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Downsizing a Claus Sulfur Recovery Unit

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Background

- The drop in crude oil prices from over \$100/barrel to less than \$30/barrel has lowered if not eliminated the economic advantage of processing high sulfur crudes. In the USA there is a significant amount of fracked shale oil available that is low sulfur. US Refineries can therefore be processing lower sulfur crudes.



Background

- Processing of lower sulfur crudes can result in a significant reduction in the amount of hydrogen sulfide (H_2S) available for processing into sulfur. In some cases this will require modification of sulfur recovery units to handle smaller quantities of H_2S .

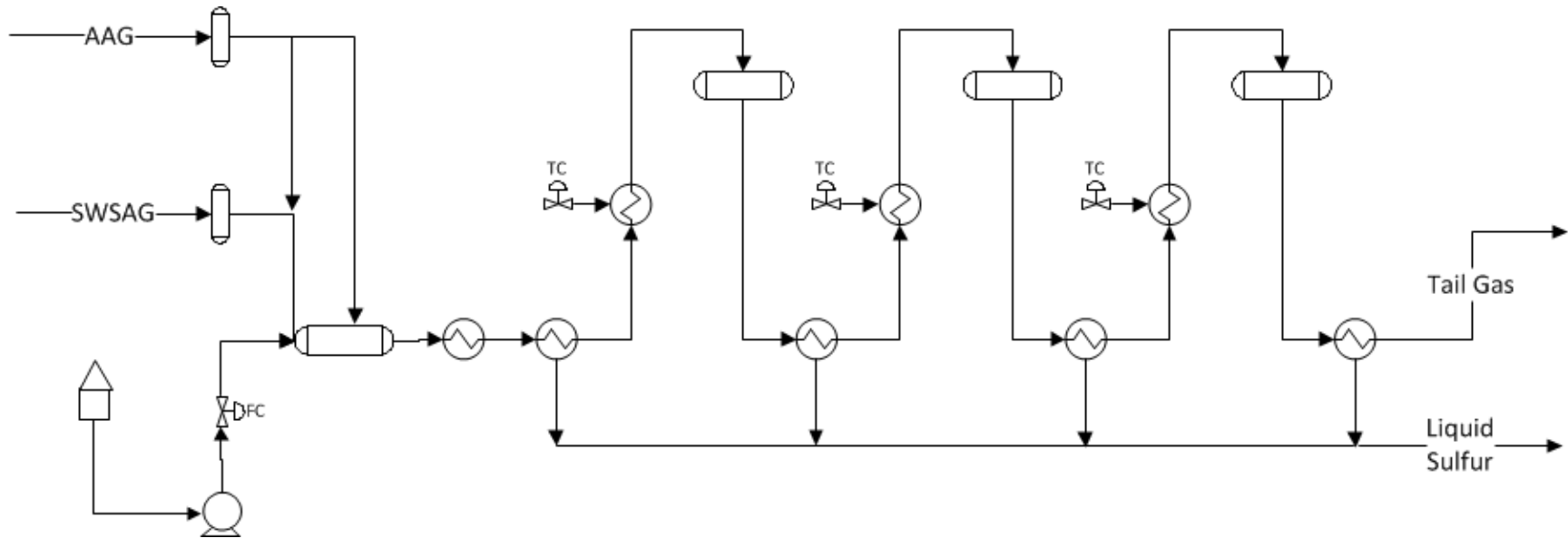


Claus Sulfur Recovery Unit

- The Claus sulfur recovery unit (SRU) converts hydrogen sulfide into elemental sulfur.
- The Claus sulfur recovery unit is typically made up of a thermal reaction stage followed by 2 or 3 catalytic reactor stages
- The typical conversion of the hydrogen sulfide and its recovery as elemental in a Claus sulfur recovery unit is 92-96%



Claus Sulfur Recovery Unit





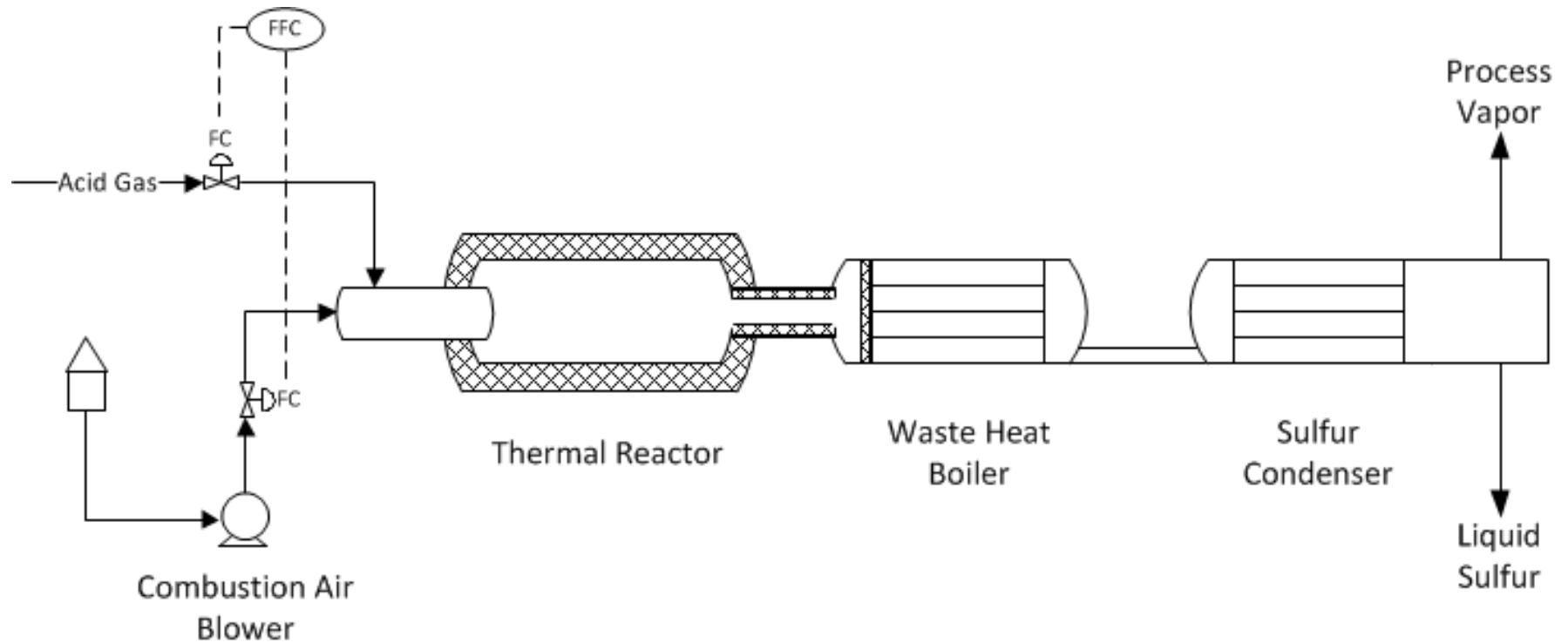
Sulfur Recovery Unit – Thermal Stage

The Thermal Stage is made up of:

- Thermal Reactor (aka reaction furnace)
- Acid Gas Burner
- Waste Heat Boiler
- Sulfur Condenser
- Combustion Air Blower
- Combustion Air Flow Control System



Sulfur Recovery Unit – Thermal Stage





Thermal Reactor

- The thermal reactor is a horizontal carbon steel vessel equipped with multiple refractory layers to protect the steel shell from very high temperatures (typically over 2000 F).
- In the reaction furnace approximately 1/3 of the H₂S is combusted to sulfur dioxide (SO₂) to meet the basic Claus reaction requirements of:





Acid Gas Burner

- Special High Intensity - Engineered burner capable of handling the acid gases, combustion air and oxygen (if used).
- Bolted via flange or welded to front of the Thermal Reactor
- Includes retractable igniter and sight port(s), which allow viewing of thermal reactor internals.



Waste Heat Boiler

- The hot gases from the reaction furnace are cooled in a waste heat boiler where steam is produced.
- Typically Fire Tube type steam boiler with external or integral Steam Drum
- Because the reaction furnace temperature is usually above 2000 °F, high pressure saturated steam (up to 600 psig) can be produced that is used to heat the catalytic reactor feeds or as motive steam for a steam driven combustion air blower.



Thermal Sulfur Condenser

- The partially cooled gases from the waste heat boiler are further cooled in the thermal stage sulfur condenser.
- Shell and Tube type heat exchanger that typically generates LP steam
- The elemental sulfur is condensed and separated with the process gas proceeding to the catalytic stages and the liquid sulfur product being routed to a liquid sulfur storage pit or tank.



Combustion Air Blower

- The oxygen for the reaction is supplied by a combustion air blower.
 - Centrifugal compressor-blower
 - Positive displacement blower for small units
- Some units may have the oxygen supplied from an offsite air separation unit at concentration significantly higher than the dry gas 21% ambient air oxygen content.



Combustion Air Flow Control System

- Monitors the flow rates of the amine acid gas, the sour water stripper acid gas, and the natural gas used for start-up or co-processing and calculates the amount of combustion air rate required to generate the sulfur dioxide (SO₂) required for the classic Claus reaction



- The system receives feedback from the SRU tail gas H₂S-SO₂ analyzer .



Sulfur Recovery Unit – Catalytic Stage

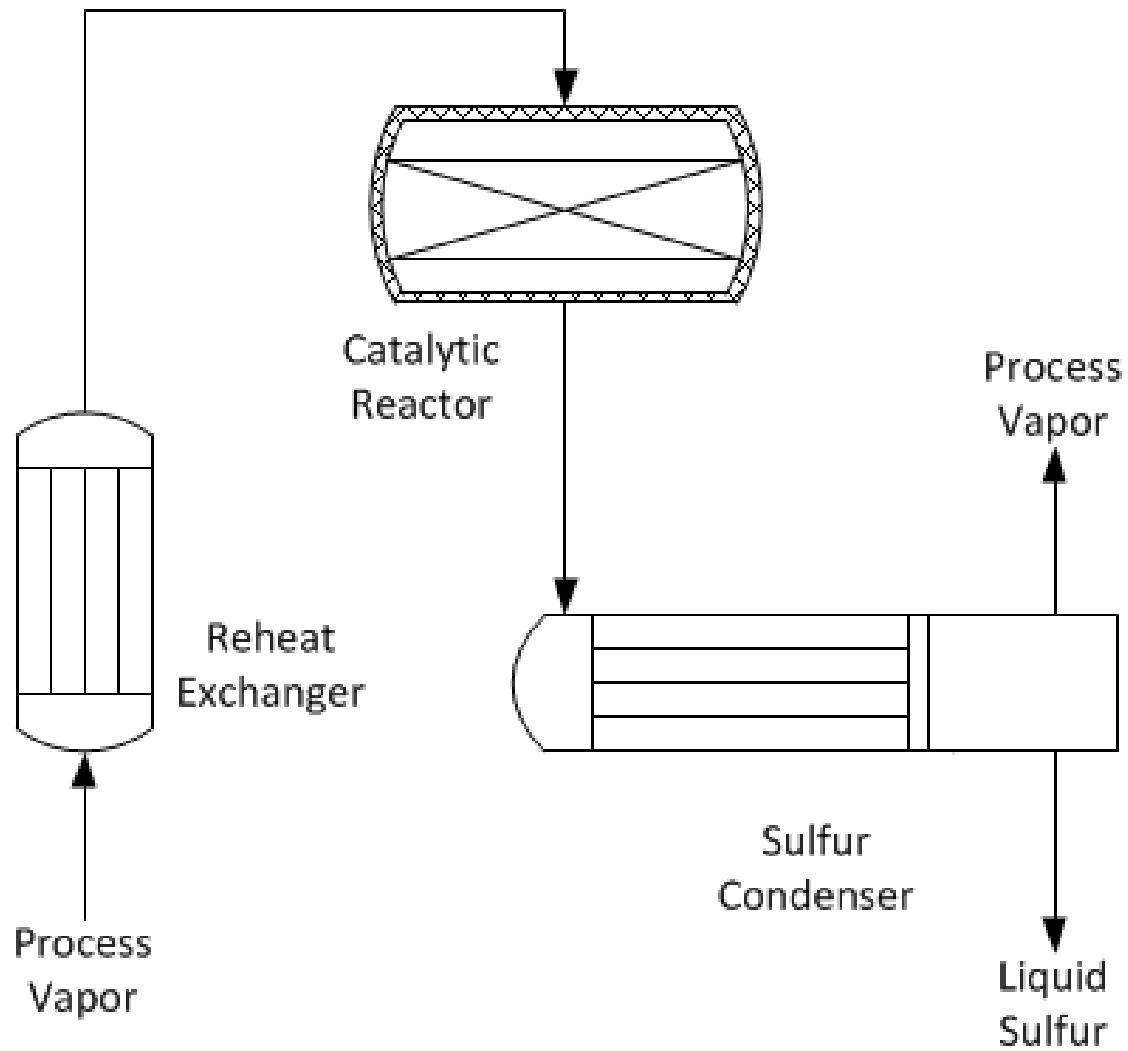
- **Catalytic Reactor Feed Heating System**
 - Heats the reactor feed to the appropriate reactor temperature
 - Indirect Reheat with HP Steam, hot oil, or electric power
 - Direct Fired In-line Burners
 - Hot Gas Bypass

- **Catalytic Reactor**
 - Activated alumina catalyst

- **Sulfur Condenser**
 - The elemental sulfur is condensed out of the process gas and separated.
 - Typically a shell & tube type exchanger with LP Steam generation



Catalytic Stage





Affects of Flow on Unit Operations

- During turndown, the mass flow through the unit is reduced. This affects heat transfer coefficients within the heat transfer equipment, such as, the sulfur condensers and reheat exchangers.

$$Q = UA\Delta T \quad U=f(\text{MassFlow}^{0.8})$$

- The total heat released due to reaction is reduced, both in the thermal reactor and the catalytic reactor(s).
- There are lower temperatures throughout the unit, due to constant atmospheric heat losses.

$$\Delta T_{\text{Proc}} = (Q_{\text{React}} - Q_{\text{Loss}})/(\text{MassFlow} * \text{HeatCap})$$



Affects of Flow on Unit Operations

- Flow Measurement and control can be limited due to basic instrumentation restrictions; the newer “smart” transmitters do improve the measurement situation and special control valves (multi-hole ball valves) can be used to mitigate the physical limitations.
- Flow Distribution in catalyst beds are a function of flow rate and therefore will be impacted by reduced flow.



Areas of Concern

- Basic Flow Ratio Control of combustion air - oxygen to amine acid gas and SWS acid gas.
- Acid Gas Burner mixing
- Combustion Air Blower
- Waste Heat Boiler heat transfer and sulfur condensation
- Sulfur Condenser heat transfer
- Sulfur Condenser fog formation
- Reheater heat transfer or air to fuel ratio for fired reheater
- Catalytic reactor insulation - Heat loss



Flow Ratio Control

- The primary control valve to evaluate is on the combustion air. This valve may have to be changed to provide reasonable controllability. If parallel flow meters are installed, then it would be very simple to install a second combustion air control valve.
- The boiler and the condenser BFW control valves and the incinerator/stack fuel gas control valve should be checked and replaced if necessary.



Acid Gas Burner

- The acid gas burner may require modifications to handle the lower acid gas flows. Most acid gas burner designs use turbulence to provide good mixing. The turbulence is generated using high velocities. These velocities were provided at the design flow rates of air and acid gas. With lower rates, the burner may not be able to generate the turbulence required for good mixing and may not perform properly. A new burner may be required, or modifications to the existing burner may be possible.



Combustion Air Blower

- The combustion air blower will continue to operate with the lower combustion air requirements. The only problem will be a very large amount of blow-off from the blower, which translates to potential noise.
- Slowing down the blower may help solve the problem.
 - Steam turbine driven allows for slowing down the turbine.
 - Electric driven would require the addition of an electronic variable speed controller.
- A good quality blow-off silencer can be provided to reduce the noise



Waste Heat Boiler

- The boiler is a heat transfer device. There will be too much surface area within the boiler to maintain the original design outlet temperature. If the outlet temperature drops below the sulfur dew point of the boiler outlet stream, the sulfur will be condensed within the boiler. Some boilers have sulfur rundown legs and some do not. Those boilers that do not have rundown legs should be checked to insure that sulfur produced within the boiler can drain through the condenser. Otherwise, a new sulfur rundown leg or seal pot will be required.



Waste Heat Boiler

- To reduce surface area, plugging of the tubes may be required and can be permanent or temporary.
 - A permanent plug would be a tapered steel plug driven into each end of the tube. A vent hole must be drilled in the tube to prevent the buildup of pressure due to heat expanding the trapped gas.
 - A temporary plug using a 3-6 inch plug of refractory can be installed. This will effectively plug the tube. Since most refractories can breath, the problem of pressure building up in the tube is reduced.



Waste Heat Boiler

- It is possible to plug only one end of the tube. However, experience indicates that sulfur gases may migrate into the dead zone of the plugged tube. This can then cause severe corrosion due to condensation of water with H_2S , SO_2 and elemental sulfur during a shutdown period of the unit.



Sulfur Condenser Surface Area

- The sulfur condensers are heat transfer devices.
- A problem with the condensers is too much surface area, which can cause the outlet temperatures to be much lower than design and impact the operation of the downstream reheat system.



Sulfur Condenser Surface Area

- The condenser flow area may be reduced by plugging condenser tubes. A tapered steel plug can be driven into each end of the tubes, with a drilled vent hole. Sometimes this vent is drilled in the tube wall to prevent process gases migrating into the sealed tubes. This is a permanent reduction in tube count.



Sulfur Condenser Surface Area

- Temporary plugging can be accomplished by attaching a flat plate over the inlet tube ends. This plate should not be sealed to the tube sheet, but should just divert the gases to the other tubes. A 1/4 to 3/8 inch space should be provided between the plate and the tube ends. Since the plate is not sealed over the tubes, the sulfur gases can be flushed out of the tubes, when the unit is purged during shutdown. This reduces potential corrosion problems.



Sulfur Condenser Mist Pad Area

- Some sulfur condensers have mist eliminators installed in the outlet channels to reduce the amount of sulfur entrainment in the condenser outlet gas. Mist eliminator operation is primarily based on impingement. With the reduced flows in the unit, the gas may not have sufficient velocity for the entrained sulfur to impact on the mist eliminator. It may be desirable to reduce the mist eliminator flow area to that recommend by the manufacturer for efficient operation.



Sulfur Condenser fog formation

- The mass velocity in the sulfur condenser tubes will be lower than design. When the tube velocity is too low, there is not enough turbulence within the tubes to cause the sulfur being formed to impinge on the tube wall and coalesce. The sulfur remains suspended in the gas phase as a fog or fine mist. This fog will tend to flow through the unit without ever coalescing and will reduce the overall sulfur recovery of the unit.



Reheater Heat Transfer

- The reheat exchanger is a heat transfer device and will be affected by the reduced flow rate. There are two compounding effects of low flow.
 - The first is the reduced heat transfer coefficient.
 - The second is lower inlet temperature because of the excess surface area in the upstream condenser. The outlet from the reheat exchanger is the catalytic reactor inlet, which is a process control point.
 - The reheat exchanger will have to be checked for proper operation and possibly replaced. In general, the exchanger will work, however, there have been cases where it was necessary to replace the exchanger. The heating media control system should be checked for proper sizing.



Bypass Reheat

- In a bypass reheat unit, the catalytic reactor inlet temperature is obtained by mixing the cold sulfur condenser outlet gas with hot gas from the middle of a two pass waste heat boiler.
 - At low flow conditions the boiler will have excessive surface area and the temperatures within the boiler will be lower than design.
 - This will require more hot gas to be bypassed to the catalytic reactor to achieve the desired reactor inlet temperature.
 - As the amount of bypass gas increases, the dew point of the reactor inlet gas increases, which can result in the gases being below the sulfur dew point. When this happens, sulfur is formed as a fine mist or fog and can pass through the unit without being removed.



Bypass Reheat

- There is also the possibility of depositing liquid sulfur onto the catalyst and plugging the catalyst pores. The plugged catalyst pores will reduce the active catalyst area and contribute to a further reduction in the sulfur recovery.
- Obviously, a bypass reheat unit will require the plugging of boiler tubes to maintain proper operation or the installation of new reheat exchangers.



InLine Burners for Reheat

- Inline burners operate by mixing the cold condenser outlet gases with hot combustion products.
- These combustion products are either from the combustion of a fuel gas or the amine acid gas feed.
 - The burner will probably require modification.
 - The inline burner control instrumentation should be evaluated and modified as necessary to provide good, stable operations.



Reactor Flow Distribution

- The next item of equipment is the catalytic reactor. The design basis for the catalytic reactor is maximum space velocity through the catalyst bed. Since the flows will be lower, the velocities will be lower and modifications may be required. Care must be used to insure that flow through the catalyst bed is uniform, without channeling or dead zones, at the low rates. This may require replacing the catalyst with smaller sized catalyst.



Reactor Insulation – Heat Loss

- A critical problem with the catalytic reactor can be inadequate insulation. Usually, on large sulfur recovery units there is 3-4 inches of insulation on the vessel shell and no insulation on the manways and catalyst dumps. Because flows and reaction heats are lower, the heat loss to the atmosphere can become critical. Additional insulation should be added to the vessel shell for a total thickness of 6-8 inches plus insulation should be added to the manways and catalyst dumps.



Summary

- FEs and CVs
 - utility and process
- Burner performance
- Blower noise
- Tube plugging in WHB and Sulfur Condensers
 - Potential need for a seal leg or seal pot on WHB
- Mist pad performance
- Sulfur fog
- Reheater duty and performance
- Reactor channeling
- Reactor heat loss
 - manways and catalyst dumps