowest concentrations of values supplied by WHO guidelines and national limit values to determine the air quality. The World Health Organization recommends reducing the emissions of SO_2 during 24 hrs to $20 \mu\text{g}/\text{m}^3$ [22].

2.8. Literature Review

There is a considerable literature related to the modeling and simulation of all/parts of gas sweetening plants. From these literatures are;

A review of the sulfur recovery process from acid gases has been presented by **Sassi& Gupta** [23]. The conventional modified Claus process and its derivatives have been presented and discussed. It is shown that all improvements towards very high sulfur recovery induce very high cost additions to an already economically deficient process. HiTAC has been shown to feature great potential for an almost complete sulfur recovery from lean acid gases. The flameless or colorless combustion has been proposed to be a very promising process for sulfur recovery and hydrogen production from rich acid gases. Therefore, these last two technologies feature the potential for reducing the complexity and the cost of the sulfur recovery process.

Hasan et al.[3] present the different process at Mellitah site in which produce a clean natural gas for export and recover 99.8% wt. of associated sulphur compound with the raw gas and/or acid gas. The recovered sulfur is produced in liquid phase then dried for storage in solid phase. The solid sulfur is exported to international market. The emission control at Mellitah plant is optimized and controlled as per latest available technology. The fuel gas utilized for all the process is completely clean gas; flue gas contains always less than 10 ppm of H_2S . As a consequence the burned gas produced mainly CO_2 & H_2O with a trace amount of SO_x . If SO_x emission at Mellitah is compared with any other industrial complex in Libya or any similar plant anywhere utilizing fuel oil and/or diesel oil then the Mellitah emissions will be the lowest.

Abbas et al.[24] presented a simulation study and modeling of equipment for gas sweetening plant with di-ethanolamine (DEA) their investigated on HYSYS in "DYNAMIC STATE". The main objective of the study is to design, optimize the sweetening process and study of absorber design in both steady and dynamic state. Simulation results show that in dynamic mode the absorption of CO_2 is constant throughout the process. In all cases, DEA was the best result in the absorption processes of CO_2 and H_2S from the natural gas in dynamic state. Results showed that, using of the (1886 kgmol/hr) DEA with $T=99^\circ F$ and $P=995$ (psia) were the best result in the absorption processes of CO_2 (0.0000004, mole fraction) and

$H_2S(0.0000001, \text{ mole fraction})$ without any fluctuation throughout the dynamic process.

Roy & Amin [2] simulate a natural gas processing plant using Aspen-HYSYS. The steady state simulation of the gas processing plant performed based on both the design and physical property data of the plant. Simulation result will be compared further with natural gas processing plant equipment. Process optimizes the operating conditions that maximize the overall profit for the process with reduction of loss and modification in present plant equipment. This project has the intention to carry out the simulation of the Bakhrabad gas processing plant (at Bangladesh) using the Aspen-HYSYS process simulator.

Abdulrahman & Sebastine [25] have achieved design calculations for gas sweetening process for Khurmala gas (in Iraq) and simulated the process by using Aspen HYSYS V.7.3. The amine process is also optimized by applying several amine types and blends. The high amounts of acid gases in Khurmala gas problem can be solved by selection and installation of appropriate gas sweetening process. The simulation work has achieved high acid removal which meets the gas pipelines specifications for almost all amine types and blends. From the simulation work, 35% DEA with $400 \text{ m}^3/\text{hr}$ circulation rate has achieved optimum gas removal and the processed natural gas stream has met the gas pipeline specification. It has been found that twenty trays achieved high acid gas loading for amine contactor tower. Several other process parameters such as water loss, acid gas removal and rich amine temperature are also investigated. From the process calculation and simulation process, it can be said that using 35% DEA is the most recommended for process. The study has found that amine blends are also gave good results and it could be considered for bulk CO_2 removal. Finally, there are other selection criteria that contributing in amine type selection such as cost and amine availability.

Also, **Abdulrahman & Sebastine** [26] examined gas removal process calculations for natural gas stream with moderate acid gas contents. Moreover, amine gas sweetening is designed to sweeten this gas stream by using 15% MEA solution as

alchemical solvent to remove acid gases. A 15% MEA solution circulation rate is calculated which is equal to approximately 490 gpm. It can be argued that 15% MEA solution and 490 gpm amine rate is effective in reducing acid gas content in a given natural gas stream which contains around 4 ppm for H_2S and 0.049 % CO_2 .

Abdulrahman *etal.*[27]were achieved Khurmala gas dehydration process simulation and optimization by using Aspen HYSYS. It can argue that Khurmala wet gas content some quintets of water vapor which may lead to sever technical problems for instance, hydrate formation and pipeline corrosion. However, this problem could be solved by designing & installing gas dehydration unit for Khurmala gas plant. Moreover, simulation work achieved high water removal. It could be argued that using TEG glycol at 4,000 kg/hr circulation rate can achieve excellent drying results. However, the adopting of high TEG circulation rate may lead to increase the process operation cost & TEG losses as well. Therefore, the using of TEG circulation rate about 2,000 kg/hr could archive acceptable drying results.

As presented all the previous studies mentioned have focused on the performance of the process, and design of the equipment's, most these studies have no concern to health and environmental impacts.

3.1. Introduction of Simulation Process

Simulation is a situation in which a particular set of conditions is created artificially in order to study or experience something that could really exist in reality. It is the act of pretending that something is real when it is not. A computer simulation is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system works. There are two modes of simulation-Steady state mode and dynamic mode [28].

3.1.1. Steady State Mode

Initially process simulation was used to simulate steady state processes. Steady state models perform a mass and energy balance of a stationary process (a process in an equilibrium state) but any changes over time had to be ignored.

3.1.2. Dynamics Mode

Dynamic simulations require increased calculation time and are mathematically more complex than a steady state simulation. It can be seen as a multiply repeated steady state simulation (based on a fixed time step) with constantly changing parameters.

3.1.3. Process Simulators

There are many types of programs that used for simulation process of industrial processes such as;

- Aspen Plus, Aspen HYSYS, Aspen Custom Modeler by Aspen technology the first use in chemical processes simulations while the second use in oil & gas process simulation.
- ProSimulators by SimInfosystems.
- ProSimPlus by ProSim.

3.1.4. Aspen HYSYS

Aspen HYSYS is a market leading process modeling tool for conceptual design, optimization, business planning, asset management and performance monitoring for oil and gas processing, petroleum refining, and separation industries.

Aspen HYSYS is a core element of Aspen Tech's aspen one Engineering applications. Aspen HYSYS has established itself as a very intuitive and easy to use process simulator in oil and gas refining industry. Users with little prior knowledge of Aspen HYSYS can pick up and train themselves in its modeling capabilities. Some of the very intuitive capabilities include a highly interactive process flow diagram for building and navigating through large simulations. The program also provides a very flexible and easy to use distillation column modeling environment. Additionally the interactive nature of HYSYS enables users to build and use their models quickly and effectively. Aspen HYSYS offers a comprehensive thermodynamics foundation for accurate calculation of physical properties, transport, properties, and phase behavior for the oil and gas and refining industries [28, 29].

3.2. Aspen HYSYS Application to simulate Sulfur Recovery Unit (SRU)

A steady-state simulation of sulfur recovery unit located in Mellitah gas plant using Aspen HYSYS simulator V 7.3 is applied through this chapter.

All the necessary information pertaining to pure component flash and physical property calculations are contained within the Fluid Package. This advantage allows defining all the required information inside a single entity. During the simulation by HYSYS V7.3 under steady state mode, a choice of a fluid package can be problematic as most fluids result in liquid formation at the turbine and hence the thermodynamic package must be discarded. A steady-state simulation of sulfur recovery unit described in [Section (2.3)].

Simulation of the SRU is based on the operating condition using HYSYS V7.3. Building a simulation model requires knowledge of process details and sufficient information regarding design and operation.

3.2.1. Assumptions

Simulation of sulfur recovery processing unit based on the following assumptions;

- All the process working in steady state mode.
- Two trains in operation at 100% capacity, one train in standby.

- All input data are field data refer to one train in operation.
- Thermodynamic package used in simulations are;
 - DBR Amine Package for (MDEA Absorption unit and H_2S absorption section) due to presence of Amines.
 - Sour Peng-Robinson for (Claus unit, Reducing reactor section and incinerator) due to presence of sulfur compounds.
 - It's supposed worthless the mechanical losses.
 - There aren't losses on the conversion energy.

3.2.2. Operating data and Conditions of the Sulfur Recovery Unit (Input Data)

The main input data of streams to the process described in section (2.3) and shown throughout flow diagrams (2.5 - 2.11) are shown in Tables (3.1-5)

Table (3.1): Main input data to Sulfur Recovery Unit [9]

Data	Stream 1	Stream 85	Stream 5	Stream 30
Temp.(°C)	48	80	37	25
Press.(barg)	141.325	141.325	141.325	101.325
<u>Comp.</u>	<u>kgmol/hr</u>	<u>kgmol/hr</u>	<u>kgmol/hr</u>	<u>kgmol/hr</u>
O_2	0	0	0	169.184
H_2S	344.4	0.329	27.38	0
H_2	0	0	0	0
H_2O	256.5	0.812	5036.074	21.24
N_2	0	0	0.025	636.455
CO	0	0	0	0
CO_2	3354.5	1.626	65.73	0
CH_4	3.15	0	0	0
$MDEA$	0	0	757.5	0
Total	3958.55	2.767	5886.709	826.879

Table (3.2): Main Parameters access to target of MDEA Absorption Unit [9]

Parameter	Data
Reduction Percent of CO_2 in S_9 , (%)	79.662
Increasing Percent of H_2S in S_9 , (%)	13.886
Recovery percent of $MDEA$ in S_{10} , (%)	100.
Separation Efficiency of Sour Water, (%)	99.516

Table (3.3): Main Parameters access to target of Sulfur Recover Unit (Claus Unit) [9]

Parameter	Data
Amount of sulfur fed to the unit in S_9 , (kgmol/hr)	369.152
Amount of Sulfur recovered, (kgmol/hr)	343.881
Sulfur Recovery Percent, (%)	93.154

Table (3.4): Main Parameters access to target of (Claus Unit + Tail Gas Treatment Unit) [9]

Parameter	Data
Amount of H_2S in Feed S_9 , (kg/hr)	392.224
Amount of H_2S recovered of (SRU+TGTU), (%)	391.973
Recovery percent of H_2S in Sulfur form, (%)	99.93

Table (3.5): Main Parameters access to target of Overall Recovery Unit [9]

Parameter	Data
Overall Plant Recovery Percent, (%)	99.794

Other data of streams for each unit will be generated respectively as results of simulation process (heat & material balance has been developed in accordance to the previous basis and data) Also, trial and error will be done to reach the optimum composition of compounds compared with the field data.

3.3. Diffusion models of air pollutants

During 1970s, scientists began to realize that air pollution is not a local phenomenon only, but it became clear in Europe first that the emissions of sulfur dioxide and nitrogen oxides from high chimneys can lead to low pH at great distances from the source, as it became clear also that the ozone in the United States is a problem in rural areas and industrial areas alike, and so it was clear from these cases that it cannot be the fully through a simple equation Gaussian model. Thus two methods for different modeling appeared, Lagrangian and Eulerian models [30].

In general, most studies using Lagrangian model been applied in Europe and on a wide range of distances and for longer periods of time, these studies have focused primarily on sulfur dioxide, but Eulerian model has been applied mostly in the

United States, a lot of areas urban and limited to episodic conditions, and focus primarily on ozone [30].

3.3.1. Climate Data Collection

For the purpose of obtaining the expected impact of Mellitah Plant on the environment in the surrounding areas it was necessary to be a lot of information and data collection, such as information on the targeted industrial facilities and climate data and maps and satellite images that will be used in the simulation deployment program to reach the desired results.

The weather is the foundation of cross-contamination and the speed of the transportation from the source to the surrounding environment for that interest them taken into account in this study, expansion and familiarity with data and private that can help us to reach results and objectives desired from this study and weather factors are the foundation component of weather and climate have been in this investigation using recorded annual averages of climatic data contained in the meteorological center in Tripoli for Zuara meteorological station, due to it is the closest to Mellitah plant targeted study for ten years (1999-2009) as follow [30]:

3.3.1.1 Temperature

For the summer months (May-September) it is ranged between 24-28 °C (Average= 26 °C). But for winter months (October-April) it is ranged between 14-24 °C (Average =20 °C).

3.3.1.2 Humidity

It is recorded between 60-80%. So average value 70%.

3.3.1.3 Wind

As shown in Figure (3.1.). The main direction of winds for summer months is East-Northern-East (about 56.25 °) with average value = 4.3 m/sec, while for winter months is West-Southern-West (about 258.75°) with average value = 4.3 m/sec.

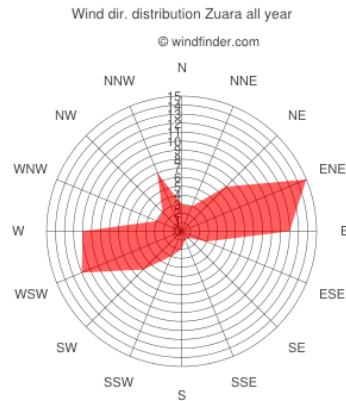


Figure (3.1): Wind directions for Zuara City [30]

3.3.2. Operating Data of Chimney

Main parameters must be insert to DISPER simulator to determine the dispersion of SO_2 in the surrounding areas. The main parameters are dimensions of incinerator and operating conditions obtained from Aspen Hysys V7.3 simulation for the incinerator are shown in Table (3.6).

Table (3.6): Dimensions and Operating conditions for Incinerator

Specification	Units	Value
Length of Chimney	m	70
Inside radius of Chimney	m	3
Pollutant (SO_2)		
Superficial velocity	m/sec	26.842
Concentration	g/sec	248.035
Energy consumed	J/hr	5.7×10^9
Temperature of Gaseous	K	1023

4.1. Results of Simulation Process of SRU

Simulation processes of Sulfur Recovery Unit (plant) are done depending on the assumptions and hypothesis discussed in chapters two and three respectively as;

- Simulation of MDEA absorption unit.
- Simulation of Claus Unit.
- Simulation of TGTU Unit.
- Simulation of Incinerator.

Results of simulation are compared with field data for each process and discussed as following;

4.1.1. Simulation of MDEA Absorption Unit

The main sections comprise of absorber and regenerator as discussed in section [2.3.1]. Simulation results of these sections are done depending on the assumptions made in section [3.2.1].

4.1.1.1 Simulation of H₂S Absorber

Simulation of the absorber section shown in Figure (2.5), is done as shown in Figure (4.1). Details of the main streams of this section are shown in Table (4.1). Readings in the table indicate the compatibility between the simulation results and the field data of the unit process. In which carbon dioxide decreasing in the load feeding (Stream 9) to the system up to 79.442% and increasing load of sulfur dioxide up to 9.212% . The top and bottom pressures used to reaches the required efficiency of separation are 126.3 and 92 kPa respectively by using 10 sieve trays.

4.1.1.2 Simulation of Regenerator

Regenerator section shown in Figure (2.6), is simulated as shown in Figure (4.1). Details of the main streams of this section are shown in Table (4.2). Good agreement between field and simulation data in which the recovery percent of MDEA in stream 10 reach to 100%, and separation efficiency of sour water in this section reaches 99.638%. So, according to this the simulation process is working efficiently. The distillation column has 201.3 and 221.3 kPa as a top and bottom pressures of the column with reflux ratio equal to 0.5 and 40 sieve trays.

The main parameters of absorption unit are shown in Table (4.3)

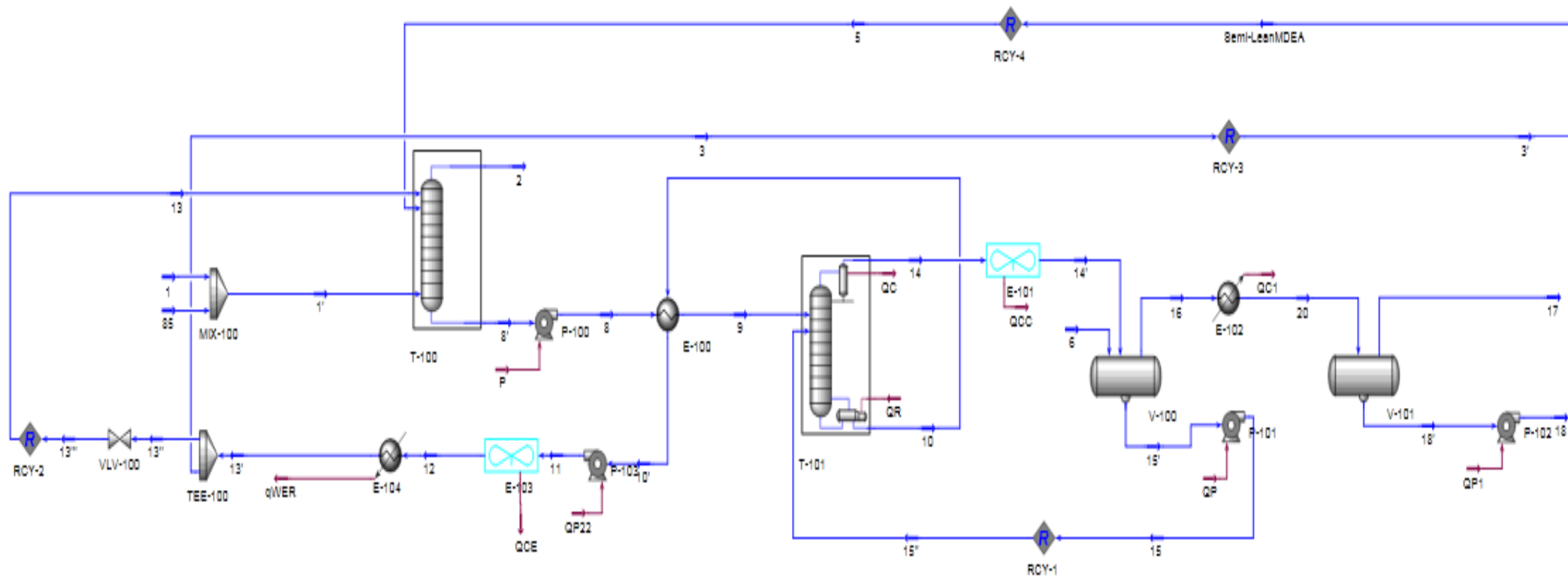


Figure (4.1): Simulation of MDEA Absorption Unit (H_2S absorber + MDEA Regenerator)

Table (4.1): Comparison between field data and results for simulation of main streams of MDEA Absorption Unit

Stream Data	Input Streams											
	Stream No. 1			Stream No. 85			Stream No. 5			Stream No. 13		
	Simulation	Field	Error %	Simulation	Field	Error %	Simulation	Field	Error %	Simulation	Field	Error %
Temp.(C)	48	48	0	80	80	0	37	37	0	36.99998489	36.999985	0
Press.(barg)	141.325	141.325	0	141.325	141.325	0	141.325	141.325	0	151.325	151.325	0
Comp.	kgmol/hr	kgmol/hr	Error %	kgmol/hr	kgmol/hr	Error %	kgmol/hr	kgmol/hr	Error %	kgmol/hr	kgmol/hr	Error %
O ₂	0	0	0	0	0	0	0.0002	0	0	0	0	0
H ₂ S	344.4	344.4	0	0.329	0.329	0	19.54658051	27.38	28.61001	20.655	20.655	0
H ₂	0	0	0	0	0	0	1.04E-04	0	0	0	0	0
H ₂ O	256.5	256.5	0	0.812	0.812	0	5010.13813	5036.074	0.515002	28650.332	28650.332	0
N ₂	0	0	0	0	0	0	2.28E-02	0.025	8.661234	0	0.025	100
CO	0	0	0	0	0	0	0	0	0	0	0	0
CO ₂	3354.5	3354.5	0	1.626	1.626	0	83.27169306	65.73	-26.6875	5.116	5.116	0
CH ₄	3.15	3.15	0	0	0	0	0	0	0	0	0	0
MDEA	0	0	0	0	0	0	755.8301915	757.5	0.220437	4331.136	4331.136	0
Total	3958.55	3958.55	0	2.767	2.767	0	5868.809534	5886.709	0.304066	33007.239	33007.264	7.57409E-05

Table (4.1):.....Continued

Stream Data	Output Streams					
	Stream No. 2			Stream No. 9		
	Simulation	Field	Error %	Simulation	Field	Error %
Temp.(C)	37.99809726	40	5.0047569	100	100	0
Press.(barg)	126.325	126.325	0	711.325	711.325	0
Comp.	kgmol/hr	kgmol/hr	Error %	kgmol/hr	kgmol/hr	Error %
O ₂	2.46E-04	0	0	2.27E-19	0	0.00E+00
H ₂ S	8.805291796	0.534	-1548.931	376.1252887	392.224	4.104468693
H ₂	1.04E-04	0	0	3.29E-20	0	0
H ₂ O	129.5600036	141.713	8.5757809	33788.22213	33802.02	0.040825585
N ₂	2.28E-02	0.025	0	1.69E-18	0	0
CO	0	0	0	0	0	0
CO ₂	2664.871401	2672.266	0.2767164	779.6422918	754.75	-3.29808437
CH ₄	3.149469603	3.15	0.016838	5.30E-04	0	0
MDEA	1.36E-02	0	0	5086.952608	5088.636	0.033081395
Total	2806.422934	2817.688	0.3997982	40030.94285	40037.63	0.016707167

Table (4.2): Comparison between field data and results of simulation for main streams of Regenerator

Data	Output Streams								
	Stream No. (17)			Stream No. (18)			Stream No. (10)		
	Simulation	Field	Error %	Simulation	Field	Error %	Simulation	Field	Error %
Temp.(C)	45	45	0	45	45	0	127.4768902	129	1.180705
Press.(barg)	181.3	181.3	0	401.325	401.325	0	221.325	221.325	0
Comp.	<u>kqmol/hr</u>	<u>kqmol/hr</u>	<u>Error %</u>	<u>kqmol/hr</u>	<u>kqmol/hr</u>	<u>Error %</u>	<u>kqmol/hr</u>	<u>kqmol/hr</u>	<u>Error %</u>
O ₂	1.42E-19	0	0.00E+00	1.22E-20	0	0	3.88E-26	0	0
H ₂ S	366.0211041	367.881	0.50557	7.10E-02	0.076	6.519051485	10.02482975	24.267	58.68946
H ₂	2.24E-20	0	0	1.93E-21	0	0	3.88E-26	0	0
H ₂ O	64.79441546	59.172	-9.501818	104.0214556	104.499	0.456984689	33666.01437	33638.35	-0.082238
N ₂	1.18E-18	0	0	1.02E-19	0	0	3.45E-26	0	0
CO	0	0	0	0	0	0	0	0	0
CO ₂	777.5421929	748.687	-3.854106	4.68E-02	0.051	8.153793424	2.067242097	6.011	65.60902
CH ₄	5.30E-04	0	0	1.61E-09	0	0	3.46E-26	0	0
MDEA	0	0	0	0	0	0	5086.952608	5088.649	0.033337
Total	1.21E+03	1175.74	-2.774273	1.04E+02	104.626	0.465139967	38765.05905	38757.28	-0.020076

Table (4.3): Comparison between main parameters of Absorption Unit

Parameters Percent	Simulation	Field Data
Reduction Percent of CO_2 in S_9 (%)	79.442	79.662
Increasing Percent of H_2S in S_9 (%)	9.212	13.886
Recovery percent of MDEA in S_{10} (%)	100	100
Separation Efficiency of Sour Water, (%)	99.638	99.516

4.1.2. Claus Unit (Sulfur Recovery Unit) [SRU].

The main sections comprise of thermal reactor section and catalytic convertors as discussed in section [2.3.2]. Simulation results of these sections are done depending on the assumptions made in section [3.2.1].

4.1.2.1 Thermal Reactor Section

Simulation of thermal reactor section shown in Figure (2.7) is done as shown in Figure (4.2). Reactions take place during the combustion of the acid gas streams in the burner placed on front of the thermal reactor. Acid gas is burnt with a controlled quantity of process air. During the acid gases combustion all the combustible components contained in the acid gases are burnt according to the following exothermic reactions [31]:



Side reactions leading to the formation of COS and CS₂ are also to be considered.

Undesired products are related to CO₂ content in acid gas. The reactions are [31]:



Values of the conversions of these reactions are evaluated according to a trial and error method, and depending on the operating data of the process. These values are 31, 3.7, 6.4, 17 and 6 % for reactions (4.1~5) respectively. The product components formed and outlet of thermal furnace satisfied with suggested chemical reactions by Porocel Corp. [32] also with field data[9]. Details of the main streams of this section are shown in Table (4.4). Readings in the table indicate the compatibility between the simulation results and the field data of the unit process. The operating conditions are 181 kPa and 1200 °C.

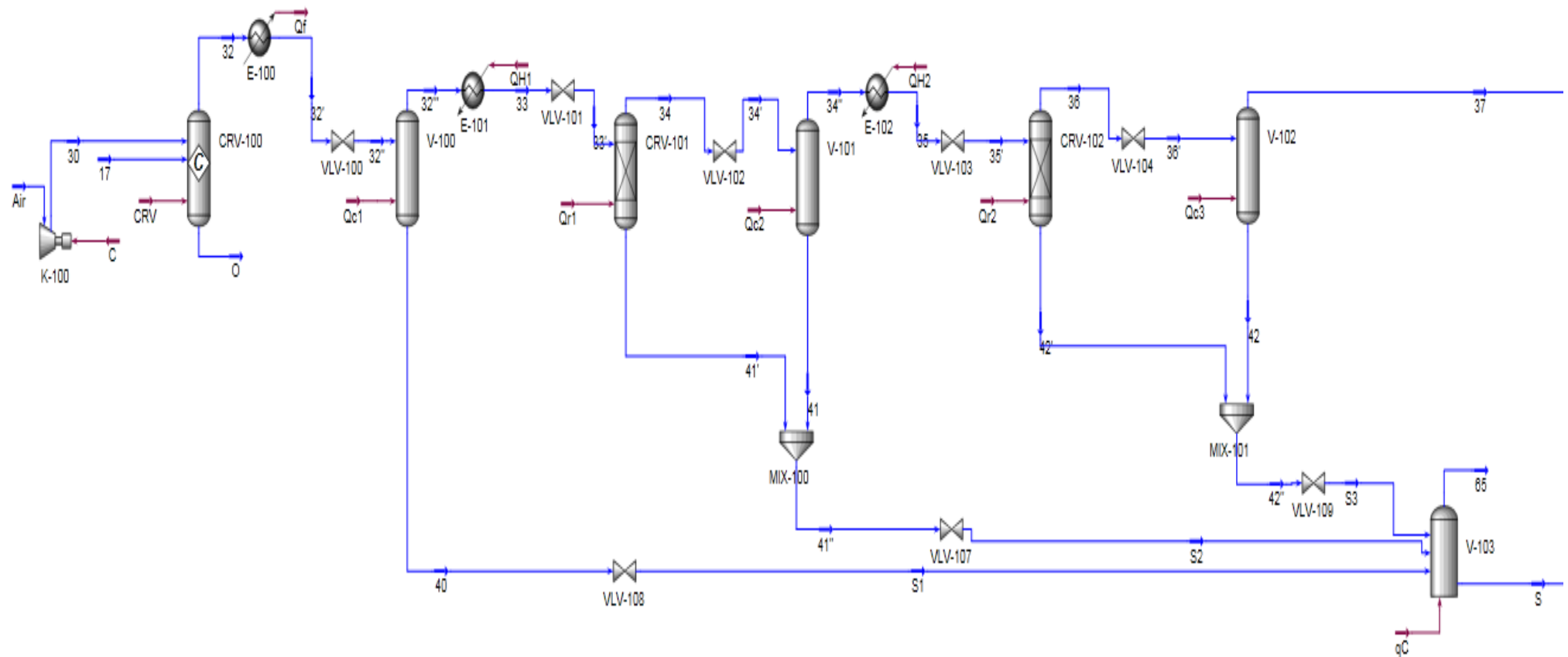


Figure (4.2): Simulation process of Sulfur Recovery Unit [Thermal Reactor + Catalytic Converters]

Table (4.4): Comparison between field data and results of simulation of main streams of Thermal Reactor Section

Data		Data	Output Data		
			Stream No. 32''		
			Simulation	Field	Error %
Temp.(C)	45	Temp.(C)	360	360	0
Press.(barg)	181.3	Press.(barg)	152.325	152.325	0
Comp.	kqmol	Comp.	kqmol/hr	kqmol/hr	Error %
<i>H₂S</i>	3.66E	<i>H₂S</i>	167.641324	170.136	1.4662834
<i>H₂O</i>	64.79	<i>SO₂</i>	93.1340689	92.97	-0.176475
<i>N₂</i>	0	<i>H₂</i>	22.6933082	22.074	-2.8056
<i>CO</i>	0	<i>H₂O</i>	261.6282522	255.984	-2.204924
<i>CO₂</i>	7.78E	<i>N₂</i>	636.4494363	636.455	0.0008742
<i>COS</i>	0	<i>CO₂</i>	761.2858728	732.863	-3.878334
<i>CH₄</i>	5.00E	<i>COS</i>	8.762545134	8	-4.167203
<i>O₂</i>	0	<i>O₂</i>	6.44E-02	0	0
Total	1208.3	<i>C₂S</i>	7.494282023	7.425	-0.933091
		<i>Sliq</i>	81.49459792	81.532	0.0458741
		Total	2040.648119	2007.851	-1.633444

4.1.2.2 Catalytic Convertors Section

Two catalytic convertors connected in series are shown in Figure (2.8). Simulation is done as shown in Figure (4.2). This step is performed in two stages on alumina catalyst; each stage conversion is achieved at optimum inlet temperature and it is followed by the condensation and the separation of the sulfur produced in the catalytic conversion. Temperatures are 305 and 239 °C with conversion 75% and 83% for each stage of catalytic convertors respectively (*by trial and error*). The main reaction involved by Porocel Corp. [32]:



The Claus reaction (4.6) is an equilibrium reaction enhanced by the low temperature. Side reactions leading to the hydrolysis of COS and CS₂ with H₂S formations are important, particularly for the first Claus reactor; the hydrolysis reactions are practically completed at high temperature over specific catalyst.



Decomposition of COS and CS₂ is principally a function of first reactor effluent temperature. Details of the main streams of this section are shown in Table (4.5). Readings in the table indicate the compatibility between the simulation results and the field data of the unit process. In which amount of sulfur recovered in sulfur form is 346.184 kgmol/hr (recovery percent equal to 97.79%), so the accuracy of simulation till this section is acceptable as shown in Table (4.6).

Table (4.5): Comparison between field data and results of simulation of main streams of Catalytic Convertors Section

Data	Output Streams								
	S1 (40)			S2 (41)			S3 (42)		
	Simulation	Field	Error %	Simulation	Field	Error %	Simulation	Field	Error %
Temp.(C)	190.0424425	190.0424425	0	231.7	228	-1.62280702	217.1244061	217	-0.05733
Press.(barg)	100	100	0	100	100	0	100	100	0
Comp.	<i>kqmol/hr</i>	<i>kqmol/hr</i>	<i>Error %</i>	<i>kqmol/hr</i>	<i>kqmol/hr</i>	<i>Error %</i>	<i>kqmol/hr</i>	<i>kqmol/hr</i>	<i>Error %</i>
H₂S	1.95E-02	0	0	1.43E-02	0	0	1.17E-03	0	0
SO₂	1.62E-02	0	0	1.05E-02	0	0	6.37E-04	0	0
H₂	6.21E-05	0	0	1.73E-04	0	0	6.30E-05	0	0
H₂O	1.265445981	0	0	3.699680774	0	0	1.624609118	0	0
N₂	1.24E-03	0	0	3.38E-03	0	0	1.23E-03	0	0
CO₂	2.08E-02	0	0	4.37E-02	0	0	1.71E-02	0	0
COS	5.14E-04	0	0	1.58E-04	0	0	4.31E-05	0	0
O₂	4.19E-07	0	0	1.01E-06	0	0	3.83E-07	0	0
S_{liq}	78.81440879	62.48	-2.614342	190.1287546	199.067	4.49006885	77.25008939	81.794	5.55531
Total	80.14474547	62.48	-2.614342	193.9030561	199.067	2.594073285	78.89519293	81.794	3.544034

Table (4.5) Continued

Data	Output Streams								
	Stream No. 37			Stream No. (38)			Stream No. 65		
	Simulation	Field	Error %	Simulation	Field	Error %	Simulation	Field	Error %
Temp.(C)	145	145	0	260	260	0	260	260	0
Press.(barg)	126.325	126	-3.544033	351.325	351	-0.09259259	351.325	351	-0.092593
Comp.	kqmol/hr	kqmol/hr	Error %	kqmol/hr	kqmol/hr	Error %	kqmol/hr	kqmol/hr	Error %
<i>H₂S</i>	12.83108329	14.405	10.926183	2.74E-02	0	0	2.62E-02	0	0
<i>SO₂</i>	4.738946047	4.43	-6.973951	1.53E-02	0	0	1.20E-02	0	0
<i>H₂</i>	22.69300967	22.074	-2.804248	1.46E-05	0	0	2.84E-04	0	0
<i>H₂O</i>	409.8138081	411.715	0.4617738	6.270807431	0	0	0.300274985	38.263	99.21523
<i>N₂</i>	636.4435878	636.455	0.0017931	1.98E-04	0	0	5.65E-03	24.25	99.9767
<i>CO</i>	0	0	0	0	0	0	0	0	0
<i>CO₂</i>	776.1054682	747.285	-3.85669	1.97E-02	0	0	7.12E-02	0	0
<i>COS</i>	0.919859855	1	-0.202599	2.64E-04	0	0	4.51E-04	0	0
<i>O₂</i>	6.44E-02	0	0	1.60E-07	0	0	1.65E-06	6.446	99.99997
<i>S_{liq}</i>	0	0	0	346.1842349	343.881	-0.66977674	0	0	0
<i>C₂S</i>	0.425775281	0.497	14.330929	0	0	0	0	0	0
<i>Svap</i>	0.404778999	3.272	87.629004	0	0	0	9.02E-03	0	0
Total	1864.440747	1841.051	-1.270456	352.5179504	343.881	-2.51161023	0.425044155	68.959	99.38363

Table (4.6): Parameters Comparison of Sulfur Recovery Unit

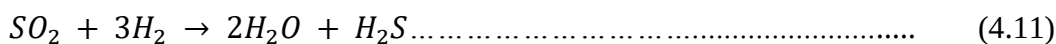
Parameter	Simulation	Field
Amount of sulfur fed to the unit in S ₉	354.0003	369.152
Amount of Sulfur recovered in S	346.1842	343.881
Sulfur Recovery Percent (%)	97.79208	93.15431042

4.1.3. Simulation of Tail Gas Treatment Unit [TGTU]

TGTU mainly comprise of Reducing Reactor Section and H_2S Absorber section as discussed in section [2.3.3]. Simulation results of these sections are done depending on the assumptions made in section [3.2.1].

4.1.3.1 Simulation of Reducing Reactor Section

Simulation of the Reducing reactor section as shown in Figure (2.9) is illustrated in Figure (4.3). The main objective of this section is converting the sulfur compounds to hydrogen sulfide by catalytic hydrogenation to become easy absorption in the next stages. The main chemical reactions taking place in the hydrogenation reactor are listed here below:



The hydrolysis reactions (4.9) and (4.10) initiated in the catalytic converter are almost led to completion; all other sulfur compounds are hydrogenated to H_2S according to the reactions (4.11) and (4.12), [9].

The main operating specifications of the absorber shown in Figure (4.3) were 401.3 and 110.3 kPa as a bottom and top pressures respectively with 7 sieve plates. The waste water effluent sends to sour water treatment unit to reuse it again, while the main stream of product [Stream 52'] send to MDEA absorber. Details of the main streams of this section are shown in Table (4.7). Readings in the table indicate the compatibility between the simulation results and the field data of the unit process. In which amount of sulfur compounds mentioned above in chemical reactions are reached to completely remove in outlet streams as shown in Table (4.7).

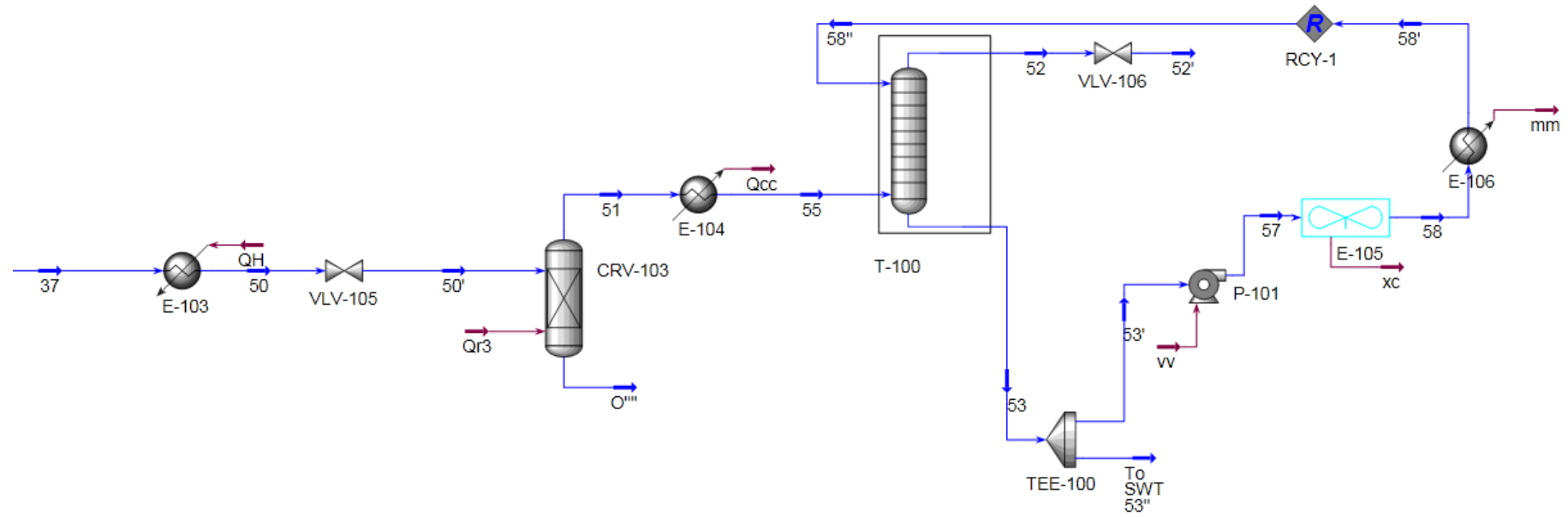


Figure (4.3): Simulation process of Reducing Reactor Section in TGTU

Table (4.7): Comparison between field data and results of simulation of main streams of Reducing Reactor Section

Data	Output Streams					
	Stream No. 52'			Stream No. 53'''		
	Simulation	Field	Error %	Simulation	Field	Error %
Temp.(C)	37.95238514	40	5.1190371	72.19080011	75	3.745599854
Press.(barg)	109.825	109	-0.756881	401.325	401	-0.08104738
Comp.	kqmol/hr	kqmol/hr	Error %	kqmol/hr	kqmol/hr	Error %
<i>H₂S</i>	19.76098035	23.941	17.45967	0.0117	0.078	0
<i>SO₂</i>	0	0	0	0	0	0
<i>H₂</i>	8.071376546	5.512	-46.43281	0.00E+00	0	0
<i>H₂O</i>	92.04978188	111.078	17.130501	325.3928	307.585	-5.78955411
<i>N₂</i>	636.439217	636.455	0.0024798	0.0044	0	0
<i>CO</i>	0	0	0	0	0	0
<i>CO₂</i>	777.3232882	747.953	-3.926756	0.178	0.747	76.17135207
<i>COS</i>	0	0	0	0	0	0
<i>O₂</i>	6.45E-02	0	0	0.00E+00	0	0
<i>S_{liq}</i>	0	0	0	0	0	0
<i>C₂S</i>	0	0	0	0	0	0
<i>S_{vap}</i>	0	0	0	0	0	0
Total	1533.709095	1524.939	-0.575111	325.5869	308.41	-5.56950164

4.1.3.2 Simulation of H_2S Absorber Section

Simulation of the H_2S absorber section as shown in Figure (2.10) is illustrated in Figure (4.4). Approximately all amounts of H_2S and about 20% of CO_2 contained in the process gas are absorbed in the MDEA contactor according to the reactions listed above in section H_2S Absorption by using MDEA. The main operating specifications of the absorber presented in Figure (4.4) were 101.3 and 104.3 kPa as a bottom and top pressures respectively with 12 sieve plates. The semi-Lean MDEA effluent from the bottom of the column recycled to MDEA regenerator to reuse it again, while the main streams of product [stream 54] send to Incinerator. Details of the main streams of this section are presented in Table (4.8). Readings in the table indicate the good agreement between both field and simulated data. In which efficiency of H_2S recovered in sulfur form is 99.21% as presented in Table (4.9). Till now the accuracy of simulation results are acceptable.

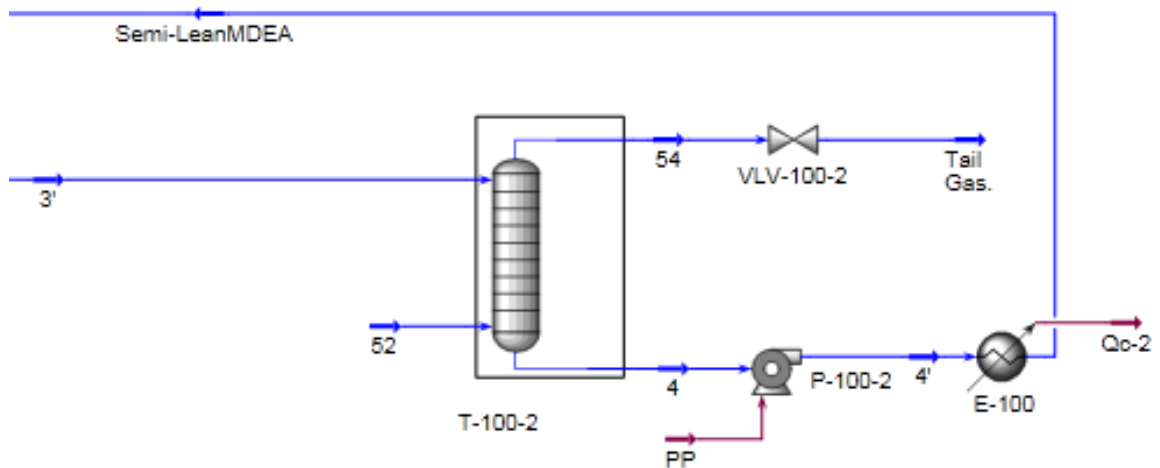


Figure (4.4): Simulation process of H_2S absorber Section in TGTU

Table (4.8): Comparison between field data and results of simulation of main stream of H_2S Absorber Section

Data	Output Data		
	Stream No. 54		
	Simulation	Field	Error %
Temp.(C)	39	40	2.5
Press.(barg)	104.3	102	-2.254902
Comp.	<u>kgmol/hr</u>	<u>kgmol/hr</u>	<u>Error %</u>
H_2S	2.9794	0.251	-1087.012
SO_2	0	0	0
H_2	8.071	5.518	-46.26676
H_2O	83.4995	78.717	-6.075562
N_2	636.4165	636.607	0.0299243
CO	0	0	0
CO_2	693.8124	683.466	-1.513813
Total	1424.8433	1404.559	-1.444176

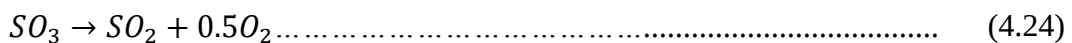
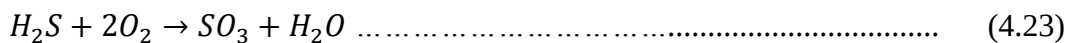
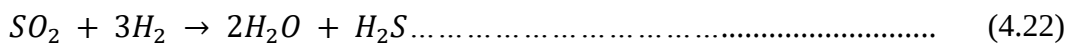
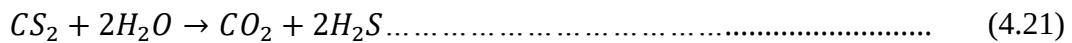
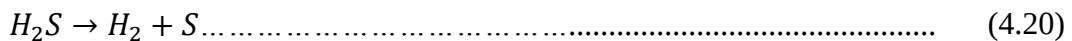
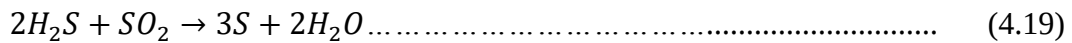
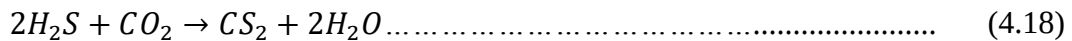
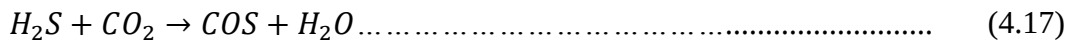
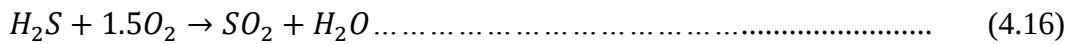
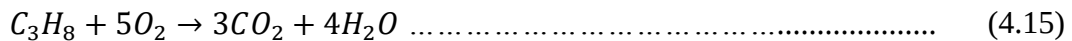
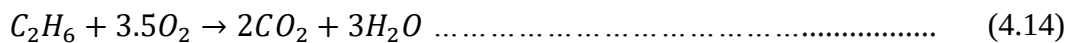
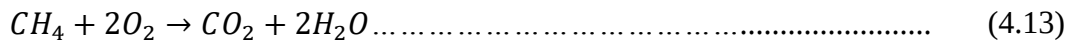
Table (4.9): Parameters Comparison of Claus Unit

Parameter	Simulation	Field
Amount of H_2S in Feed S_9	376.12529	392.224
Amount of H_2S recovered of (SRU+TGTU)	373.14589	391.973
Recovery percent of H_2S in Sulfur form (%)	99.21	99.93

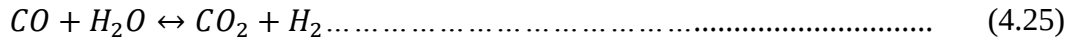
4.1.4. Simulation of Incineration Unit [Incinerator]

Simulation of Incinerator unitas shown in Figure (2.11) is illustrated in Figure (4.5).The incineration of tail gas produced in the SRU and coming from TGTU section is necessary to transform all sulfur compounds present in SO_2 ; flue gases produced in the incineration are allowed to be discharged to atmosphere via a stack.The tail gas ignition temperature is much higher than the actual tail gas temperature, being the fuel components in tail gas present at very low concentrations; for this reason, the tail gas combustion has to be supported by fuel gas combustion.

The incinerator combustion chamber temperature is of $750^{\circ}C$; this temperature has been chosen to assure an almost complete combustion of H_2S and of other sulfur compounds contained in the tail gas; incinerator temperatures not lower than $700^{\circ}C$ are probably acceptable for the almost complete H_2S oxidation; temperatures exceeding $800^{\circ}C$ will lead to a remarkable high fuel gas consumption.Also, the oxygen excess in flue gas is a very important factor for the tail gas incineration; in fact, oxygen excess favors the oxidation of sulfured compounds, besides increasing is not desirable due to SO_3 and NO_x formation.Reactions in the incinerator burner are all hydrocarbon oxidation/combustion as follow:



The first four chemical reactions are almost quantitative. But the chemical reactions concerning H_2 and CO are non-quantitative, but depend on the equilibrium.



In order to start the oxidation (incineration) reactions in the desired direction, it is necessary that the tail gas is heated up to at least 350-400°C. At incineration temperature a part of the hydrocarbons contained in the support fuel gas is not completely oxidized and residual CO is present in the incinerator flue gas discharged to atmosphere (about 100-300 ppm residual CO are expected at 750°C). The tail gas combustion is achieved in a special burner. Products of combustion stay a certain residence time in the incinerator combustion chamber to complete the reactions and are discharged to the atmosphere, through the HP steam superheater, via the existing stack.

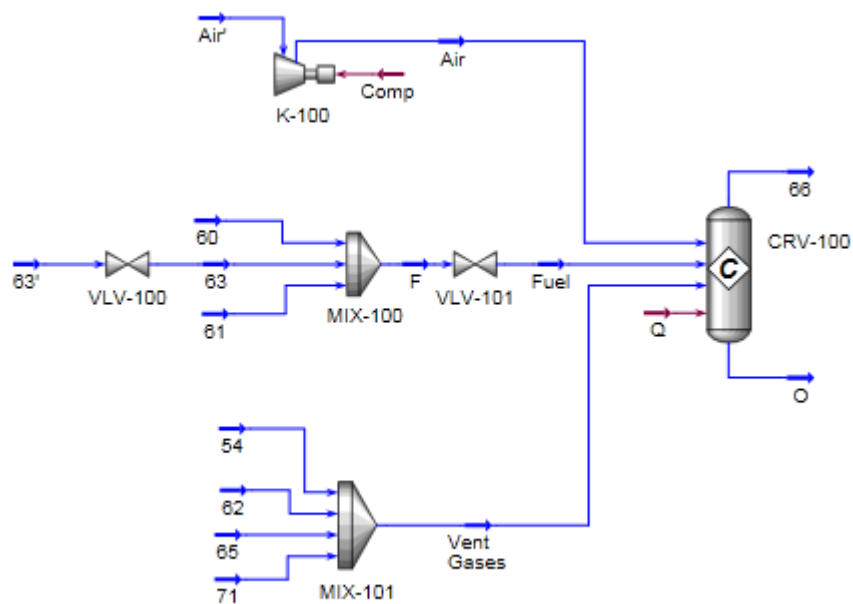


Figure (4.5): Simulation process Incinerator

Readings in the Table (4.10) indicate the good agreement between both field and simulated data. In which overall plant recovery percent of H_2S recovered in sulfur form is 98.029% and 99.794% simulated and field data respectively. Till now the accuracy of simulation results are acceptable.

Table (4.10): Comparison between field data and results of simulation of main stream of Incinerator

Data	Input Streams											
	Air Stream			Stream No. 60			Stream No. 63			Stream No. 61		
	Simulation	Field	Error %	Simulation	Field	Error %	Simulation	Field	Error %	Simulation	Field	Error %
Temp.(C)	30	30	0	50	50	0	15.87	15	-5.8	30	30	0
Press.(barg)	101.3	101.3	0	111.3	111.2	-0.08993	251.3	251.3	0	111.3	111.3	0
Comp.	kgmol/hr	kgmol/hr	Error %	kgmol/hr	kgmol/hr	Error %	kgmol/hr	kgmol/hr	Error %	kgmol/hr	kgmol/hr	Error %
H ₂ S	0	0	0	0	0	0	0	0	0	0.675	0.675	0
SO ₂	0	0	0	0	0	0	0	0	0	0	0	0
H ₂	0	0	0	0	0	0	0	0	0	0	0	0
H ₂ O	151.055	151.055	0	0.78	0.78	0	0	0	0	0	0	0
N ₂	2728.712	2728.712	0	1.44	1.44	0	3.83	3.83	0	2.309	2.309	0
CO	0	0	0	0	0	0	0	0	0	0.159	0.159	0
CO ₂	0	0	0	1.26	1.26	0	0.79	0.79	0	0.478	0.478	0
COS	0	0	0	0	0	0	0.92	1	0	0	0	0
CH ₄	0	0	0	44.76	44.76	0	108.47	108.47	0	66.132	66.132	0
C ₂ H ₆	0	0	0	2.19	2.19	0	15.04	15.04	0	9.078	9.078	0
C ₃ H ₈	0	0	0	1.17	1.17	0	2.38	2.38	0	1.433	1.433	0
nC ₄ H ₁₀	0	0	0	0	0	0	0	0	0	0.558	0.558	0
nC ₅ H ₁₂	0	0	0	0	0	0	0	0	0	0.159	0.159	0
O ₂	725.354	725.354	0	0	0	0	0	0	0	0	0	0
C ₂ S	0	0	0	0	0	0	0.26	0.26	0	0	0	0
Total	3605.121	3605.121	0	51.6	51.6	0	131.69	131.69	0	80.981	80.981	0

Table (4.10).....Continued

Data	Input Streams								
	Stream No. 54			Stream No. 62			Stream No. 65		
	Simulation	Field	Error %	Simulation	Field	Error %	Simulation	Field	Error %
Temp.(C)	39	40	2.5	38	40	5	260	260	0
Press.(barg)	104.3	102	-2.254902	126.3	102	-23.824	101.3	101.3	0
Comp.	kgmol/hr	kgmol/hr	Error %	kgmol/hr	kgmol/hr	Error %	kgmol/hr	kgmol/hr	Error %
H ₂ S	2.9794	0.251	-1087.012	8.8053	0.534	-1548.93258	2.62E-02	0	0
SO ₂	0	0	0	0	0	0	1.20E-02	0	0
H ₂	8.071	5.518	-46.267	1.00E-04	0	0	2.84E-04	0	0
H ₂ O	83.499	78.717	-6.076	129.56	141.713	8.576	0.3003	38.263	99.215
N ₂	636.417	636.607	0.02992	2.28E-02	0.025	8.8	5.65E-03	24.25	99.9767
CO	0	0	0	0	0	0	0	0	0
CO ₂	693.812	683.466	-1.514	2664.871	2672.266	0.277	7.12E-02	0	0
COS	0	0	0	0	0	0	4.51E-04	0	0
CH ₄	0	0	0	3.149	3.15	0.015	0	0	0
C ₂ H ₆	0	0	0	0	0	0	0	0	0
C ₃ H ₈	0	0	0	0	0	0	0	0	0
nC ₄ H ₁₀	0	0	0	0	0	0	0	0	0
nC ₅ H ₁₂	0	0	0	0	0	0	0	0	0
O ₂	6.45E-02	0	0	2.00E-04	0	0	1.65E-06	6.446	99.999
S _{liq}	0	0	0	0	0	0	0	0	0
C ₂ S	0	0	0	0	0	0	0	0	0
SO ₃	0	0	0	0	0	0	0	0	0
S _{vap}	0	0	0	0	0	0	0.00E+00	0	0
Total	1424.843	1404.559	-1.444	2806.409	2817.688	0.40028	0.416	68.959	99.397

Table (4.10).....Continued

Data	Output Streams					
	Stream No. 71			Stream No. 66		
	Simulation	Field	Error %	Simulation	Field	Error %
Temp.(C)	135	135	0	750	750	0
Press.(barg)	102	102	0	101.3	101.3	0
Comp.	<u>kqmol/hr</u>	<u>kqmol/hr</u>	<u>Error %</u>	<u>kqmol/hr</u>	<u>kqmol/hr</u>	<u>Error %</u>
H ₂ S	2.38E-02	0.09	-73.555	0	0	0
SO ₂	1.32E-02	0	0	13.952	1.519	-818.501
H ₂	0	0	0	2.744	2.759	0.534
H ₂ O	0.797	47.111	98.309	931.451	1015.772	8.301
N ₂	10.229	0	0	3382.966	3427.46	1.298
CO	0	30.29	-100	10.394	10.414	0.1858
CO ₂	1.89E-02	0	0	3645.350	3646.386	0.0289
COS	2.00E-04	0	0	0	0	0
CH ₄	0	0	0	0	0	0
C ₂ H ₆	0	0	0	0	0	0
C ₃ H ₈	0	0	0	0	0	0
nC ₄ H ₁₀	0	0	0	0	0	0
nC ₅ H ₁₂	0	0	0	0	0	0
O ₂	2.713	8.02	66.169	142.717	166.067	14.061
C ₂ S	0	0	0	0	0	0
SO ₃	0	0	0	0	0.031	0
S _{vap}	2.30E-03	0	0	0	0	0
Total	13.798	85.511	83.864	8129.575	8270.408	-1.73235

Results shown in Table (4.10) indicate to that, the difference between simulated and field data of SO_2 is very high (the error reaches 818.501 % based on field data), [about 12.433 kgmol/hr]. According to the mass law conservation, the amount of sulfur entering into the incinerator in compounds form (H_2S , CO_2 , and CS_2) is about 95.885 kgmol/hr. These compounds are converted through combustion reactions into 189.633kg/hrof SO_2 gas as recorded by simulation not 97kg/hr as recorded by field data [9]. That reveal there is an error in the field reading of SO_2 .

Generally, emission of gas pollutants from the natural gas sweetening plants will produced when burning of tail gases (acidic waste) during the amine extraction process and during a burning process. Uses of incinerators in the sweetening plants mainly produce emission gas of SO_2 . In this kind of plants use incinerators to tail acidic gases with high chimneys for expulsion the resulting gases to the upper layers of atmosphere, also the temperature of combustion will be high to ensure conversion of H_2S to SO_2 . Use of temperatures not exceeding 750 °C leading to the incomplete combustion of hydrocarbons, especially when high humidity air used in the combustion process, which also leads to form CO , which have a fatal effect on the health of workers, especially in cases of stillness atmospheric air, as it should be noted that the NO_x gases will not form in any way due to lower combustion temperature.

4.2. Comparison of the Gaseous Emissions with International Standard Limitations

Comparison of simulation and field data with the standard limitations [mentioned in section (2.8)] is shown in Table (4.11). Result reveals SO_2 concentration emitted has some deviation more than the allowable international standard limits. In which emission concentrations of SO_2 . Results against the standard limits of four international codes, American (USEPA), Canadian (CEPA), European (ECE) and Saudi (KSA). The (+) sign represents the percentage by which an emission rate of a certain gas exceeding a certain standard limit, and the (-) sign represents the percentage by which an emission rate falls below a standard limit.

Table (4.11): Comparison of Simulation&field data with International Standard Limits of SO₂

<i>ISL</i>	<i>USEPA</i>	<i>ECE</i>	<i>KSA</i>	<i>Egypt</i>
<i>Units</i>	<i>lb/MW.hr</i>	<i>mg/Nm³</i>	<i>lb/MBtu</i>	<i>mg/Nm³</i>
Standard Data	0.9	300	2.3	2500
Simulation Data	1819.91	1307.94	533.36	1307.94
Field Data	730.17	524.76	213.99	524.76
Simulation Dev.%	+202112.50	+335.98	+23089.39	-47.68
Field Dev. %	+81030.38	+74.92	+9203.89	-79.01

Sulfur dioxides emitted exceed all the standard limits set by the USEPA, CEPA, ECE and KSA several times corresponding to standard deviations ranging from 202,112.5% (USEPA), 23,089.39% (KSA) to 335.98% (ECE). However, sulfur dioxide emissions remain within the standard limit set by the Egypt such that the difference between the estimated value and the USEPA limit corresponds to a standard deviation of 47.68%.

Also, there is a main problem of the adjacent area of the Mellitah plant is a dust of byproduct (solid sulfur) that containing in two large temporary storage warehouses. This sulfur is volatilizing with the winds into the neighboring areas [11].

Quantity of CO₂ in the acid gas is 3645.350 kgmol/hr, in which equivalent 160.4 ton/hr, which is completely emitted to atmosphere from the incinerator stack. In addition to this quantity there is also CO₂ emission from the consumed fuel gas at Mellitah complex which is approximately equal to 144 ton/hr [3], taking into consideration that emission of such amount of CO₂ consuming a considerable amount of O₂ which is mean that total CO₂ emission at Mellitah site is equal to 304.4 ton/hr. Above mentioned quantity of CO₂ is emitted to atmosphere, it is to be mentioned that till now there is no proven method to eliminate and/or minimize CO₂ emission [3, 9, 11]. This part of emission could be subjected to deep investigation in order to get rid of CO₂ and produce the required fuel from Mellitah complex without CO₂ production.

4.3. Suggested industrial solutions of environmental problems for nearby areas of Mellitah Complex.

The main suggested industrial solution to reduce gas emissions polluting the environment from the SRU are as follows:

1. Development of additional units (absorption units) to remove sulfur dioxide resulting from the incinerator for reuse.
2. To access the high efficient absorption in absorption that used to remove sulfur compounds and CO_2 , so must be using other solvent with high capacity and low energy consumption (in reboiler), proposed solvent is UCARSOL [33].
3. Use of a solid sulfur (byproduct) in the manufacturing of useful industry materials, such as sulfuric acid or sulfonic acid, which are used as raw materials in other chemical, petrochemical and petroleum industries.
4. Reduce energy consumption as much as possible hence the reduction of emissions is associated with the energy production also reduction of CO_2 emissions by utilizing other sources of energies and using heat integration for the plant units.

4.4. Dispersion of SO_2 emitted from the chimney

Estimated SO_2 emitted from the chimney of the Incinerator of Mellitah gas plant in the local atmosphere are achieved by using DISPER V4.0. According to determined results from simulation process by Aspen Hysys as shown in Table (4.10) for SO_2 emission, the amount of emissions reaches about (892.928 kg/hr), and with known the average speeds and directions of dominant winds (shown in section 3.3.1) in combination with the emission rates are used to calculate the concentration distribution of SO_2 over the surrounding area of the Mellitah plant as shown in Figures (4.6) and (4.7).

The simulation results reveal that the Mellitah gas plant is the main source of sulfur oxides in the area, SO_2 dispersions over the surrounding area (Figure 4.6) can reach all the populated areas in the vicinity of Sabratah city reach high concentrations ranging from 134.89 to 269.7817 $\mu\text{g}/\text{m}^3$. Such concentration can be blamed for functional changes in human lungs if exposure continues for 10 minutes duration. It is recommended that exposure for SO_2 should not exceed 500 $\mu\text{g}/\text{m}^3$ over an average duration of 10 minutes [22]. Health impacts attributed to SO_2 at 125 $\mu\text{g}/\text{m}^3$ concentrations during 24 hrs is also reported [22].

The World Health Organization recommends reducing the emissions of SO_2 during 24 hrs to $20 \mu\text{g}/\text{m}^3$ and using the daily limit rather than the annual limit [22]. While for Surman, Alharsh and Az-Zawia city concentrations reach ranging from 134.89 to $202.33 \mu\text{g}/\text{m}^3$ this range also high with respect to a WHO air quality regulations. For Al-Ajaylat city, SO_2 concentrations are low and in the allowable range, whereas ranging between 20 and $6 \mu\text{g}/\text{m}^3$.

The same behavior are shown in Figure (4.7) for summer winds, but the effect will be in the reverse direction. SO_2 dispersions over the surrounding area (Figure 4.7) can reach all the populated areas in the vicinity of Zuara city reach high concentrations ranging from 337 to $415 \mu\text{g}/\text{m}^3$, this concentration can be blamed for functional changes in human lungs if exposure continues for 10 minutes duration.

Generally, the dispersion of sulfur dioxide occurs by Winter and Summer winds have no influence for a radius of 10 km from the emission point source, so there is no effect on the workers inside the complex.

5.1. Conclusion

Mellitah complex is one of the new worldwide energy supply project. A simulation of sulfur recovery processing unit (SRU) of Mellitah gas plant is done. The main units simulated are MDEA absorption unit, Claus unit, TGT unit, and Incinerator. Results of simulation compared further, verified and agreed with field data.

The amount of sulfur recovered reaches 97.79% that is satisfied with field data (93.13%). The main compositions of emission produced from incinerator stack of SRU are (CO_2 , N_2 , O_2 , SO_2 , and H_2O with small amount of H_2). That reveals to Mellitah plant is applying the latest technology to prevent the emission of H_2S , but the SO_2 concentration emitted with high concentration reaches 1307.94 mg/m³, it have great deviation more the allowable international standard limits. Also, there is very huge quantity of CO_2 emitted to atmosphere (equivalent to 160.4 ton/hr). So, SO_x and CO_2 emissions and dust of sulfur are the main problems that exist for Mellitah plant, which affect the internal environment of nearby area around the plant.

Results of dispersion of air pollutants concentrations show that atmospheric air of Mellitah Gas Plant neighboring regions suffers from the presence of SO_2 contaminant greatly affect the health of the population. But has no effect for a radius 10 km around the complex. So it is necessary to tighten emission control over such industrial plants to be reduced to a minimum to meet allowable limits by publication of the international standards air issued by the World Health Organization.

5.2. Recommendations

Due to a considerable change in the climate and to prevent/minimize the pollution of the plant, the following recommendation is being carried out for a new technology leading to satisfy energy/products requirements without pollutants production;

1. Addition of other development of additional units (absorption units) to remove sulfur dioxide resulting from the incinerator to reuse.

2. Reuse of solid sulfur (byproduct) in the manufacturing of useful industry materials, such as sulfuric acid or sulfonic acid, which are used as raw materials in other chemical, petrochemical and petroleum industries.
3. Optimize and reduce energy consumption as much as possible hence the reduction of emissions is associated with the energy production also reduction of CO_2 emissions by utilizing other sources of energies and using heat integration for the plant units, or by utilizing other sources of energy such as solar energy instead of fossil energy
4. The cost analysis of CO_2 capture processes must be done.

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