IMPROVING CLAUS SULFUR RECOVERY UNIT RELIABILITY THROUGH ENGINEERING DESIGN

by

Steve Fenderson

GOAR, ALLISON, & ASSOCIATES, INC.
P.O. Box 131390
Tyler, Texas 75713

Preprint of Paper to be given at the

BRIMSTONE ENGINEERING
SULFUR RECOVERY SYMPOSIUM
September 15-18, 1998

IMPROVING CLAUS SULFUR RECOVERY UNIT RELIABILITY THROUGH ENGINEERING DESIGN

TABLE OF CONTENTS

INTRODUCTION

In today's sulfur recovery unit (SRU) operating environment, greater emphasis must be placed on operating reliability than ever before. Most environmental agencies are very reluctant to grant operating variances for conditions that would result in emission levels greater than permitted. Many companies are attempting to lengthen the time between scheduled maintenance shutdowns. Higher sulfur feedstocks and additional hydroprocessing have used any excess SRU capacity that may have been initially installed.

These factors all contribute to the importance of overall SRU operating reliability. Gone are the days when the primary reason for having an SRU was to satisfy the permit questionnaire and when little emphasis was placed on how efficiently or how much of the time the SRU actually operated. Most environmental districts require complete emission monitoring reports, some districts even require on-line measurements be continuously sent to their offices, and violations require immediate action. It is imperative for the profitability of the refinery or gas plant that the SRU operate at very near 100% on-stream time.

Overall SRU reliability can be increased through proper design methods and practices. Significant improvements in reliability can be achieved with a relatively modest increase in the initial capital cost of the SRU. However, many of the features that can be incorporated into a design are difficult and/or significantly more expensive to implement into an existing plant. Therefore, it is extremely important for the plant owner to insure the SRU is designed for optimum reliability at the earliest stage of design. This can be assured by either:

1. knowing that your designer will incorporate all practical features into the design;

2. carefully specifying specific features that are to be incorporated into the design (this is particularly important in fixed price bids), or

3. conducting regular detailed reviews, with approval, of all phases of the design.

DESIGN BASIS

The most important step in the development of any design is to establish a firm design basis as early in the project as possible and limit any changes in the design basis to those areas that are absolutely necessary. Items that should be established and incorporated into the design include:

- Design feedstock including complete composition, temperature, and pressure,
- Design processing capacity including any turndown/turn-up requirements,
- Specific processing requirements such as minimum sulfur recovery and product quality,
- The available utilities and any limitations on the conditions, availability, etc. of specific utilities, and
- Specific design features that should be incorporated.

SRU DESIGN

In this paper, we will present some of the ideas, opinions, and design standards that Goar, Allison & Associates, Inc. (GAA) utilizes in the process engineering design of SRU's. GAA does not directly supply complete SRU's or equipment utilized in the construction of SRU's. Our engineering activities are generally limited to the process design of the SRU. Therefore, we are more concerned with supplying a design that will be friendly to operate, will achieve expected process performance, and will operate reliably; rather than designing a plant that is the least expensive, but might not meet the other objectives.

The SRU can be divided into three major design areas: (1) piping, (2) major equipment, and (3) instrumentation. Each of these areas can greatly impact the overall performance and reliability of the SRU and is discussed below. The ideas presented are those of GAA and are not intended to be a complete listing of all possible arrangements and/or configurations.

PIPING

Piping design and layout is one of the most important aspects of the SRU design. The rules for piping design are relatively simple and will be discussed first.

1. Make all piping free-draining,
2. Keep piping runs as short as practical,
3. Keep all piping hot, but not too hot,
4. Steam jacket all liquid sulfur lines,
5. Utilize crosses at all direction changes in all liquid sulfur lines, and
6. Slope all liquid sulfur lines to promote draining.

These items may seem obvious, but we visit many plants in which some or even all of these rules have been violated. In general, these rules can be condensed into the basic overall SRU design rule of "keep it free-draining and keep it hot".

The SRU is a vapor phase process unit other than the liquid sulfur product. Any collection of liquids in piping can cause operating control problems, additional pressure drop through the SRU, equipment damage, and/or corrosion, etc. It is particularly important that no liquid sulfur be allowed to collect in piping where it could ignite with resulting personnel safety and equipment damage problems. The piping design should insure that any liquid will drain to a major equipment item, where it can be drained from the plant. Block valves should be located at high points to avoid liquid collecting against a closed valve.

Keeping the pipe runs short and keeping the process hot compliment each other. It is easier to keep the process hot if the pipe runs are short, Uninsulated flanges and valves frequently causing problems. These items literally act as air-cooling fins promoting condensation, corrosion, and plugging in the piping system. Flange sets and valves should have easily removable insulation covers that can be removed and reinstalled for maintenance activities. All lines containing ammonia and/or sulfur vapor should use only steam jacketed control and block valves.

The rules for liquid sulfur lines are similar; "keep the runs short and keep them hot". However, for liquid sulfur the rules are more stringent. Sulfur will freeze into a rock hard solid between 245-250°F. It is therefore imperative to maintain the piping above 250°F. This is normally done using steam jacketed lines with 50 psig steam, which is approximately 300°F, in the jacket. Steam jacketing does not solve all of the potential problems. The steam supply and condensate piping, and particularly the steam trap installations are often improperly installed. Steam/condensate jumpers from one jacketed section to the next should always be arranged to prevent condensate accumulation in the jacket. Steam traps should be installed at frequent intervals. As a general rule, condensate should be trapped from the system each 50-100 ft. of jacketed pipe run. All steam supply, steam/condensate jumpers, condensate lines, and flanges should be well insulated. Flange insulation should be removable for maintenance activities.

Regardless of how carefully the liquid sulfur piping system is designed, heated, and insulated; most lines will plug at some time. Because of the probability of plugging, all change of direction in liquid sulfur piping should utilize a cross. This allows the piping to be rodded in both directions to break the plug. Elbows and Tee's should never be used. In addition to always using crosses at change of direction, steam jacketed block valves should be installed near the source of the liquid sulfur to allow on-line rodding. Free access spacing equal to the straight pipe run must be provided to allow rodding in both directions at the crosses.

Liquid sulfur is a relatively viscous fluid, and can be extremely viscous at some temperatures. Gravity flow liquid sulfur piping should be designed to run only about 1/3 liquid full at the maximum anticipated liquid sulfur rate. Except for very small units or tail gas coalescers GAA recommends no smaller than 3" X 4" liquid sulfur lines. Also, all liquid sulfur piping should be sloped 1/8-1/4" per foot toward the outlet of the piping to promote draining.

SRU tail gas piping from the final condenser to the incinerator or tail gas cleanup unit is often the source of plugging and corrosion. The outlet of the final condenser is the coolest point in the SRU; the tail gas is saturated with sulfur vapor; and has a very high water content. Tail gas piping should be kept as short as possible and must be kept hot. Tail gas line heating can be done through steam jacketing, electric heat tracing, or steam tracing. Steam jacketing is best, but is probably not practical from a cost standpoint except in very small plants. Electric and steam tracing are both effective, but are often not properly installed.

MAJOR EQUIPMENT

The major equipment items are discussed generally in the order of process flow through the SRU. The concepts presented are intended to improve the SRU reliability and are not intended to be complete design guidelines. A general comment that applies to all equipment items is to provide pressure point/sample point connections between all major equipment items. These will prove invaluable in troubleshooting the SRU.

Acid Gas Feed Knockout Drums:

> GAA strongly feels each SRU should have an independent knockout drum on each acid gas feed stream. The purpose of the drum is to remove any entrained liquids from the acid gas feed stream and to catch any liquid slugs that may come from upsets in the upstream amine regenerator or sour water stripper (SWS). Entrained liquids are typically sour water, hydrocarbons, and amines. Entrained liquids leaving the knockout drum can cause problems with feed metering, plugging in the burner, refractory damage to the burner and reaction furnace, undesirable side reactions in the reaction furnace, increased air demand, reduction of SRU capacity, and plugging of downstream equipment. There has never been a knockout drum built too large, but we frequently encounter knockout drums that are much too small.
>
> GAA prefers to include inlet deflector baffles and knitted mesh mist eliminator pads in knockout drum designs. Instrument bridles can be used in amine acid gas drum service; however, GAA feels each SWS gas drum level instrument connection should be independent and 2" minimum nozzle size. The reason for independent connections is to keep the instru-

ment as close as possible to the drum to facilitate keeping the nozzle, valve, and instrument hot to prevent the formation of ammonium salts. The nozzles, valves, and instruments should all be heat traced. GAA also recommends using a small steam or condensate purge to keep the nozzle flushed.

The drums should be equipped with pumps to transfer any collected liquids to the appropriate upstream processing unit. The pumps are normally designed to operate on a start-stop basis. Pumps are activated depending on high-low level detection either by hardware or software level switches. Each drum should have dual pumps, one on-line and a spare. GAA recommends independent spare pumps for each drum. When the spare pump is shared between the amine acid gas and SWS gas drums, it is likely that the discharge valving will not be properly arranged, and the liquid will be sent to the wrong upstream unit.

Combustion Air Blowers:

GAA always recommends multiple air blowers. For single train installations, we recommend installing either two 100% capacity blowers or three 50% blowers. Multistage centrifugal blowers are preferred. High speed single wheel blowers and positive displacement blowers generally tend to require more maintenance. The blower can be either electric motor or steam turbine driven. Depending on the local utility situation, either the motor or turbine may be more reliable. However, turbines generally require more maintenance than electric motors.

Main Burner and Reaction Furnace:

The main burner and reaction furnace combine to form the SRU thermal reactor. The burner and reaction furnace are normally mounted horizontally with the burner coaxialy mounted on the end of the reaction furnace. The thermal reactor is the heart of the SRU even though it is frequently selected or designed without considering its level of importance. GAA considers the main burner to be the most important piece equipment in the SRU. The burner must perform the function of burning 1/3 of the feed H_2S to SO_2 to satisfy the stoichiometric requirements of the modified Claus process, while also destroying impurities in the acid gas feeds and consuming all of the oxygen in the combustion air. The burner must be capable of performing efficiently at normal operating feed rates and low turndown rates. The burner must also be capable of substoichiometric burning of natural gas during start-up and shut down operations.

GAA recommends using a high intensity, very efficient mixing burner. Many inefficient burners have been employed in SRU's. Frequently these burners do not achieve adequate destruction of impurities, do not achieve complete oxygen consumption, and form some SO_3. These shortcomings can result in equipment corrosion, catalyst deactivation, and plugging of piping, equipment, and catalyst beds. All of these adverse results reduce the SRU reliability by requiring the unit to be shut down for maintenance repairs, catalyst change, or unblocking an obstruction.

The burner must accomplish the combustion reactions. The combustion reactions are relatively fast. The reaction furnace provides the residence time at high temperature required for the Claus reaction and side reactions to occur. Many feed impurities and intermediate components must be destroyed in the reaction furnace or they will cause downstream problems. These components must have adequate time for the reactions to reach completion/equilibrium. The reaction furnace should have 0.6-1.5 seconds residence time. The furnace is often equipped with choke rings, checker brick walls, and other internal components that improve mixing, and therefore, improve reaction completion. The specific features and residence time required for an individual reaction furnace are dependent on several factors including the operating temperature and expected feed impurities.

The burner and furnace are typically constructed of carbon steel. The very severe high temperature, reducing atmosphere process operating conditions in the burner and furnace require protection of the carbon steel. The carbon steel must be protected from acid corrosion (liquid phase H_2O, SO_2, SO_3) and high temperature sulfide corrosion by H_2S. The primary form of protection is insulating the steel from the processing atmosphere with a multi-layer refractory lining. The refractory lining should be designed to maintain the inside metal temperature between 400-600°F. Experience has shown this temperature range to be adequate to avoid both excessive acid and sulfide corrosion.

The normal furnace operating temperature is 1800-2000°F; however, the hot face material must be capable of withstanding temperatures of 2500-3000°F which can occur during start-up firing of natural gas. GAA feels all new SRU reaction furnace linings should utilize at least 90% alumina hot face material. Brick linings are more durable than castable or plastic ram materials. The initial installation of brick may be slightly more expensive, but brick normally provides a longer lining life and requires less maintenance. The brick used for the hot face should be mullite-bonded material. The high alumina hot face brick is very dense, has good high temperature strength, but has poor insulating properties.

The second refractory layer should be low iron, class 2600 or 2800 insulating firebrick (IFB). The IFB is a lower density, greater porosity brick than the hot faced high alumina brick, and therefore, has better insulating properties. Insulating castable refractory is also used as the backup layer to the hot-faced brick. If insulating castable is used, it is important to insure the inner surface of the castable is perfectly round. Any out of roundness makes installation of the outer brick layer more difficult and can result in an uneven installation that may have voids between the layers.

If an IFB layer is used, the outer layer (layer next to the shell) is often a 1/8-1/4" layer of ceramic fiber paper. This material has very good insulating properties. Often the ceramic fiber paper provides more insulation that the two layers of brick.

The reaction furnace internal features mentioned above (choke ring, checker wall, etc.) must be incorporated into the refractory lining design. Materials with high temperature properties at least equivalent to the hot face brick are used for these services.

GAA also recommends installation of an external rain shield over the reaction furnace and refractory lined portion of the main burner. The rain shield extends the life of the furnace and burner by protecting the carbon steel shell and internal refractory from thermal shock, which can occur from sudden rain storms, and cold winter winds. The rain shield should cover at least the upper 270° of the shell and have an upper vent. It should provide an insulating air gap that allows free air flow between the shell and rain shield. The hot shell induces convective air flow. The insulating air layer stabilizes the shell temperature and prevents overcooling the shell, which could result in acid condensation and internal corrosion. In very cold locations, the rain shield often completely covers the shell. Louvers are installed in the bottom and are used to regulate the air flow through the gap between the shell and rain shield.

Waste Heat Boiler:

<u>Tubesheet Ferrules and Refractory</u>

The waste heat boiler (WHB) tubesheet forms the outlet end of the thermal reactor, either as the rear wall of the reaction furnace or the end of a transition piece. The tubesheet and tube inlets, and transition piece if present, must be protected from the same sever operating conditions described above for the burner and reaction furnace. The transition piece protection must be similar to the furnace.

The WHB tubesheet and tube inlets have traditionally been protected using high alumina ceramic tube ferrules/inserts and approximately 4" of

90+% alumina castable refractory on the tubesheet face between the ferrules. Once installed, the castable is cured into a solid block containing the ferrules. Properly curing the castable is often difficult. It is difficult to maintain the recommended time-temperature profile by firing the SRU main burner and operations is normally being pushed to get the SRU back on-line after a shutdown. Inadequate/improper curing generally results in reduced WHB tubesheet refractory effectiveness and life.

The WHB tubesheet refractory has been an area of high maintenance, particularly in SRU's undergoing frequent start-up/shutdown cycles. It is difficult to properly support the castable refractory. Movement in the tubesheet that takes place during cycling and flexing of the tubesheet often cause cracking of ferrules and refractory. Once a crack develops, it allows the hot process gases to reach the tubesheet and/or tube. High temperature sulfide corrosion often occurs, eventually resulting in tube failure. Boiler feedwater (BFW) leakage into the hot refractory lined reaction furnace causes additional damage. Very significant SRU down time is required for retubing and refractory repairs.

GAA feels the newer design thick hex-head ferrules for the WHB tubesheet are a significant improvement. The hex-head design protects the tubesheet and the tube inlet in one step. The hex-heads fit together to completely cover the tubesheet in the tube field area. Ceramic fiber paper is placed between the heads to fill any spaces between heads. The hex-head ferrules can be installed much quicker that the conventional ferrules and castable refractory. The individual ferrules can move slightly as the tubesheet moves without causing breakage/cracking. The only castable refractory is outside the tube field near the outer edge of the tubesheet where it is easier to support and is less subject to movement.

<u>Waste Heat Boiler Design</u>

SRU WHB's are fire tube type waste heat recovery boilers. They serve the dual purpose of recovering high level heat by generating steam and cooling the process gas from 2000+°F to typically about 600°F. The steam/water side of SRU WHB's should be designed in accordance with ASME Section I. The process side of the WHB should be designed in accordance with ASME Section VIII.

We find many WHB's that have some significant design deficiencies. This is particularly true in some of the high pressure boilers. Some features GAA recommends for WHB's which are often not included are:

- Flange only head type tubesheets. These tubesheets are thinner and designed to flex and to avoid large temperature differentials across the hot tubesheet which can occur in thicker tubesheets.

- Strength welding of tubes to tubesheet. We frequently see boilers up to even 600 psig operating pressure that have only rolled and seal welded tubes.
- Thermosyphon type designs (with steam drum) for operating pressures above 200 psig and 100 LTPD capacity. This is particularly important for any unit that is using or might consider using oxygen enriched combustion.
- Outlet channel designed with bottom or tangential outlet nozzle to prevent sulfur collection, and free draining piping to the first condenser.
- Single tube pass boilers unless plot space requires a two pass design. If a two pass design is used, both the rear turnaround chamber and outlet chamber must be equipped with a sulfur drain and sulfur seal, or be free draining to the first condenser.
- Independent WHB (not part of a multi-pass unit that also includes multiple condenser passes).
- At least three intermittent blowdown points.
- At least 2", 11 BWG minimum wall tubes.

GAA also recommends the following features be considered for large units:

- Alonizing the process side of the tubesheets and tubes.
- On-line monitoring and closed loop control of boiler water pH, conductivity, etc.

Sulfur Condensers:

The Claus SRU process consists of three repeating steps (heating, reaction, and cooling/condensing). Sulfur condensers serve the primary function of cooling and condensing sulfur formed in the upstream reaction step. Sulfur condensers are normally horizontal, kettle type shell and tube boilers. However, sulfur condensers are unique heat exchangers. In addition to condensing product sulfur from the process gases, the liquid sulfur must also be separated from the process gases before they flow to the next processing step. This is normally done in an oversized outlet channel. Sulfur condensers are also unique because the process gas flow rate through the condenser must be maintained within a specific operating range/velocity or there will be adverse effects on the process. The term to describe this flow property is mass velocity, which is normally expressed as ‘pounds of process gas flow per second per square foot of cross sectional flow area’. The recommended mass velocity operating range is 1.5-5.5 lb/sec-ft2.

Ideally, sulfur is condensed from the process gas at the cool condenser tube wall, flows from the tube into the outlet channel, is separated from the process gas, and is drained from the condenser. If the mass velocity is too high, liquid sulfur can be entrained in the process gas and be carried to the next stage or from the SRU instead of draining from the tube. If the mass velocity is too low, sulfur can condense in the vapor as a very small droplet or fog. The sulfur fog droplets are so small the gas stream carries them much like atmospheric fog or smoke to the next stage or from the SRU. In either of these cases, sulfur recovery is lost. Lower recovery does not directly affect SRU reliability, but lower SRU recovery will cause additional load on the downstream tail gas cleanup unit or increase the plant emissions. Either of these conditions may ultimately cause the SRU to be shut down prematurely for maintenance.

GAA prefers straight shell designs with partially tubed tubesheets instead of true kettle configurations for sulfur condensers. GAA recommends the following features be incorporated into the design of sulfur condensers.

- Flange only head type tubesheets. These tubesheets are thinner and designed to flex and reduce the tube to tubesheet stress and avoid/reduce the need for stay rods.
- Seal welding of tubes to tubesheet. We frequently see condensers that have only rolled tubes. Rolled only tubes are much more prone to leakage which will cause plugging, corrosion, and catalyst damage.
- Independent condensers, not part of a multiple condenser pass unit, except for small capacity SRU's.
- Consistent tube size and length for all condensers. This makes stocking enough condenser tubes to retube one condenser more practical and will allow emergency maintenance repairs to be made quicker. GAA prefers using 20 ft. long, 1-1/2", 12 BWG minimum tubes for condensers.
- Inlet channel filled with refractory to the bottom of the lowest tube row to insure free draining.
- Adequate outlet channel sizing to allow disengagement of liquid sulfur from the process gas. This is frequently not possible/practical with multi-pass units.
- Horizontal, removable knitted mesh mist eliminator pads in the condenser outlet channels.
- Full opening channel cover plates to provide access to the complete tubesheet and mist eliminator pads.
- Outlet channel bottom sulfur drain with a steam jacketed boot for trash collection and side outlet.

- Condensers slope 1/8" per foot toward the outlet to aid in sulfur drainage from tubes. All flange connections should be horizontal or vertical to grade.
- Inlet end of the condenser fixed horizontally but mounted on springs to allow vertical movement.
- Outlet end of the condenser mounted on a slide plate to allow horizontal movement.
- Inlet channel including cover plate should be lined with a 2-3" thick layer of insulating refractory if the inlet process gas is expected to be greater than 600°F. If the channel is refractory lined, it should be protected externally with a rain shield. External insulation should not be applied to refractory lined channels.
- The outlet channel including cover plate, and inlet channel if it is not refractory lined, should be fully insulated.

GAA prefers generating 40-60 psig steam in the shells of all but the final sulfur condenser, and to generate low pressure, 15-20 psig, steam in the final condenser. If there is no use in the plant for the low pressure steam, it can be condensed in an air cooled exchanger and returned to the sulfur condenser shell in a closed loop system.

Some designs utilize one or more of condensers as BFW preheaters upstream of the WHB. The lower level heat from the condenser is used to increase the generation of higher pressure steam by preheating the WHB feedwater. The condenser shell must operate at the BFW header pressure with this design. GAA feels this puts excessive stress on the tube to tubesheet attachment and reduces unit reliability. If sulfur condensers are used as BFW preheaters, we believe the tubes should be strength welded to the tubesheet. We have also found some designs in which the first condenser is intended to be a BFW preheater but some steam is generated on the shell side of the sulfur condenser. Because the shell is not designed for vaporizing conditions, vapor blanketing of some tubes can occur. This can result in overheating the tubes and sulfide corrosion.

Some designs also use cold BFW on the shell of the final sulfur condenser to minimize the process outlet temperature and maximize sulfur recovery. As mentioned above, GAA prefers to generate low pressure steam to minimize the process outlet temperature because if the BFW is too cold, there is a potential to freeze sulfur in the tubes.

Sulfur seals, look boxes, and rundown lines may be considered part of the piping system, but are discussed here because of the impact they can have on the sulfur condensers. GAA believes it is essential for each sulfur condenser to have an independent sulfur seal and look box. The ability to observe the sulfur production from each condenser is a very valuable process evaluation and troubleshooting tool. The sulfur rate, consistency of rate, color, temperature, and presence of bubbles are all important information items that can only be obtained from individual seals and look boxes.

Each sulfur condenser drain line, sulfur seal, look box, and rundown line to the sulfur pit should be fully steam jacketed. The drain line between the condenser and seal should have a steam jacketed plug valve located as close as practical to the condenser to allow on-line rodding of the drain line and sulfur seal. Clear access must be provided for rodding the drain line, and overhead access must be provided to rod the seal.

We understand in some plants Shell has implemented a method to flush sulfur seals to keep the seals open and free flowing. They have installed steam jacketed piping with block valves from the discharge of the sulfur pump to the inlet of each sulfur seal. This allows flushing the individual seals by closing the block valve in the drain line from the condenser and flowing product sulfur from the pump discharge through the seal and back to the sulfur pit. GAA believes this is an excellent and safe method to keep the seals free flowing. Some plants use steam to periodically blow the sulfur seals when there is an indication of partial plugging. While this method normally works, GAA feels it should not be done as a routine practice because of the safety risks from the hot liquid sulfur.

Sulfur seals should be designed to hold the higher of the dead head pressure of the combustion air blower or inlet acid gas pressure plus at least 1 psi. This is to insure the seals will not be blown by a blocked-in condition and provides some safety margin for somewhat lower sulfur density that may result from dissolved gas evolution from product sulfur. All sulfur seals should be the same depth. GAA suggests the seals for the second third and fourth condensers be identical. This makes maintaining a common spare more practical. Many companies make the first condenser drain line and seal oversized so it can act as a relief valve for the SRU if needed. GAA agrees with this approach.

From the look boxes, flow to the sulfur pit may be through individual rundown lines or a common rundown line. GAA prefers to use a common rundown line even though it will result in a longer overall path to the sulfur pit because it requires only one pit cover penetration. Individual rundown lines are shorter, but each line requires a pit cover penetration. As mentioned in the piping section, gravity flow liquid sulfur piping should be designed to run only 1/3 full and should slope about 1/4"/ft. of pipe run toward the sulfur pit.

Reheaters:

Reheaters definitely offer more options to the process designer than any other item in the SRU. There are two general types of reheaters, direct and indirect. There are also multiple options within each type. In general, GAA prefers the indirect methods to the direct methods; however, each method has specific applications where it should be considered. Each reheat method will be discussed briefly below.

Direct Reheat Methods

Direct reheat methods use a hot gas stream that is mixed with the process gas to increase the temperature of the mixed stream to the desired inlet temperature of the downstream catalytic reactor. The hot gas stream may originate within the process or from combustion. The direct reheat methods are hot gas bypass, acid gas fired line burner, and natural gas fired line burner. If any of the direct methods are used, it is very important to insure there is adequate mixing of the streams upstream of the temperature control point.

Hot Gas Bypass: This method has been used in many SRU's. It uses a hot stream from the first pass outlet of the WHB (1000-1200°F) to mix with process gas streams from the sulfur condensers. It is inexpensive to install, but it has the disadvantages of lowering sulfur recovery by bypassing conversion steps with a portion of the process gas, poor turndown performance, and high temperature sulfide corrosion of carbon steel piping and control valves. The corrosion problems can be minimized with proper metallurgy, but this is often not done because the cost is higher, and low cost is a primary reason to use hot gas bypass reheat. GAA feels the only reason to use hot gas bypass reheat in current designs is for very small, isolated location plants that do not have access to high pressure steam or adequate, reliable electric power supplies.

Acid Gas Fired Line Burner: Acid gas fired burners have been used in many SRU's. Their primary advantage the ability to achieve any desired catalytic reactor inlet temperature. However, line burners have disadvantages. The overall sulfur recovery is normally reduced because acid gas bypasses some conversion steps. The burner air/fuel ratio must be closely controlled or oxygen breakthrough, soot formation, and/or SO_3 formation is likely. Many reheat burners have experienced all of these problems. The acid gas fired burners must also be capable of substoichiometric natural gas firing during start-up and shut down operation. Oxygen breakthrough and/or soot formation are potential problems during natural gas firing. The ignition systems provided with line burners have normally been very unreliable. Sometimes hours are required to relight a burner after a shut down.

Acid gas fired reheat burners should only be considered if the amine acid gas stream is at least 50% and preferably 65% H_2S and does not contain NH_3 or butane and heavier hydrocarbons. If acid gas fired line burners are used, the following features should be incorporated to insure optimum operation without creating downstream problems:

- High intensity burner with wide turndown capabilities and ability to fire natural gas at 90% or less than stoichiometric air without soot formation or oxygen breakthrough.
- Properly designed air, acid gas, and natural gas feed controls.
- Properly designed safety shutdown controls.
- Direct ignition using a high energy spark igniter.

If these features are incorporated into the reheater design, the installed cost is relatively expensive.

Natural Gas Fired Line Burners: Natural gas fired burners have similar advantages and disadvantages to acid gas fired burners. The natural gas fired burners and their associated control systems are somewhat less complicated since only one fuel source is involved, and acid gas does not bypass conversion steps. However, they have the disadvantage of introducing additional volumetric flow into the SRU which requires larger downstream equipment and results in greater sulfur vapor and entrainment losses.

Natural gas fired burners should be considered only if the fuel source/natural gas has a constant composition. **Refinery fuel gas should never be used for fuel in an SRU.** Another fuel to consider is hydrogen if it is available and constant composition. Hydrogen has the advantage of no possibility of forming soot. If natural gas fired burners are used, the same features listed for the acid gas fired burners should be incorporated into the natural gas fired reheat burner designs.

Indirect Reheat Methods

Indirect reheat methods use a heat source that does not come into direct contact with the process gas. The temperature of the heat source must be sufficient to increase the condenser outlet stream temperature to the desired inlet temperature of the downstream catalytic reactor. Indirect reheat methods are generally simpler to control and result in higher sulfur recovery because no acid gas bypasses conversion steps. The indirect reheat methods are steam heated, hot oil heated, indirect fired, salt bath, electric, and gas-gas heat exchange. Steam, hot oil, and electric heated reheaters are currently most popular. The other methods are rarely used today.

Steam Heated: High pressure steam (greater than 400 psig) is the most popular source of heat for SRU reheaters. Steam reheaters are very reliable and the easiest to operate and control. Steam reheaters are also relatively inexpensive. The only major disadvantage of steam heaters is that the process outlet temperature is limited by the steam temperature. The maximum practical reheater outlet temperature when using 600 psig steam is about 460°F. This can be a problem for the first stage reactor, particularly if significant quantities of COS and CS_2 are formed in the burner/reaction furnace. Catalyst bed heat soaks and rejuvenation procedures are limited when using steam reheaters. However, if a high quality main burner is installed, the need for these procedures should be greatly reduced. If import high pressure steam is not available, the SRU WHB can generate it.

GAA prefers to use a steam reheater design in which the high pressure steam is on the tube side of a U-tube type heat exchanger. This type design avoids having to design the shell for the high pressure steam and avoids tube to tubesheet stresses which can cause failures with steam leakage into the process and SRU shutdown too make repairs. The U-tube bundle, free to expand within the shell, avoids these mechanical stresses.

Hot Oil Heated: Hot oil heated reheaters are relatively easy to control and operate and can achieve higher temperatures than steam reheaters. Hot oil heated reheaters are reliable; however, an external source of hot oil is required which lowers the overall reliability unless redundant sources are available. A hot oil unit can be expensive to install and contains several additional equipment items that must be operated and maintained

Indirect Fired Reheater: Indirect fired reheaters are infrequently used. They are normally utilized only for the first stage reheater to achieve higher temperatures than is possible with steam reheaters. Indirect fired reheaters can achieve the higher temperatures; however, they are expensive to install, require an additional set of firing controls, and are thermally inefficient. GAA feels the utilization of indirect fired reheaters should be very rare.

Salt Bath: Salt bath heaters have been used in a number of SRU's, primarily in Alberta. All reheaters can utilize a common salt bath. They are relatively simple in design and simple to operate with process temperature control using a cool gas bypass. There is an extra set of firing controls for the salt bath temperature which is controlled by regulating the firing rate of the bath heater. One problem associated with salt bath reheaters is almost all installations result in pocketing of the process piping. Maintenance activities can also be complicated by the fact the eutectic salt mixture is a solid at normal ambient temperatures.

Electric Reheaters: Electric reheaters are now being used much more frequently. The primary application of electric reheaters is for small SRU’s (less than 30 LTPD) that would probably have used hot gas bypass reheat 20 years ago and as trim heaters downstream of steam reheaters. The electric reheaters are relatively inexpensive, can achieve the required temperatures, are simple to operate, and easy to maintain. The primary limitation of electric reheaters is the maximum practical heat load, about 100 kW (340,000 Btu/hr). Electric power for large electric reheaters can also be a major cost. If electric reheaters are used, low heat flux, non-baffled elements should be utilized.

Gas-Gas Reheaters: Gas-gas reheaters are rarely used today. Normally, the effluent gas from the first catalytic reactor is used to heat the feed to the third reactor. Some designs even try to supply reheat to both the second and third reactors. Gas-gas reheaters look good on paper, but have a number of problems. Since the process gas must pass through both the shell side and tube side of the exchanger, the pressure drop through the SRU is higher than for other methods. Many gas-gas reheater designs pocket the process piping on one or both sides of the exchanger. This can and does result in sulfur collecting in the low points. Turndown performance is poor. Heat transfer is inefficient which results in large, expensive exchangers.

Catalytic Reactors:

Catalytic reactors, also referred to as catalytic converters, sulfur converters, sulfur reactors, etc., are normally contained in a common horizontal carbon steel vessel for SRU's up to about 300 LTPD capacity. Individual reactor vessels are normally used in larger plants. Catalyst beds are typically 36-48" deep and centered on the horizontal center line of the reactor vessel. Inadequate design and careless installation of bed supports, particularly the wire mesh screen support, has resulted in many dumped catalyst beds and SRU downtime to reinstall the catalyst and clean downstream equipment. GAA feels the following features should be incorporated into the catalytic reactor design.

- Internal 2-4" thick refractory lining including internal partitions below the top of the catalyst bed to protect the shell from possible internal sulfur fires.
- External insulation for heat conservation and to prevent corrosion of the vessel shell.
- Catalyst support by refractory covered steel beams that support stainless steel or Alonized steel grating covered with two layers of stainless steel screen. The lower screen should be 4 X 4 mesh, and the upper screen 8 X 8 mesh. Both screens should be tied to the grating using stainless steel wire.
- Elevated with bottom outlet directly over the follow condenser.
- Inlet flow distributors to prevent impingement of process gas directly onto catalyst bed which can cause flow channeling and bed movement.
- Catalyst bed size based on space velocity of 700-1000 SCFH/ft^3 of catalyst.
- Two 3" layers of active catalyst bed support balls. The lower layer should be 1/2" diameter balls, and the upper layer 1/4" diameter balls.
- Except for very small catalyst beds, each reactor should have at least 9 thermocouples located at 25%, 50%, and 75% of bed length and depth. For very large beds, the thermocouples should be located on no more than 8 ft. spacing. The bed thermocouples should be monitored regularly to track any catalyst deactivation.
- High macroporosity activated alumina or titanium oxide catalyst should be used.
- Nitrogen or steam snuffing connections at the inlet of each reactor for extinguishing internal sulfur fires. Nitrogen is preferred. The snuffing block valve should be steam jacketed and located as near the inlet nozzle as practical. Ideally the block valve is solenoid activated with the switch on the main control panel or accessible to the operators at grade.

Sulfur Pit:

Product sulfur is normally collected in a below grade, concrete pit equipped with steam coils to keep the sulfur molten. The pit does not directly affect the SRU process operation until the SRU must be shut down because of problems with the pit. Some common sulfur pit problems are steam coil leakage, sulfur pump failure, internal sulfur fires, and even internal explosions. There are a few design features that will significantly improve the reliable operation of the sulfur pit.

- Construct the pit using sulfate-resistant concrete with limestone-free aggregate.
- Use alloy piping for the steam coil steam supply downcomers and condensate risers, and any internal components such as ladder rungs that will be alternately covered with liquid sulfur and then exposed to air as the pit level changes.
- Install dual steam jacketed sulfur transfer pumps.
- Use a fully steam jacketed steam eductor to continuously draw atmospheric air into the pit, sweeping vapor space to prevent the accumulation of H_2S.
- Steam snuffing connection(s) for extinguishing internal sulfur fires. The number of inlets depends on the size and configuration of the pit. The snuffing block valve should be at least 50 ft. away from the pit and accessible to the operators at grade.

INSTRUMENTATION

Well designed and properly applied instrumentation is required for efficient and reliable SRU operation. An SRU with the best designed piping and equipment cannot achieve its intended function without proper instrumentation. Today, extremely good instrumentation is available, and no plant should be limited by lack of proper instrumentation. However, even with excellent equipment available, instrumentation must be properly designed and installed. We often find high quality instrumentation that is improperly sized and installed and, therefore, cannot properly control the plant. GAA's general philosophy for instrumentation is provide adequate but not excessive instrumentation and keep it as simple as possible. Excess instrumentation can often cause more problems than it was intended to solve and can decrease overall SRU reliability. A major factor in the proper application of instrumentation is being aware of the operating atmosphere in which the instruments are expected to operate. There will always be some residual H_2S and SO_2 in the SRU area. Instruments must be protected from these corrosive components through purging and sealing. Copper and brass components (tubing, valves, electrical connections, etc.) should never be used in SRU's unless they are inside a purged enclosure. Some key instrumentation areas are discussed below.

Acid Gas Feed Knockout Drums:

Knockout drum controls are simple. As mentioned in the equipment section, the drums should be equipped with either hardware or software switches that start and stop the pumps that transfer liquid collected in the drum to the appropriate upstream collection vessel. Each drum should also be equipped with level indication and alarms and a high level switch that activates the shutdown system. The amine acid gas drum high level switch should activate an SRU shutdown. The SWS gas drum high level switch should only block the SRU SWS gas feed.

Feed Flow Measurement and Control:

Proper feed flow measurement and control is critical to reliable efficient operation of SRU's. GAA prefers to control the acid gas header and knockout drum pressure inside the SRU battery limits with a flow controller on cascade control from the pressure controller. The feed flow meters should be located upstream of the control valve. This insures constant pressure on the flow meter and avoids the need for pressure compensation of the measured flow. Conventional orifice plates or low pressure drop venturi meters are normally used. SWS gas flow meters should be heated and the pressure taps purged to prevent plugging with ammonium salts.

Combustion Air Blowers:

GAA recommends independent surge controls for each air blower. This allows blowers to be started and switched without causing one or both blowers to surge. GAA's preferred surge control method is to measure the suction flow to the blower and vent the blower discharge to the atmosphere to maintain a minimum flow that is safely above the surge point. GAA does not feel the blower control systems which operate on discharge pressure control and/or suction throttling operate well.

The blowers should be equipped with vibration monitoring systems. Generally, vibration alarms are adequate to alert the operator to switch to the spare blower. Automatic high vibration shutdowns are not normally installed

Combustion Air Control:

Control of combustion air feed to the SRU is the most critical for efficient, reliable operation of the SRU. GAA prefers a combustion air control system that is split into two sections, a main air flow loop based on acid gas flow rate and a trim air flow loop based on the tail gas analyzer. Air demand is calculated from the acid gas flows and used as a feed forward ratio set point for the main air control loop. The main air loop supplies about 90% of the total air to the burner.

The trim air loop operates on feedback control from the tail gas analyzer. The analyzer measures the relative amount of H_2S and SO_2 in the tail gas. The analyzer controller provides a remote set point signal to the trim air loop based on the relationship $2SO_2 - H_2S = 0$. When this relationship is satisfied, the optimum amount of combustion air is being supplied to the SRU. If the result is positive, too much air is being fed and the rate should be reduced. Likewise, if the result is negative, too little air is being fed and the rate should be increased.

It is apparent that the tail gas analyzer must work properly to achieve optimum air control with efficient, reliable operation. If the air controls are off, inadequate impurity destruction with equipment plugging and/or equipment corrosion may occur. The tail gas analyzer must be properly located, use proper sampling (preferably supplied by the analyzer manufacturer), and be properly calibrated. This requires correct initial design and regular maintenance.

Main Burner and Reaction Furnace:

The burner and reaction furnace require a significant amount of instrumentation; however, most is not directly associated with process control of the SRU but is used to monitor the operation. A key to reliable operation of burner and furnace instrumentation is to adequately purge each instrument nozzle even when the SRU is shutdown. The process gas contains elemental sulfur which will condense and solidify if allowed to enter the cool instrument nozzles. The purge rate should be measured with a rotameter to verify flow.

The temperature in the reaction furnace should be monitored. This is a valuable tool to determine if conditions have changed and affected combustion. GAA feels an optical pyrometer supplied by E^2T Corporation is currently the most reliable method of monitoring reaction furnace temperature. The pyrometer must be properly calibrated and maintained to supply reliable information. Various types of thermocouple assemblies have been tried in this service. Most do not supply consistent, reliable information, or fail within a few months.

The most critical burner instruments are the flame scanners. If the flame scanners are unreliable, it can result in numerous unwarranted, nuisance shut downs. SRU's require special flame scanners because the H_2S flame provides weak ultraviolet radiation. Depending on the burner, some scanners may work and others will not. GAA believes the most reliable and versatile scanners currently available are supplied by Iris. Reliable scanner operation requires proper installation which includes sighting, grounding, calibration, etc.

Waste Heat Boiler:

The level controls associated with the WHB are critical. Level control in small WHB's is normally simple single element level control. Large, high pressure boilers should normally utilize more sophisticated three element level control which uses steam production rate and boiler level to set the BFW flow control loop. The three element control system reacts quicker to changes in load on the boiler and allows the steam drum to be smaller. WHB's also must have low, low level switches that will initiate an SRU shutdown. Malfunctions in the level control/shutdown system can result in WHB tube failure and major SRU downtime.

Sulfur Condensers:

The only process controls associated with sulfur condensers are generally simple level controls. There are no shutdown switches normally associated with sulfur condensers.

Reheaters:

There were many different reheater types discussed above. Most reheater types will utilize a slightly different control system. All reheaters will employ a temperature control loop; the differences occur in the stream actually controlled. Direct fired line burners require the most complicated controls and include automatic shutdowns associated with the firing controls. The details of all options is outside the scope of this overview discussion.

Catalytic Reactors:

Catalytic reactor inlet temperature is controlled by varying the reheater outlet temperature. There are no other controls associated with the reactors. The installation of thermocouples to monitor bed temperatures, flow distribution, and catalyst activity was discussed in the equipment section.

Shutdown System:

One of the primary improvements that can be made in many SRU's is the installation of a reliable safety shutdown system. The purpose of the SRU shutdown system is to: (1) safely shut down the SRU to protect personnel and/or equipment if critical operating variables move outside the safe operating range, and (2) insure a safe, orderly start-up of the SRU. We find many plants in which the shutdown system is non-functional or has devices bypassed which defeats its intended function. Operations personnel tend to do whatever is necessary to keep the SRU on-line even though it can often result in unsafe operating conditions. The bypass is often installed because of excessive nuisance shutdowns.

The main reasons shutdown systems do not operate properly are poor design, inappropriate equipment installed, excessive shutdown input devices, and poor maintenance. As mentioned previously, high quality equipment is available. If the system is properly designed, with properly selected and installed equipment, and is properly maintained, the shutdown system can perform its intended function reliably without nuisance shutdowns. GAA believes the shutdown system should include only those items that are necessary to insure protection of personnel and equipment. Excessive inputs tend to make the system much more unreliable, more difficult to start-up, and subject to nuisance shutdowns.

Personnel at each plant may have specific items they feel should initiate a shutdown. GAA feels the following items should initiate an SRU shutdown in all SRU's:

- One or more operator activated manual switches
- High level in amine acid gas knockout drum
- Low amine acid gas flow rate
- Low combustion air blower discharge pressure
- Low main combustion air flow
- Loss of main burner flame as detected by two of two flame scanners
- Low waste heat boiler water level

Upon activation of the shutdown system, the SRU is shut down by blocking all feeds to the plant. These are acid gas (amine acid gas and SWS gas if present), all combustion air (main air, trim air, and any air to pilot or line burners), natural gas (to main, line, or pilot burners), and oxygen if used.

The following sequence of key start-up steps should be required by the shutdown system:

- Nitrogen purge of the main burner and reaction furnace, 5 purge volumes in 5 minutes minimum.
- Flame ignition, either main flame using a high energy direct ignition of air and natural gas or a spark ignited air-gas pilot. GAA has had very good experience using the direct ignition devices which are available from several suppliers.
- If a pilot is used, flame must be verified before introducing air and natural gas to ignite the main burner.
- Main flame must be verified by a flame scanner prior to introducing amine acid gas.
- Amine acid gas must be introduced prior to introduction of SWS gas.

Following these steps insures a safe start-up and minimizes the chance of damaging SRU equipment and catalyst.

SUMMARY

The above discussion has presented many of the items and areas where GAA feels the process designer can make significant improvements in SRU reliability. Most items have been included because we have observed problems that could have been alleviated or at least minimized if the suggested features had been implemented.