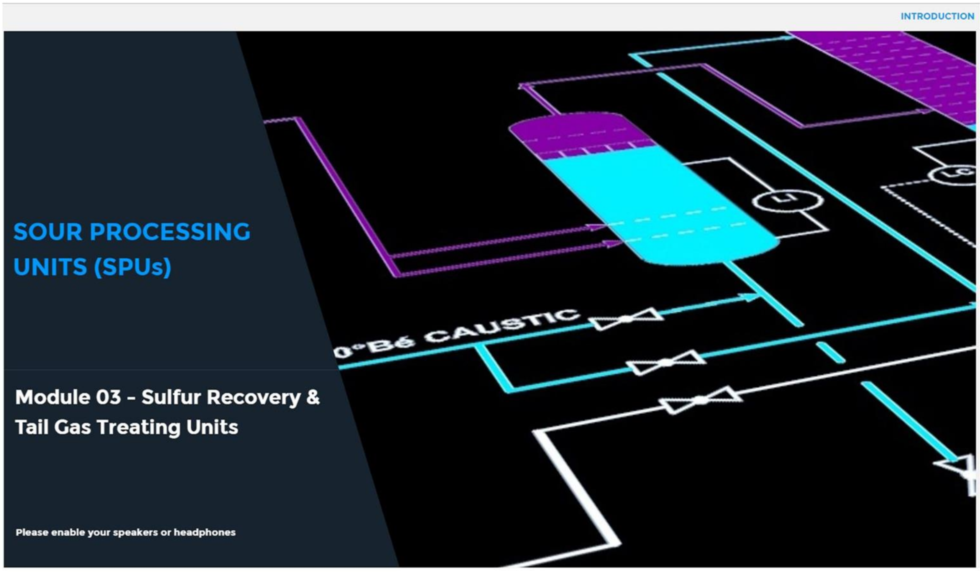
BU MEASUREMENT & ANALYTICS

Refinery Process Units

Sour Processing Units (SPUs) – Module 3: Sulfur Recovery & Tail Gas Treating Units



Welcome to the Sour Processing Units Module 03, which covers the Sulfur Recovery & Tail Gas Treating Units.

For the Sulfur Recovery & Tail Gas Treating Units, upon completion of this module, you should be able to:

Describe the process flow

Name the principal items of equipment

Describe their function

Understand the principles of operation

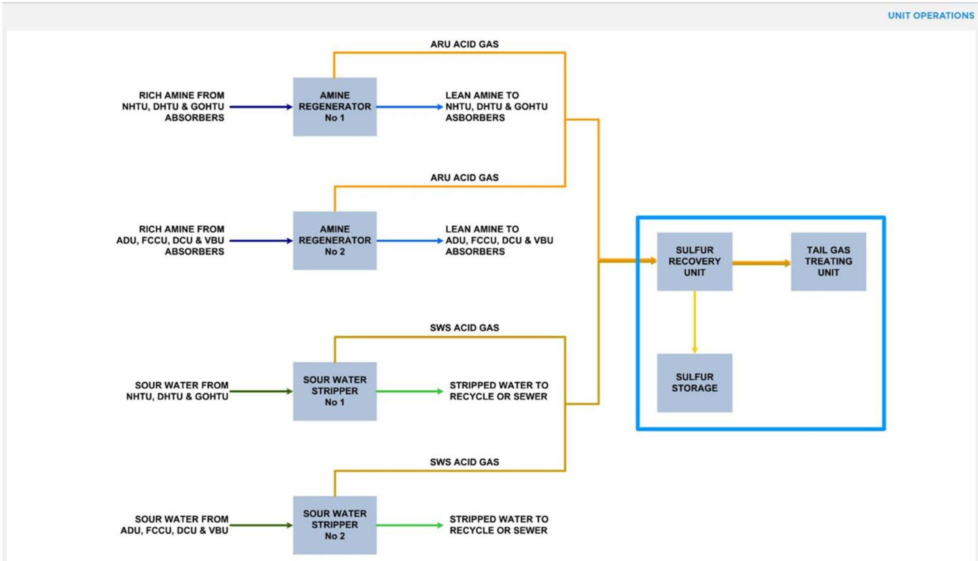
Recognize their internal components

Additionally, you should be able to demonstrate an awareness of:

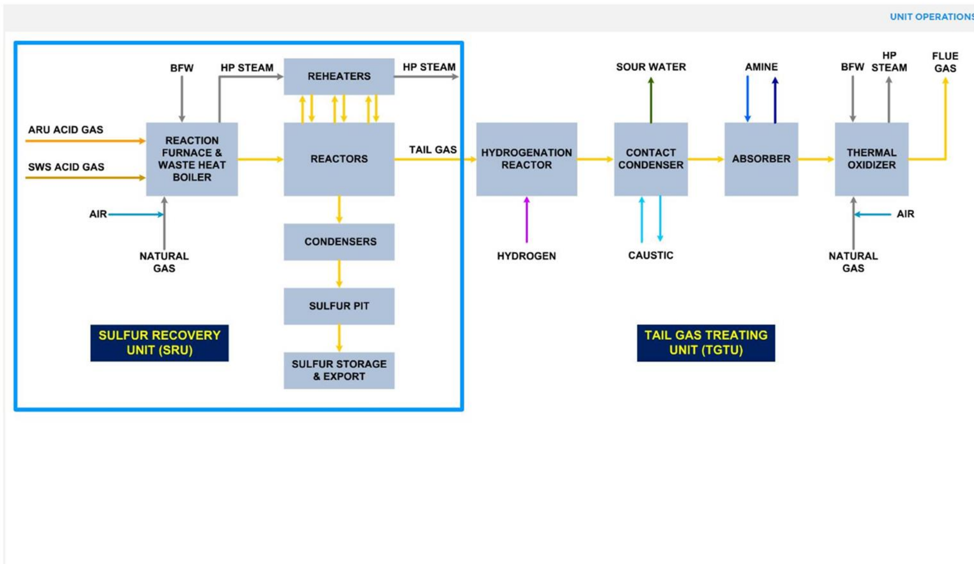
Important process variables and how they’re controlled

Major operating constraints

Typical operating problems

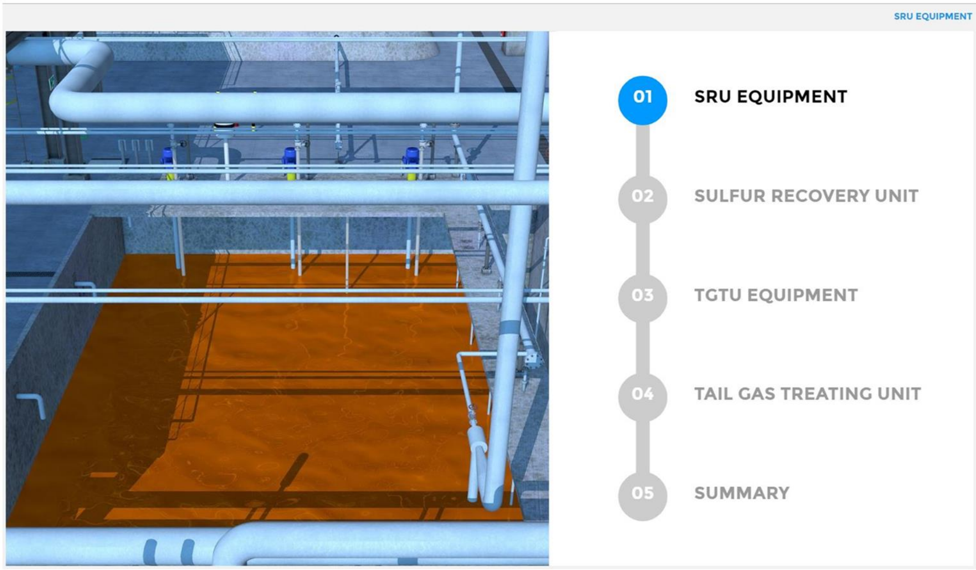


The purpose of the Sulfur Recovery Unit is to convert hydrogen sulfide, present in the Regenerator and Sour Water Stripper acid gas, into elemental sulfur, which is sold either as a fertilizer or as sulfuric acid plant feedstock.

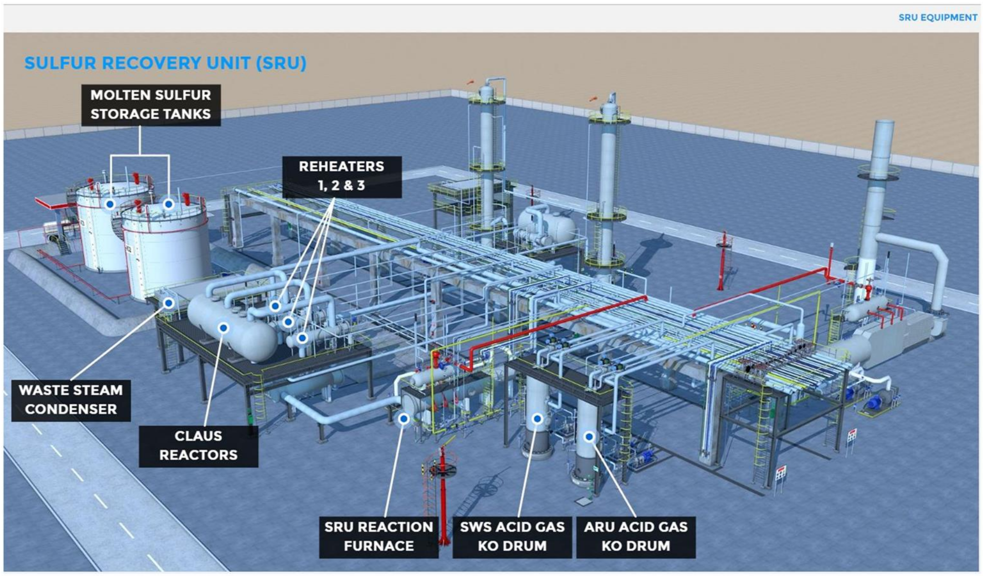


This diagram shows the unit operations for the SRU and TGTU.

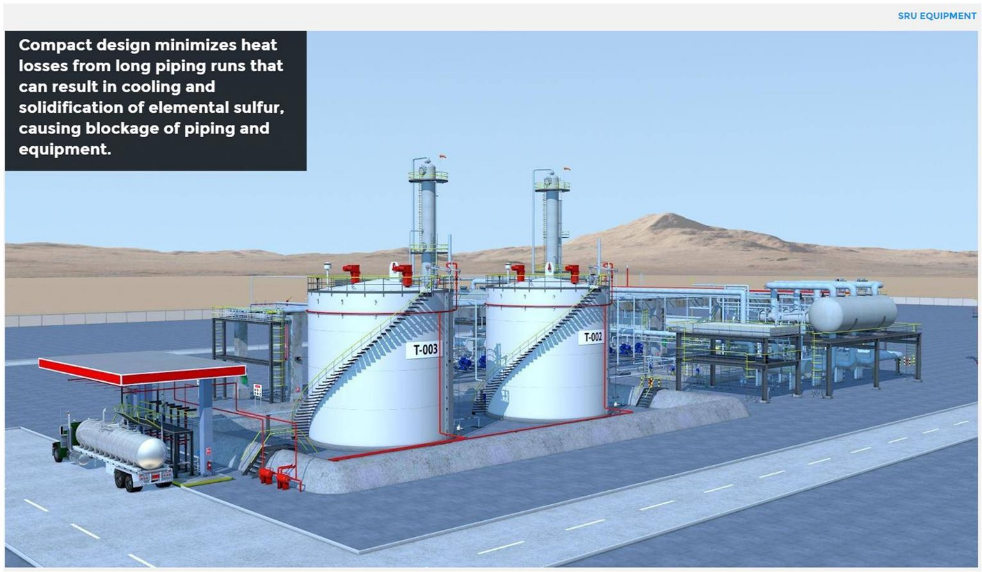
We're going to study the SRU first.



Let’s take a look at the Sulfur Recovery Unit equipment.



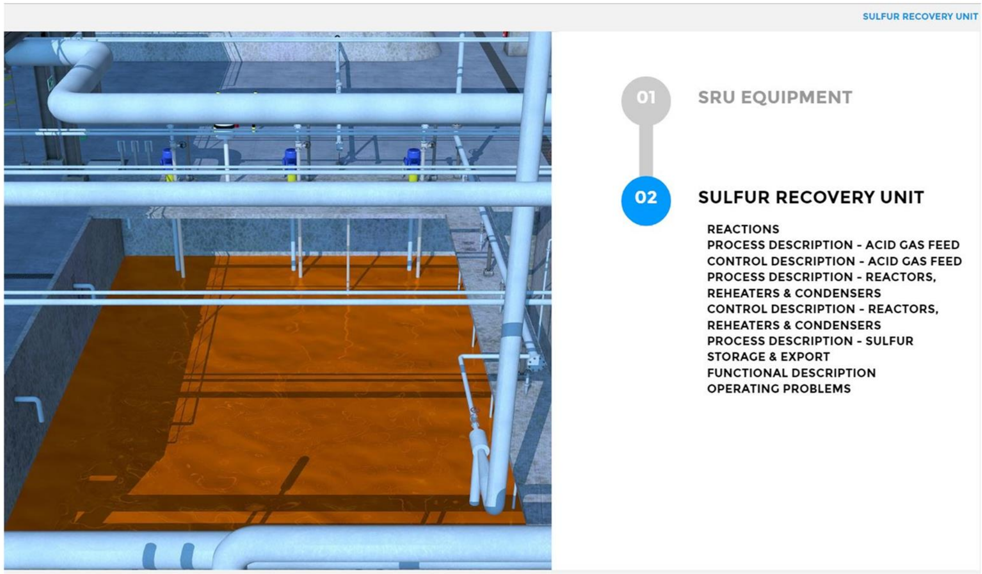
Pictured here we have a 3D model of an SRU.



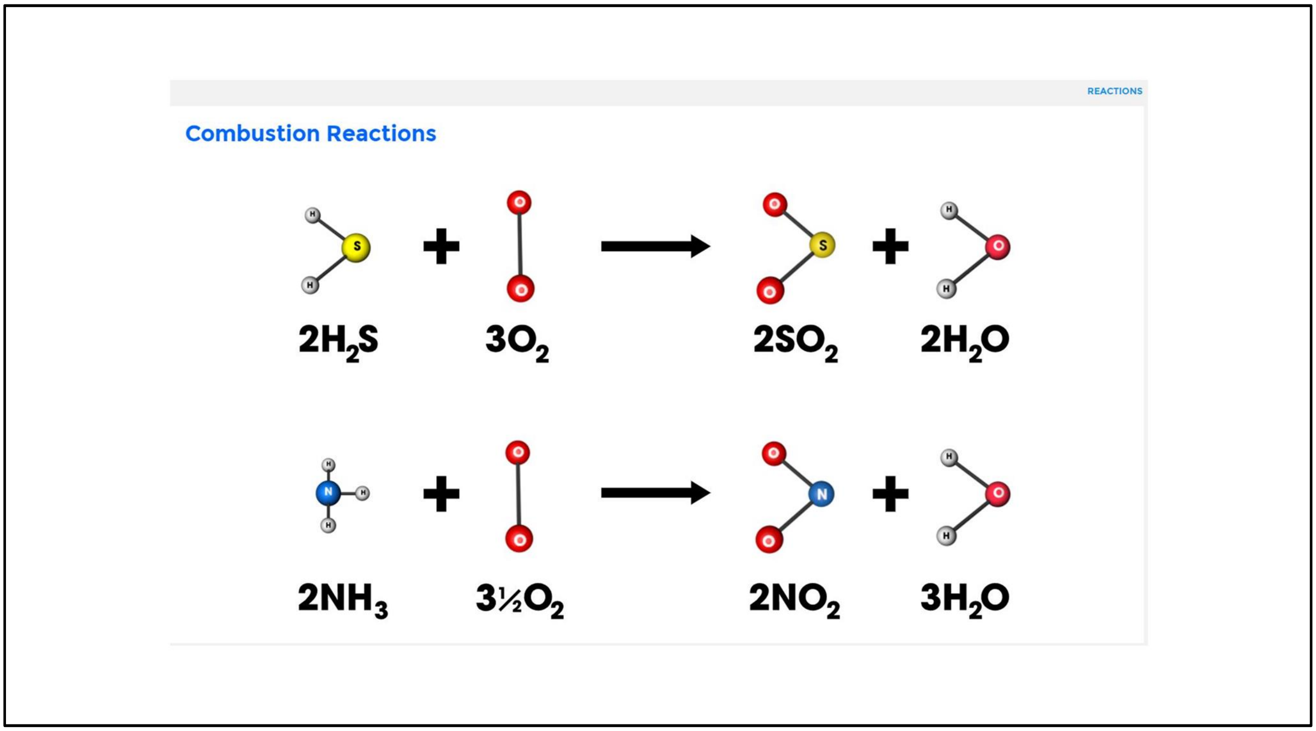
The layout of Sulfur Recovery Unit equipment is quite compact, primarily to minimize heat losses from long piping runs that can result in cooling and solidification of elemental sulfur, causing blockage of piping and equipment.

ARU and SWS acid gases are combusted with air in a Reaction Furnace - the hot combustion products pass through a Waste Heat Boiler, raising high pressure steam before passing to a series of Reactors, Reheaters and Condensers that convert the combusted gases into sulfur vapor, which is condensed and collected in a pit.

From the pit, the molten sulfur is exported as a heated liquid in rail cars or road tank trucks or it is cooled and pelletized and exported in solid form.



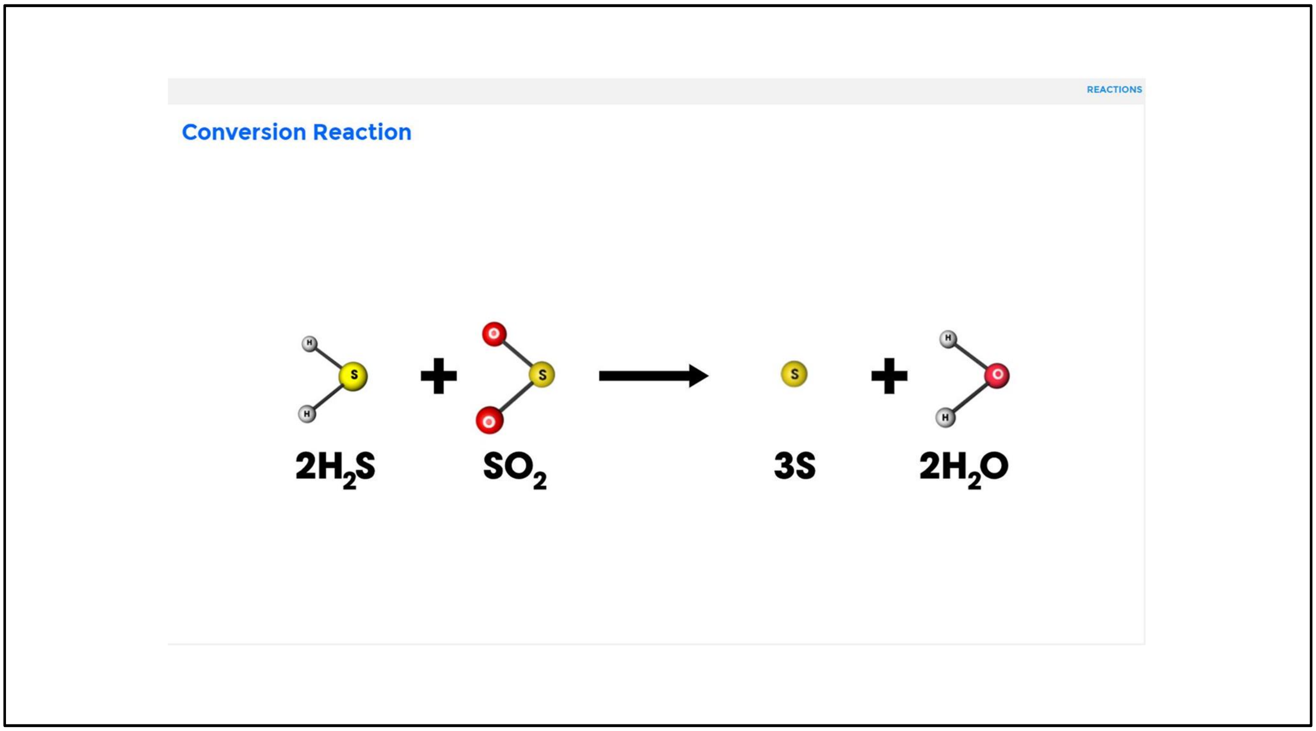
Moving on, let’s make a start on the SRU.



Reactions

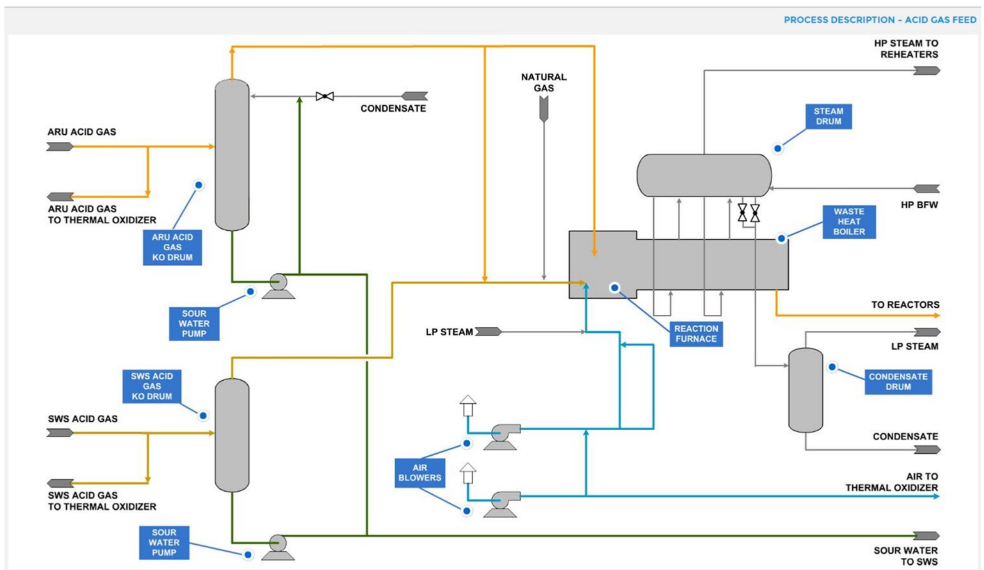
There are two types of reaction that take place in the SRU. The first, combustion reactions, occur at high temperatures in the Reaction Furnace:

> A portion of the hydrogen sulfide present in the ARU and SWS acid gas feed streams is combusted in air to form sulfur dioxide and water vapor
>
> All of the ammonia present in the SWS acid gas feed is combusted to form nitrogen oxides and water vapor - this reaction is very important because failure to completely destroy the ammonia can result in formation of ammonia-sulfur compounds that deposit in downstream equipment, causing blockages



The second type of reaction takes place at lower temperatures in the Condensers and Reactors, converting hydrogen sulfide and sulfur dioxide to elemental sulfur and water vapor.

Initial side reactions also produce small quantities of carbon disulfide (CS_2) and carbonyl sulfide (COS), which are subsequently hydrolyzed to form hydrogen sulfide and carbon dioxide.



Process Description – Acid Gas Feed

Two Acid Gas KO Drums trap and remove any liquid present in the amine regeneration unit and sour water stripper acid gas streams, that could cause damage to equipment refractory lining or downstream catalyst.

Recovered liquid is pumped back to the Sour Water Stripper.

The amine acid gas is scrubbed with condensate as it passes through the KO Drum.

Air Blowers supply combustion air to the Reaction Furnace burner and also to the Thermal Oxidizer at the back end of the TGTU.

The acid gases pass to the Reaction Furnace burner and are combusted.

Natural gas is used to heat the system at startup and to maintain temperatures in the event of an acid gas feed outage.

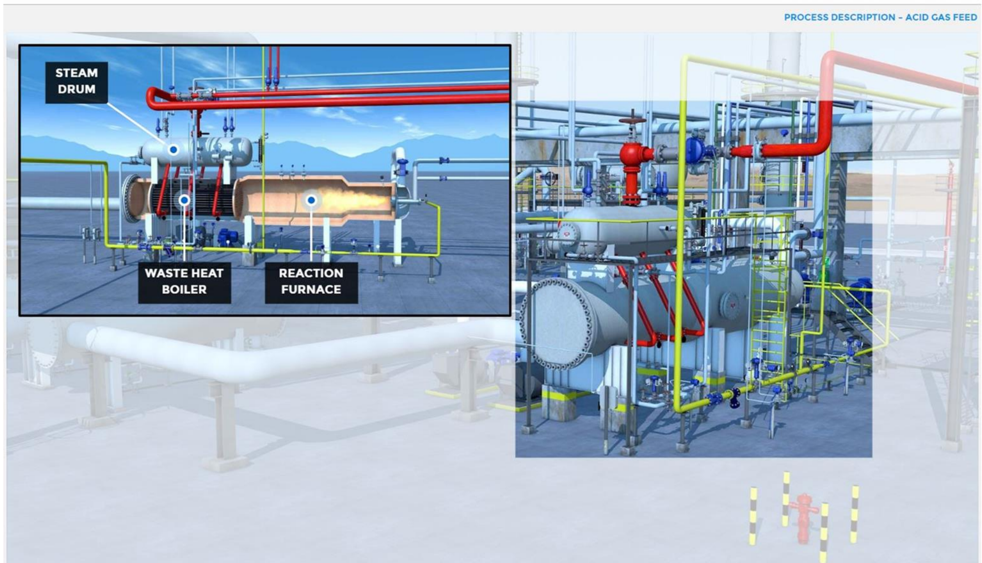
Hot combustion products leave the Reaction Furnace and pass through the tubes of a fixed tubesheet Waste Heat Boiler, giving up heat to raise high pressure steam before passing to the downstream Reactors, Reheaters and Condensers.

The high pressure steam generated passes to the downstream Reheaters.

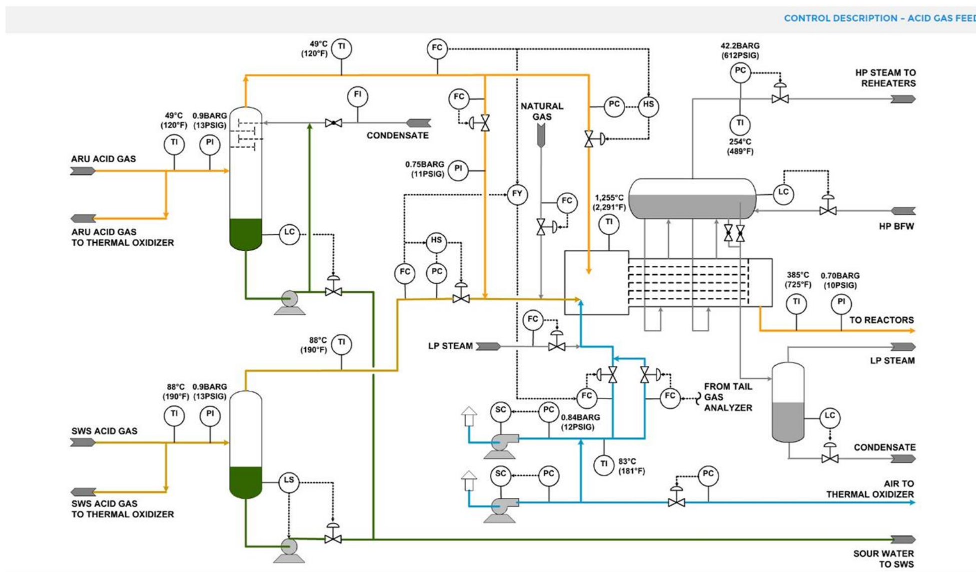
A makeup of boiler feed water passes to a High Pressure Steam Drum, located above the Waste Heat Boiler.

Water circulates between the HP Steam Drum and the Waste Heat Boiler by thermosyphon effects.

Intermittent and continuous blowdowns are withdrawn from the HP Steam Drum into a Condensate Drum, where a portion flashes and is withdrawn from the top as low pressure steam – liquid is withdrawn from the bottom and returned to the Deaerator for re-use.



This image shows the Reaction Furnace, where hydrogen sulfide and ammonia are combusted and the Waste Heat Boiler, where heat is recovered from the hot combustion gases and used to raise high pressure steam.



Control Description – Acid Gas Feed

The Sour Water Pump for the Amine Acid Gas KO Drum runs continuously and sour water is withdrawn on level control. For the SWS Acid Gas KO Drum, the pump is auto-started on a high level and auto-stopped on a low level.

Upstream of the Reaction Furnace, the Amine Acid Gas stream splits - with most of it passing to the main burner on flow or pressure control and a flow controlled slipstream passing to join the SWS Acid Gas for the purpose of aiding combustion.

The SWS Acid Gas passes to the Reaction Furnace on either flow or pressure control.

The flows of Amine Acid Gas and SWS Acid Gas are summed and the output sent to control the main flow of combustion air to the burner.

A second parallel slave flow controller that receives a signal from a master analyzer on the tail gas at the back end of the SRU provides trim air.

The function of the air controllers is to maintain the ratio of hydrogen sulfide to sulfur dioxide formed in the combustion reactions at 2:1. The discharge pressure of the Air Blower is maintained at 0.84 barg (12psig) by a pressure controller that adjusts the rotational speed of the blower.

Air is also supplied to the Thermal Oxidizer in the TGTU on demand by a pressure controller.

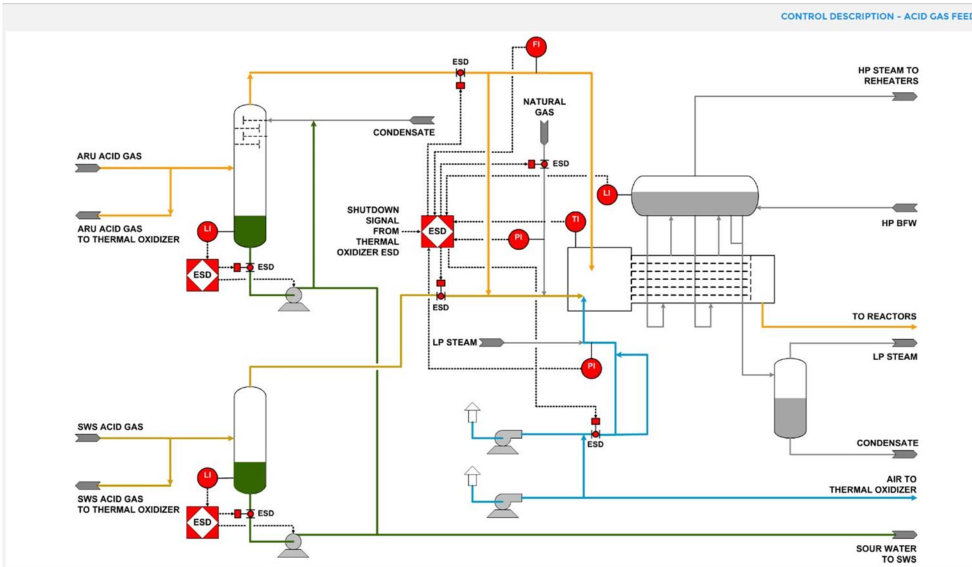
The temperatures of the combusted acid gases across the Waste Heat Boiler are important - the upstream temperature must be kept above 1,250ºC (2,291ºF) to ensure the ammonia in the SWS acid gas is completely destroyed – the downstream temperature is held at around 385ºC (725ºF) to aid conversion of hydrogen sulfide and sulfur dioxide to elemental sulfur.

Makeup boiler feed water is supplied to the HP Steam Drum on level control. HP Steam, at 42.4 barg (612 psig) is withdrawn on pressure control and passed to the downstream Reheaters.

Intermittent and continuous blowdowns are withdrawn from the HP Steam Drum into a Condensate

Drum, with condensate being returned to the Deaerator on level control.

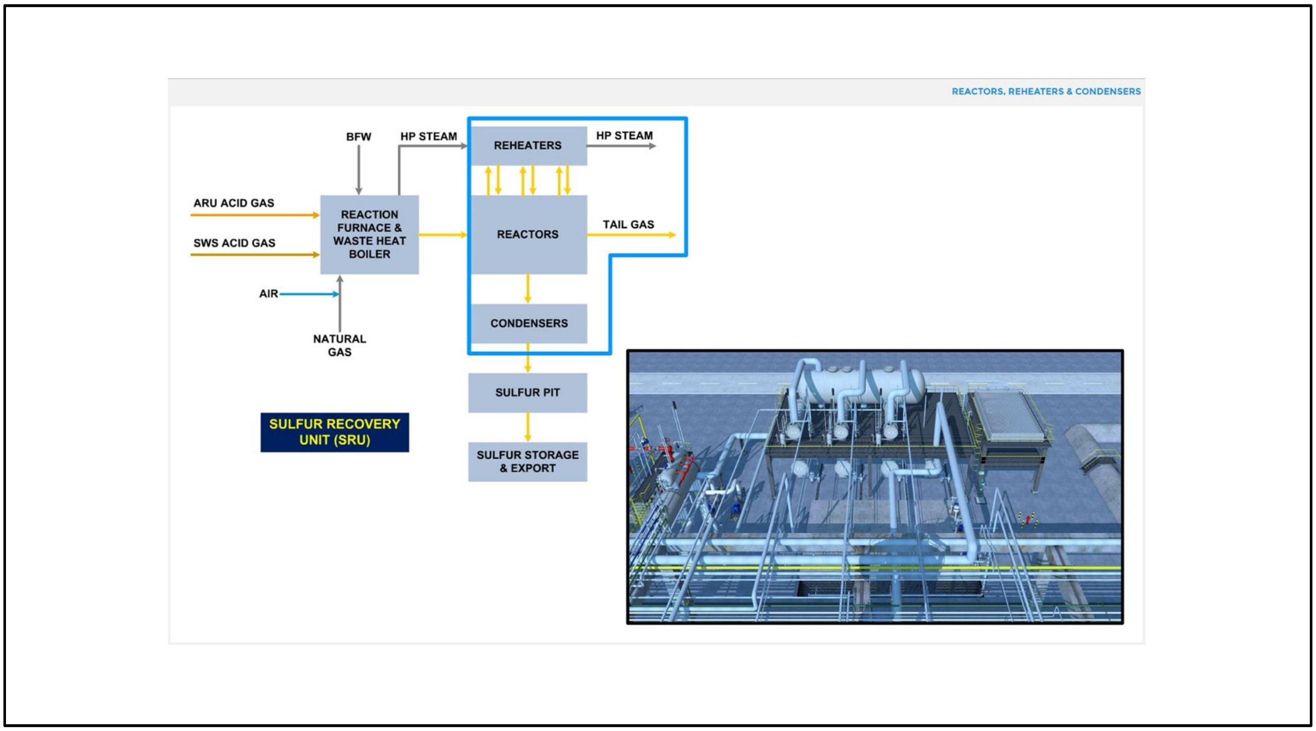
Flow controlled LP Steam and flow controlled natural gas are used during process upsets that necessitate removal of acid gas feed in order to purge the system of acid gas and fire natural gas to maintain temperatures in preparation for a resumption of acid gas feed.



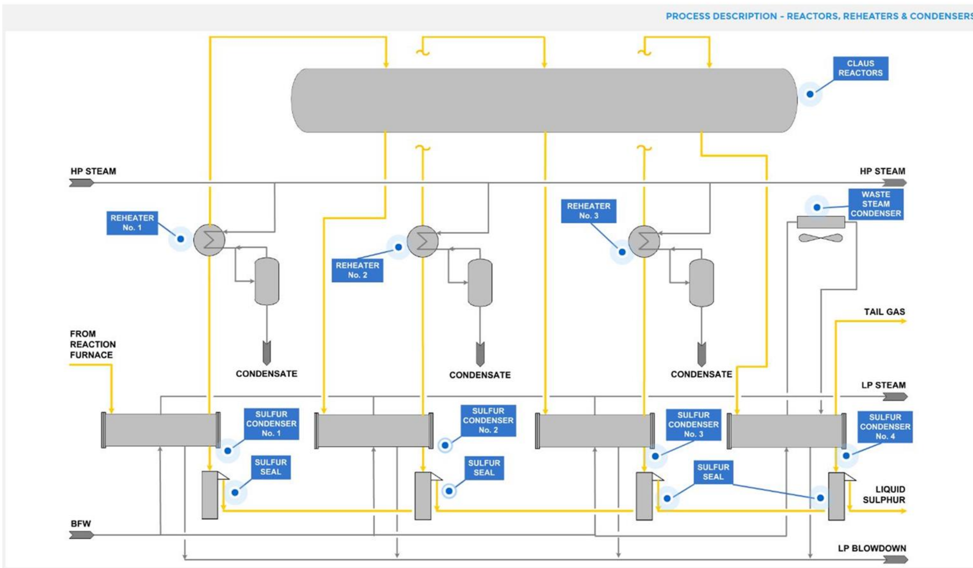
The Reaction Furnace and Waste Heat Boiler have three ESD systems providing protection. Trip initiators and actuators are shown here.

The Acid Gas KO Drums each have low level trips that prevent the Sour Water Pumps running dry and suffering mechanical damage in the event of loss of level

The Reaction Furnace and Waste Heat Boiler are protected against conditions that may lead to an internal explosion or overheating (for both acid gas and natural gas firing modes) by isolating all fuels and combustion air. The ESD system is also activated by an ESD shutdown of the Thermal Oxidizer on the downstream TGTU



Next, we'll take a look at the Reactors, Reheaters and Condensers.



Process Description – Reactors, Reheaters & Condensers

Combustion gases from the Reaction Furnace and Waste Heat Boiler enter Sulfur Condenser No 1, giving up heat to boiler feed water, which in the process is converted into low pressure steam.

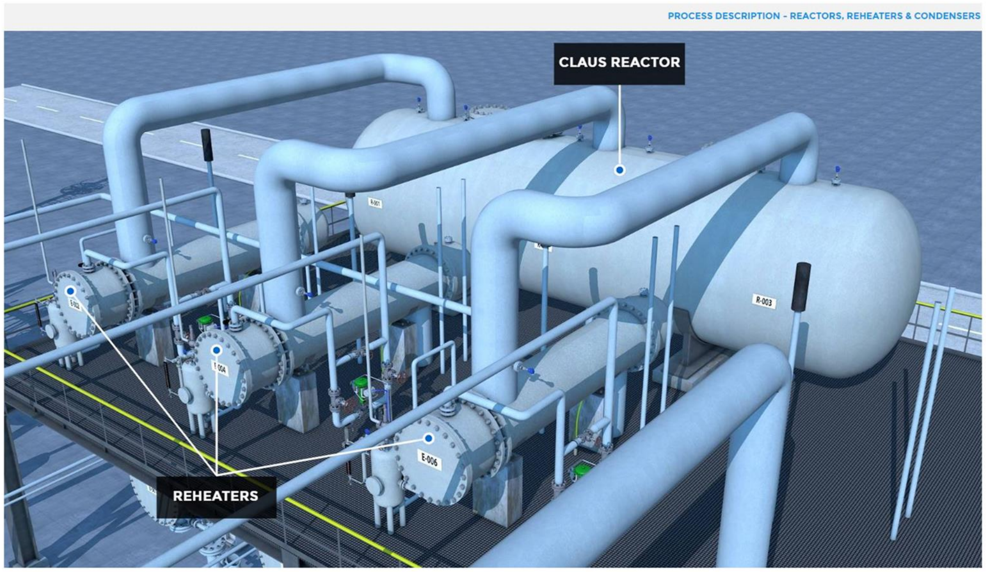
When cooled, the elemental sulfur present in the combustion gases condenses, forming a liquid level which is drained down to a below-ground Sulfur Pit via a Sulfur Seal.

Combustion gases exit Sulfur Condenser No 1, are reheated by high pressure steam in Reheater No 1 and pass to the first of three catalyst beds in the Claus Reactors. The Reactor catalyst beds are made up of layers of activated alumina (on top) and titania (on the bottom).

Over the activated alumina, more hydrogen sulfide and sulfur dioxide are converted to elemental sulfur. Over the titania, carbon disulfide and carbonyl sulfide by-products are hydrolyzed to form hydrogen sulfide and carbon dioxide.

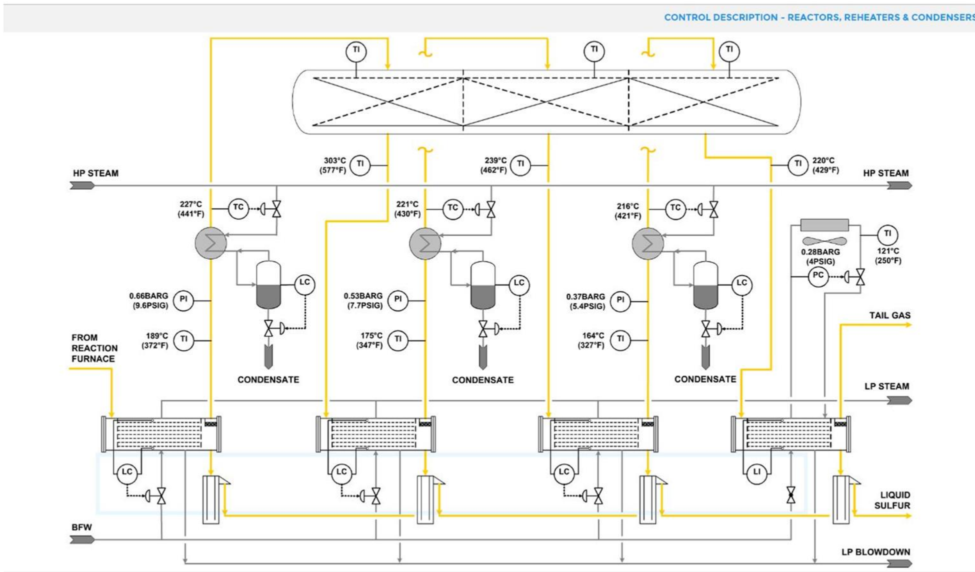
The reactor effluent from the first catalyst bed passes to Sulfur Condenser No 2 and the cycle of condensing, liquid sulfur withdrawal, reheating and further reaction are continued for 3 stages.

In the final condenser, the low pressure steam is completely condensed and returned to the condenser to maximize cooling and recovery of liquid sulfur.



This image shows a Claus Reactor with the Reheaters.

And this image, shows the Sulfur Condensers and the associated Sulfur Seals.



Control Description – Reactors, Reheaters & Condenser

The combustion gases exiting Sulfur Condenser No 1 at 189ºC (372ºF) are reheated by heat exchange with high pressure steam.

A temperature controller adjusts the amount of high pressure steam to maintain a temperature of 227ºC (441ºF) inlet the first catalyst bed of the Claus Reactors.

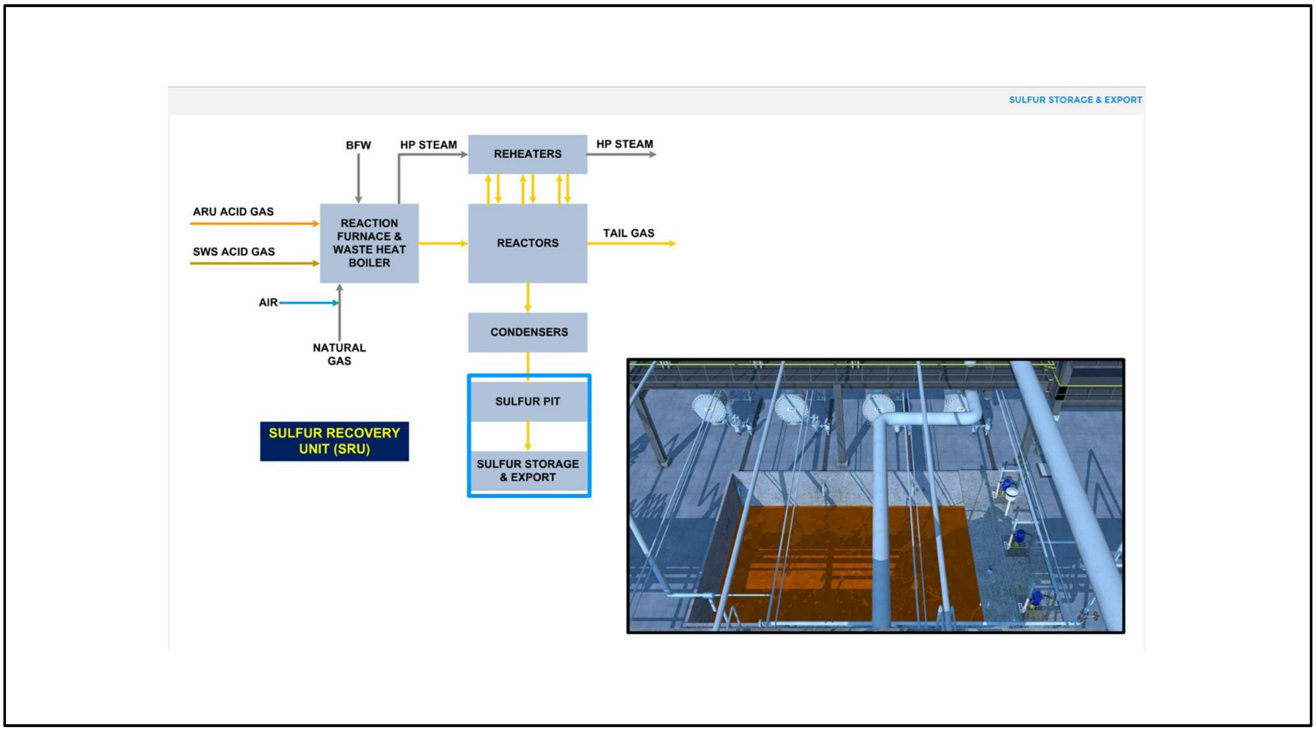
The reactions that occur across Bed 1 are mildly exothermic with the reactor effluent exiting at 303ºC (577ºF) and passing to No 2 Condenser.

This cycle is repeated for the remaining stages of conversion.

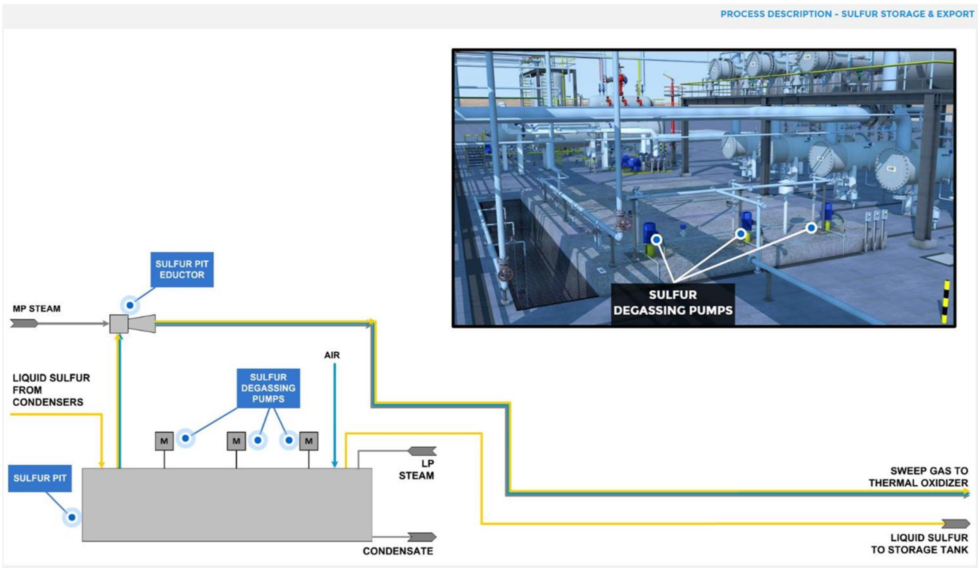
For each stage, the temperatures inlet the Claus Reactors fall by around 6ºC (11ºF) and the exotherms progressively decline as reactions approach completion.

The shell-side water levels in Sulfur Condensers Nos 1, 2 and 3 are automatically maintained by makeup of boiler feed water. The level in Sulfur Condenser No 4 is manually adjusted.

The pressure in the shell-side of Sulfur Condenser No 4 is maintained at 0.28 barg (4psig) by regulating the amount of low pressure steam condensed.



Next, we'll take a brief look at the sulfur storage and export facilities.



Process Description – Sulfur Storage & Export

Liquid Sulfur from the Condensers drains down into the below-ground Sulfur Pit via Sulfur Seals that prevent atmospheric air being drawn back into the process equipment and piping.

The sulfur in the pit is heated by steam coils to prevent it cooling and solidifying.

The purpose of the Sulfur Pit is to remove sour gases that are dissolved in the liquid sulfur (typically around 250-300 ppm wt H_2S) - these sour gases can form flammable mixtures with air, leading to an explosion either in the pit or in the downstream storage tank.

A Sulfur Pit Eductor, powered by medium pressure steam, provides the motive force for continuously sweeping the surface of the liquid sulfur with air - sour gases are removed as they bubble out of the sulfur and are passed to the Thermal Oxidizer for destruction by combustion.

Sour Degassing Pumps agitate and spray the liquid sulfur inside the pit, creating an environment that encourages flashing of sour gases.

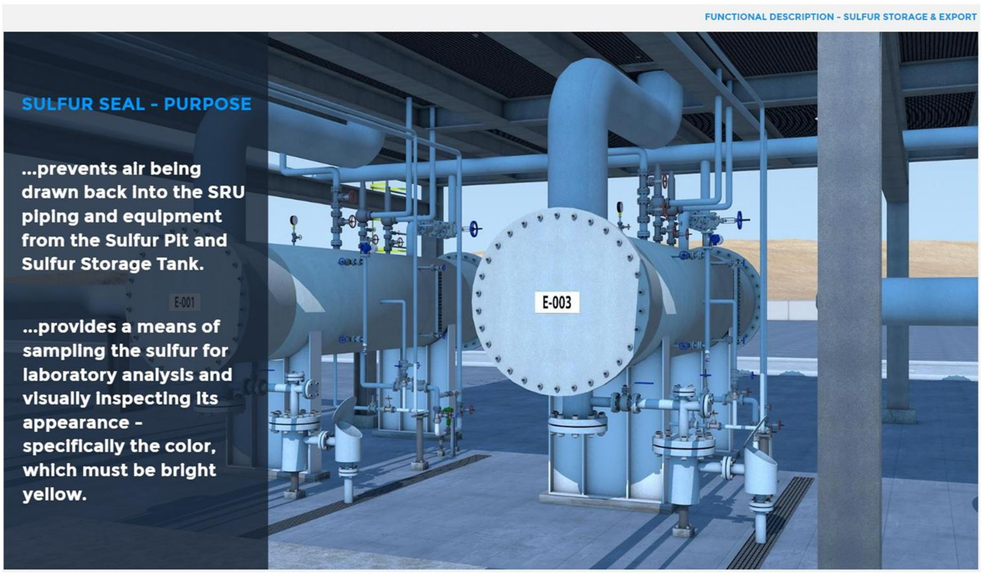
There are no control systems for the Sulfur Pit.

Degassed liquid sulfur exits the Sulfur Pit and is pumped to a storage tank from where it is either:

Loaded into heated road tank trucks or rail cars and exported

Passed to a sulfur handling unit where it is cooled and solidified in pelletized form for bulk or bagged shipment

This image will give you some idea of the magnitude of the size of pelletized sulfur storage facilities.

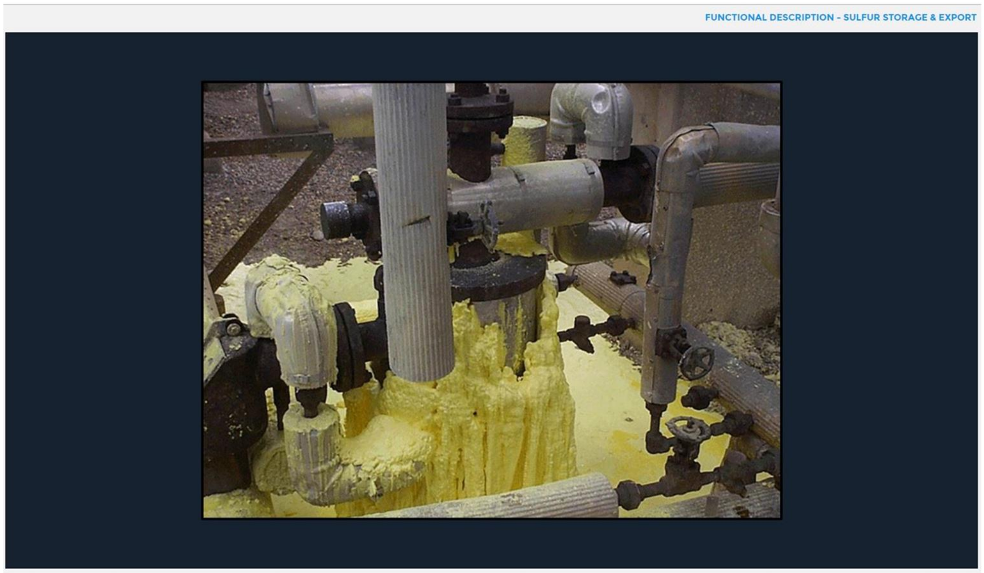


Functional Description - SRU

The purpose of the Sulfur Seal is to prevent air being drawn back into the SRU piping and equipment from the Sulfur Pit and Sulfur Storage Tank.

The Sulfur Seal also provides a means of sampling the sulfur for laboratory analysis and visually inspecting its appearance - specifically the color, which must be bright yellow.

The Sulfur Seal is a pipe within a pipe – liquid sulfur exits the Condenser above, flows down through the core and back up through the annulus, exiting from the top and passing to the below-ground Sulfur Pit.



If you're familiar with the term 'looks like you've blown a seal', then you'll appreciate that this can also happen on the SRU if the pressure in the process becomes high enough or, more commonly, if the seal becomes plugged with solidified sulfur. Here's what it looks like.

The function of the Sulfur Pit is to degas the liquid sulfur formed in the four Condensers, rendering it safe for storage and transportation. The pit has three compartments, separated by partitions.

Liquid sulfur enters the first compartment and is recirculated within that compartment by the first Degassing Pump.

A liquid degassing catalyst is added to the suction of the pump to aid degassing.

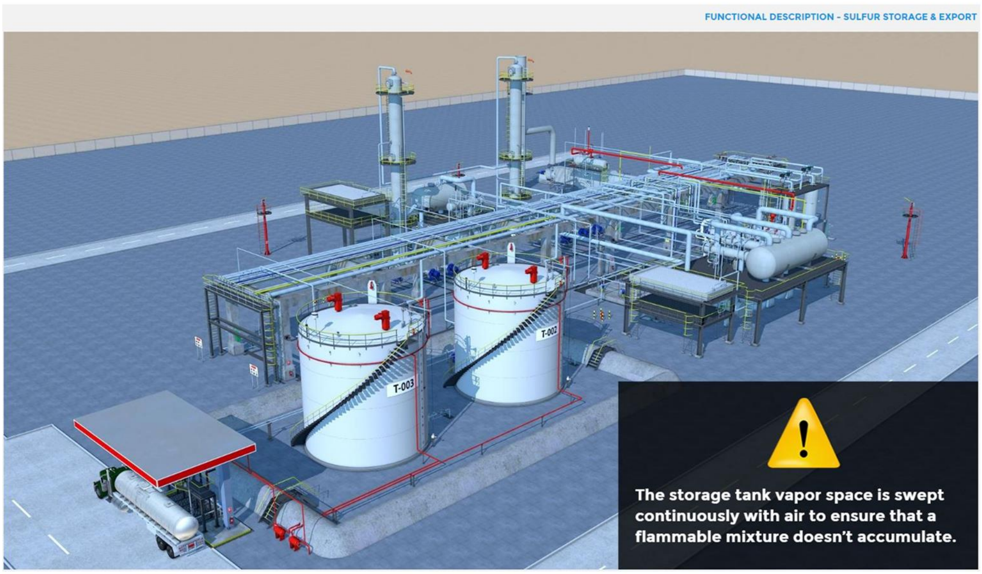
Liquid sulfur flows under the first partition into the second compartment, where catalyst injection and recirculation are repeated.

Liquid sulfur overflows the second partition, entering the third compartment, which is sized to provide 2 days of sulfur storage.

From the third compartment, degassed liquid sulfur is pumped to a storage tank.

As gases bubble out of the liquid sulfur, they are swept out of the pit by a flow of air, induced by an eductor.

The sweep gas passes to the Thermal Oxidizer.

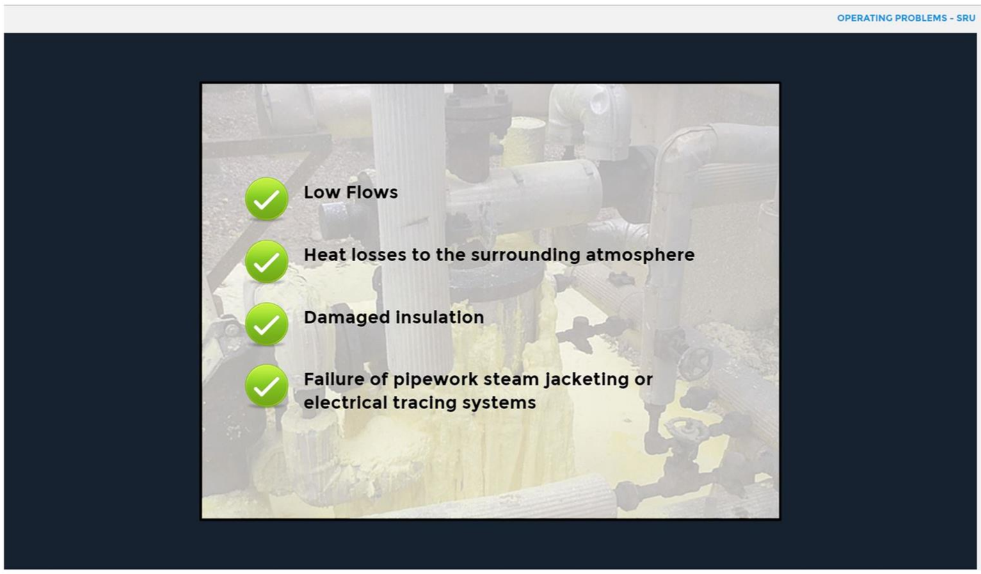


The Storage Tank holds a liquid sulfur inventory that is used to fill heated road tank trucks and/or rail cars for shipment to customers.

Alternatively, the Storage Tank may provide feed to a pelletizer unit.

Immersed low pressure steam heating coils and mixers ensure the sulfur doesn't stagnate and solidify in the tank.

In common with the Sulfur Pit, the storage tank vapor space is also swept continuously with air to ensure that a flammable mixture doesn't accumulate.



Operating Problems - SRU

Probably one of the biggest SRU operating headaches is cooling, solidification and plugging of lines and equipment with sulfur. There are several causes:

> Low flows (particularly when the plant is being started up or has suffered a major process upset and been switched to natural gas firing mode)
>
> Heat losses to the surrounding atmosphere (aggravated by cold weather conditions)
>
> Damaged insulation
>
> Failure of pipework steam jacketing or electrical tracing systems

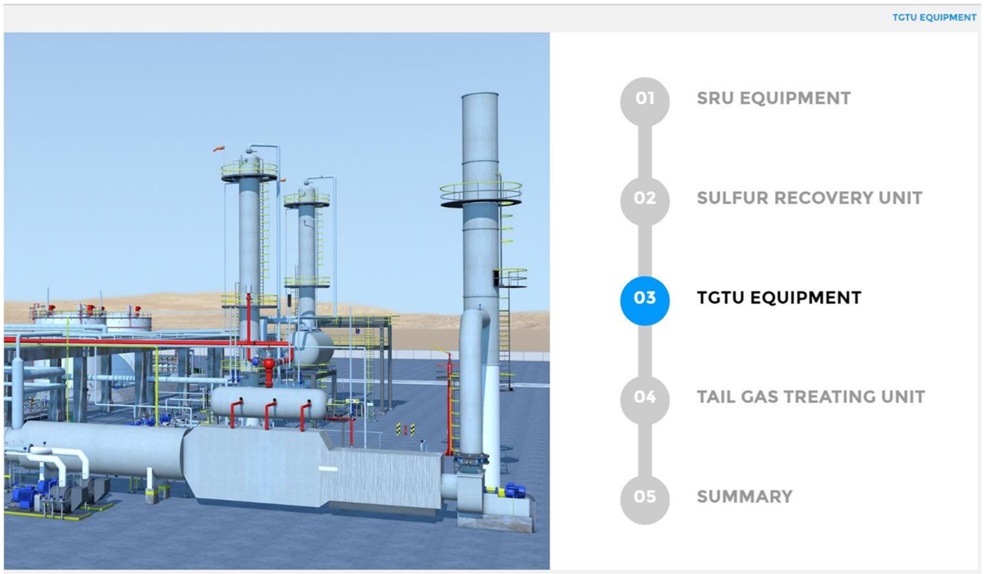
A range of design features are used to minimize the potential for blockages - they require constant operational and maintenance attention to make sure they are functioning correctly.

This image shows bolt-on steam jacketing in the process of being attached to the outside of a liquid sulfur transfer line.

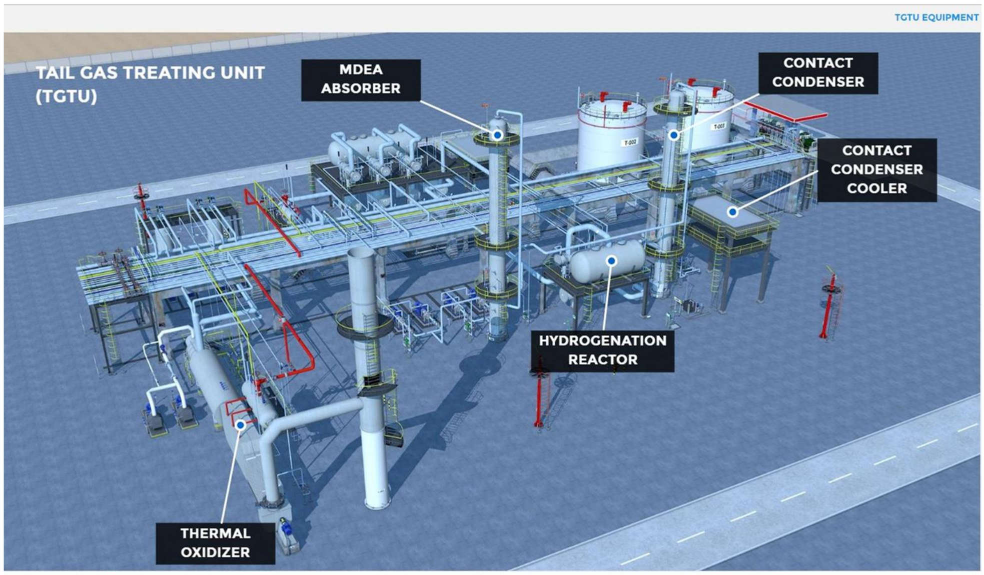
This image shows a double-pipe steam jacketing arrangement, with sulfur flowing through the core, steam flowing through the annulus and condensate being withdrawn by traps placed at suitable intervals.

And these images show a couple of steam jacketed valves.

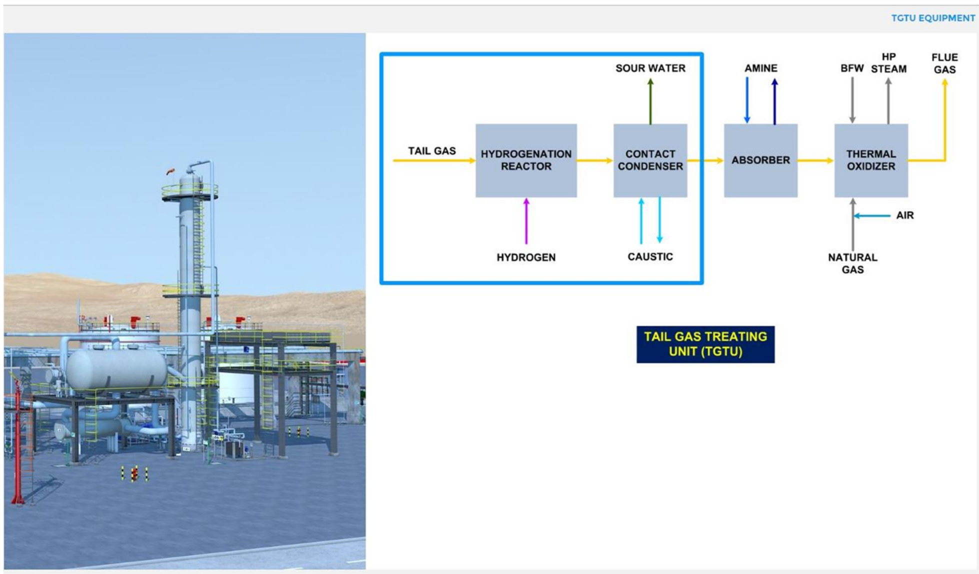
If steam is used for heating, there must be a continuous flow and condensate must not be allowed to accumulate in the annular area.



Next, we'll take a look at the Tail Gas Treating Unit equipment.



Pictured here we have a 3D model of the TGTU.

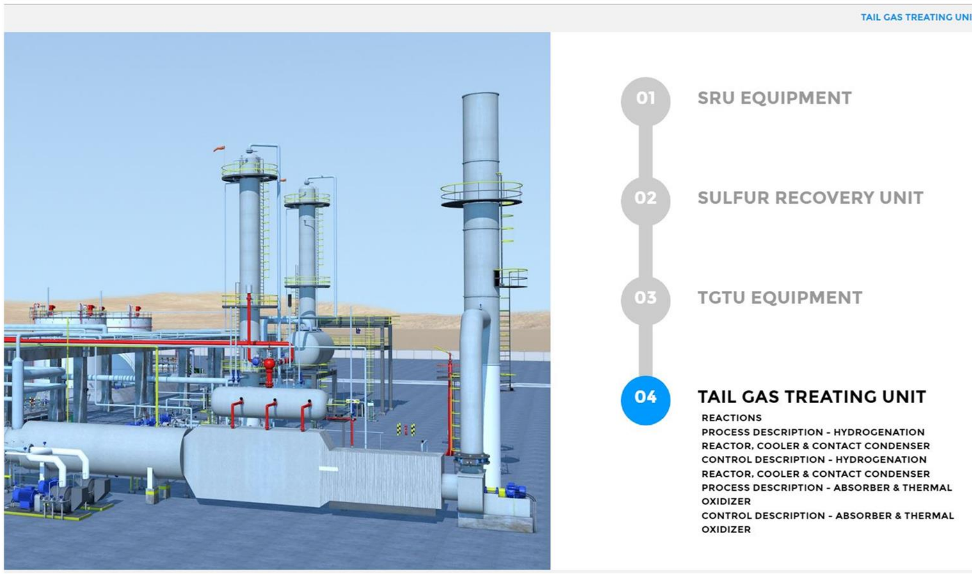


The purpose of the TGTU is to break down all unrecovered sulfur, unconverted SO_2 and reaction by-products of CS_2 and COS to form hydrogen sulfide.

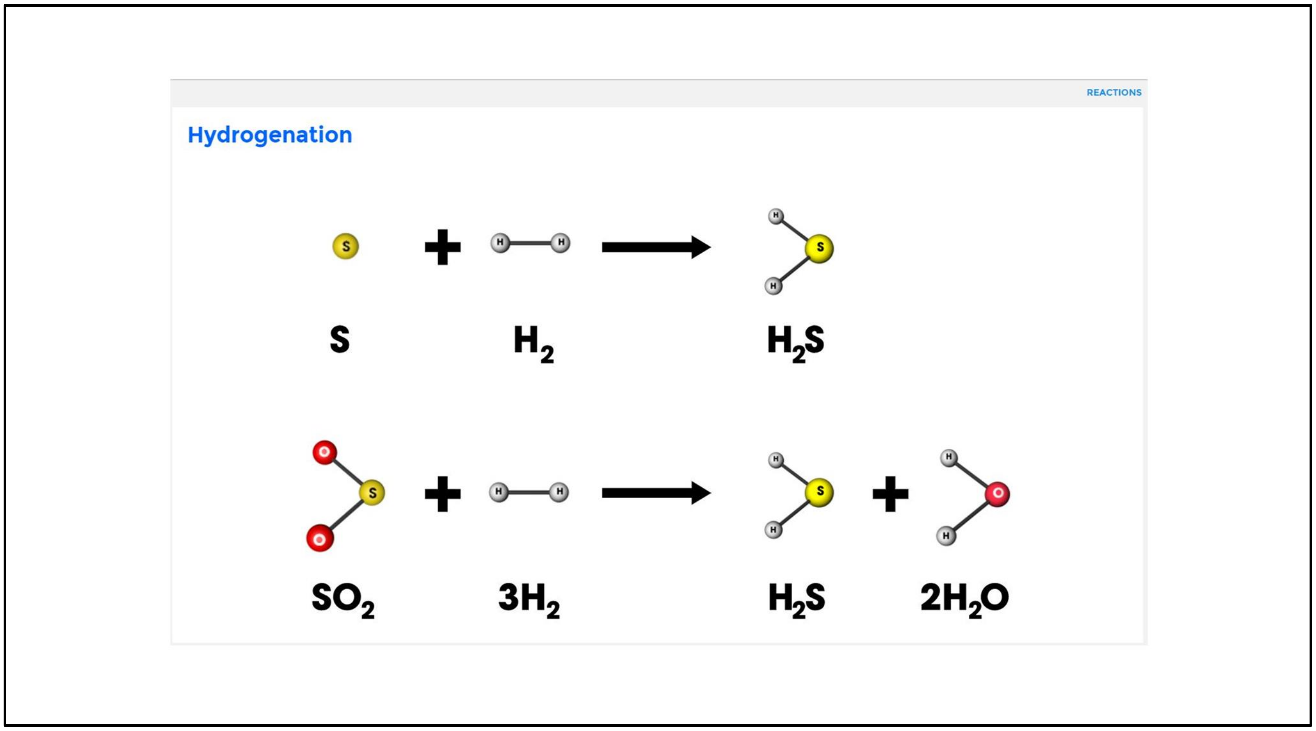
The hydrogen sulfide is then absorbed into an amine solution, which is subsequently regenerated and H_2S is recycled back to the SRU Amine Acid Gas KO Drum.

Any remaining traces of H_2S not removed by the amine are thermally oxidized to SO_2 before being released to atmosphere.

We'll start with the Hydrogenation Reactor and Contact Condenser.



Moving on, let's make a start on the TGTU.

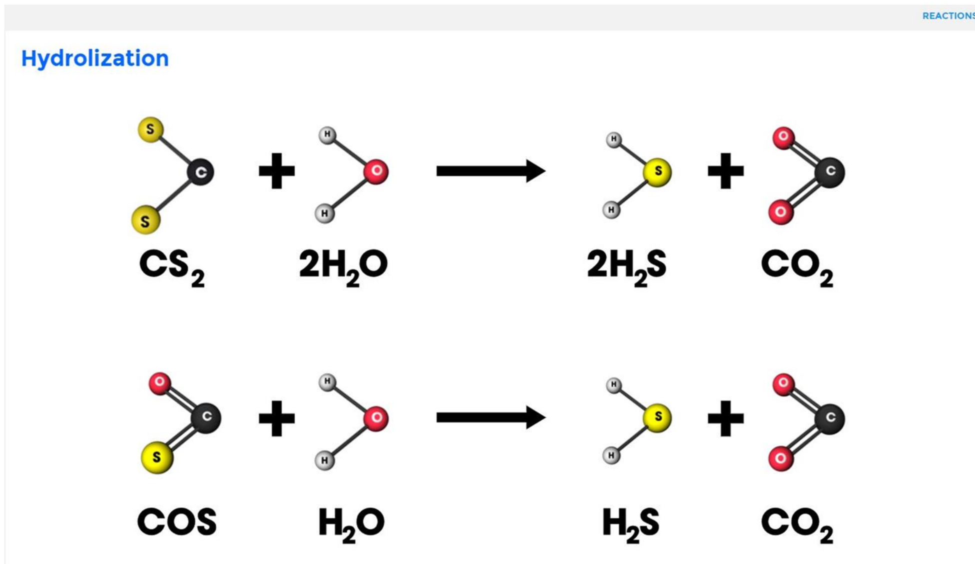


Reactions

First the reactions. In the Beavon Sulfur Recovery (BSR) Hydrogenation Reactor, two types of reaction take place.

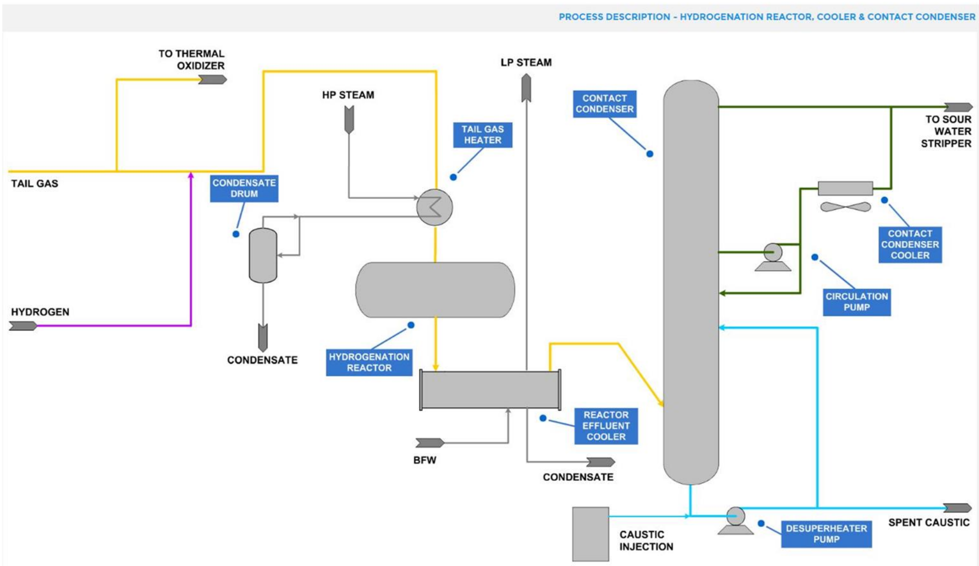
Hydrogenation:

> Sulfur reacts with hydrogen (supplied by the Hydrogen Generation Unit) to form hydrogen sulfide
>
> Sulfur dioxide reacts with hydrogen to form hydrogen sulfide and water vapor



Hydrolization:

Carbon disulfide and carbonyl sulfide react with water vapor to form hydrogen sulfide and carbon dioxide



Process Description - Hydrogenation Reactor, Cooler & Contact Condenser

SRU Tail Gas mixes with makeup hydrogen from the Hydrogen Generation Unit, is heated by high pressure steam in the Tail Gas Heater, enters the top of the Hydrogenation Reactor and passes over a fixed bed of cobalt molybdenum catalyst.

Through a combination of hydrogenating and hydrolizing, all sulfur and sour compounds are converted to hydrogen sulfide.

In the event of a process upset or at startup conditions, tail gas is bypassed directly to the Thermal Oxidizer.

The hot reactor effluent passes through a Reactor Effluent Cooler, giving up heat to boiler feed water and in the process raising low pressure steam.

The cooled reactor effluent enters the base of the Contact Condenser, the purpose of which is to desuperheat the reactor effluent in preparation for removal of hydrogen sulfide by amine absorption.

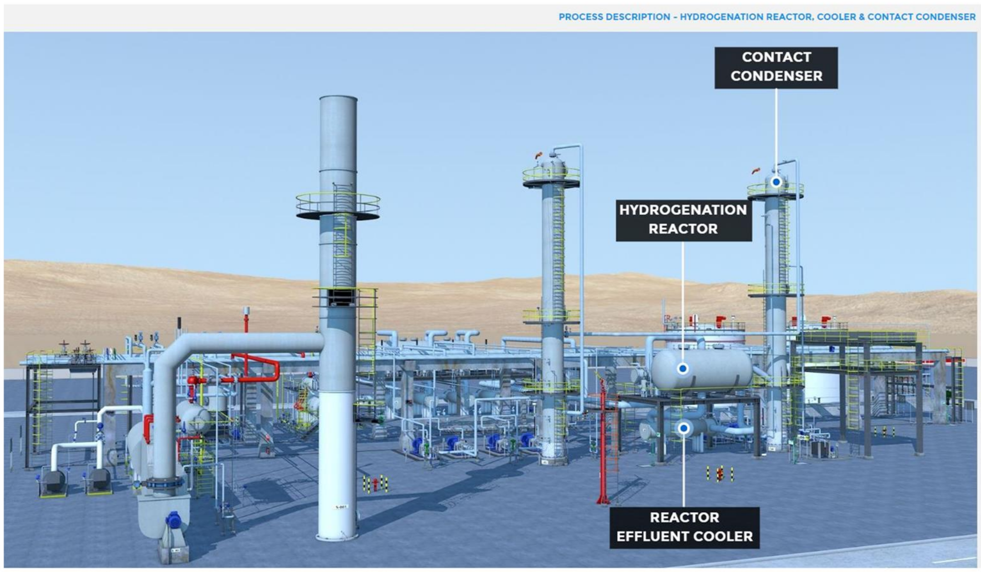
In the Contact Condenser, a Desuperheater Pump passes a mild caustic solution up to the mid- section from where it flows downwards, counter-currently scrubbing the rising reactor effluent.

In addition to cooling, the caustic solution neutralizes any SO_2 that might breakthrough from the upstream Hydrogenation Reactor during process upsets - SO_2 causes corrosion in the Contact Condenser and downstream Amine Absorber.

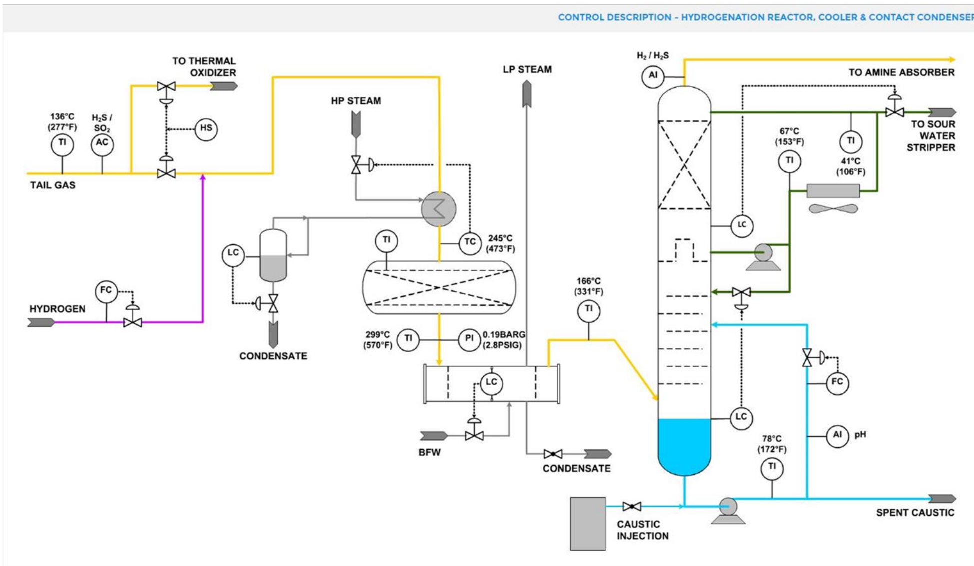
The pH of the circulating caustic solution is maintained between 8 and 9 by purging spent caustic and adding fresh caustic.

In the upper section of the Contact Condenser, the rising reactor effluent is further cooled by a circulating water stream. Excess water is passed to the Sour Water Stripper for treating and re-use.

The cooled reactor effluent, containing hydrogen sulfide, passes to the Amine Absorber.



This image shows the Hydrogenation Reactor, Reactor Effluent Cooler and Contact Condenser.



Control Description- Hydrogenation Reactor, Cooler & Contact Condenser

A hand switch enables the operator to divert SRU tail gas to the Thermal Oxidizer in an emergency.

Hydrogen, from the HGU, is injected into the SRU tail gas stream on flow control.

The combined hydrogen-tail gas stream inlet the Hydrogenation Reactor is maintained at 245ºC (473ºF) by a temperature controller that adjusts the amount of high pressure steam passing to the Tail Gas Heater.

The high pressure steam condenses and collects in a Condensate Drum, from where it is withdrawn on level control.

The Hydrogenation Reactor effluent exits at 299ºC (570ºF) and is cooled to 166ºC (331ºF) in the Reactor Effluent Cooler by exchanging heat with boiler feed water, which enters on level control.

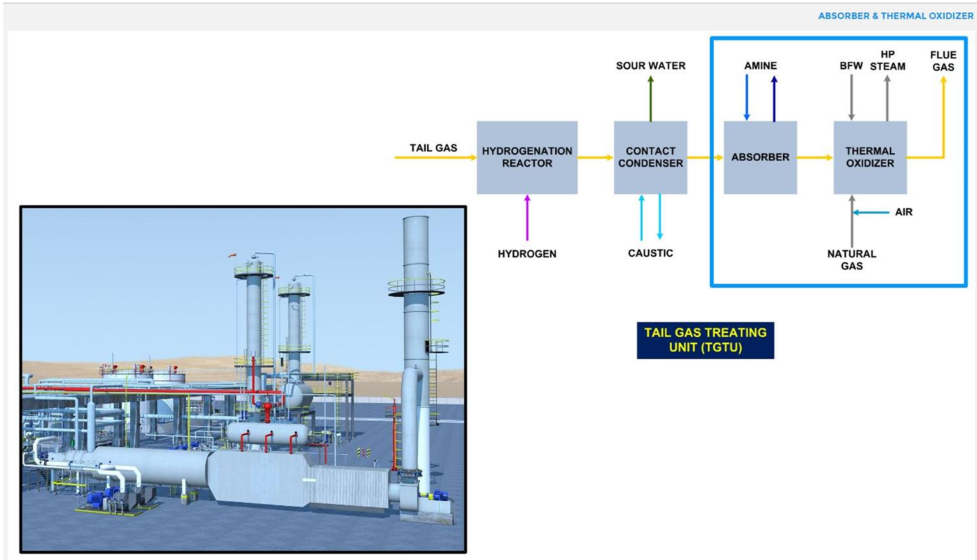
In the lower trayed section of the Contact Condenser, upflowing reactor effluent is counter-currently scrubbed with a flow controlled stream of mild caustic solution.

The level in the bottom of the Contact Condenser is maintained by addition of a slipstream of circulation water from the upper section.

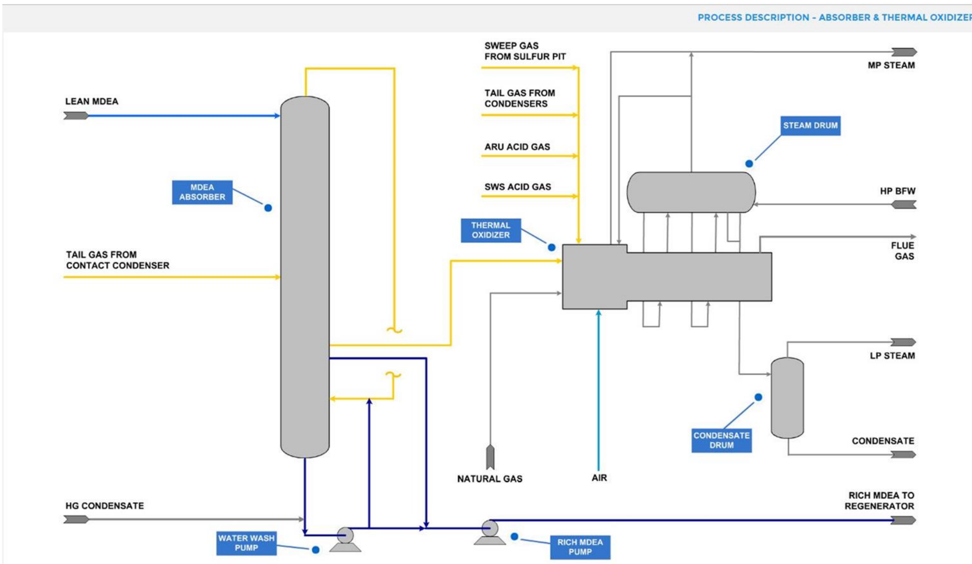
An on-stream analyzer provides data to help the operators maintain the pH of the circulating caustic solution between 8 and 9.

The level in the chimney tray below the upper packed section is maintained by a level controller that passes excess water to the Sour Water Stripper.

An analyzer, located in the Contact Condenser overheads measures the hydrogen and hydrogen sulfide content - this enables the operator to check that sufficient H_2 is being added to the Hydrogenation Reactor to convert sour gases to H_2S.



Moving on, we have the Absorber and Thermal Oxidizer.



Process Description - Absorber & Thermal Oxidizer

Tail gas, containing hydrogen sulfide, exits the top of the Contact Condenser and passes to the upper section of the MDEA Absorber.

The upflowing tail gas is counter-currently scrubbed with downflowing lean MDEA, which absorbs most of the hydrogen sulfide.

Sweetened tail gas exits the upper section of the Absorber and enters the lower section, where it is scrubbed with circulating wash water to recover any entrained MDEA, exiting through a demister pad and passing to the Thermal Oxidizer.

Rich MDEA (from the upper section) and reject wash water (from the lower section) combine and are passed to an MDEA Regenerator, where hydrogen sulfide is recovered and recycled to the Amine Acid Gas KO Drum for reprocessing.

The regenerated amine returns to the top of the Absorber as Lean MDEA.

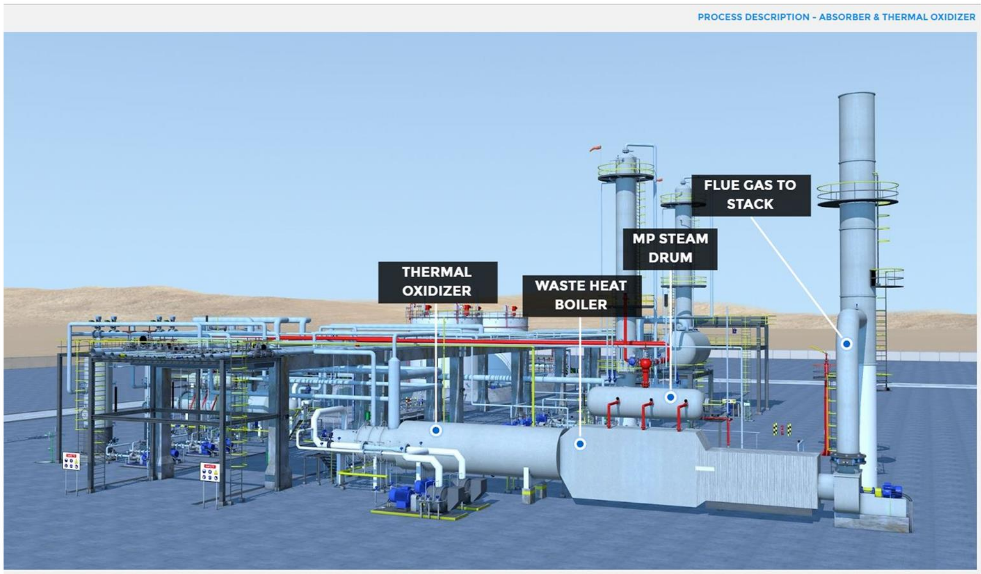
The Thermal Oxidizer is fired on natural gas.

Combustion air, supplied by the SRU Air Blowers, ensures there is always sufficient air present to fully incinerate a number of vent gas streams containing varying quantities of noxious and toxic gases, producing a flue gas stream containing around 4% vol oxygen and less than 10ppm vol hydrogen sulfide that can be vented to atmosphere via a stack.

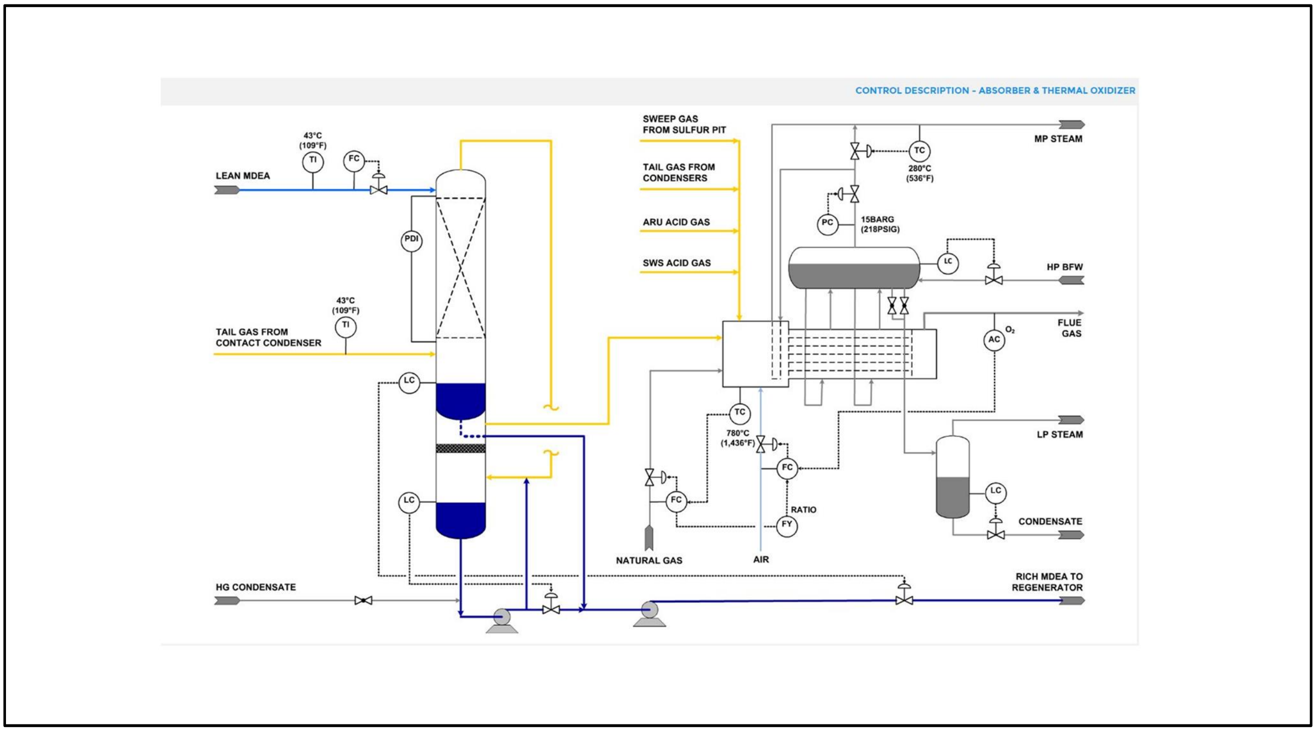
Heat is recovered from the hot flue gases and used to generate medium pressure steam.

Boiler feed water is added as makeup and intermittent and continuous blowdowns are passed to a Condensate Drum and re-used.

Medium pressure saturated steam passes through a superheater coil before being routed to the refinery MP Steam header.



This image shows the Thermal Oxidizer, Waste Heat Boiler, MP Steam Drum and flue gas piping to the stack.



Control Description - Absorber & Thermal Oxidizer

Lean MDEA is added to the upper section of the Absorber on flow control.

Rich MDEA accumulates below the packed section and is pumped to the Regenerator on level control.

Wash water accumulates in the lower section and is also pumped to the Regenerator on level control, joining the rich MDEA.

The Thermal Oxidizer flue gas oxygen content and firebox temperature are critical to ensuring all H_2S is fully combusted to SO_2 before being vented to atmosphere.

A cascade master analyzer controller, measuring flue gas oxygen content, resets a slave combustion air flow controller, ensuring there is more than enough oxygen required for combustion.

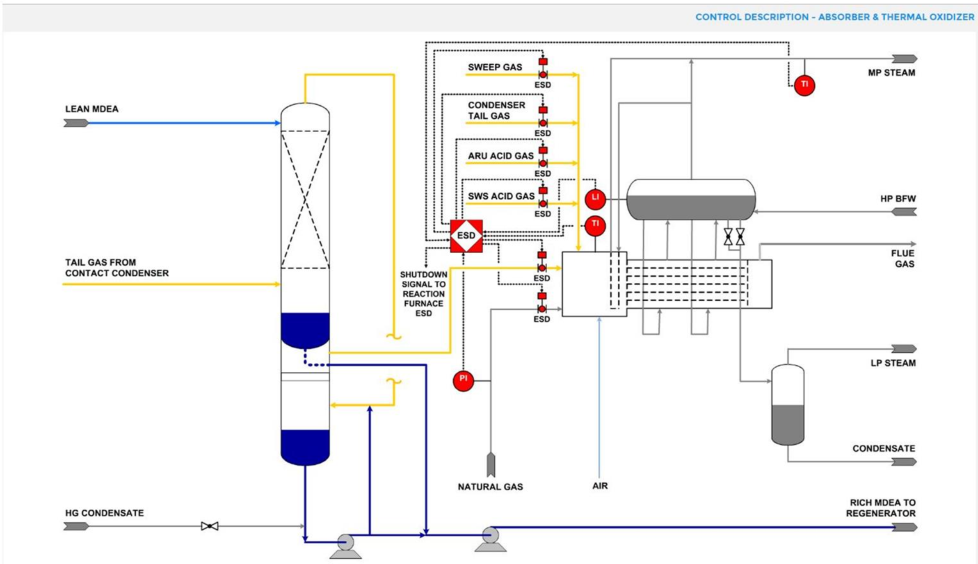
A cascade master temperature controller resets a slave natural gas flow controller to maintain the firebox temperature at 780ºC (1,436ºF).

Additionally, the flow of combustion air is ratioed to the flow of natural gas.

The pressure in the MP Steam Drum is maintained at 15 barg (218 psig) by a pressure controller that releases steam to the refinery MP Steam header.

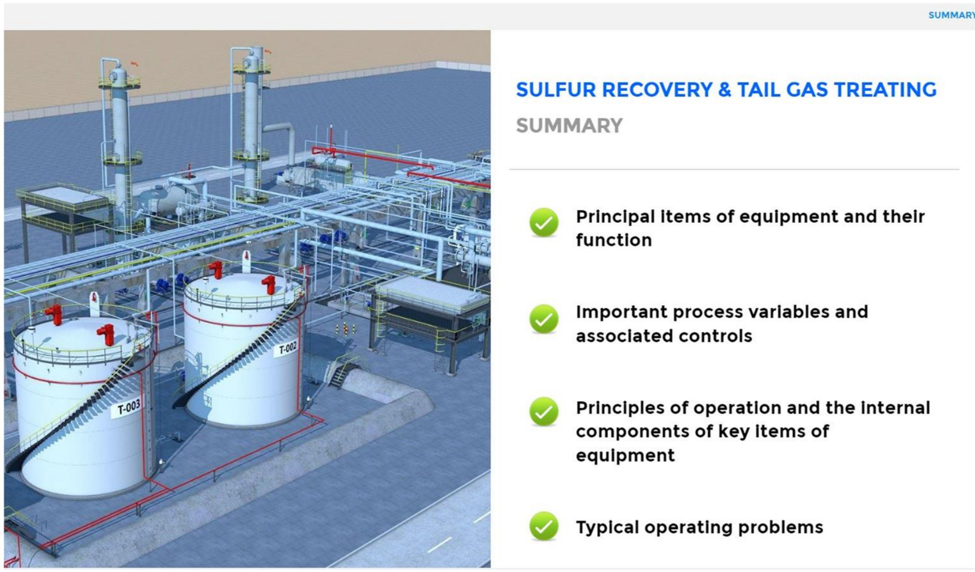
A temperature controller maintains the MP Steam at 280ºC (536ºF) by adjusting a bypass around the steam superheater coil.

Boiler feed water is added to the MP Steam Drum and condensate is withdrawn from the Condensate Drum on level control.



The Thermal Oxidizer is protected against conditions that may lead to an internal explosion or overheating by isolating incoming sour gases and the natural gas fuel to the burner - trip initiators and actuators are shown here.

When activated, the Thermal Oxidizer ESD system simultaneously activates an ESD shutdown of the Reaction Furnace and Waste Heat Boiler on the upstream SRU.



And this completes SPU Module 03 in which we've covered the Sulfur Recovery & Tail Gas Treating Units.

To summarize:

The purpose of the Reaction Furnace is to combust H_2S and NH_3, forming a gas with a specific $H_2S:SO_2$ ratio.

The purpose of the Waste Heat Boiler is to recover heat from Reaction Furnace combustion gases to raise HP Steam.

The purpose of the Reactors, Reheaters and Condensers is to convert H_2S and SO_2 into elemental sulfur.

The purpose of the Sulfur Pit is to degas liquid sulfur, rendering it safe for storage and transportation.

The purpose of the Hydrogenation Reactor is to convert unrecovered sulfur, unconverted SO_2 and reaction by-products into H_2S.

The purpose of the Contact Condenser is to cool the H_2S formed in the Hydrogenation Reactor in preparation for removal by amine absorption.

The purpose of the MDEA Absorber is to remove the H_2S formed in the Hydrogenation Reactor.

The purpose of the Thermal Oxidizer is to combust all noxious and toxic effluent gases to form combustion products that can be safely released to atmosphere.

For the Sulfur Recovery and Tail Gas Treating Units, you should now be familiar with:

Principal items of equipment and their function

Important process variables and associated controls

Principles of operation and the internal components of key items of equipment

Typical operating problems

Your task now is to take the SPU Module 03 Quiz to ensure you have fully understood the material. If you find the questions challenging, you should consider repeating this module before moving on to the next one.

Good luck!

You can now close this module.