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Optimization of Sulfur Recovery and Tail Gas Treatment Units Using Aspen Hysys and Matlab Integration

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Abstract

The sulfur recovery unit (SRU) is an important part of gas processing and crude oil refinery plants. The primary purpose of SRU is to convert sulfur components in the acid gas stream, such as H_2S, SO, SO_2, and COS, to elemental sulfur to comply with rigorous environmental regulations regarding release of these components into atmosphere. SRU with Tail Gas Treating Unit (TGTU) was simulated using Aspen HYSYS simulation software, with actual plant data was used to validate the model. MATLAB was integrated with Aspen HYSYS to optimize ten operating variables of SRU and (TGTU) using genetic algorithm without affecting Sulfur Recovery Efficiency (SRE). When the model was used, sulfur output increased by 2%, Net High-Pressure Steam (HPS) increased by 9%, and Low-Pressure Steam (LPS) decreased by 8%, resulting in an increase in SRE. Using this approach, similar SRUs with varying feed conditions and properties might be optimized.

Key words: Sulfur recovery unit; Tail Gas Treating Unit; Optimization, Aspen HYSYS Simulation; MATLAB; Genetic Algorithm.

Introduction:

Sulfur recovery unit (SRU) plays an important role in the oil and gas industry, as well as being the world's primary supplier of elemental sulfur. Fertilizers, rubber, pharmaceuticals, and cosmetics all require elemental sulfur. Acid gases, particularly those containing sulfur components such as H_2S, SO_2, and COS have harmful effects on the environment and humans[1, 2], so several environmental restrictions have been developed to prevent their release into the atmosphere. To avoid paying a higher fine or being forced to shut down, refineries and gas plants must recover sulfur components from acid gas before burning it in the flare. As a result, most refineries and gas plants construct SRUs with two Claus sections and tail gas treating units, and occasionally three Claus sections[3]. Acid gas processing plants have a high capital and operating cost. Therefore, decision-makers consider them a production cost; even though, they are net energy producers. These units also produce high-pressure steam and low-pressure steam in addition to elemental sulfur[4].

Many efforts were made to identify the most suitable operating variables that maximize steam output and enhance sulfur recovery efficiency (SRE) to reduce hazardous emissions, as this unit has a significant impact on the Total Annual Cost (TAC) of the entire plant.

Ghahraloud et al. [5]established a mathematical model based on Energy and Mass conservation laws to maximize sulfur recovered from Claus Process, Genetic Algorithm (GA) was used to solve the model, which improved the process by 4.63 % over the base case.

Flavio Manenti et al.[6] increased the quantity of steam produced from a sulfur recovery unit by 6% without impacting the amount of sulfur recovered. To do this, they built a kinetic model involving 2400 reactions and 140 species.

Anoop Jagannath et al. [7], used commercial software "Aspen HYSYS" to simulate the process and validate the model. They changed operating conditions and added new Heat Exchangers (HEX) in various positions to increase HPS production. Seven cases

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have been analyzed and compared to each other and to the basic case; two cases out of seven achieved the shortest Pay Back Period (PBP) and the largest HPS production.

Asil et al. [8] compared and selected the optimal enrichment scheme among three schemes with the highest SRE using Aspen HYSYS and Promax. In addition, two scenarios were investigated to compare the effects of combustion air and acid gas feed preheating on running costs and Sulfur Recovery Unit Efficiency.

Salisu Ibrahim et al. [9] proposed a dual-stage acid gas combustion in two Claus furnaces with intermediate sulfur and H_2O extraction this resulted in the removal one of the costlier catalytic stages. Aspen HYSYS and CHEMIKEN PRO were employed to model and simulate the thermal and catalytic sections respectively.

Ramees K. Rahman et al. [3]developed a kinetic model for removing undesired components. they used CHEMIKEN Pro and Aspen HYSYS to simulate the thermal and catalytic sections, respectively, their simulation resulted in a reduction in SRU's fuel gas consumption by 97 % while maintaining undesired component elimination.

Salisu Ibrahim et al. [10] Aspen HYSYS to simulate SRU and investigated the effects of preheating the inlet air, oxygen enrichment of acid gas feed, and methane co-firing on furnace temperature and destruction of Benzene, Toluene, Ethylbenzene and Xylene (BTEX). A kinetic model was used to optimize these variables with the goal of increasing SRE and achieving effective BTEX destruction.

Samane Zarei et al. [11] used simulation software to investigate the impact of O_2 and H_2S concentrations in thermal reactor feed on the system's environmental behavior, and then used the results to create a reaction model that was modified to experimental and plant data. They discovered that changing the oxygen concentration in acid gas feed could reduce environmental emissions by 58.98% and improve sulfur recovery efficiency (SRE) by 48.41% but changing the H_2S concentration had a greater impact on SRE reach to 71% and that reflected on the environment at the same time as the environmental pollutants are reduced by 80.41 %.

In this work, Aspen HYSYS was used in conjunction with genetic algorithm in MATLAB to optimize ten variables of a refining plant's SRU to maximize HPS, LPS, and sulfur recovery. The optimization variables are temperature of combustion air, outlet temperature of thermal waste heat exchanger, temperature of the three sulfur condensers outlet, temperature of two catalytic reactors inlet, makeup hydrogen for hydrogenation reactor flow rate and temperature of TGTU waste heat exchanger outlet. Based on past research, this effort may be the first to optimize such a large number of variables and treat the TGTU and SRU as a single unit simultaneously. Previous models are complicated and less flexible and need a good knowledge of the unit, but the proposed model is more intuitive and easier to apply, and the objective is more flexible to be adjusted to meet site requirements which differ from place to place.

Methodology:

SRU and TGTU are first simulated on Aspen HYSYS using the Sulsim (Sulfur recovery) property package in sub flow sheets that simulate SRU unit operations as this property package contains properties that developed by sulfur experts for simulating the modified Claus process[12], in the same time the acid gas property package is used in the main flow sheet that simulate heating equipment before each unit as the streams contain acid gases, and then the simulated case was tested using data from the real plant. With 98 percent similarity, the data retrieved from Aspen HYSYS matches the data collected from the plant. Then MATLAB code is built to produce variables that were transmitted to a simulated case on Aspen HYSYS and then obtain objective function elements from Aspen HYSYS using the genetic algorithm (GA) toolbox available in MATLAB. The flow of programming code is depicted in Figure 1.

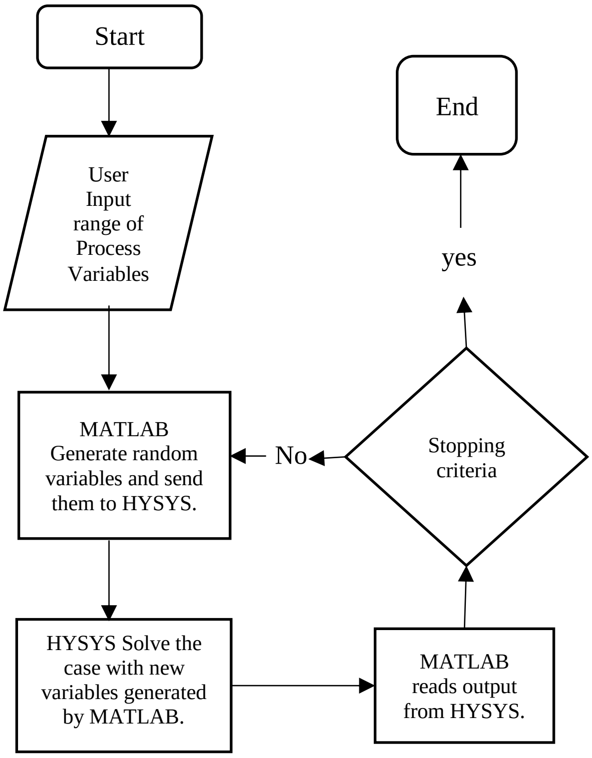

Figure 1: Flow diagram for programming process.

Case Study:

SRU for a huge refinery in Egypt was used as a case study, The design capacity of the unit is 325 t/d, The SRE of the SRU and TGTU is 99.9+%. As a plant flow diagram, the Sulfur Recovery Unit (SRU) case is simulated using Aspen HYSYS, and Figure 2 depicts the simulation flow sheet. Before thermal and catalytic reactors, HPS is used to pre-heat combustion air and process gas streams, while super-heated steam is utilized to pre-heat the tail gas stream before the TGTU Hydrogenation reactor. HPS is produced from Waste Heat Exchanger (WHE) in thermal stage and LPS is produced from Sulfur Condensers and TGTU Waste Heat Exchanger. The amount of steam required to raise the temperature of the combustion and acid gas streams to the desired temperature and create HP

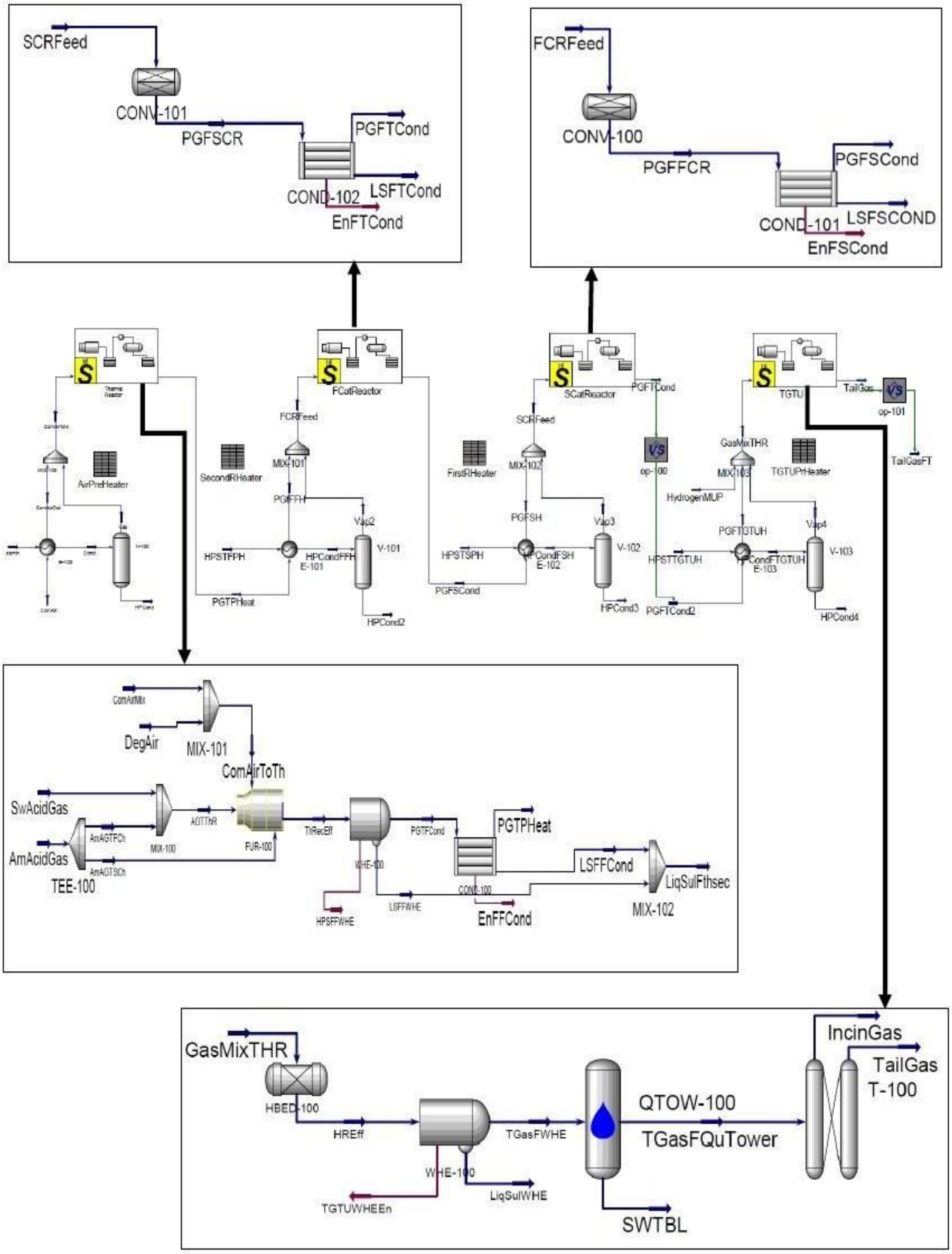

Figure 2: SRU and TGTU flow sheet

condensate with 0.4 % vapor phase was calculated using the spreadsheet model available in Aspen HYSYS Palette. For this aim, Anoop Jagannath et al [7] employed the adjust model, however, the spreadsheet model allows the simulated case to converge faster.

Data retrieved from the simulated case study showed very good matching with data collected from the plant as the total sulfur produced from the simulated case is 187 kmol/h is nearly equal to the actual plant production 190 kmol/h, Figures 3, 4, 5, 6, and table 1 show that simulation results are validated with plant data for important streams.

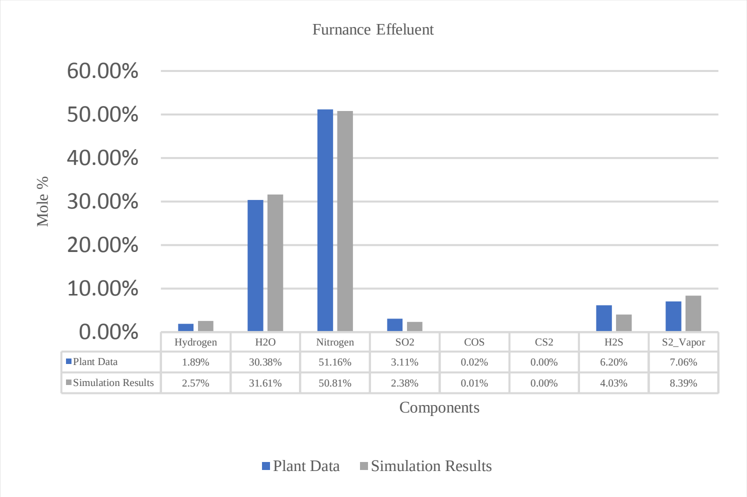

Figure 3: Comparison between the composition of furnace effluent stream in plant and simulation results

Table 1: Comparison between conditions of important streams in plant and simulation results

Conditions	Furnace Outlet PD	Furnace Outlet SR	TGTU Inlet PD	TGTU Inlet SR	Absorber Inlet PD	Absorber Inlet SR	Incinerator Inlet PD	Incinerator Inlet SR
Mol. Flow (Kmol/h)	860	866	1573	1653	1000	997	977	995
Temp (°C)	1356	1324	240	240	38	38	40	40
Press. (Kg/Cm^2)	0.50	0.64	0.19	0.28	0.05	0.08	0.02	0.03

**PD is symbol to plant data
**Sr is symbol to simulation results.

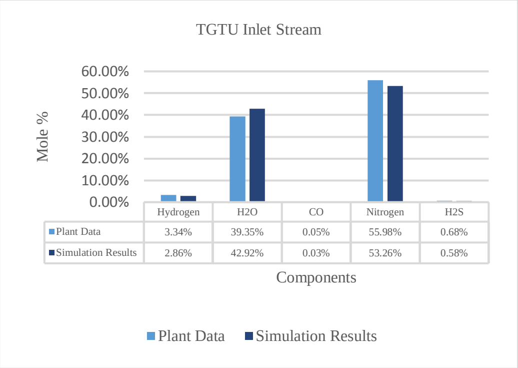

Figure 4: Comparison between the composition of TGTU inlet stream in plant and simulation results.

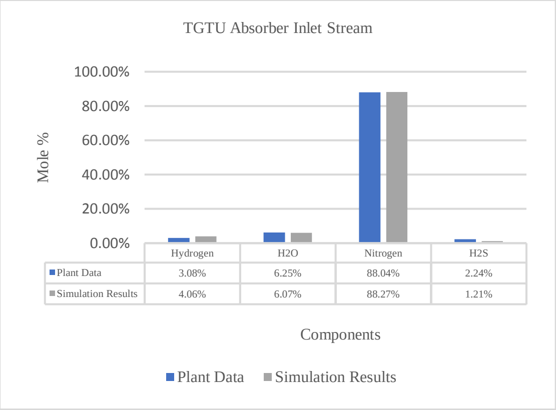

Figure 5: Comparison between the composition of TGTU absorber inlet stream in plant and simulation results

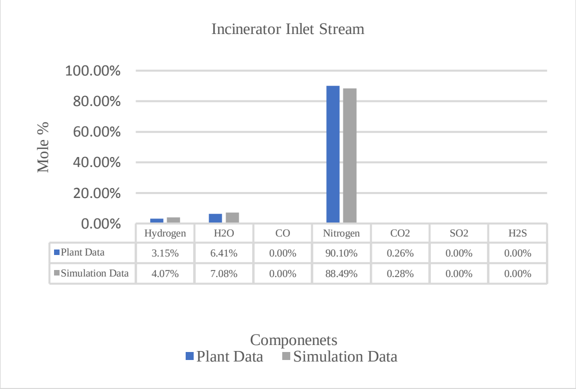

Figure 6: Comparison between the composition of incinerator inlet stream in plant and simulation results

The plant has three identical Claus trains that feeds from amine unit and sour water stripping unit as sour water produced from refinery contains (H_2S and NH_3)[13], two of which are in service and one of which is on standby, as well as one TGTU, As a result, the acid gas feed to SRU trains is divided by two, and one Claus train is simulated, with the tail gas stream produced from the simulated SRU being multiplied by two before being treated in the TGTU. Figure 2 depicts the flow sheet. The combustion air flow rate was calculated to be sufficient to convert one-third of H_2S to SO_2 while also completing the oxidation of other hydrocarbons; its value was set as a fixed variable. Gas recycled from TGTU contains a relatively little amount of H_2S, which may be ignored in comparison to H_2S in the acid gas feed stream. As a result, the recycle stream is ignored to shorten the time necessary to converge the Model. The dimensions of the reactors have been altered to match the dimensions of actual plant reactors.

SRU waste heat reboilers producing saturated HPS with pressure 45.8 kg/cm^2 which is utilized to pre-heat the combustion air and acid gas streams before they enter the catalytic reactors, and the reminder of saturated HPS that produced in the SRU will be superheated at quality that consistent with the Refinery steam network. The sulfur condensers and TGTU waste heat reboiler is producing saturated LPS with pressure 4.8 kg/cm^2. The hydrogen source for hydrogen that fed into the hydrogenation reactor has the following properties: (Temp.: 40 $^{\circ}$C, Press.: 20 kg/cm2, and 96.4 percent mole fraction from hydrogen).

Optimization Process:

The goal of optimizing ten variables was to enhance sulfur recovery, which has a significant impact on the unit's overall efficiency and emission disposal to the environment, as the goal of installing the unit is to reduce harmful emissions to levels that comply with environmental requirements. Additionally, the optimization process tries to enhance the net quantity of HPS (HPS produced from WHE minus HPS consumed in preheating processes), as well as the amount of LPS produced from sulfur condensers. The final two factors have a significant impact on the unit's profit since the steam produced is re-used in the plant, lowering the plant's running costs. the total amount of SO_2, H_2S, COS, and CS_2 created on the gas stream that was transported to the incinerator was entered into an objective function as a cost, and the optimization procedure tended to lower this amount in order to maximize the total objective function.

The upper and lower limitations for decision variables in the Genetic Algorithm Toolbox were set based on the design constraints, duties, and safety considerations of the actual unit in the plant. The objective of the optimization is to maximize Sulfur production, HPS and LPS, while minimizing (H_2S,

SO_2, COS, CS_2) emissions, Hydrogen and Cooling Water flow rates. The objective function tends to prioritize sulfur production first in order to achieve the highest sulfur recovery efficiency for environmental reasons, followed by maximizing Net HPS production (HPS produced minus HPS consumed heating in the unit), and finally maximizing LPS production and minimizing makeup hydrogen and cooling water. The device that used for the optimization process has the following specification (Processor: Intel(R) Core (TM) i7-4710MQ CPU @ 2.50GHz 2.50 GHz, Ram: 8 GB).

Equations:

HPS Equations:

$$HPS_C = HPS_{cah} + HPS_{c1r} + HPS_{c2r}. \quad (1)$$

$$SHPS_C=HPS_{chr}. \quad (2)$$

$$HPS_P = HPS_{ptwhe}. \quad (3)$$

$$HPS_N = HPS_P – (HPS_C + SHPS_C). \quad (4)$$

LPS Equations:

$$LPS_p = LPS_{pfc} + LPS_{psc} + LPS_{ptc} + LPS_{ptwhe}. \quad (5)$$

Elemental sulfur equation:

$$S_p = S_{pfc} + S_{psc} + S_{ptc}. \quad (6)$$

Objective function:

$$ObFun =\min -(S_{pf}. S_p + HPS_{pf}. HPS_N + LPS_{pf}. LPS_p – Ppf. (H_2S_{si} + SO_{2si} + COS_{si} + CS_{2si}) – CW_{pf}. CW_C – H_{pf}. H_c) \quad (7)$$

Constraints

$$T_{call} <= T_{ca} <= T_{Caul}. \quad (8)$$

$$T_{gfwhell} <= T_{gwhe} <= T_{Tgfwheul}. \quad (9)$$

$$T_{gffscll} <= T_{gffsc} <= T_{gffscul}. \quad (10)$$

$$T_{gtfrll} <= T_{gtfr} <= T_{gtflul}. \quad (11)$$

$$T_{gfsscll} <=T_{gfssc} <= T_{gfsscul}. \quad (12)$$

$$T_{gtsrll} <=T_{gtsr} <= T_{gtsrul}. \quad (13)$$

$$T_{gftscll} <=T_{gftsc} <= T_{gftscul}. \quad (14)$$

$$T_{tgthrll} <= T_{tgthr} <= T_{gthrul}. \quad (15)$$

$$H_{thrrll} <= H_{thrr} <= H_{thrrul}. \quad (16)$$

$$T_{tgftwhell} <= T_{tgftwhe} <= T_{tgftwheul}. \quad (17)$$

Results and discussion:

Decision Variables:

Ten decision variables were studied in case studies to see how they affected objective function aspects (Net Production from HPS, LPS and Liquid Sulfur). The results are summarized in the graphs below.

Figure 7 shows that increasing the combustion air temperature has a minor effect on objective function elements, as HPS production is unaffected by the increase in combustion air temperature because HPS consumed for heating the combustion air stream is recovered in the Waste Heat Exchanger (WHE) in the thermal section due to an increase in furnace flame temperature. This occurs until the temperature reaches 205 °C, after that any increase above this temperature reduces the net HPS production. However, the overall effect is around 0.04 percent of total HPS produced. While LPS production decreases somewhat as combustion air temperature rises, total sulfur generated rises slightly, indicating that increasing the temperature of inlet combustion air improves thermal reactor efficiency.

Figure 8 depicted the relationship between the objective function elements and the second decision variable, the temperature of the gas stream produced by WHE in the thermal portion. We discovered that while the temperature of WHE output gas has no effect on the amount of generated sulfur, when the temperature is reduced, the net amount of HPS increases and

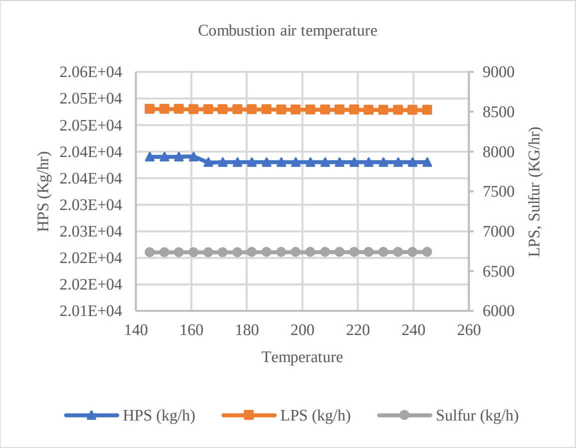

Figure 7: The effect of combustion air temperature on HPS, LPS and sulfur production

LPS decreases.

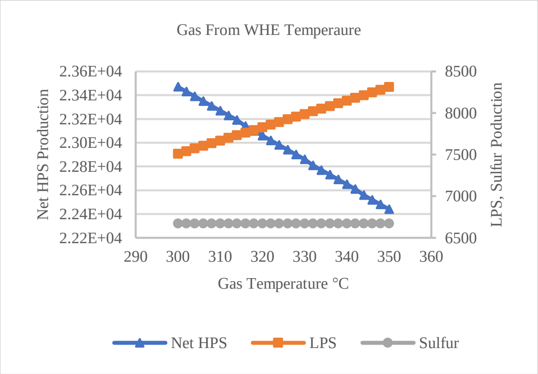

Figure 8: The effect of WHE outlet temperature on HPS, LPS and sulfur production

The relationship between the temperature of the process gas from Sulfur condensers and the goal function elements is depicted in Figure 9. It is worth to notice that as the temperature rises, net HPS production increases but sulfur and LPS production drops. This can be explained by the fact that as the temperature of the condenser output increased, the amount of HPS necessary to raise the temperature of the process gas to the temperature that required by the catalytic reactor dropped, resulting in an increase in net HPS generation. The amount of condensed sulfur and LPS decrease as the temperature difference between the inlet and outlet gas stream decreases as the condenser output temperature increases.

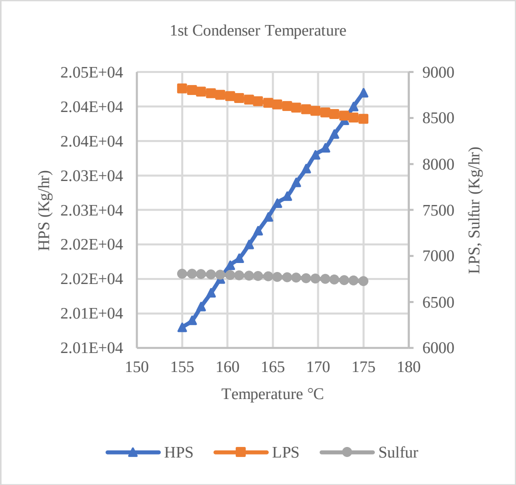

Figure 9: The effect of condenser outlet stream temperature on HPS, LPS and sulfur

Figure 10 shows that as the temperature at the input of catalytic converters increases, net HPS and sulfur production decline, whereas LPS increases as the HPS consumed for heating process gas to catalytic converter temperature increases. While sulfur production decreases because the reaction between SO_2 and H_2S is an exothermic reaction[14], the rate of reaction decreases as temperature increases, increasing converter inlet temperature leads to increase process gas outlet temperature, so the temperature difference between the inlet and outlet of sulfur condensers will increase if the outlet temperature is fixed, which explains the increase in LPS production when the temperature of the catalytic converter inlet is increased.

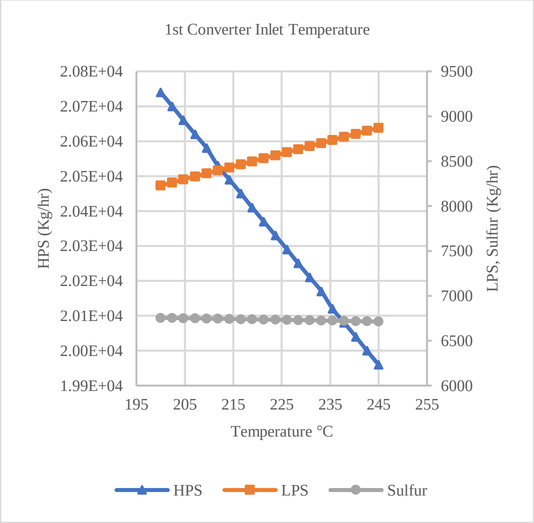

Figure 10: The effect of catalytic converter inlet stream temperature on HPS, LPS and sulfur production.

Other elements of the objective function, such as harmful emissions to the environment, such as H_2S, SO_2, CS_2 and COS which should be minimized, and the amount of cooling water required to cool recycled gas stream to absorption tower temperature, are influenced by decision

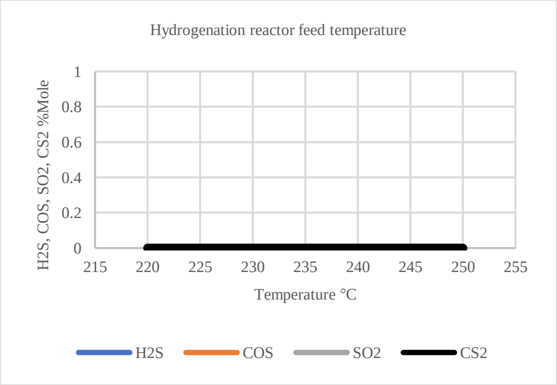

Figure 11: The effect of Hydrogenation reactor inlet stream temperature on the concentration of sulfur components in incinerator gas stream.

variables related to Tail Gas Treating Unit (TGTU). The main goal of the TGTU is to convert all sulfur compounds in the tail gas after the Claus converter to H_2S[15], then send the sulfur-free gas to the incinerator and the other gas stream back to the SRU for more sulfur recovery. At all ranges of choice variables, the flow rate of hazardous components (H_2S, SO_2, CS_2, COS) in the gas stream supplied to the incinerator was almost zero as shown in the studied cases, and illustrated in figures 11, 12 and 13.

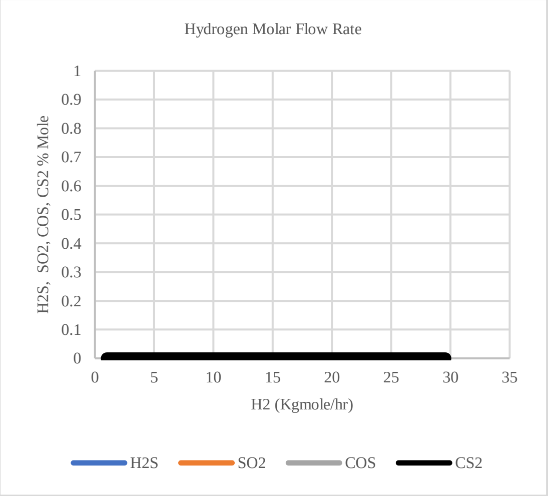

Figure 12: The effect of Hydrogen flow rate on the concentration of sulfur components in incinerator

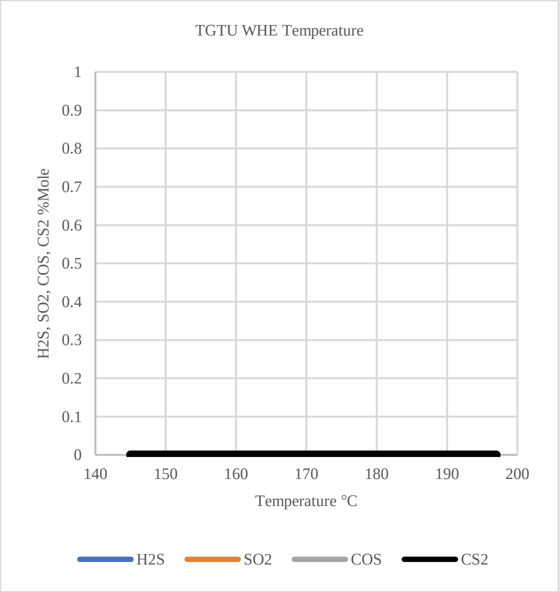

Figure 13: The effect of WHE outlet temperature on the concentration of sulfur components in incinerator gas stream.

Figures 14, 15 and 16 show that TGTU decision variables have little influence on the total sulfur output of the unit, which is due to the unit's high sulfur recovery efficiency of more than 99.99 %, which means that nearly no sulfur compounds escape to the environment. On the other hand, while net HPS production decreases as the hydrogen molar flow rate and inlet temperature of the hydrogenation reactor rise, LPS production rises as the hydrogenation reactor's outlet temperature rises, which influences LPS generated by TGTU WHE. The third TGTU decision variable is the temperature of the WHE output stream, which has only a little effect on LPS generation that decreases when temperature of WHE output stream increases, as the temperature difference between the outlet and inlet temperatures of WHE gas streams decreases.

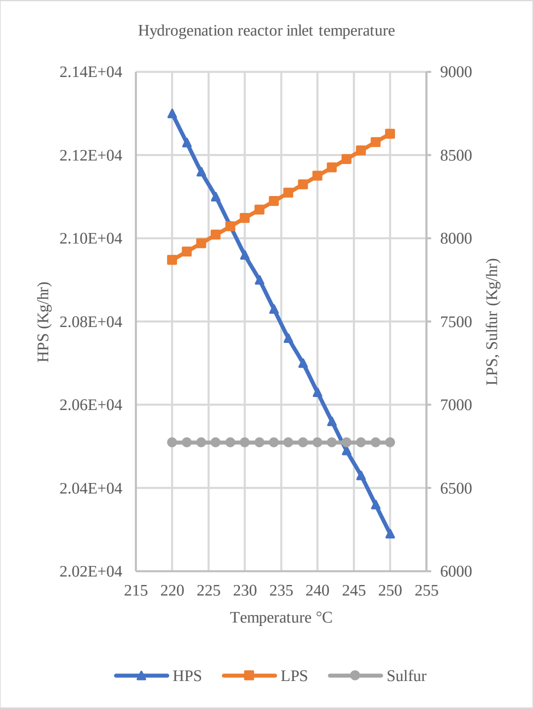

Figure 15: The effect of Hydrogenation reactor inlet stream temperature on HPS, LPS and sulfur production.

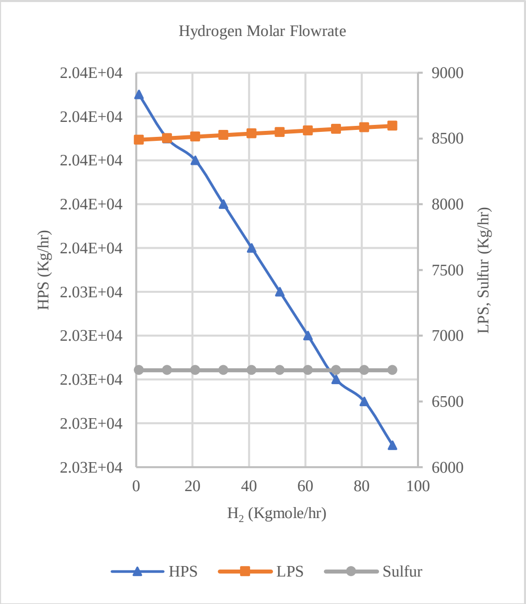

Figure 14: The effect of Hydrogen flow rate on HPS, LPS and sulfur production.

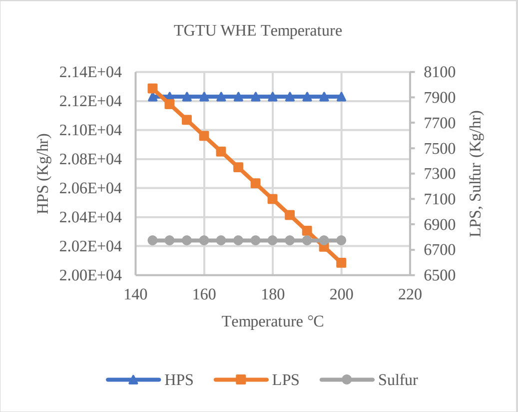

Figure 16: The effect of WHE outlet stream temperature on HPS, LPS and sulfur production.

First, the values of decision variables at which the plant is presently working were recorded and used as a base case in a simulation case, which was then compared to the values created by the optimization process. Table 3 illustrates this comparison. Table 2 shows that liquid sulfur production increased by 2%, HPS from Thermal WHE decreased by 1%, and HPS used to preheat gas streams and combustion air streams before reactors decreased by 41%, resulting in a total increase in Net HPS production by 9%, LPS production decreased by 8%, cooling water decreased by 4%, and hydrogen consumed in hydrogenation reactors decreased by 52%. In both the base and optimized scenarios, the amount of H_2S, SO_2, COS, and CS_2 transferred to the incinerator is zero. Table 3 summarizes the values of decision variables in each case and can be used to explain these results. When the temperature of combustion air was reduced from 240°C to 145°C in the base case, HPS that was used to heat the stream was reduced. At the same time, the flame temperature of the thermal reactor was reduced, resulting in a lower outlet temperature of the gas stream from the reactor, which influenced the amount of HPS produced from thermal WHE. As the temperature of sulfur condensers decreased in the optimized case the amount of liquid sulfur that condensed from the gas stream increased and LPS production should be increased but LPS in the optimized case decreased and this because the temperature of inlet gas stream to first catalytic converter in the optimized case is 40 °C less than base case led to depression in converter outlet stream temperature at the same time the third sulfur condenser outlet temperature in the optimized case is 6 °C higher than the base case resulted in more depression in total LPS production.

Table 2: Values of objective function elements in base case and optimized case

Objective Function Elements	Base Case	Optimized Case	Difference	Difference %
Liquid sulfur Produced (T/Y)	47,836	48,880	1,044	2%
HPS Produced(T/Y)	186,188	183,950	-2,238	-1%
HPS Consumed (T/Y)	36,944	21,754	-15,189	-41%
Net HPS (T/Y)	149,244	162,196	12,952	9%
LPS Produced (T/Y)	55,316	51,042	-4,274	-8%
Cooling water used (T/Y)	11,698,707	11,215,311	-483,396	-4%
Hydrogen Used (T/Y)	0,460	0,222	-0,238	-52%
H_2S in incinerator gas (T/Y)	0,000	0,000	0,000	0%
SO_2 in incinerator gas (T/Y)	0,000	0,000	0,000	0%

Table 3: Values of Optimized variables in base case and optimized case

Decision Variables	Base Case	Optimized Case	Difference
Combustion Air Temperature °C	240	145	-95
Thermal WHE Temperature °C	338	300	-38
1st Sulfur Condenser Temperature °C	178	160	-18
1st Converter Temperature °C	240	200	-40
2nd Sulfur Condenser Temperature °C	173	159	-14
2nd Converter Temperature °C	200	200	0
3rd Sulfur Condenser Temperature °C	165	171	6
Hydrogen Molar Flow Rate (Kgmole/hr)	20.7	10	-10.7
Hydrogenation Reactor Temperature °C	240	220	-20
TGTU WHE Temperature °C	170	145	-25

Conclusion:

- SRU was optimized using Aspen HYSYS and MATLAB software, resulting in a 9 percent increase in net HPS production and a 2% increase in sulfur recovery, but an 8 percent decrease in LPS production.
- Adding TGTU to the optimization process resulted in a 52% reduction in makeup hydrogen used in the hydrogenation reactor, as well as a 4 % reduction in cooling water rate.
- When a calculation sheet model is added to a simulated case instead of an adjust model, the time to conversion is reduced, allowing more trials to be completed in an acceptable amount of time.
- The proposed model might be utilized in practice to optimize SRU decision variables when unit feed conditions change.

Future Work:

The recycle stream from the TGTU unit is supposed to be a fixed stream to reduce flowsheet conversion time, however in practice, the condition of this stream changes as SRU operational variables change. However, adding a recycle block to the flow sheet significantly increases the time required to converge.

Abbreviations definition:

HPS_C: Total pressure steam consumed in SRU.
HPS_{cah}: High pressure steam consumed for heating combustion air stream.
HPS_{c1r}: High pressure steam consumed for heating process gas before first catalytic reactor.
HPS_{c2r}: High pressure steam consumed for heating process gas before Second catalytic reactor.
$SHPS_C$: Total Super Heated high pressure steam consumed in SRU.
HPS_{chr}: High pressure steam consumed for heating tail gas before hydrogenation reactor.
HPS_N: Net high pressure steam produced form SRU.
LPS_p: Total low pressure steam produced from SRU and TGTU.
LPS_{pfc}: Low pressure steam produced from first sulfur condenser.
LPS_{psc}: Low pressure steam produced from second sulfur condenser.
LPS_{ptc}: Low pressure steam produced from third sulfur condenser.
LPS_{ptwhe}: Low pressure steam produced from TGTU waste heat exchanger.
S_p: Total elemental sulfur produced from SRU.
S_{pfc}: elemental sulfur produced from first sulfur condenser.
S_{psc}: elemental sulfur produced from second sulfur condenser.
S_{ptc}: elemental sulfur produced from third sulfur condenser.
H_2S_{si}: Amount of H_2S produced in incinerator stream.
SO_{2si}: Amount of SO_2 produced in incinerator stream.
COS_{si}: Amount of COS produced in incinerator stream.
CS_{2si}: Amount of COS produced in incinerator stream.
CW_C: Total Cooling water consumed in TGTU.
S_{pf}: Sulfur price.
HPS_{pf}: High pressure steam price.
LPS_{pf}: Low pressure steam price.
P_{pf}: Air pollutants price.
CW_{pf}: Cooling water price.
H_{pf}: Hydrogen Price.
T_{call}: Lower limit temperature of Combustion air stream.

T_{ca}: Temperature of Combustion air stream.
T_{Caul}: Upper limit temperature of Combustion air stream.
$T_{gfwhell}$: Lower limit temperature of acid gas stream from thermal waste heat exchanger.
T_{gwhe}: Temperature of acid gas stream from thermal waste heat exchanger.
$T_{Tgfwheul}$: Upper limit temperature of acid gas stream from thermal waste heat exchanger.
$T_{gffscll}$: Lower limit temperature of acid gas stream from first sulfur condenser.
T_{gffsc}: Temperature of acid gas stream from first sulfur condenser.
$T_{gffscul}$: Upper limit temperature of acid gas stream from first sulfur condenser.
T_{gtfrll}: Lower limit temperature of acid gas stream to first catalytic reactor.
T_{gtfr}: Temperature of acid gas stream to first catalytic reactor.
T_{gtflul}: Upper limit temperature of acid gas stream to first catalytic reactor.
$T_{gfsscll}$: Lower limit temperature of acid gas stream from Second sulfur condenser.
T_{gfssc}: Temperature of acid gas stream from Second sulfur condenser.
$T_{gfsscul}$: Upper limit temperature of acid gas stream from Second sulfur condenser.
T_{gtsrll}: Lower limit temperature of acid gas stream to second catalytic reactor.
T_{gtsr}: Temperature of acid gas stream to second catalytic reactor.
T_{gtsrul}: Upper limit temperature of acid gas stream to second catalytic reactor.
$T_{gftscll}$: Lower limit temperature of acid gas stream from third sulfur condenser.
T_{gftsc}: Temperature of acid gas stream from third sulfur condenser.
$T_{gftscul}$: Upper limit temperature of acid gas stream from third sulfur condenser.
$T_{tgthrll}$: Lower limit temperature of tail gas stream to hydrogenation reactor.
T_{tgthr}: Temperature of tail gas stream to hydrogenation reactor.
T_{gthrul}: Upper limit temperature of tail gas stream to hydrogenation reactor.
H_{thrrll}: Lower limit of hydrogen molar flow rate to hydrogenation reactor.
H_{thrr}: Hydrogen molar flow rate to hydrogenation reactor.
H_{thrrul}: Upper limit of hydrogen molar flow rate to hydrogenation reactor.
$T_{tgftwhell}$: Lower Limit temperature of tail gas stream from TGTU WHE.
$T_{tgftwhe}$: Temperature of tail gas stream from TGTU WHE.
$T_{tgftwheul}$: Upper Limit temperature of tail gas stream from TGTU WHE.

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