

Energy and Environmental Conservation by SRU TGTU Amine Optimization

Mohammed Albuainain, Dedik Rahmat Ermawan

Fadhili Gas Plant Department, Saudi Aramco, Fadhili, Saudi Arabia

Email address:

mohammed.buainain.4@aramco.com (Mohammed Albuainain), dedikrahmat.ermawan@aramco.com (Dedik Rahmat Ermawan)

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Abstract: Energy and environmental conservation have become the topic of every major and minor discussion around business conduct and industry. Managing site energy utilization has been always crucial for ensuring an efficient and environmentally friendly operations. Sulfur Recovery Unit (SRU) Tail-Gas Treatment Unit (TGTU) Amine energy utilization, i.e. process cooling and amine pumping, is technically dictated by amine circulation. Design amine rate cannot be reliably applied to drive TGTU energy usage to optimum point as it fails to consider others process parameters such as train capacity and amine strength. This potentially hinders TGTU operation from achieving its optimum operating point. A comprehensive optimization study using advanced process simulation and empirical modeling analysis to develop operating envelope correlations was completed. The study resulted in the development of the “TGTU Amine Energy Optimization Smart Advisory Dashboard”, which intuitively optimizes site energy utilization in a digital-interface form. Subsequently, the results were incorporated in a live model providing real-time Operational Analytics and decision-making capabilities for plant engineers and operators. The dashboard is capable to dynamically map and drive the site energy utilization to its optimum point, by providing multiple benefits that include prescribing a reliable amine rate as a dynamic operating envelope in order to drive TGTU energy utilization efficiency, mapping TGTU energy utilization and corresponding energy saving as the amine circulation is optimized, and continuous monitoring of “Environmental Performance”, i.e. carbon footprint corresponding reduction as a result. The study represents a good example of how to capture low-hanging fruit in energy efficiency with no capital expenditure, thus cost-effectively contributing to achieving sustainability targets.

Keywords: Sustainability, Energy Efficiency, Optimization, Operational Analytics, Sulfur Recovery, Tail-Gas Treatment

1. Introduction

Energy and environmental conservation have become the topic of every major and minor discussion around business conduct and industry. The energy transition in the face of climate change dictates that businesses manage their effects on the environment and people more effectively, as this is evident to contribute financial and reputational benefits [1]. The topic of energy efficiency is thus integral to industrial operators' ability to reduce their emissions and improve their bottom-line. The International Energy Agency (IEA) emphasizes that energy efficiency measures play a critical role in reducing emissions by curbing energy demand growth through different sectors, as it could contribute to 40% of the emissions abatement required by the Paris Agreement [2]. The oil and gas industry are no strange to such discussion as

they are leaders in continuously improving energy efficiency measures since the 1970s [3]. In this study we focus on the Tail-Gas Treatment process of the Sulfur Recovery Unit typically present in oil and gas operations.

Managing site energy utilization has been always crucial for ensuring an efficient and environmentally friendly operations. Sulfur Recovery Unit (SRU) Tail-Gas Treatment Unit (TGTU) Amine section energy utilization, i.e. process cooling and amine pumping is technically dictated by amine circulation [4]. Design amine rate cannot be reliably applied to drive TGTU energy usage to optimum point as it fails to consider some others process parameters, i.e. train capacity and amine strength. This potentially hinders TGTU operations from its optimum operating point. Therefore, a comprehensive technical assessment was conducted to develop a smart advisory dashboard which prescribe a

reliable amine rate by acknowledging aforementioned actual process conditions. This could potentially minimize TGTU's energy utilization and minimize site carbon footprint.

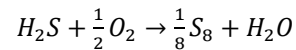
In this paper, we discuss the typical sulfur recovery process and associated tail-gas treatment operations along with their environmental legislation drivers. Then we briefly explain the theory of linear regression and process optimization as the foundation for our optimization study. We then employ a well-structured methodology to optimize the process parameters by employing advanced process simulation and empirical modeling analysis to develop dynamic operating envelopes. The results are then plotted and analyzed, and subsequently incorporated in a dashboard that provide smart advisory solution to users; resulting in enhanced operational, financial and environmental performance. We conclude the study with a set of recommendations for further improvement.

2. Background and Context

2.1. Sulfur Recovery Process Overview

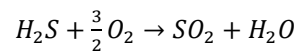
Sulfur recovery refers to the conversion of H_2S to elemental sulfur, usually as a by-production of oil & gas processing. Carl Friedrich Claus developed the original sulfur recovery process back in 1883. In this process, partial oxidation is used to produce elemental sulfur from hydrogen

sulfide gas (H_2S) in a single step of a pre-heated catalyst bed [5].

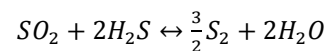


At that time, sulfur recovery was limited due to the fact that the reaction was extremely exothermic and lack of controllability of the reaction temperature.

The Claus process was later modified in 1938 by I. G. Farbenindustrie A. G. in Germany, where the oxidation of 1/3 H_2S to SO_2 was achieved in a boiler while remaining 2/3 H_2S are reacted with SO_2 over a catalyst. This became the standard process for recovering sulfur. In the modified Claus process, the reaction is carried out in two steps, air reacts with H_2S in a thermal stage, oxidizing only one-third to SO_2 [5].



The remaining H_2S in the thermal stage is reacted with SO_2 giving elemental sulfur vapor. This is referred to as the Claus reaction and it is endothermic limited by equilibrium.



A typical Sulfur Recovery Unit (SRU) process using the Claus reaction is shown in figure 1.

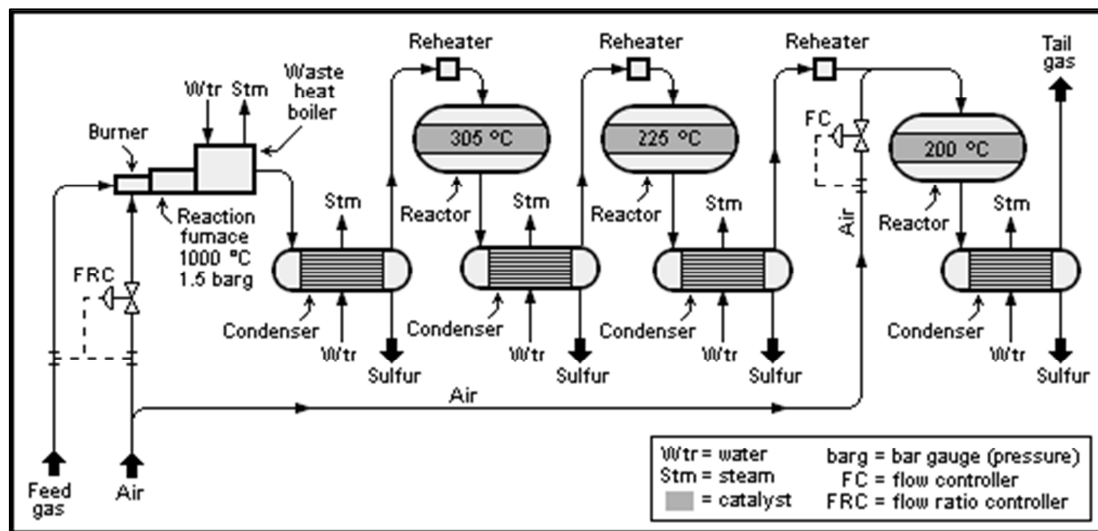
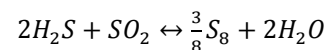
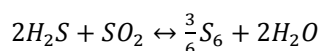


Figure 1. Typical Process Flow Schematic of SRU [6].

The typical Claus process has usually two stages, a thermal stage and a catalytic stage. In the thermal stage, the two reactions indicated above occur producing sulfur vapor which condensed in the first condenser to liquid sulfur. The liquid sulfur is drained through a hydraulic seal to a sulfur collection pit, while the remaining gas is reheated and routed to the catalytic section. In the catalytic section, SO_2 is reacted over activated alumina in exothermic reactions represented by the below chemical equations [5].



After each catalytic reactor, liquid sulfur is removed in the sulfur condenser, thereby shifting the reaction to the right, (shifting the equilibrium reaction to produce more sulfur). The effluent tail-gas containing sulfur compounds and vapor is routed for a tail-gas treatment unit (TGTU) for enhanced recovery of sulfur and improved environmental performance, as typically (depending on local environmental regulations) incineration in a thermal oxidizer to SO_2 before dispersion to the atmosphere is usually employed [5].

2.2. Environmental Regulations

As the world becomes more aware of environmental sustainability and health matters in relation to human consumption and production, so will international and national environmental regulations and policies [7]. Over the last 30 years, the world has witnessed increased environmental regulation on the consumption, production and release of many chemicals. Additionally, the global impact of climate change and associated chemicals that have direct impact in global warming such as carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) is driving more pressure on an international and national scale to reduce emissions. Such emissions reductions can be achieved through multiple levers that include energy efficiency, electrification, technology and innovation improvements [8].

More recently, the concept of ESG investing (ESG stands for environmental, social, and corporate governance) have taken center-stage as the debate on addressing climate change and the energy transition continues [9]. ESG investing refers to the global trend of shifting capital investment from high-emissions sources (e.g.: fossil-fuels, ICE engines, etc.) to environmentally sustainable investments such as renewables and bioenergy [10]. International regulations and policies are starting to establish ESG investing frameworks that mandate certain allowable levels of release of environmental pollutants as a pre-condition to investment decisions making. For example, International Finance Corporation (IFC), an organization part of The World Bank, provides low-interest loans, zero to low-interest credits, and grants to developing countries that support a wide array of investments in such areas as education, health, public administration, infrastructure, financial and private sector development, agriculture, and environmental. In 2012, IFC released the IFC's Environmental and Social Performance Standards as

part of the IFC's Sustainability Framework (Table 1). These standards define IFC clients' responsibilities for managing their environmental and social risks, requiring them to apply a certain level of Performance Standards (PS) that applies to all investment and advisory clients whose projects go through IFC's initial credit review process [11].

Table 1. IFC's Sustainability Framework Performance Standards (PS).

PS1	Assessment and Management of Environmental and Social Risks and Impacts
PS2	Labour and Working Conditions
PS3	Resource Efficiency and Pollution Prevention
PS4	Community Health, Safety, and Security
PS5	Land Acquisition and Involuntary Resettlement
PS6	Biodiversity Conservation and Sustainable Management of Living Natural Resources
PS7	Indigenous Peoples
PS8	Cultural Heritage

Effectively, environmental regulations are only becoming more stringent, requiring greater effort of technological innovations to reduce environmental pollutants to the lowest possible level while maintain profitable operations.

2.3. Sulfur Tail-Gas Cleanup

As the previous section outlines, environmental regulations are becoming more and more stringent. In the past, the tail-gas from the Claus processing stage was normally incinerated, however, such arrangements are not permitted anymore due environmental regulations. The tail-gas contains small quantities of sulfur which needs clean up. Such process can occur in one of three ways: reduction to H₂S, SO₂ scrubbing, and catalytic oxidation. For the subject of this paper, the discussion will be limited to the reduction process.

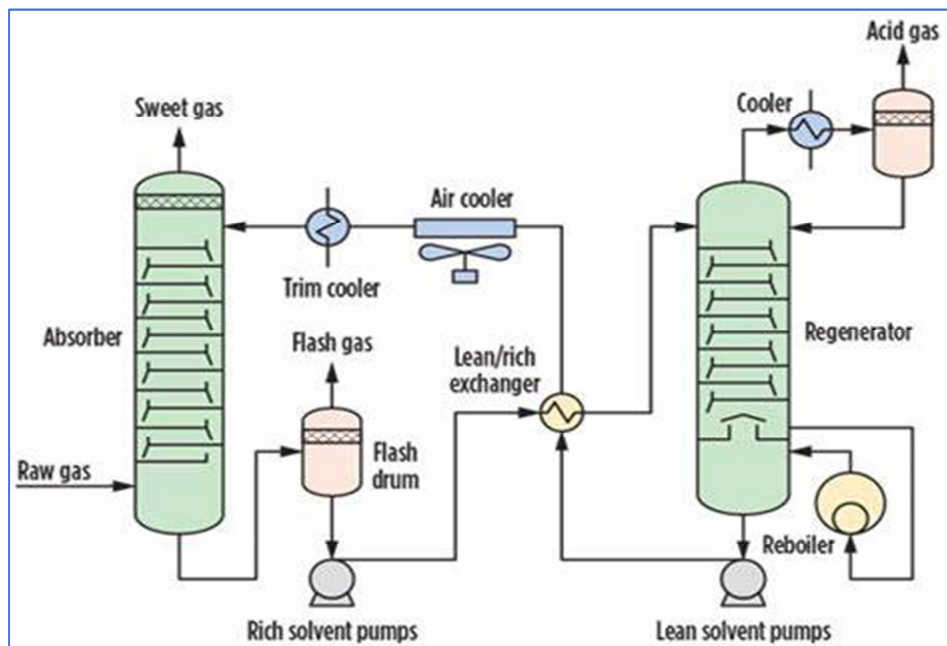


Figure 2. Typical Amine Section of TGTU [12].

In the reduction tail-gas cleanup process, all the sulfur compounds in the tail-gas are converted to H₂S by hydrogenation. The converted H₂S is selectively absorbed with amine-based solvent before being regenerated. After regeneration, the rich gas is recycled back to the Claus unit. The common amine solvents include generic MDEA (40-50 wt%), among other solvents. Cooling of lean amine is important for H₂S-amine equilibrium and improve the selectivity of H₂S over CO₂. With the tail-gas treatment unit (TGTU), only CO₂ is emitted from the process with minimal amounts of SO₂ (depending on efficiency). The major energy consumers in the TGTU are the rich/lean amine pumps, and the lean amine cooler. Typical amine section of TGTU process is shown in figure 2.

3. Linear-Regression and Optimization Theory

3.1. Linear Regressions Analysis

Linear regression is a simple but powerful tool in mathematics that enables informed relationship interpretation between variables. Regression models in general refer to the tool used to describe the relationship between variables by fitting a line to data points. It simply enables the estimation of the effects of changes on dependent variables in relation to the independent variables. There are many types of regression models including linear, logarithmic, and nonlinear [13].

Simple linear regression applies in analyzing two variables and the relationship strength between them. It can also be used to predict the value of a dependent variable as the independent variable changes. Simple linear regression assumes homogeneity of variance (minor change in errors), independence of observations (no inter-relationships between data points) and normality in probabilistic distribution, in addition of course to the relationship being linear [13].

The formula for simple linear regressions is:

$$y = \beta_0 + \beta_1 X + \epsilon$$

Where;

y is the dependent variable;

X is the independent variable;

β_0 is the intercept at $X = 0$;

β_1 is the regression coefficient;

ϵ is the error of the model;

Linear regression is widely used in empirical modeling analysis and process optimization, where in the former models are built based on observable data and in the latter a dependent variable is maximized or minimized based on varying input variables and constraints.

3.2. Optimization in Process Engineering

In chemical engineering, process optimization refers to the

application of mathematical optimization techniques to the improvement of chemical unit operations and unit processes. This involves the modeling and simulation of complex process operations and observing trends and relationships between variables. In the age of computing, process simulation software lends themselves as very powerful tools in conducting multivariable complex optimization models to find out the best possible solution to an optimization problem given a set of constraints. Linear regressions, among other techniques are employed as well [14].

In this paper, simulation software was used to optimize the amine circulation and cooling rate at the TGTU section of a sulfur recovery unit [15]. The results were then extrapolated using linear regression modeling to create optimum operating envelopes in accordance with the optimized case study. The following section provides a deep-dive into the methodology and analysis along with the results obtained, with the aim of optimizing energy consumption and environmental performance.

4. SRU TGTU Amine Optimization Case Study

4.1. Methodology

Simulation engine has been employed (Figure 3) to assist the technical assessment and develop the “SRU TGTU Amine Energy Optimization Smart Advisory Dashboard”.

In the simulation, the TGTU hereinafter referred as Shell Claus Off-Gas Treating (SCOT) Unit is modeled with acid gas feed into the SCOT absorber and lean amine entering in cross-current flow arrangement. The off-gas from the SCOT absorber is sent to a thermal oxidizer while the rich amine is pumped to the lean-rich exchanger. The rich amine is then sent to the SCOT regenerator to be stripped by steam and regenerate the amine to be recycled back to the absorber. The acid gas from the regenerator is sent back to the Claus section. The lean amine is pumped back to the SCOT absorber through the rich-lean exchanger, the fin-fan cooler and then through the trim cooler. This arrangement represents the typical SCOT unit operation with the major energy consumers being the amine pumping, fin-fan cooling and reboiler duty.

In the simulation model, a systematic method was followed (Figure 4). In the initialization step, design input parameters such as inlet conditions, equipment data, and concentrations were used in the model set-up. Next, the model was validated by the design output parameter and stream conditions. Then in the simulation step, the base model simulation was executed and the optimization of manipulated variables and objective function along with its constraints was completed. Finally, the results were analyzed and extrapolated to form the optimum operating envelopes.

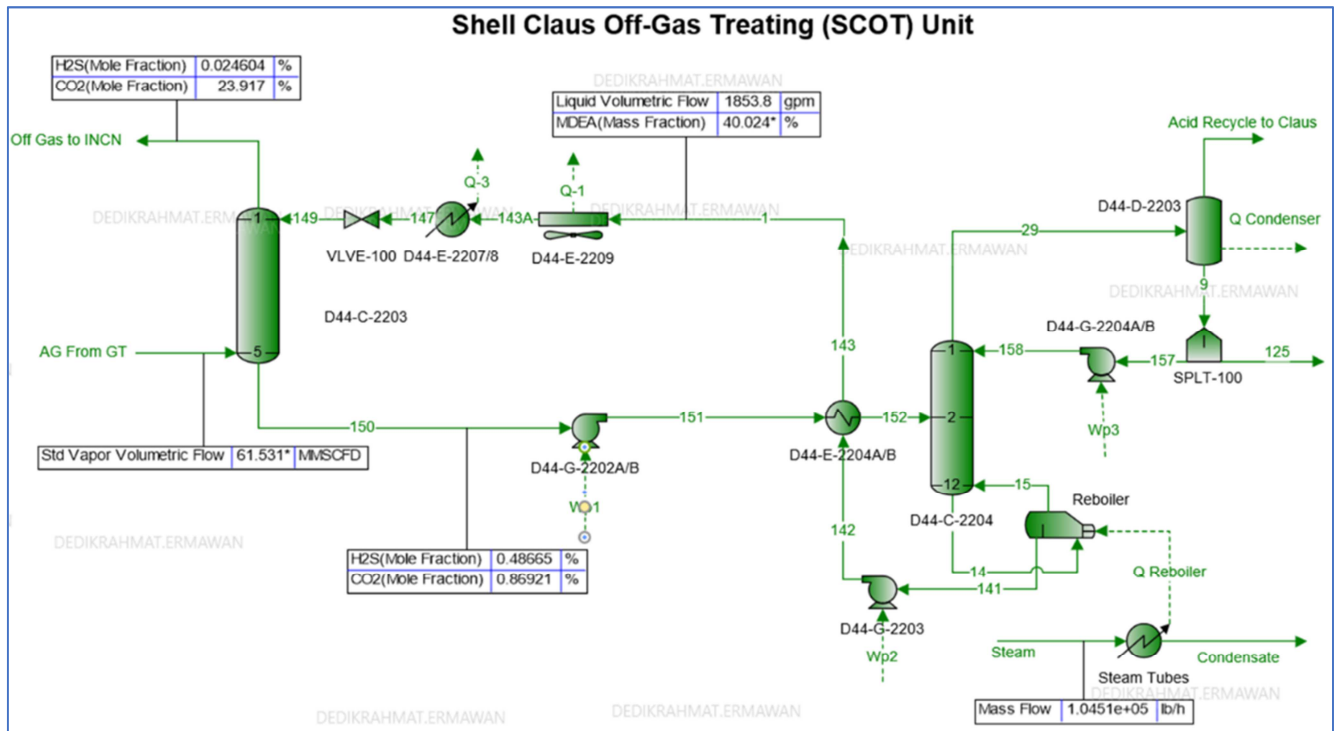


Figure 3. Simulation Flowsheet.

The methodology incorporates the optimum stream conditions obtained for the simulation at 40% and 35% amine strength (optimum amine circulation rate as a function of feed capacity and amine strength). The results were then extrapolated to 30% amine strength using linear extrapolation. The obtained amine circulation rate and corresponding train capacity were then used to develop the Optimum Operating Envelope. At the same time, the energy

consumption for major equipment were calculated and plotted against optimum amine circulation rate to obtain the Energy Utilization Correlation. This was subsequently used to construct the Energy Map Analysis, which lively provides site energy usage. This map has been then incorporated in the dashboard to intuitively represent TGTU energy optimization, i.e. rich/lean amine pumps and process cooling.

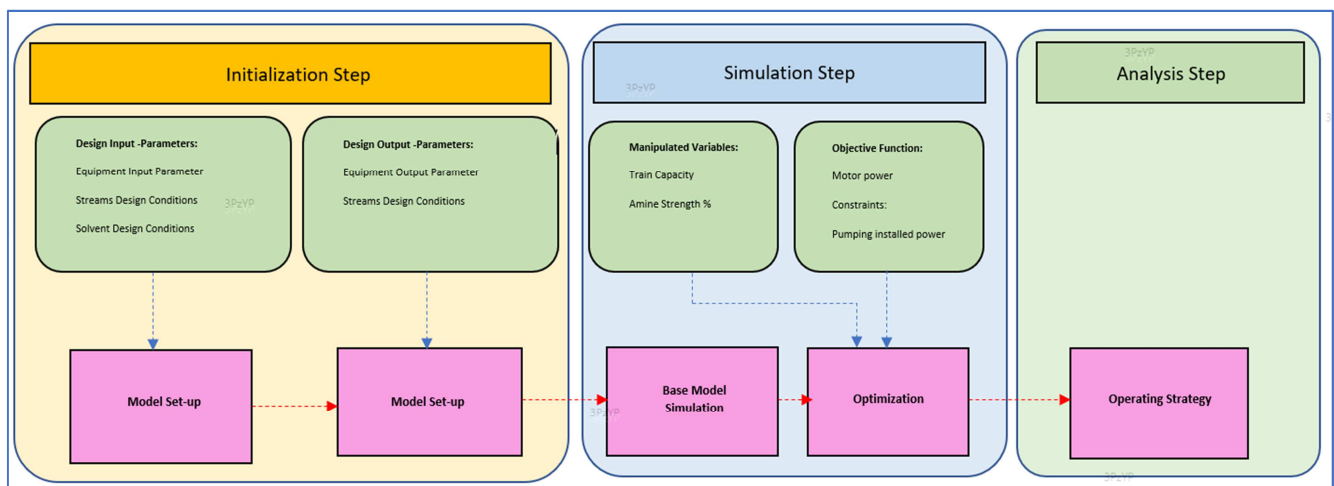


Figure 4. Methodology Flowchart.

4.2. Data & Simulation

The below data is obtained from simulation for amine strength of 40 and 35%.

Table 2. Simulation Data.

AG Flowrate, SCFM	Amine Strength, %	OFF Gas H ₂ S, PPM	OFF Gas CO ₂ , %-mol	Amine Rate, GPM	Lean Pump Power, HP	Rich Pump Power, HP	Lean Amine Cooler Duty, BTU/hr
42,728.89	40.00	246.00	23.92	1,853.80	211.49	141.60	46,326,602.24
38,194.20	40.00	246.00	23.98	1,641.00	187.10	125.33	41,000,777.34
34,722.00	40.00	247.00	24.04	1,479.00	168.67	113.03	36,976,161.16
31,249.80	40.00	247.00	24.10	1,324.00	150.82	101.11	33,077,314.24
27,777.60	40.00	247.00	24.16	1,166.00	132.74	89.04	29,128,159.61
24,305.40	40.00	247.00	24.23	1,012.00	115.12	77.27	25,279,620.39
42,728.89	35.00	247.00	23.82	1,930.00	221.53	148.70	49,182,605.42
38,194.20	35.00	247.00	23.90	1,723.00	196.20	131.75	43,576,298.07
34,722.00	35.00	247.00	23.96	1,552.00	176.63	118.65	39,244,151.47
31,249.80	35.00	246.00	24.02	1,388.00	157.98	106.17	35,115,870.61
27,777.60	35.00	247.00	24.09	1,219.00	138.65	93.23	30,834,690.44
24,305.40	35.00	247.00	24.16	1,058.00	120.23	80.90	26,757,376.01

Based on the simulation data obtained above which reflects the optimum amine circulation rate as a function of train capacity (AG flowrate) and amine strength, the optimum conditions at 30% amine strength were obtained using linear extrapolation, as per below formula and table.

Extrapolation formula:

$$y(x) = b + \frac{(x-a)}{(c-a)}(d-b)$$

Where;

- a: amine strength at 40%;
- b: amine rate at 40%;
- c: amine strength at 35%;
- d: amine rate at 35%;
- x: amine strength at 30%;
- y(x): amine rate at 30%;

Table 3. Extrapolated Data.

AG Flowrate, SCFM	Amine Strength, %	OFF Gas H ₂ S, PPM	OFF Gas CO ₂ , %-mol	Amine Rate, GPM	Lean Pump Power, HP	Rich Pump Power, HP	Lean Amine Cooler Duty, BTU/hr
Extrapolated data to 30 %:							
42,728.89	30.00	246.50	23.87	2,006.20	231.58	155.80	52,038,608.60
38,194.20	30.00	246.50	23.94	1,805.00	205.31	138.17	46,151,818.79
34,722.00	30.00	247.00	24.00	1,625.00	184.59	124.28	41,512,141.79
31,249.80	30.00	246.50	24.06	1,452.00	165.15	111.23	37,154,426.97
27,777.60	30.00	247.00	24.13	1,272.00	144.55	97.42	32,541,221.28
24,305.40	30.00	247.00	24.20	1,104.00	125.34	84.53	28,235,131.62

The results at 40% amine strength were used as the basis to evaluate the energy map and savings, as well as emissions reduction.

Table 4. Energy Consumption.

Major Energy Consuming Equipment in TGTU Amine Section							
Amine Strength, %	Amine Rate, USGPM	Rich Amine Pump, BTU/hr	Lean Amine Pump, BTU/hr	Lean Amine Cooler, BTU/hr			
40.00	1,853.80	538331.33	360,445.86	Fan-Motor Energy	244,181.69		
	1,641.00	476253.70	319,014.70	Fan-Motor Energy	216,109.94		
	1,479.00	Pump Motor	287,706.14	Fan-Motor Energy	194,896.69		
	1,324.00	Energy	257,366.24	Fan-Motor Energy	174,346.36		
	1,166.00	337883.09	226,644.43	Fan-Motor Energy	153,530.86		
	1,012.00	293033.76	196,698.66	Fan-Motor Energy	133,245.70		

Table 5. Energy Map & Saving.

Amine Strength, %	Opt'd Amine Rate, USGPM	Rich Amine Pump, BTU/hr	Lean Amine Pump, BTU/hr	Lean Amine Cooler, BTU/hr	TOTAL BTU/hr
40.00	1,853.80	538,361.70	360,477.44	244,188.00	1,143,027.14
40.00	1,641.00	476,347.52	319,079.33	216,143.09	1,011,569.94
40.00	1,479.00	429,137.48	287,563.85	194,793.11	911,494.44
40.00	1,324.00	383,967.38	257,410.15	174,365.66	815,743.19
40.00	1,166.00	337,923.02	226,672.83	153,542.84	718,138.69
40.00	1,012.00	293,044.34	196,713.67	133,247.18	623,005.19

Amine Strength, %	Opt'd Amine Rate, USGPM	TOTAL BTU/hr	SAVING, %
40.00	1,853.80	1,143,027.14	1.35%
40.00	1,641.00	1,011,569.94	12.69%
40.00	1,479.00	911,494.44	21.33%
40.00	1,324.00	815,743.19	29.59%
40.00	1,166.00	718,138.69	38.02%
40.00	1,012.00	623,005.19	46.23%

Table 6. Emissions Map & Reduction.

Amine Strength, %	Opt'd Amine Rate, USGPM	Rich Amine Pump TPA	Lean Amine Pump TPA	Lean Amine Cooler TPA	TOTAL TPA	Reduction, %
40.00	1,853.80	2,529.96	1,694.02	1,147.53	5,371.50	1.35%
40.00	1,641.00	2,238.53	1,499.47	1,015.74	4,753.74	12.69%
40.00	1,479.00	2,016.67	1,351.37	915.40	4,283.45	21.33%
40.00	1,324.00	1,804.40	1,209.66	819.41	3,833.48	29.59%
40.00	1,166.00	1,588.02	1,065.22	721.55	3,374.80	38.02%
40.00	1,012.00	1,377.12	924.43	626.18	2,927.73	46.23%

4.3. Analysis

As hinted before, solely applying design amine ratio cannot drive site energy utilization to optimum point as it fails to consider others process parameters, i.e. train capacity and amine strength. By utilizing process simulators, the correlation for each parameter can be identified thus allowing a dynamic representation for amine ratio – amine circulation

needed for specific process condition. Exercising through the simulation software, amine ratio correlations were identified. This dynamically provide an accurate prediction for the required amine circulation by considering the actual train load and amine strength. By extrapolating the trend, Amine Ratio Operating Envelope can be then developed (Figure 5). Having the envelope, amine circulation can be minimized thus drive site energy utilization to its optimum.

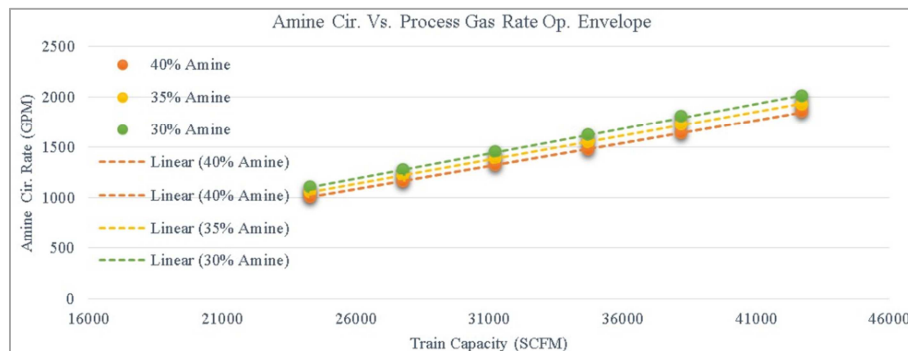


Figure 5. Amine Ratio Operating Envelope.

As the operating envelope (Figure 5) could guide the TGTU operating point to its optimum condition, site energy utilization can be minimized. The simulation software was then employed to predict the site energy utilization correlation as the amine circulation was optimized (Figure 6).

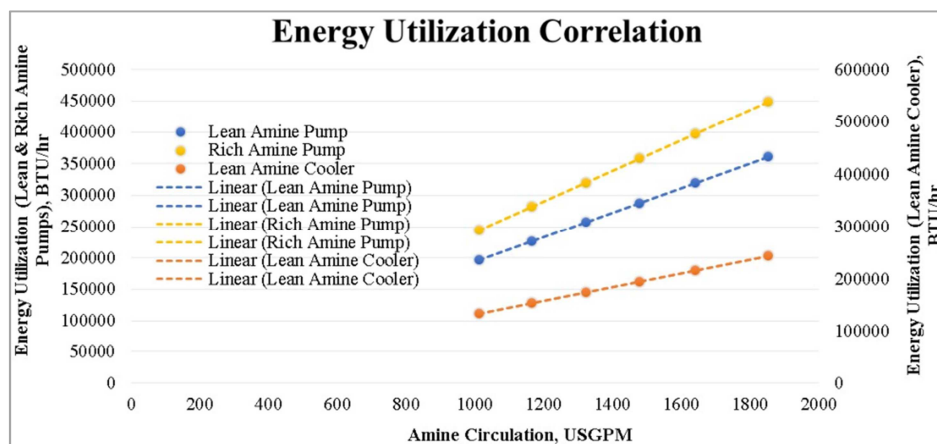


Figure 6. Energy Utilization Correlation.

The correlations were then utilized to develop the TGTU Energy Utilization Map (Figure 7) which lively provides site energy usage. This map has been then incorporated in the dashboard to intuitively represent TGTU energy optimization, i.e. rich/lean amine pumps and process cooling.

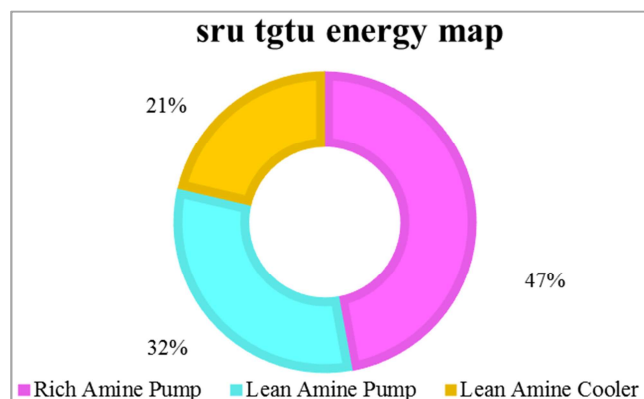


Figure 7. TGTU Energy Utilization Map.

Moreover, as the site energy utilization can be minimized,

the site carbon footprint can be also lowered. This is logic, as the electrical power demand can be lowered, the emission for generating electrical power can be minimized. The TGTU carbon footprint profile as well as emission reduction can be lively observed through the “SRU TGTU Amine Energy Optimization Smart Advisory Dashboard”.

To have better prediction, the simulation (Figure 8) has been also employed to estimate the emission factor – tons of emission for each generated power unit. This emission factor was then utilized to lively estimate the emission based on the energy utilization profile and to generate the carbon footprint profile (Figure 9).

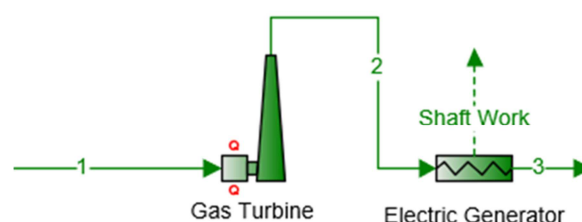


Figure 8. Emission Factor Simulation.

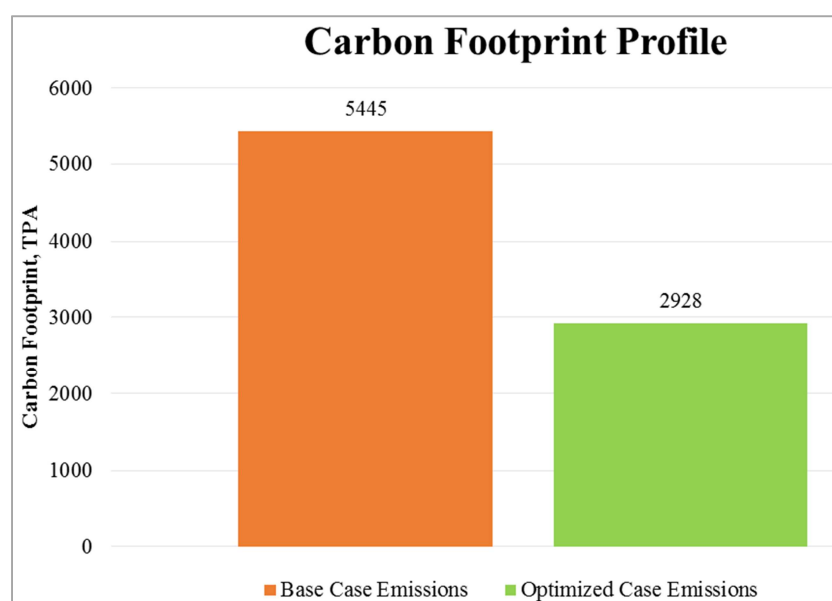


Figure 9. Carbon Foot-Print Profile.

In order to assess the effects of this optimization scheme on other environmental performance parameters such as SO_2 emissions and water balance, the base design case was compared to the optimized simulation case. The comparison results showed no significant effect on those outlined parameters and therefore will not disturb the overall environmental performance of the process.

The H_2S content in the off-gas leaving the Absorber is well maintained without any unwanted spikes in the optimization routine, in-fact the simulation software set the off-gas specs as the key target-parameter in the model. In this case, the corresponding SO_2 emission should be well maintained without major interruption. Whilst, the water balance

performance should not be compromised, as optimizing in lean amine rate will theoretically have no effect to the water entrainment losses in Absorber as well as water evaporative losses in the Regenerator.

4.4. SRU TGTU Amine Energy Optimization Smart Advisory Dashboard

Based on the results of the study, the following Excel-based dashboard was developed (Figure 10). The dashboard lively represents the optimum TGTU amine circulation process parameters and can be used to obtain the optimum amine circulation rate based on specific process gas flowrate

and amine strength. Subsequently, the results were incorporated in a live model (figure 11) providing real-time Operational Analytics and decision-making capabilities by providing an augmented operational and environmental performance monitoring solution for plant engineers and

operators. The dashboard is capable to dynamically map and drive the site energy utilization to its optimum point, resulting in cutting annual operating cost by 20% from base case level and lowering site carbon footprint by up to 46% from the optimized unit operations boundary.

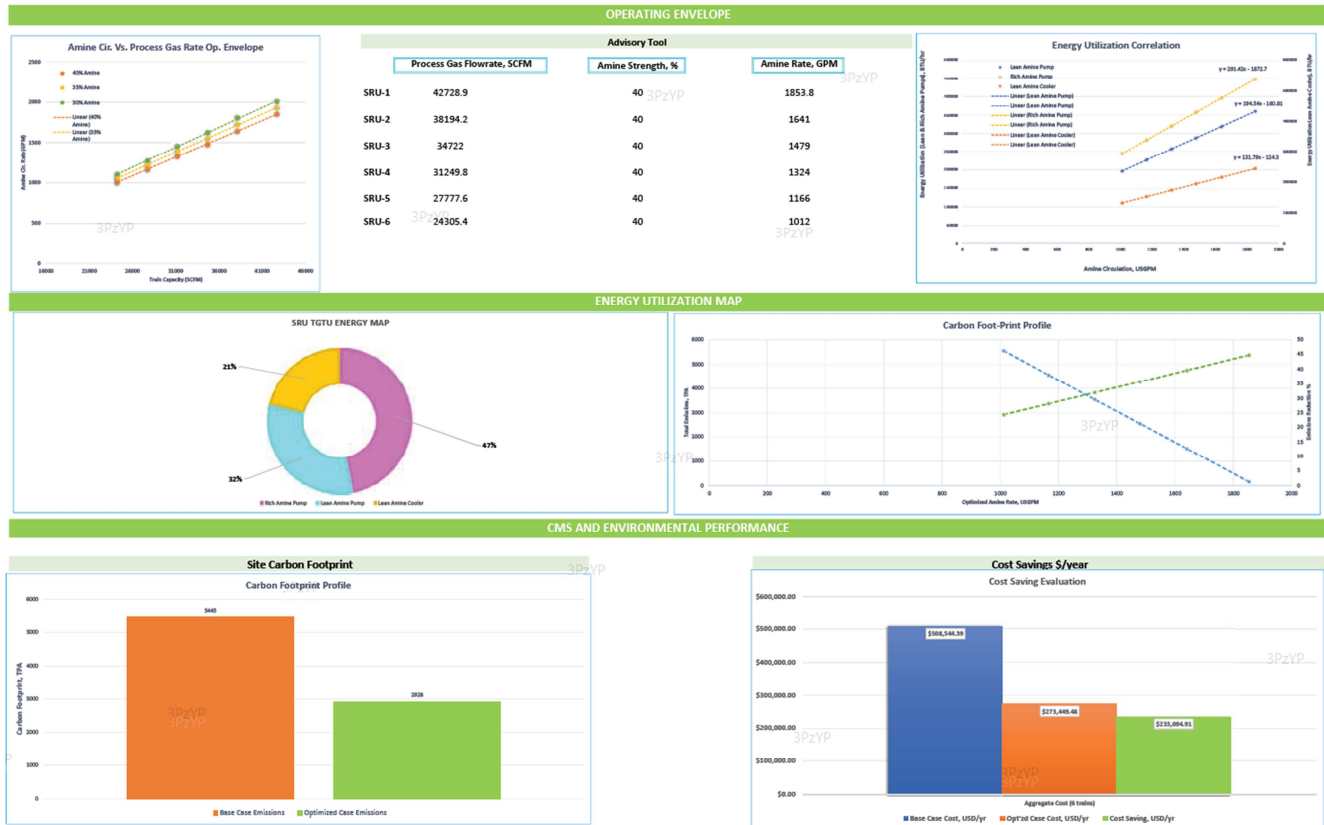


Figure 10. SRU TGTU Energy Optimization Excel-based Dashboard.

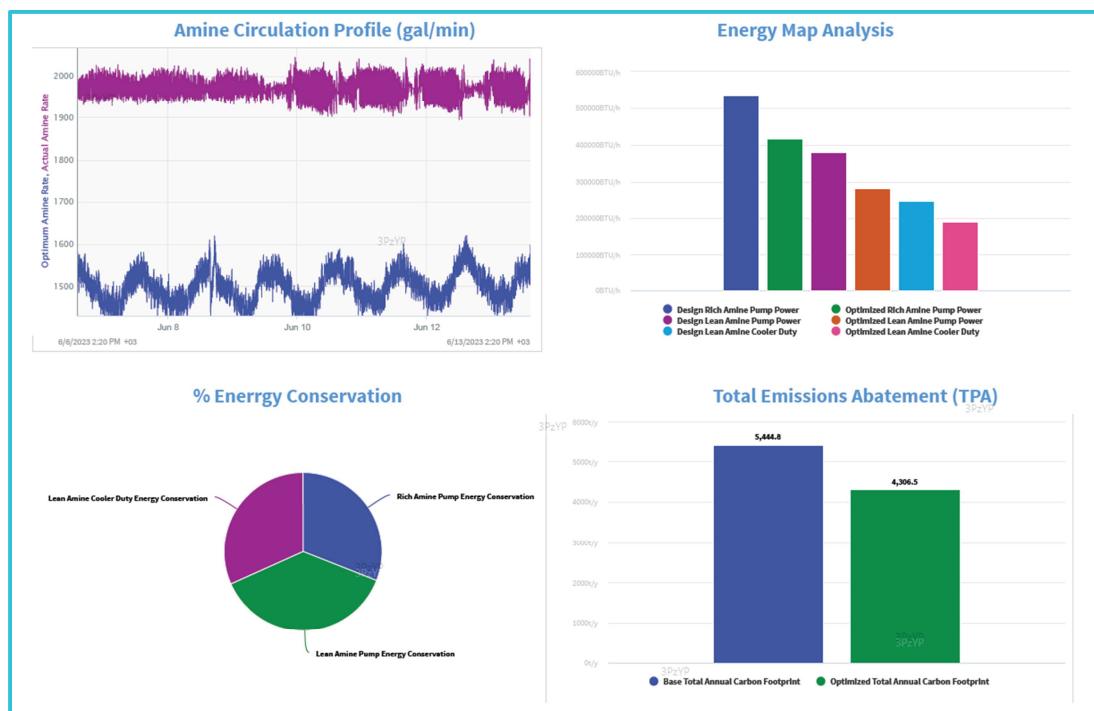


Figure 11. Real-Time Operational Analytics Smart Advisory Dashboard.

5. Conclusion & Recommendations

Intensively assisted by the simulation software, an SRU TGTU Amine circulation process was modeled and optimized as a function of feed gas flowrate and amine strength. The results show significant improvements in energy consumption and environmental performance as the amine circulation rate is more dynamically matched to the actual process conditions compared to the base case scenario. Subsequently, the “SRU TGTU Amine Energy Optimization Smart Advisory Dashboard” has been developed, which is able to provide the following improvements:

- 1) Prescribe a reliable amine rate as a dynamic operating envelope in order to drive TGTU energy utilization to optimum point.
- 2) Map TGTU energy utilization and corresponding energy saving as the amine circulation can be optimized.
- 3) Constantly monitor “Environmental Performance”, i.e. carbon footprint and corresponding reduction as the amine circulation is optimized.

The study can benefit from further improvements as per below recommendations:

- 1) Expand the analysis to include all the equipment in the TGTU amine circulation section, e.g. Chiller Package.
- 2) Utilize hybrid software simulations for more granular results.
- 3) Incorporate the live dashboard into Distributed Control Systems (DCS) operations to allow live data streaming capabilities and process control optimization.

The study represents a good example of how to capture low-hanging fruit in energy efficiency with no capital expenditure, thus cost-effectively contributing to achieving sustainability targets.

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