RAMESHNI & ASSOCIATES
TECHNOLOGY & ENGINEERING LLC

SRU's Revamp – Case Studies

Mahin Rameshni, P.E. – President & CEO

Rameshni & Associates Technology & Engineering (RATE) CA, USA

www.rate-engr.com

The sulphur recovery units (SRU) in the oil and gas industries are found in diverse facilities such as gas plants, refineries, SYN gas applications and sour gas field developments. Such plants are generally designed according to certain criteria such as recovery, capacity, acid gas feed compositions and tail gas treating requirements according to the regulations and operating conditions as known at the time of design. Often, the regulations or operating conditions change over time which results in a need to revamp the SRU.

RATE has extensive experience in the revamp of the existing sulphur plants for different scenarios. The cause of the SRU's revamp could be one or more of the following.

1. The sulphur plant feed compositions have changed due to a change of feedstock at the facility.

2. The sulphur plant is designed for amine acid gas only and the design has to be modified to process an ammonia acid gas stream.

3. As a result of changes in environmental regulations, the pit vent , degassing vent, needs to be recycled back to the front of SRU plant and/or from the sulphur storage tank and truck/rail loading rack. These vent streams can all be collected and recycled to the reaction furnace via a blower.

4. As a result of modification in other parts of the facility, such as adding a flue gas desulfurization unit to collect the sulphur compounds, a new stream containing SO2 is generated and it has to be routed to the sulphur plant.

5. Adding a new tail gas unit to the existing SRU, the recycle stream from the TGU needs to be treated in the SRU.

6. As a result of facility expansion, the capacity of the SRU needs to be increased from small percentage such as 20% to 100% to double the capacity using oxygen enrichment options.

7. Where the feed composition to the sulphur plant is changed to a leaner acid gas, modification may be required to maintain a stable flame in the reacti9on furnace using techniques such as fuel gas firing or oxygen enrichment or even adding acid gas

enrichment or changing the catalyst to Ti for a better hydrolysis of COS/CS2. (RATE developed a special scheme in regard to fuel gas firing).

8. In some cases like gasification applications such as syngas, using 100% oxygen enrichment to achieve stable combustion temperature is required. For a coal to chemicals application where to properly process several lean streams, some streams are routed to the tail gas unit and an additional hydrolysis reactor was added in the tail gas unit. (RATE developed a special scheme in that regard).

9. New feed compositions may contain new impurities such as BTEX or others that polishing unit may be required upstream of SRU such as carbon filter, or changes in the SRU operation such as fuel gas firing, oxygen enrichment or the acid gas enrichment.

10. The design capacity of the SRU significantly reduced where the current equipment cannot maintain a stable operation due to high turn down and equipment has to be modified.

11. As a result of changes in the environmental regulation, the amine solvent in the tail gas has to be changed to a more efficient and selective solvent.

12. As a result of changes in environmental regulations, a caustic scrubber has to be added after the incinerator to absorb the SO2.

13. To reduce the natural gas consumption, reduce CO2 emission, simplify operation changing the RGG/inline burner in the TGU to indirect steam heater and to use low temperature hydrogenation catalyst in the TGU reactor.

14. The old sulphur plants used to be designed with the fired heaters using natural gas or acid gas firing. In order to improve the sulphur recovery, reliability and operability in many the sulphur plants fired heaters are changed to steam heaters.

15. In some of the old amine units the amine acid gas from the regeneration column is not adequately cooled so the acid gas saturated with water at 180°F was routed to the SRU. To prevent entering excess water from entering the SRU burner / reaction furnace we installed a cooler to cool the acid gas to 110 -120°F to remove the water in the amine acid gas K.O. drum prior entering the SRU burner and furnace.

16. Adding sulphur degassing to the existing facility

17. Evaluate all the SRU equipment for additional capacity / oxygen enrichment

In the following sections each case study and the details of the revamps will be discussed in more detail.

Case 1 - Study

Sulphur plants are designed based on the specific crude which is processed at the facility at the time of the design. If the crude changes it could be to a more sour crude meaning more H2S has to be processed or to a more sweet crude meaning less H2S has to be processed. RATE has done case studies for both options where changes are to process more sweet crude would not have an impact as long as the H2S concentration is within range of original design and the volumetric of the gas are within the original design otherwise modification or revamp may be required to modify the unit for the new condition. If the changes are to process more sour crude with more H2S, then if there is an increase in the volumetric rate, in order to maintain the hydraulic capacity, oxygen enrichment has to be considered. The level of the oxygen depends on the level of additional capacity, which will be discussed under case study No. 6.

RATE did such evaluation for 5 existing SRU recently for a refinery in South America and concluded that the existing sulphur plants are able to handle the new crude however, the existing amine units required modifications.

Case 2 - Study

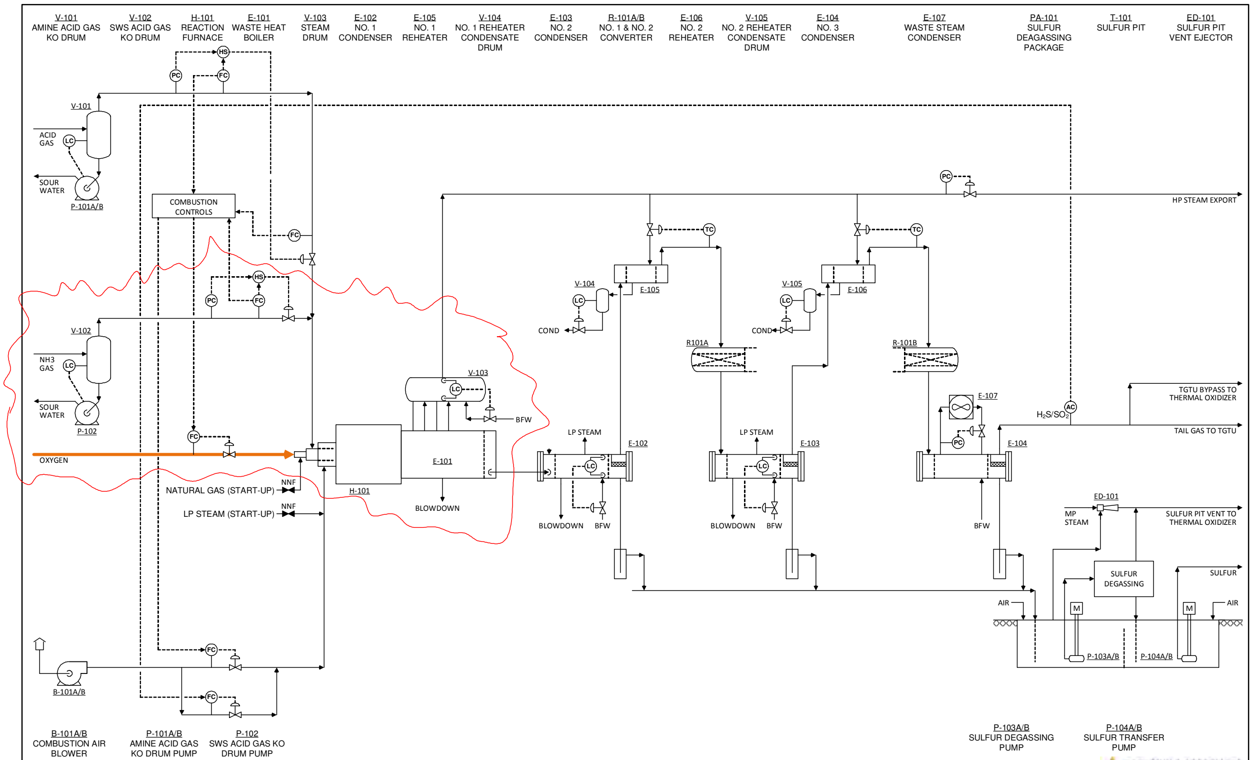
If the original sulphur plants are designed for processing the amine acid gas only and it now required processing the ammonia acid gas from the sour water stripper.

There is 2 scenarios have to be considered:

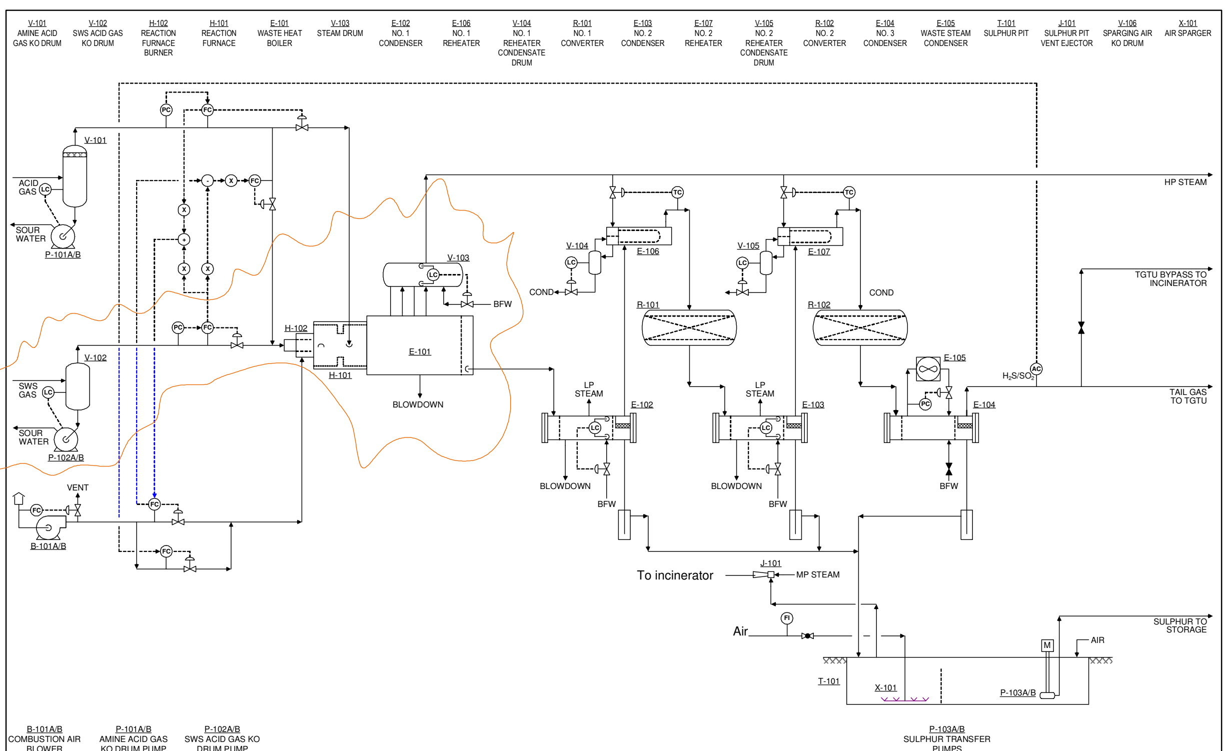
- The original SRU is designed based on amine acid gas flow only, if the amine acid gas rate will stay the same then the additional flow rate of ammonia acid gas could not be added unless oxygen enrichment is used to maintain the hydraulic capacity of the system. As part of the revamp the original burner has to be replaced to a new burner where it is more suitable for the new condition. Other equipment such as reaction furnace, waste heat boiler and the first condenser has to be evaluated and also refractory has to be upgraded for oxygen enrichment application. The reaction furnace has to have an adequate residence time for ammonia destruction as shown in figure 1.

- If the amine acid gas rate is reduced to the level that the ammonia gas could be added to keep the same volumetric or hydraulic to the unit then oxygen is not required for the purpose of having additional capacity. Oxygen may still to be used if the combustion temperature is not adequate to achieve complete ammonia destruction. The burner has to be replaced and the reaction furnace has to have an adequate residence time.

  The case study was conducted and the conclusion was if there was a reduction in the amine acid gas and no oxygen was required. If the amine acid gas rate kept as before, then oxygen was required. However, a new ammonia acid gas K.O. drum and a pump, a new SRU burner to handle ammonia, and a new reaction furnace was added where was replaced with the existing equipment and a new oxygen line and instrumentation was added. The burner management system had to be revised to include the ammonia acid gas and oxygen. The options are shown below.



PROCESS FLOW DIAGRAM - CLAUS SULFUR RECOVERY UNIT



PROCESS FLOW DIAGRAM - CLAUS SULPHUR RECOVERY UNIT

Case 3 - Study

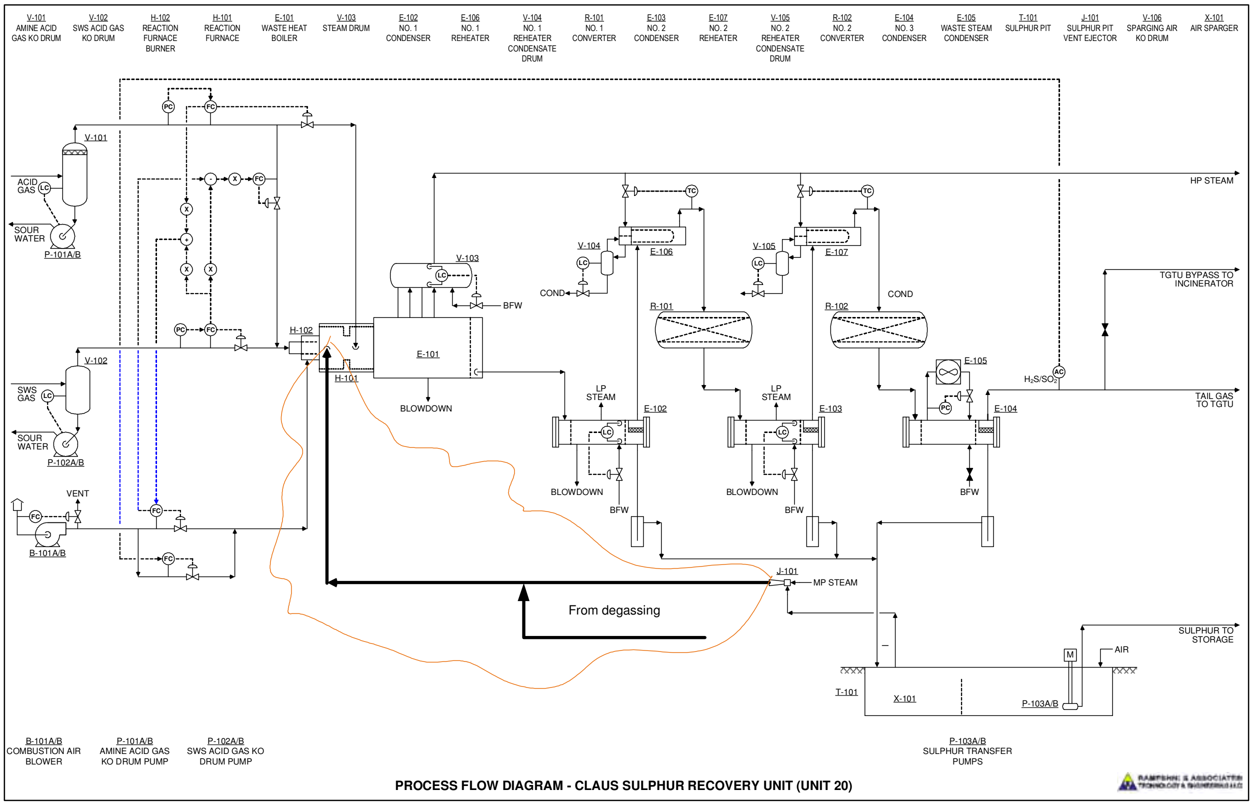
The pit vent, degassing vent, sulphur storage tank, and truck loading all contain sulphur compounds that will impact the emissions if they are routed to the incinerator. They could be routed to the reaction furnace or to the tail gas unit via a blower or eductor.

There are several keys should be considered for routing the vent to the reaction furnace. Two problems with routing vent gas to the thermal reactor: solid sulphur accumulates in the air plenum (which can be melted out by temporarily minimizing main air), and increased backpressure on the vent gas blowers increases blower operating temperature from compression heat (about 15ºF/psi), thus increasing blower maintenance. It is vise to have incinerator as an alternate disposition in the event of the loss of the sulphur plant. Vent air could be large percentage of total combustion air which is required in sulphur plant, especially if oxygen enrichment is being used in the SRU, air and oxygen control and oxygen demand and metering needs to be looked at very closely.

In one refinery the vent gas was injected into the air plenum as close to the burner as possible, and offset consistent with the direction of main air swirl. One rotary lobe blower pulls ambient air through the tanks, and a second through the two sulphur where the vent gas was injected into the air plenum as close to the burner as possible, and offset consistent with the direction of air swirl.

The vent gas accounts for ~ 10% of the total air flow. Solid sulphur tends to accumulate in the air plenum, but not to the extent of impeding air flow. It can typically be melted out at low unit loads by temporarily minimizing the (cold) main air rate.

The case study was conducted to collect the pit vents from three sulphur pits, sulphur storage tanks and they were combined to one stream and boosted by the eductor to the reaction furnace. The existing sulphur plant was using mid-level oxygen enrichment, the oxygen had to be increased for the hydraulic purposes and to accommodate the temperature drop and the connection was a separate nozzle to the existing burner.



Case 4 - Study

The SO_2 stream from Belco or Cansolv could be processed in the sulphur plant

The following steps should be taken for the SO_2 stream.

a. Identification of the optimal tie-in point for the new SO_2-rich stream

b. The control strategy for the new SO_2 stream.

c. Revised Heat & Material Balances for the SRU and Tail Gas Treating (TGT) units

d. Identification of any equipment that may need replacement or upgrading as a result of the changes.

e. A cost estimate for any required changes in equipment, piping, controls etc.

f. Hydraulic evaluation for the new conditions

SO_2 Feed Optimization

The location of SO_2 stream to the sulphur plant needs to be optimized for the following reasons.

- Avoid reduction of the reaction furnace temperature

- Prevent water condensation and corrosion
- Provide proper insulation
- Air demand considerations
- Provide a proper angle tee for mixing
- Provide purge connection
- Prevent localized cold spot in the condenser
- Choose the optimized location

The SO_2 recycle lines tees into the process gas between the waste boiler and the first condenser. The tie-in is a tee connection without any injection nozzle/quill. The SO_2 recycle itself consists of any SO_2 and water and is recycled at a temperature between 75°F and 90°F. Moreover, there is not any insulation or heat tracing on the line. All of these circumstances, taken together, lead to the strong possibility of both water condensation in the line plus a relatively low-temperature stream in the feed to the first condenser, without any assurance of good mixing with the hot gas leaving the waste heat boiler. This could easily result in localized cold spots in the condenser and condensation of sulphuric acid or one of its salts, which may be a cause of some of the corrosion experienced in the first condenser. The single most important recommendation for handling this SO_2 stream is that the recycle line be heat traced and insulated to prevent any additional cooling of the stream and condensation of water. In addition, the tie-in should have some type of injection nozzle to ensure good mixing with the process gas. One refinery had similar problems with corrosion in the first condenser until they installed a simple injection nozzle, which appears to have reduced or eliminated corrosion in the first condenser. It is also possible to change the location of the SO_2 recycle injection point. It may be preferable to inject the SO_2 recycle stream into the second chamber of the reaction furnace. This change in recycle location does not affect the overall sulphur recovery but it does shift the major sulphur condensation load from the second condenser to the first condenser. It does have the benefit operationally of catching more sulphur upstream of the catalyst beds, which might be fouled. Regardless of where the SO_2 stream is injected, the recycle line should be heat traced and insulated. If it is injected into the second chamber of the reaction furnace, it will have to be tied into the amine acid gas line to the second chamber. It is very important to locate this tie-in as close to the reaction furnace as possible. In addition, both lines amine acid gas and SO_2 recycle must be purged when there is no flow through these lines.

The study was conducted, the unit was operating with oxygen enrichment and SO2 acts as the reducing agent, therefore, the oxygen consumption reduced. If the temperature reduced significantly then the SO2 stream should be added to the first condenser outlet.

Case 5 - Study

There are many old sulphur plants around the world that were built many years ago when regulations did not require ail gas treating units. The tail gas feed from the last sulphur condenser was routed to the incinerator. Due to new regulations many facilities are required to add a new tail gas treating. If the tail gas treating system is conventional tail gas/amine unit, then the acid gas from the tail gas regeneration column has to be recycled to the front of the SRU. This stream is normally added to the amine acid gas stream prior entering the acid gas K.O. drum. This stream contains H2S, CO2 and H2O and it is very small stream and does not generally have a significant impact on the existing sulphur recovery unit. As part of the design a new tail gas unit, a new material balance should be prepared so the operator of the sulphur plant has the more up-to-date data.

Case 6 - Study

The existing sulphur plant capacity could be expanded up to the double capacity by using the oxygen enrichment from 20% up to 100% oxygen enrichment. The major evaluation is on the burner, reaction furnace and waste heat boiler and refractory type has to be evaluated before employing the oxygen enrichment. In the TGU, the evaluation is based on solvent circulation, quench and the amine cooling system.

- Low-level Oxygen enrichment

Oxygen is introduced into the combustion air to attain an Oxygen concentration of up to almost 28%. An additional capacity of about 20 - 25% of the original design capacity is achievable via this technique.

- Medium-level Oxygen enrichment

Oxygen is introduced into the combustion air to attain an Oxygen concentration between 28% and 45%. An additional capacity of up to 75% of the original design capacity is achievable via a specially designed burner such as oxygen burner.

- High-level Oxygen enrichment

Oxygen is introduced into the combustion air to attain an Oxygen concentration between 45% and 100%. An additional capacity of up to 150% of the original design capacity is achievable. A number of different technologies are commercially available Oxygen process. The Oxygen level can be configured in various ways to fit the needs of different facilities depending on the overall sulphur plant capacity requirement, desired operating scenario, existing equipment conditions, plot space available and existing facility layout.

During the evaluation the following need to be taken into consideration.

- Higher Combustion temperature so the existing refractory lining should be evaluated. In many cases, the refractory system will need to be upgraded to accommodate higher operating temperature. The maximum operating temperature is limited by refractory to about 2700 °F to 2900 °F (for short time excursions).
- If the burner needs to be replaced to a new one, the size of the existing nozzle should be evaluated for the new burner location.
- If the reaction furnace contains a choke ring or checker wall, it should be evaluated for flame impingement with a new burner flame characteristics.
- Higher partial pressure of elemental sulphur, SO_2 and H_2O vapor, leads to higher sulphur dew points.
- Producing more H_2, which is beneficial in TGU as a reducing agent, can be used as a fuel in the incinerator.
- Increase the efficiency of downstream Claus catalytic reactors.
- Better destruction of ammonia, HCN, heavy hydrocarbons and BTEX, or any contaminants, requires a higher combustion temperature.
- The gas volumetric is about the same, no changes in residence time.
- Oxygen line should be provided to the unit; therefore, burner management system ESD system, and oxygen demand controls should be added or modified for Oxygen supply.
- Purging requirements will be different and should be considered.
- Pilot /ignition requirement should be evaluated.
- Acid Gas piping pressure drop and instrumentation should be evaluated to maintain the pressure profile throughout the unit.
- The plot plan is to be evaluated if the burner is replaced.
- The location for the flame scanners should be evaluated with the burner replacement for the replacement or relocation. RATE recommends IRIS S-550 type flame scanners since it will not be affected as the results of pipe x-raying, heats and radiation on the site and seems more robust for the sulphur plants.
- The flow meters and control valves on the acid gas lines should be evaluated for a higher flow rate and turndown issues.

- The existing refractory should be evaluated for a higher combustion temperature in the reducing atmosphere. The principle of using double combustion for processing rich H_2S acid gas is that 90% alumina refractory with silica, at reducing atmosphere, has a maximum temperature limitation, and using 94% alumina refractory with magnesium is very sensitive to thermal shock at reducing atmosphere and may not be very cost effective, but it will handle higher combustion temperature. The melting point of 90% alumina with silica and 94% alumina with magnesium is about 3400℉ and 3500℉ respectively. However, the ferrules should be evaluated for this combination.

- Higher operating temperature, resulting in higher heat duty, which requires more cooling.

- Having more sulphur vapor from reaction furnace needs more heat for redistribution.

- Recombination of CO to COS, and H_2, S_2 to H_2S releases additional heat in front of several feet of boiler tubes, which is not predicated by some simulator. It increases the heat flux near the critical tube to tube sheet weld (maximum metal temperature), and inlet tube sheet refractory and ferrules, maximum heat flux in tubes requiring mechanical attention.

- Improved heat transfer as the result of higher radiant film coefficient.

- Steam drum size, downcomer/riser size and number, nozzle sizes, associated piping and instrumentation should be evaluated.

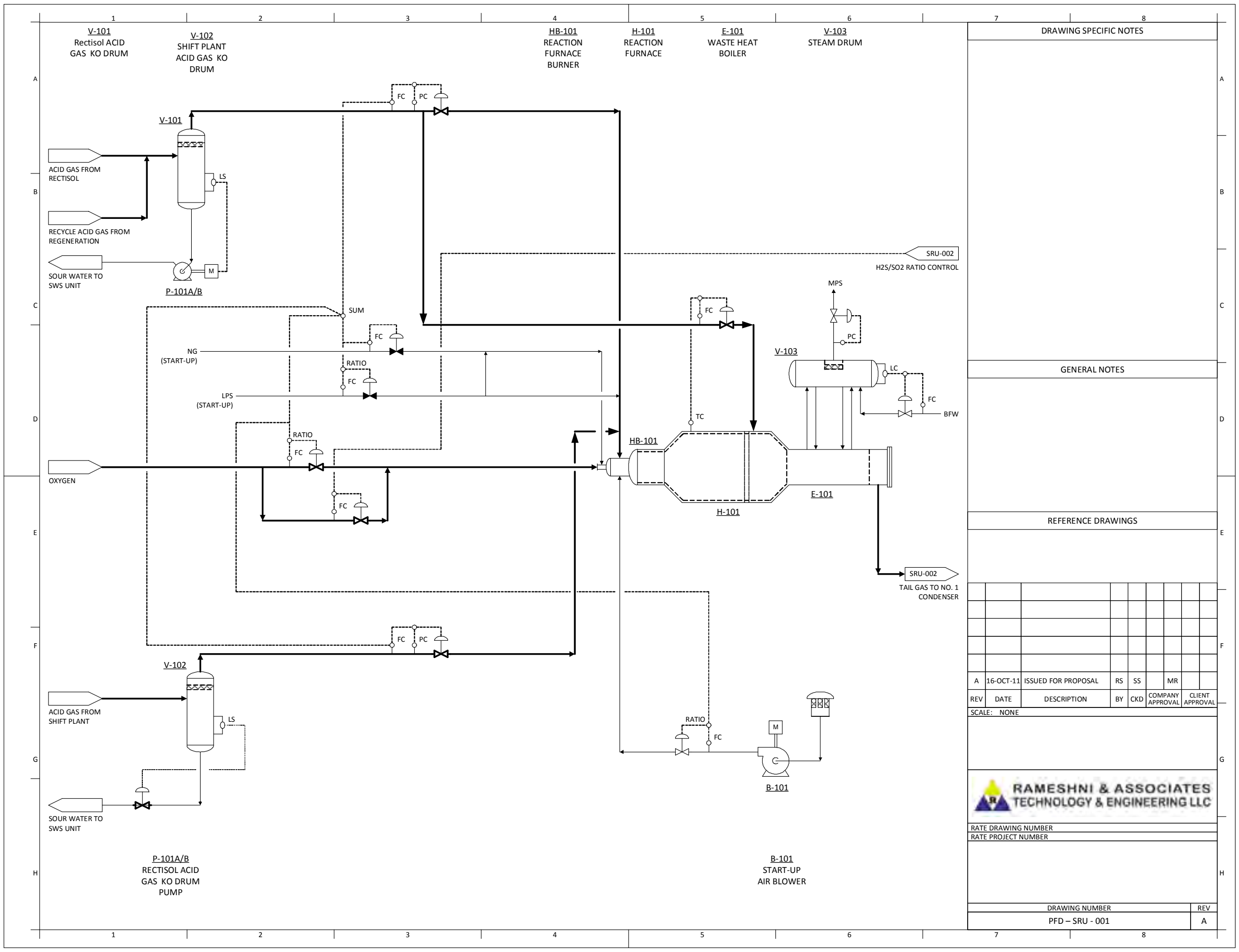
- Relief capacity, BFW /steam rate will be increased.

- Mass velocities should not be exceeded or heat flux issues may arise, which may cause vapor blanketing of the tubes and high temperature in the tube and tube-sheet.

- The peak heat flux occurs at the outlet of the ceramic ferrules; therefore, the heat flux should be limited to a maximum 50,000 to 70,000 Btu/hr-ft^2 to prevent eddying.

- The temperature of tube to tube-sheet weld should be limited and evaluated for the possibility of sulfidic corrosion of carbon steel.

Based on our extensive experience, a detailed study should be conducted to determine the required level of oxygen enrichment then all the existing equipment has to be evaluated and the possible modification has to be identified to the existing equipment, instrumentation, burner management system implementation with oxygen control system, possible refractory upgrade, possible new oxygen burner, new reaction furnace, and tail gas modification for the additional solvent circulation rate/concentration, pumps, cooling system for the quench and for the amine system. The following diagram represents 100% oxygen for lean gases in SYN gas application.



Case 7 - Study

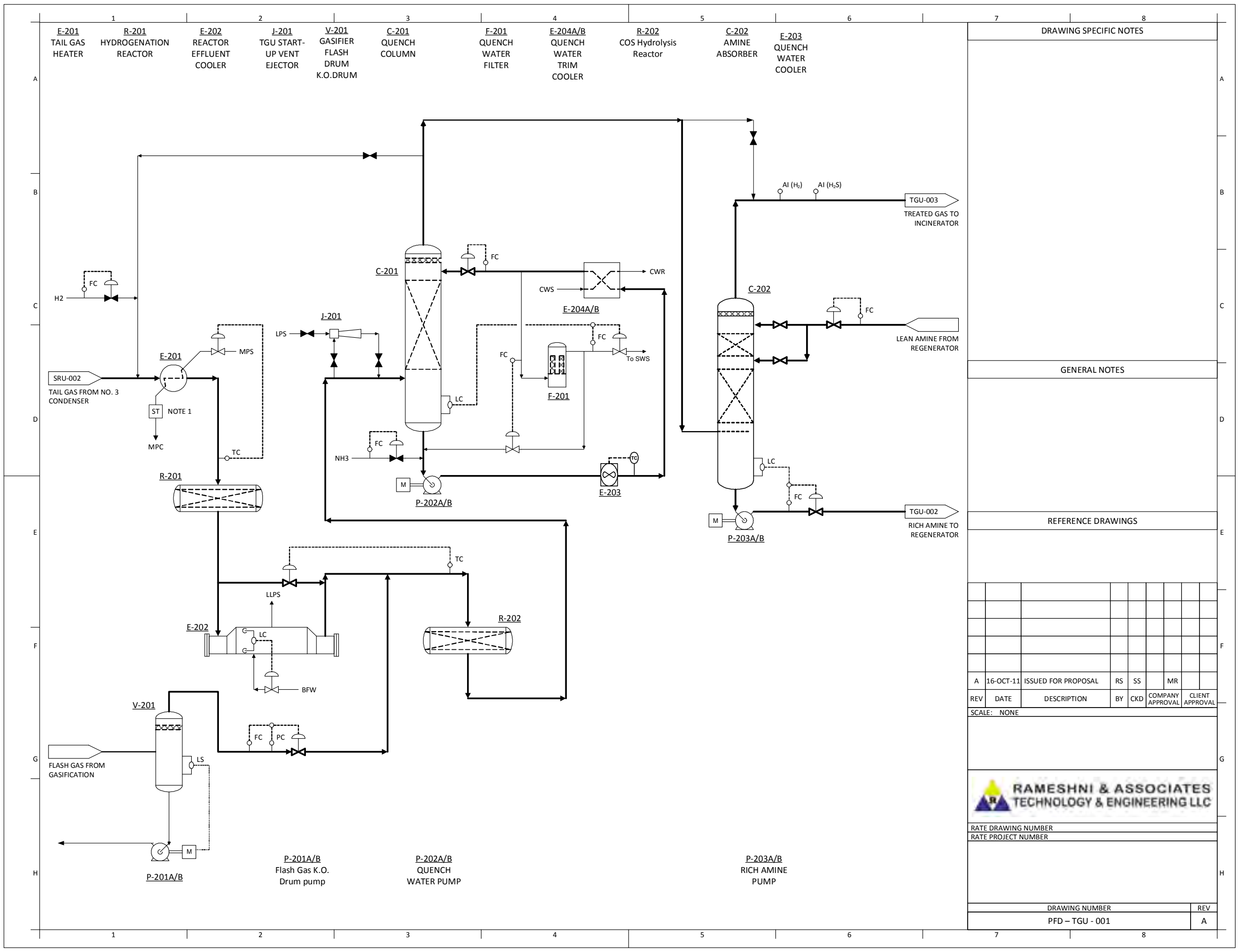
There are many cases of sulphur plants that are designed for a rich acid gas application but they need to operate with lean acid gas. In order to overcome the unstable flame temperature, sometimes fuel gas firing with natural gas quality will boost the temperature. However, if the usage is significant then will have impact on hydraulic and sometimes the acid gas rate has to be reduced. Another option is to add oxygen enrichment and the level has to be defined to maintain the sulphur production refer to case study no. 6. Other option is to add the acid gas enrichment upstream of the SRU to enrich the gas depending on the project could be as a common regeneration with the tail gas unit regeneration system.

In sour gas field developments or Early Production Facilities where natural gas or oxygen is not available **RATE developed a special scheme** and it was offered. The scheme is to burn the fuel gas (does not need to be natural gas) with excess air first in the high intensity burner with zero to small portion of the acid gas in the burner and most or all of the acid gas goes to the reaction furnace not to the burner for the lean acid gas cases. In this configuration the fuel gas and excess air burns stoichiometric (while conventional SRU is sub- stoichiometric) so there is no soot formation and the composition of the fuel gas is not important because we have excess air while we process the lean gas. As the acid gas changes to higher H2S concentration, we reduce the fuel and air and more acid gas goes to the burner. In this configuration, there will be a 2-zone reaction furnace with more residence time than the conventional design twice or more even though there is no ammonia but for destruction of BTEX.

Case 8 - Study

In some gasification applications, 100% oxygen enrichment is used to achieve stable combustion temperature. For a coal to chemicals application where to properly process several lean streams, some streams are routed to the tail gas unit and an additional hydrolysis reactor is also added in the tail gas unit.

RATE developed an exclusive scheme, where we processed some of the lean stream in the SRU by using 100% oxygen enrichment. We had other streams where the rate was high with a very small amount of H2S. Processing such streams in the SRU would reduce the combustion temperature significantly due having ammonia present in the gas, in order to maintain the adequate combustion temperature for ammonia destruction, we processed some of the lean acid gas in the tail gas unit. In addition due to lean acid gases, significant COS & COS produced in the reaction furnace having TI catalyst in the SRU converters would not have 100% conversion. The remaining of COS /CS2 were hydrolyzed by providing an additional hydrolysis reactor after the tail gas hydrogenation reactor. The lean acid gas is combined with the hydrogenation reactor outlet and is routed to the hydrolysis reactor. The scheme is shown below.



Case 9 - Study

We experienced in many projects where the design basis was not fully developed or uncertainly about the actual feed compositions, or different feed compositions using different wells over the years. The new feed compositions may contain new impurities such as BTEX or others that polishing unit may be required upstream of SRU such as carbon filter, or changes in the SRU operation such as fuel gas firing, oxygen enrichment or the acid gas enrichment. Based on our experience a study has to be conducted to determine the most economical option to overcome the situation. We experienced carbon filter for sour gas field development are the best option where there is no oxygen, there is no high quality fuel and adding acid gas enrichment is a major investment and plot space and other economical factor was taken into consideration.

Case 10 - Study

The turn down ratio for a SRU is normally 20 to 25% (4:1 or 5:1) of the design capacity without any additional provision in the design. . During the original design, if higher turn down is required it has to be specified. In particular the following items should be considered: the flow meters, the burner, the reactors, SRU condensers and the TGU columns. If the existing sulphur plants requires much higher turn down, like 8:1-10:1, it is difficult to have a stable operation with the original burner, a uniform distribution in the reactor, prevent fogging in the sulphur condensers, a uniform distribution in the columns and the adequate loadings throughout the columns.

The design capacity of the SRU significantly reduced where the current equipment could not maintain a stable operation due to high turn down and equipment has to be modified.

We experienced this scenario, where the SRU burner had to changed, some of the condenser tubes had to be plugged even we had to install a sheet plate to cover some of the tubes to prevent sulphur fogging, and insert a sleeves inside of the reactors or columns to reduce the internal diameter and add minimum bypass to the pumps and circulate more liquid to the towers than needed to maintain the velocity.

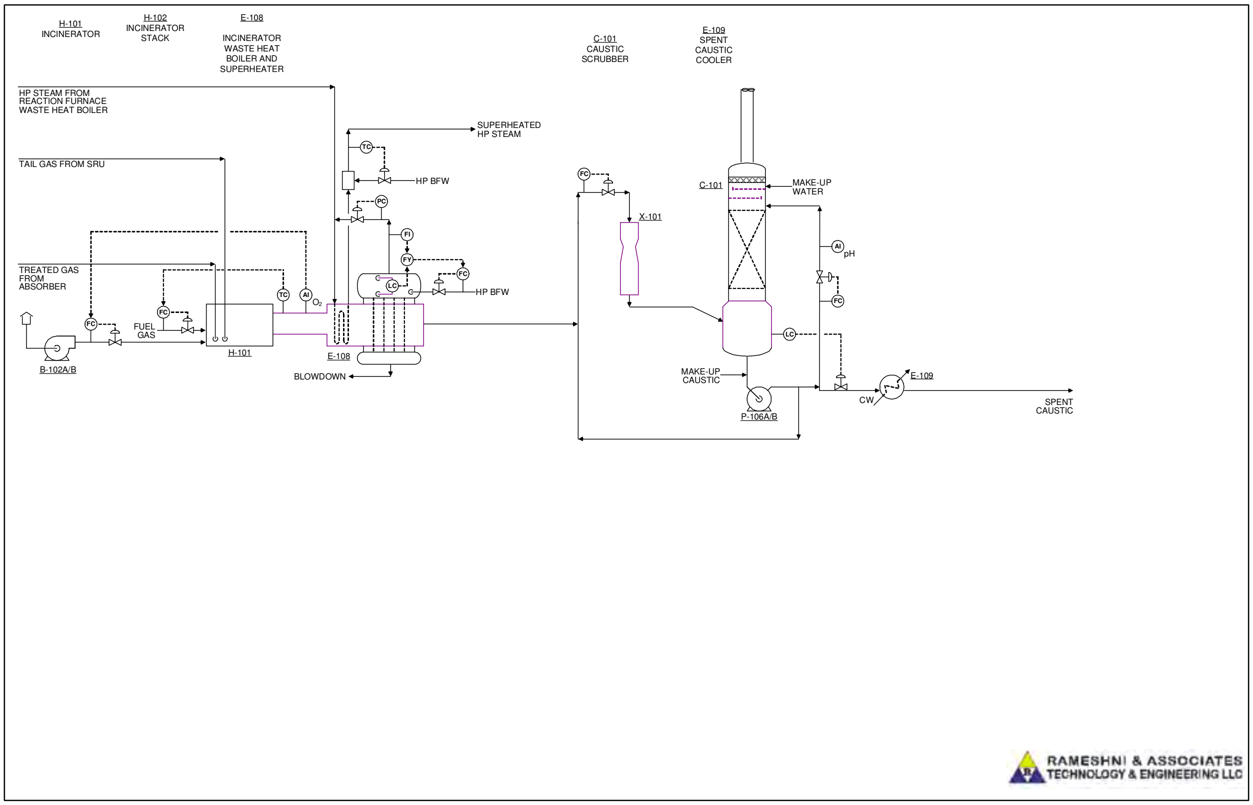
Case 11 - Study

We experienced in some cases where the facility had to change their solvent as a result of changes in the environmental regulation, the amine solvent in the tail gas has to be changed to a more selective solvent. The changes are from generic MDEA to TG-10, HS-103, Flexsorb SE-plus, Huntsman-300, or similar. In most cases the original design could be kept as long as the circulation rate is similar, and the reboilers have an adequate capacity and the material of construction are the same. The generic solvent the SO2 emission could be maintained around 150-250 ppmv while the new regulation and World Bank are asking under 50 ppmv of SO2. Changing the solvent is one of the modifications in this regard.

Case 12 - Study

The nominal SO2 emissions have been 250 ppmv in many countries. The regulation is changing to a tighter emission and even the World Bank is asking the emission under 50 ppmv of SO2 from the tail gas incineration stack. As a result of changes in the environmental regulations, a caustic scrubber could be added after the incinerator to absorb the SO2.

It depends on the regulation the emission of SO2 could be achieved near zero. The spent caustic has to be disposed and could be routed to the waste water treatment if the facility has one otherwise the spent caustic is a mixture of sodium sulfite and sodium bi-sulfite. If the existing incinerator was not forced draft, it would be required to convert it to the forced draft incinerator with or without heat recovery system to have enough pressure throughout the system. The scheme is shown below.



Case 13 - Study

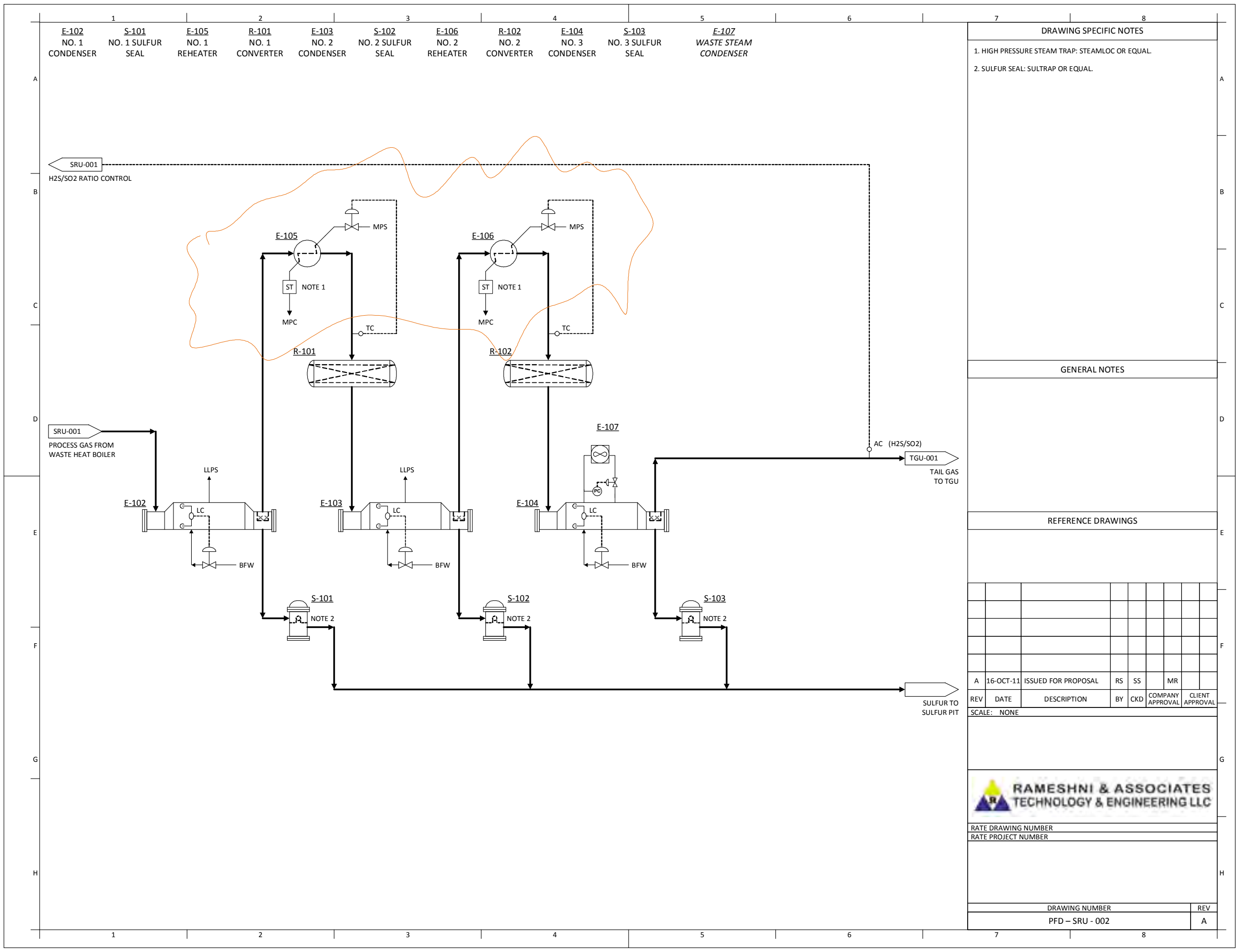
The conventional tail gas treating was designed with an RGG or INLINE BURNER which required natural gas. To reduce the natural gas consumption, reduce CO2 emissions, and simplify operation, the RGG/inline burner in the TGU was changed to an indirect steam heater with low temperature hydrogenation catalyst in the tail gas reactor. However, keep in mind that operating hydrogenation reactor at the higher temperature would be required for a better hydrolysis of COS and CS2 where the emission is tight, it is wised to have FIRED HEATER to have a higher temperature to the reactor where using steam heater could not obtain such high temperature.

Case 14 - Study

Old sulphur plants used to be designed with the fired heaters using natural gas or acid gas firing. Depending on the number of Claus stages, 2 or 3 fired heaters had to be installed within sulphur plants.

The fired heaters require high maintenance, are more difficult to operate and have a negative impact on the sulphur recovery efficiency. If natural gas is used, the result is an increase CO2 emissions plus the cost of natural gas.

In order to improve the sulphur recovery efficiency, reliability and operability in many sulphur plants, fired heaters are changed to indirect steam heaters.



Case 15 - Study

We have experienced that in some old facilities, the amine acid gas from the amine regeneration column is not adequately cooled so that acid gas saturated with water at 180℉ was routed to the SRU. For a unit without a TGU, the excess water affects the overall sulfur recovery efficiency. To prevent excess water from entering to the SRU burner / reaction furnace we installed a cooler to cool the acid gas to 110 -120℉ to remove the water in the amine acid gas K.O. drum prior entering the SRU burner and furnace. The operation was improved significantly after the water was removed.

Case 16 - Study

There are some facilities where the sulphur is not degassed and the liquid sulphur is solidified and transported. Based on new regulation, the liquid sulphur has to be degassed to 10-30 ppmw of H2S before solidify or transport as liquid. The degassing could be done inside or outside of the pit. If degassing occurs inside of the pit, it requires 12 to 24 hours residence time depending on the selected technology. If the degassing is outside of the pit, normally 30 minutes residence time is required. The degassed sulphur could be stored in a second compartment of the sulphur pit or above ground storage tank.

In most cases existing sulphur pits do not have an adequate residence time for internal degassing and in most cases external degassing is selected unless the owner decides to change the pit to a larger pit and use internal degassing.

Case 17 - Study

RATE executed many projects related to revamps for increasing recovery, increasing capacity, reduce sulphur emission such as SO2, energy optimization, utility optimization, reduction fuel consumption, reduce losses, and improve control systems. The equipment evaluation for increasing capacity using oxygen enrichment is described below.

SRU Burner & Reaction Furnace

Low-level Oxygen enrichment is accomplished by injecting pure Oxygen or Oxygen-rich air into the combustion air; i.e., Oxygen is premixed with combustion air upstream of the burner. No burner modification is required in the existing SRU, other than providing the tie-in point for Oxygen injection in the combustion airline. For medium-level or high level Oxygen enrichment with rich H2S, the burner designed for air-only operation might not withstand the higher combustion temperature. In any case, direct injection of Oxygen through separate nozzles from combustion air is recommended; hence, special burners designed for direct Oxygen injection should be installed.

For lean H2S acid gas and high Oxygen enrichment, single combustion is adequate; therefore, there is no need for an additional reaction furnace if the refractory lining is adequate, only burner needs to be replaced.

The existing reaction furnace should be evaluated for low level of Oxygen no changes or concern is required. For medium or high level of Oxygen, the following factors should be considered if: the modification for sulfur plant has high content of H2S, a new reaction furnace is required as a first combustion chamber; and, the existing reaction furnace will be used as a second combustion chamber, if the existing reaction furnace is well maintained and the refractory lining is adequate. The following are the Oxygen enrichment impacts the burner and reaction furnace design:

1. Higher Combustion temperature, then existing refractory lining should be evaluated. In many cases, the refractory system will need to be upgraded to accommodate higher operating

temperature. The maximum operating temperature is limited by refractory to about 2700 °F to 2900 °F (for short time excursions).

2. If the burner needs to be replaced to a new one, the size of the existing nozzle should be evaluated for the new burner location.

3. If the reaction furnace contains a choke ring or checker wall, it should be evaluated for flame impingement with a new burner flame characteristics.

4. Higher partial pressure of elemental sulfur, SO2 and H2O vapor, leads to higher sulfur dew points.

5. Producing more H2, which is beneficial in TGU as a reducing agent, can be used as a fuel in the incinerator.

6. Increase the efficiency of down stream Claus catalytic reactors.

7. Better destruction of ammonia, HCN, heavy hydrocarbons and BTEX, or any contaminants, requires a higher combustion temperature.

8. The gas volumetric is about the same, no changes in residence time.

9. Oxygen line should be provided to the unit; therefore, burner management system ESD system, and oxygen demand controls should be added or modified for Oxygen supply.

10. Purging requirements will be different and should be considered.

11. Pilot /ignition requirement should be evaluated.

12. Acid Gas piping pressure drop and instrumentation should be evaluated to maintain the pressure profile throughout the unit.

13. The plot plan is to be evaluated if the burner is replaced.

14. The location for the flame scanners should be evaluated with the burner replacement for the replacement or relocation. RATE recommends IRIS S-550 type flame scanners since it will not be effected as the results of pipe x-raying, heats and radiation on the site and seems more robust for the sulfur plants.

15. The flow meters and control valves on the acid gas lines should be evaluated for a higher flow rate and turndown issues.

16. The existing refractory should be evaluated for a higher combustion temperature in the reducing atmosphere. The principle of using double combustion for processing rich H2S acid gas is that 90% alumina refractory with silica, at reducing atmosphere, has a maximum temperature limitation, and using 94% alumina refractory with magnesium is very sensitive to thermal shock at reducing atmosphere and may not be very cost effective, but it will handle higher combustion temperature. The melting point of 90% alumina with silica and 94% alumina

with magnesium is about 3400℉ and 3500℉ respectively. However, the ferrules should be evaluated for this combination.

Waste Heat Boiler and Steam Drum

Hot gases leaving the reaction furnace are cooled in the waste heat boiler by generating steam. The existing waste heat boiler and steam drum should be evaluated, for low level of Oxygen, no changes or concern is required. For medium or high level of Oxygen with rich H2S content the existing waste heater could be used as a second pass waste heat boiler and a new waste heat boiler should be added as a first pass waste heat boiler.

For lean H2S acid gas and high Oxygen enrichment, single combustion is adequate therefore, there is no need for the additional waste heat boiler, if the existing waste heat boiler is well designed and well maintained.

The following is the Oxygen enrichment impacts the waste heat boiler design.

1. Higher operating temperature, resulting in higher heat duty, which requires more cooling.

2. Having more sulfur vapor from reaction furnace needs more heat for redistribution.

3. Recombination of CO to COS, and H2, S2 to H2S releases additional heat in front of several feet of boiler tubes, which is not predicated by some simulator. It increases the heat flux near the critical tube to tube sheet weld (maximum metal temperature), and inlet tube sheet refractory and ferrules, maximum heat flux in tubes requiring mechanical attention.

4. Improved heat transfer as the result of higher radiant film coefficient.

5. Steam drum size, downcomer/riser size and number, nozzle sizes, associated piping and instrumentation should be evaluated.

6. Relief capacity, BFW /steam rate will be increased.

7. Mass velocities should not be exceeded or heat flux issues may arise, which may cause vapor blanketing of the tubes and high temperature in the tube and tube-sheet.

8. The peak heat flux occurs at the outlet of the ceramic ferrules; therefore, the heat flux should be limited to a maximum 50,000 to 70,000 Btu/hr-ft2 to prevent eddying.

9. The temperature of tube to tube-sheet weld should be limited and evaluated for the possibility of sulfidic corrosion of carbon steel.

Claus Catalytic Stages

1. The gas leaving reheaters enter to the Claus Catalytic reactors. The impact of oxygen enrichment on Claus Catalytic stages as follows:

2. Larger temperature rises across the reactors and having higher sulfur partial pressures. Since the Claus reaction is favored by lower temperatures having higher sulfur partial pressure increases the extent of the Claus reaction.

3. The volumetric flow will be the same but there is more vapor sulfur present in the gas stream.

4. The COS and CS2 hydrolysis will improve due to a higher temperature in the Claus reactors.

5. If the conversion of sulfur plant to oxygen enrichment is for processing for lean or very lean H2S acid gas, then the alumina catalyst in the first Claus reactor is to be converted to Titanium at the bottom up to 50% and alumina catalyst at the top to improve the hydrolysis of COS and CS2 as the result of high CO2 concentration in the acid gas and reverse reaction.

6. For the conversion of sulfur plant to high level of oxygen enrichment if the outlet piping of the first Claus reactor is CS, the material should be evaluated for changing to SS or refractory piping due to a higher temperature outlet.

Reheaters & Hot Gas Bypass Reheat

The gas leaving condensers enter the reheaters. The impact of Oxygen enrichment on reheaters having higher temperature, decreases the hot gas by-pass flow. However, the material and thermal stress in the existing piping should be reviewed for revamp projects.

Claus Sulfur Condensers

The gas leaving the Claus reactors enter the sulfur condensers. The high level of Oxygen enrichment has impact as follows:

1. The sulfur condenser duties increase, because of higher inlet temperature.

2. Condensers will have a higher mass flux of lb/hr/ft2 as the results of higher duties and the target should be defined.

3. The No. 1 and No.2 sulfur condenser may require a higher heat duty or the replacement to a new condenser sometimes is required. The impact on the other condenser is not significant.

4. All the relief valves are to be re-rated for the new process conditions.

5. All the utility lines such as BFW, steam and instrumentation should be evaluated for the new process conditions.

6. All the sulfur run down should be evaluated because of higher sulfur production.

TGU Hydrogenation Reactor, Waste Heat Exchanger & Contact Condenser

The function of the hydrogenation reactor is to convert sulfur compounds (mostly SO2) to H2S and hydrolysis of COS and CS2. The effect of Oxygen enrichment as follows:

1. Increase the concentration of sulfur compounds in the tail gas feed, which result at a larger temperature rise across the hydrogenation reactor and higher duties in the waste heat exchangers and contact condenser.

2. Since the SO2 concentration is higher in the tail gas feed, during conversion to H2S in the reactor increase, the water vapor in the reactor is added to the water from the sulfur plant in the tail gas feed.

3. There is a significant increase of the heat duty of the contact condenser-cooling loop includes water and air cooler.

4. There is a significant increase on water circulation, pump capacity, and piping.

5. A noticeable lower pH is due to a higher H2S and CO2 partial pressure, and lower NH3 content.

6. The corrosion rate in the contact condenser, in the warmer sections, should be monitored more often.

7. The tail gas volumetric flow rate is lower, even though it is required to acquire a more cooling system.

8. If the conversion of sulfur plant to oxygen enrichment is for processing for lean or very lean H2S acid gas, then the unit should be evaluated for a promoted COMO catalyst for a lower COS outlet, because CO concentration is high and has a tendency to convert to COS.

9. For the conversion of sulfur plant to high level of oxygen enrichment, if the outlet piping of the hydrogenation reactor is CS, the material should be evaluated for changing from CS to SS or CS refractory piping to a higher temperature outlet.

TGU Amine Absorption & Regeneration

The impact of the Oxygen enrichment on the TGU amine absorption and regeneration as follows:

1. The feed to the TGU amine unit has a higher H2S concentration and higher H2S partial pressure.

2. Required more amine circulation rate or higher amine concentration.

3. Required more reboiler and OVHD condenser duty.

4. Required more cooling duty in the lean amine circulation loop.

5. Piping and instrumentation should be evaluated case-by-case, especially for rich amine piping in terms of velocity, pressure drop, and higher flashing in the rich solution.

6. The capacity of relief valve should be evaluated.

7. The flow rate of acid gas from the amine regeneration reflux drum to the SRU is higher; therefore, the reflux drum size, instrumentation, velocity and pressure drop should be checked.

8. The rich solvent will have a higher loading; therefore, critical equipment such as lean/rich exchanger should be evaluated for corrosion and erosion.

Incineration

Oxygen enrichment will have the following impact on the incineration system:

1. Reduction of the volumetric flow from the amine absorber to the incineration.

2. Increased the H_2 concentration and reduced N_2 concentration, which reduces the fuel gas demand.

3. Increased the SO_2 and water concentration in the stack.

4. If the unit is equipped with the degassing unit, the H_2S content of the liquid sulfur will be increased and more H_2S will be routed to the incineration.

5. The stack emission for sulfur species should be evaluated to meet the environmental regulations.

Liquid Sulfur Handling/Granulation

Oxygen enrichment will have the following impact on the liquid sulfur handling and granulation:

1. Increased sulfur production.

2. Rundown piping and sulfur seal pots may require larger size or the existing to be replaced for an additional sulfur production.

3. As the result of higher sulfur production, the sulfur pit residence is reduced. The existing sulfur pit should be evaluated and may require a new sulfur pit, which will add some additional piping.

4. The H_2S content of the liquid sulfur will be increased and more H_2S will be routed to the incineration.

5. Sulfur pumps require a higher capacity and higher discharge head.

6. If the unit is equipped with the degassing unit, the capacity of the degassing unit should be evaluated for the additional sulfur capacity.

7. If the unit is equipped with granulation of sulfur, the capacity of solidification and bagging should be evaluated for the additional sulfur production.

Controllability

Below is a list of the primary changes that RATE has incorporated in the controls for our sulfur recovery units over the last 20 to 30 years that have improved the controllability of our units:

1. Use of distributed control systems for controlling the combustion air and acid gas feeds (and other control functions) to the sulfur recovery unit.

2. Use of calculation algorithms to calculate actual air or oxygen demands to process the acid gases in the sulfur recovery unit (including capability of adjusting air demands for compositional changes in acid gases).

3. Use of calculation algorithms to regulate the flows of sour water stripper gas and amine to front and rear chambers of the reaction furnace to provide optimal operating temperatures in the Reaction Furnace to thermally decompose ammonia in the first chamber by splitting the acid gases.

4. Use of "Smart" type flow transmitters with pressure and temperature compensation to provide more accurate flow rates with automatic conversion to mass flow rates and also to provide greater turndown capability – up to 6 or 7 to 1.

5. Use of newer H2S / SO2 analyzer for more reliable trim air controls.

6. Use of Venturi type flow meters in acid gas and air streams to provide more accuracy at turndown rates.

7. Use of three element boiler feed water controls for Waste Heat Boiler controls.

8. Use of both special thermocouple designs and optical pyrometers for Reaction Furnace .

9. Use of latest flame scanner technologies for Reaction Furnace flame detection.

10. Adaptive gain control on the tail gas analyzer trim control

11. Muti-variable control for the sulfur plant

12. Advanced Control Technology

Other Considerations

The impact of the Oxygen enrichment on major equipment is discussed. However, it is required for the designer to evaluate all the related equipment, piping, instrumentation, relief valves, and the mechanical design issues for a higher sulfur production and higher acid gas throughput to the unit.

Oxygen Enrichment Control System

The following diagrams represent the control system conversion for the burner management system for the Oxygen Enrichment for the revamp and the new projects for single and double combustion.

If the sulfur plant revamp is for lean H2S concentration, single combustion is adequate. If the sulfur plant revamp is for rich H2S concentration, double combustion is required as the result of the refractory temperature limitation.

Oxygen Piping Criteria

Most oxygen piping systems are of steel or stainless steel materials and operate at pressures of 1000 psig or less and temperatures are below 200 °F. Stainless steel has the maximum allowable velocity in the pipe. The oxygen valves are chosen from Monel or Inconel, which are permitted at the high velocity and pressures up to 1000 psig. Oxygen piping systems shall be kept as simple as possible, with the smallest possible number of valves, fitting, branches and nozzles. All process control valves should be in throttling service. Only globe valves or needle valves shall be used for throttling. Staged Combustion Oxygen Enrichment is shown below.