Oxygen Enrichment of Sulfur Recovery Units to Boost Capacity, Conserve Capital, and Improve Environmental Performance

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OXYGEN ENRICHMENT OF SULFUR RECOVERY UNITS TO BOOST CAPACITY, CONSERVE CAPITAL, AND IMPROVE ENVIRONMENTAL PERFORMANCE

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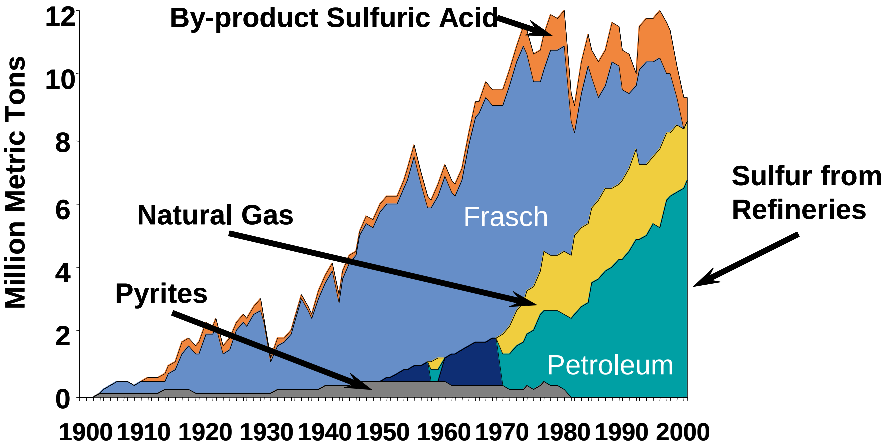
1. INTRODUCTION

Current trends in the characteristics of crude oil supply, petroleum product demand, and tightening environmental regulations require continuous change in the worldwide refining industry. Refiners are confronted with more stringent specifications on motor transportation fuels, greater demand for light transportation fuels, and increasing dependence on heavy, sour crude oil feedstock. Environmental regulations in Europe, North America, Asia and other regions all require progressively cleaner motor transportation fuels. Product demand is continually shifting from heavy bottom of the barrel products toward light transportation fuels. Simultaneously, an overall lighter product mix must be produced from a heavier crude slate.

These developments have led to reconfiguring refinery processes with greater use of hydroprocessing to upgrade crude oil into light transportation fuels and to improve fuel quality. More hydrotreating and increased processing severity is required for removing sulfur and nitrogen compounds from fuels to meet future environmental regulations. The resulting increase in production of hydrogen sulfide (H_2S) and ammonia (NH_3) has placed new demands on the processing capability of refinery sulfur recovery units (SRU's).

A good example of the challenge can clearly be seen in the graph depicting how the sources of U.S. sulfur production have shifted dramatically (Figure 1). The growth in sulfur from oil refining is particularly noticeable and is expected to continue. This trend is reflective of most other regions in the world and refiners and sour gas processors need to find the most economic way to handle these increases. In many cases, oxygen enrichment has proved to be the best solution to boost SRU capacity.

Figure 1
Change in U.S. Sulfur Production Sources During the 20th Century



Source: USGS

Oxygen enrichment of the combustion air to the reaction furnace is a proven means of increasing SRU capacity, and of improving the SRU's ability to handle contaminants. Expanding SRU capacity with oxygen enrichment is gaining broad acceptance for handling extra acid gas loading at significantly reduced capital expense. Oxygen enrichment is also finding application as the answer to requirements for SRU redundancy and improved sulfur recovery.

The concept of increasing SRU capacity with oxygen enrichment has been of interest for at least thirty years, and has been applied on a commercial scale since 1985. The typical SRU reaches its ultimate sulfur production capacity when the maximum allowable front-end pressure prevents further increase in feed rate. Oxygen enrichment reduces the flow of process gases by reducing the quantity of nitrogen that enters with the combustion air. This reduction in process flow rate allows a corresponding increase in SRU acid gas feed rate and subsequent increase in sulfur production.

Commercial application of oxygen enrichment with acid gas feeds rich in H_2S has been limited by the maximum allowable operating temperature of the SRU reaction furnace refractory. Commercially available refractory have demonstrated reliability at process temperatures of up to about 2800 °F (1540 °C). Some companies prefer to conservatively limit process operating temperatures to a range as low as 2500-2600 °F (1370-1430 °C). Of course, the choice of maximum allowable furnace operating temperature has a bearing on the SRU throughput that can be achieved without special temperature moderating techniques. Furthermore, the increase in furnace temperature is to some degree self-moderating, since a higher temperature increases H_2S dissociation, which is an endothermic reaction. Dissociation also reduces the amount of H_2S remaining for reaction and therefore less combustion is required, ultimately decreasing the heat release and temperature.

2. SRU OXYGEN ENRICHMENT THEORY

The underpinning theoretical concept that makes oxygen enrichment such an effective means of debottlenecking Claus sulfur plants is briefly explained in this section.

In the Claus process about one-third of the hydrogen sulfide in the acid gas stream is combusted to sulfur dioxide which further reacts with the remaining hydrogen sulfide to form elemental sulfur and water in the vapor phase. The combustion reaction and approximately 60-70% of the conversion of hydrogen sulfide to sulfur, take place in the thermal reactor at temperatures between 1100 and 1400^o C for typical refinery acid gas streams. The remaining equilibrium conversion of hydrogen sulfide to sulfur takes place in a series of catalytic reactors at much lower temperatures. Representative reactions are summarized below:

$$\begin{array}{lcll}
H_2S + 3/2\ O_2 & \rightarrow & SO_2 + H_2O & \text{(Combustion reaction)} \\
2H_2S + SO_2 & \leftrightarrow & 3S + 2H_2O & \text{(Claus reaction)} \\
\hline
3H_2S + 3/2\ O_2 & \leftrightarrow & 3S + 3H_2O & \text{(Overall reaction)}
\end{array}$$

Stoichiometrically, 100 kmol/h of hydrogen sulfide requires 50 kmol/h of oxygen. If all of the oxygen is provided by the air, 189 kmol/h of nitrogen comes along with the 50 kmol/h of oxygen. This nitrogen (over 50% by volume in the feed) contributes to a large amount of the pressure drop through the SRU. Oxygen enriched operation reduces the amount of nitrogen entering the process. Table I shows how nitrogen is replaced by acid gas while keeping the total molar/volumetric flow rate (and hence the pressure drop) through the SRU equal or less than in the air-based case at varying levels of oxygen enrichment. Acid gas throughput to the SRU is dramatically increased. The constant total flow rate at the reaction furnace and lower flow rates downstream (compared to the air-based case) maintain the pressure drop through the SRU at less than or equal to that for the air based case despite much higher acid gas throughputs. This is the underlying principle for the effectiveness of oxygen enrichment as a debottlenecking solution in the refining, chemical and other process industries.

TABLE I

WHY OXYGEN ENRICHMENT INCREASES SRU CAPACITY

Oxygen Enrichment (%)	20.9 (Air)	25	50	100
Acid Gas (kmol/h)	100	113	170	226
Oxygen (kmol/h)	50	57	85	113
N_2+Ar (kmol/h)	189	169	84	0
Total Flow to RF[1] (kmol/h)	339	339	339	339
Total Flow to TGCU[2] (kmol/h)	293	286	261	235

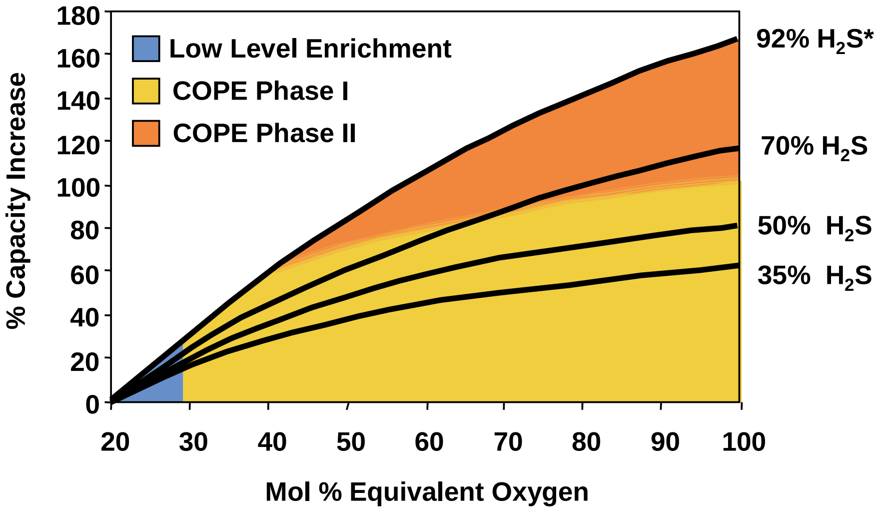
1 RF = Reaction Furnace
2 TGCU = Tail Gas Clean-up Unit

Total Flow Constant
Acid Gas Flow increases as O2 % increases

3. OXYGEN ENRICHMENT TECHNOLOGIES

Figure 2 illustrates the expected capacity increase for various acid gas stream concentrations and enrichment levels. The range of oxygen concentration can vary from 21% up to 100%, and different technologies are required at various oxygen enrichment levels. Overlaid on Figure 2 are the three proven SRU oxygen enrichment technologies offered by Air Products and Goar, Allison & Associates (GAA).

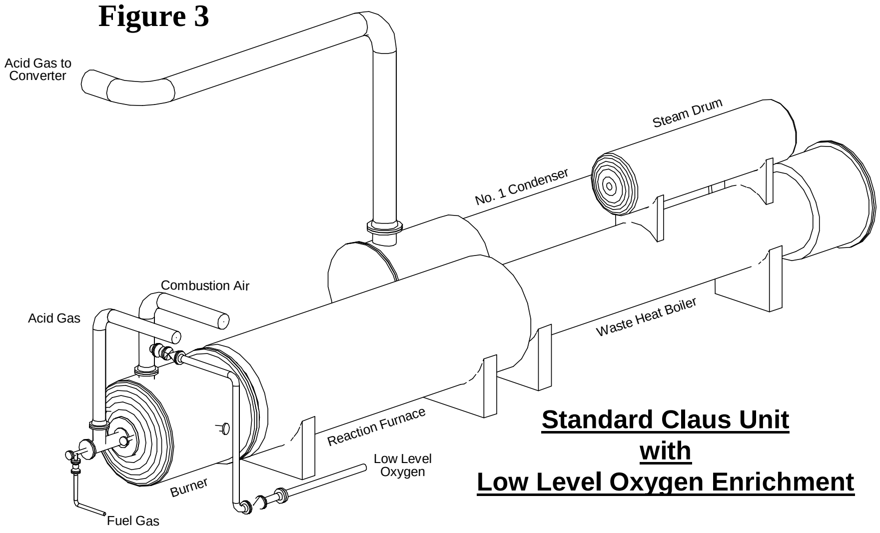
Figure 2
SRU Capacity Increase with Oxygen Enrichment



3.1 Low-level oxygen enrichment technology (LLE)

Oxygen is injected into the combustion air main as illustrated in Figure 3 through a custom-designed diffuser, which provides good mixing and oxygen safety. Considerations related to oxygen compatibility and cleanliness of the air main and other components usually limit this technology to enrichment levels of about 28%. Because this technology requires minimum capital investment and process modification, it is the easiest to implement and typically offers an incremental SRU capacity increase of 10–30%.

Figure 3



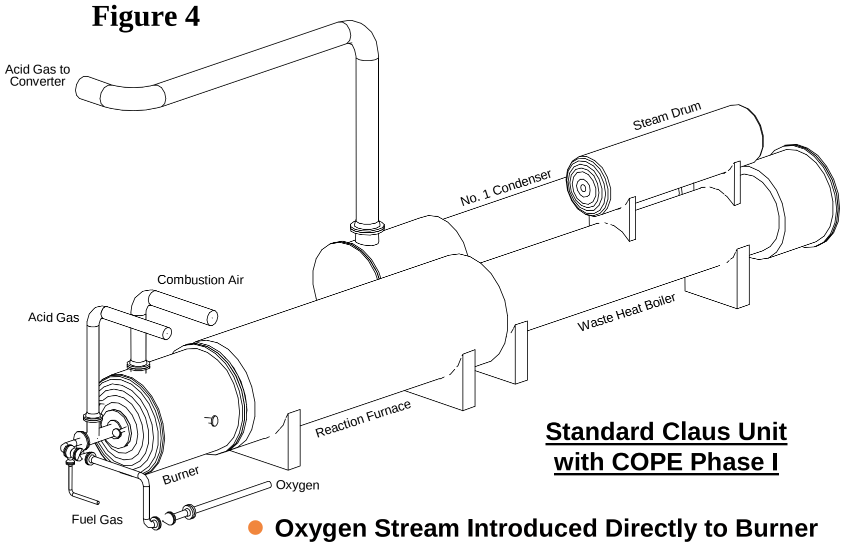
Standard Claus Unit
with
Low Level Oxygen Enrichment

- **Oxygen Stream Introduced to Air Stream**
- **Limited to 28% Oxygen Enrichment**

3.2 Mid-level oxygen enrichment technology (COPE™ Phase I)

The COPE process is an SRU oxygen enrichment technology jointly developed by Air Products and GAA. Oxygen enrichment levels exceeding 28% require the use of a special burner with discrete oxygen port(s) to safely handle oxygen. The air and oxygen are not premixed as in the LLE technology because of material compatibility concerns and enter separately via a specially designed burner as shown in Figure 4. The COPE burner can safely handle the incoming gas streams and has large turndown, high-intensity mixing, and excellent ammonia destruction capability. COPE Phase I allows capacity increase of up to 70% at oxygen enrichment levels of up to 40–45% for typical refinery acid gas streams. The upper limit of this technology is set by the temperature limitations of the furnace refractory.

Figure 4



Standard Claus Unit with COPE Phase I

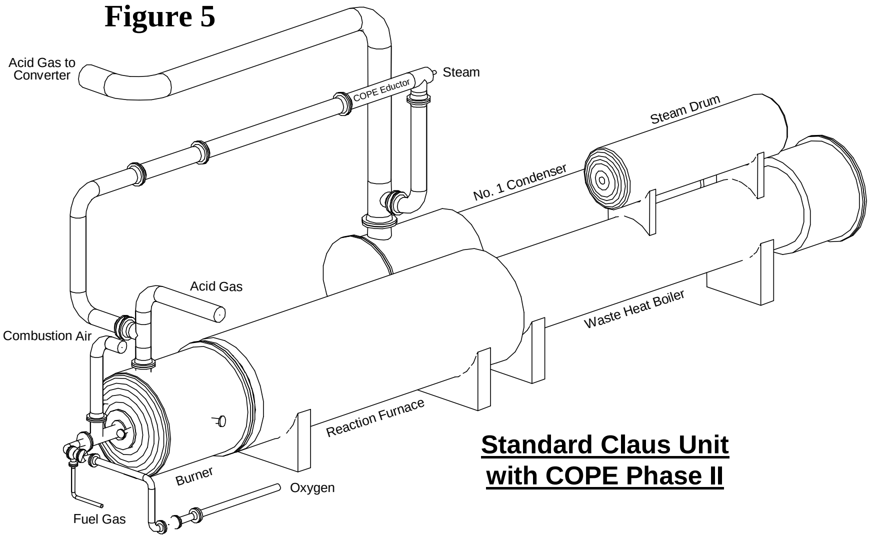
- **Oxygen Stream Introduced Directly to Burner**
- **Oxygen Enrichment Limited by Working Temperature of the Refractory**

3.3 High-level oxygen enrichment technology (COPE™ Phase II)

High reaction furnace temperatures typically encountered above 40-45% oxygen enrichment for rich acid gas streams require the implementation of special temperature moderation technologies for further gains in capacity. Two different approaches have been commercialized for deploying high-level oxygen enrichment: 1) the use of relatively cool gas recycle to quench the flame (GAA/Air Products' COPE Phase II Process) and 2) the use of staged combustion with intermediate cooling – the "SURE" process.

COPE Phase II is a patented temperature moderation technology developed to allow even greater capacity increase beyond that achievable from mid-level enrichment. This technology can be deployed at oxygen enrichment levels up to 100%, more than doubling the capacity of an existing SRU. In addition to a COPE burner, a steam ejector or a recycle blower is installed downstream of the first sulfur condenser to recycle a portion of the cooled process gas to the COPE burner and the RF for temperature moderation. Gas recycle is easy to operate and does not increase the pressure drop of the overall system since the increased pressure drop in the RF and waste heat boiler is compensated by a lower pressure drop downstream. Figure 5 shows an SRU modified with COPE Phase II.

Figure 5



- **Recycle Stream Added to Moderate Flame Temperature to Desired Set Point**
- **Enrichment up to 100% Oxygen; Potentially Yields up to 150% SRU Capacity Increase**
- **Easy Upgrade from COPE Phase I**

The COPE technology allows an SRU to operate over the entire range of oxygen enrichment levels, from an air-based mode to 100% oxygen, for the greatest possible operational flexibility. Oxygen is used only when needed, and transition from air-based to oxygen-based operation and back is easily accomplished.

This array of technologies gives refiners the flexibility to scale easily from LLE to COPE Phase I to COPE Phase II as their acid gas processing needs increase.

4. GENERAL BENEFITS OF OXYGEN ENRICHMENT

4.1 Capacity Increase and Full Redundancy

The most common driver for implementing SRU oxygen enrichment is to increase processing capacity. The need for additional capacity may stem from refinery expansion, additional hydroprocessing, or a shift to heavier and more sour crudes to improve refinery margins. When an SRU is bottlenecked by hydraulic or residence time limitations, oxygen enrichment of the combustion air reduces the nitrogen flow through the SRU, thereby allowing an increase in the acid gas and sour water stripper gas streams. Also, oxygen enrichment is a low cost method of providing 100% SRU redundancy (two or more trains) and meeting regulatory agency mandates for redundant SRU capacity.

4.2 Capital cost savings

Depending on the enrichment technology, the cost of implementing SRU oxygen enrichment is only 5-20% of the cost for building a new SRU. Oxygen enrichment can also be economical for grassroots plants due to smaller equipment for the same capacity.

4.3 Operational Flexibility

A refinery can use oxygen enrichment as a means to handle varying acid gas processing needs such as, for example, the higher load from a sour crude campaign. There is no reason to incur a capital penalty and operating difficulty associated with building an oversized SRU that is fully utilized just a few times a year. Since the oxygen is often a variable cost with a relatively small fixed component (depending on supply mode), there is less of a financial penalty for operating at below the maximum capacity compared to investing in a new plant.

An oxygen-enriched SRU is better equipped to handle hydrocarbon breakthroughs. Also, the need to flare acid gas, store intermediate products or cut refinery feed due to SRU limitations is substantially eliminated.

4.4 Operational Reliability

Oxygen enrichment operation has on/off capabilities with seamless ramp up to oxygen-enriched operation or ramp down back to full air-based operation. This feature allows the full original turndown capabilities of the air-based plant with the full maximum throughput capabilities of an oxygen-enriched operation on an as-needed basis. Thus, oxygen is only used when needed, thereby minimizing operating costs.

Flame scanners on the Reaction Furnace burner can be problematic in air-based operation resulting in nuisance SRU shutdowns. Oxygen-enriched operation results in a more intense flame thus improving the operation of the flame scanners and thus addresses one of the more common SRU nuisance problems.

The COPE II process can utilize the high-pressure steam that is generated within the Claus Plant. At full design loads the ejector requires only 5 to 10% of the total of the steam that is generated in the WHB. Thus, the ejector scheme can be supported by the SRU plant and does not require electricity as an external utility.

4.5 Improved Conversion and Reduced Emissions

The reduction of diluent nitrogen results in higher partial pressure of hydrogen sulfide (H_2S) in the process stream, which leads to higher conversions in the SRU catalytic reactors. Also, the relative SRU tail gas flow rate is progressively reduced as oxygen enrichment is increased. The reduction in nitrogen entering the Tail Gas Cleanup Unit (TGCU) results in higher hydrogen sulfide partial pressures in the amine absorber. This results in better absorption and lower sulfur emissions than the air-based SRU operation.

4.6 Hotter Flame and Better Contaminant Destruction

SRU oxygen enrichment results in higher reaction furnace (RF) temperatures contributing to better destruction of ammonia, HCN and heavy hydrocarbons (BTX) in the RF. Incomplete destruction of ammonia, due to RF temperatures lower than 2200-2300 °F (1200-1260 °C) can result in the formation of ammonium salts that will cause plugging and increased pressure drop in the cooler sections of the SRU. Further, higher flame temperatures with oxygen enrichment will eliminate the need for “split flow” operation where some of the acid gas is diverted to the rear of the RF to achieve higher temperatures. This practice is not the most desirable both from a control standpoint as well as the risk of having contaminants thermally cracked and/or slip through onto the catalytic stage of the SRU.

4.7 Quick Implementation

SRU oxygen enrichment can be implemented quickly. No “down time” is required for low-level enrichment (up to 28% oxygen in air) as an oxygen diffuser can be hot tapped into the air main. For higher levels of oxygen enrichment tie-ins and modifications can be achieved within the timing of a normal turnaround.

4.8 Compact Footprint

The space requirement for implementing SRU oxygen enrichment is negligible compared to a new SRU. At refineries limited by space availability proximate to their amine unit, oxygen enrichment may turn out to be the only practical and economical solution. The oxygen storage or on-site generation plant can on the other hand be conveniently sited where space is available, even at a considerable distance from the existing SRUs.

For the COPE II Process, the ejector is located at an elevation above the first condenser and reaction furnace to allow all ejector piping to be self-draining. It is also very easy to install a spare ejector if desired. There is no impact on the SRU footprint.

4.9 Proven Safety

Oxygen-enriched operation has proven to be both reliable and safe regardless of the chosen technology. The COPE Process in itself has successfully demonstrated in excess of 275 train years of oxygen-enriched operation without incident.

5. KEY EQUIPMENT AND PROCESS DESIGN FEATURES

The large increases in SRU capacity achieved with oxygen enrichment produce large increases in heat transfer duty for the waste heat boiler and No. 1 condenser. This equipment must be closely checked to determine adequacy for all significant SRU capacity increases. The majority of COPE Phase I and COPE Phase II installations are retrofits. Although process conditions are altered substantially by a COPE retrofit, the existing equipment is entirely adequate in most cases, both in the SRU and the associated SCOT type tail gas cleanup unit. This is demonstrated by the low requirement for replacement of major equipment as shown in Table II.

Table II. COPE Process Retrofits
Required Equipment Replacements.

Retrofit Type:	COPE Phase I	COPE Phase II
Units in Operation/Design	15	8
Furnaces	1 (1)	2
Waste Heat Boilers	4	2
Steam Drum (only)	3	0
No.1 Sulfur Condenser	0	2

Notes:

1. Two additional furnaces were replaced with furnaces of the same size due to their physical condition and ease of installation.

Among the SRU's requiring some replacement of major equipment, up to 250% of nameplate capacity was achieved. Among units that required no replacement of major SRU equipment, up to 185% of nameplate capacity was achieved. Where a SCOT type TGCU was involved, additional quench water-cooling surface was added in most cases, since quench water-cooling duty increases in direct proportion to increased SRU capacity.

6. PROCESS IMPACT AND IMPROVEMENTS

6.1 Combustion and Enhanced Dissociation in the COPE Burner

The injection of high purity oxygen takes place at the tip of the burner gun directly into the combustion zone. Introducing the oxygen directly into the center of the flame produces a short, localized, high temperature zone that maximizes the dissociation of H_2S into hydrogen and sulfur. Operating experience with the COPE burner has verified that this direct injection of oxygen enhances H_2S and NH_3 dissociation. These highly endothermic reactions provide dual benefits by reducing the flame temperature and also reducing the consumption of oxygen for a fixed amount of acid gas feed.

The destruction of ammonia in a sulfur recovery unit is always of major concern. At the very hot furnace conditions of the COPE Process, ammonia is removed to a negligible concentration, so that the potential for downstream problems are eliminated. The high operating temperature in the furnace also minimizes the formation of soot from hydrocarbons that may be present in the acid gas feed, and prevents formation of CS_2 that may be formed from the hydrocarbons.

6.2 Improved SRU Recovery

One of the unexpected results of oxygen enrichment is that the overall sulfur recovery of the SRU is increased by as much as 0.5%. This happens because removal of nitrogen from the process gas increases the H_2S and SO_2 concentrations in the Claus converters and leads to higher equilibrium conversion. Another consequence of the removal of nitrogen is a greater temperature rise across the Claus converters. Since the converters are usually designed for a particular outlet temperature, the inlet temperature can be reduced. This decreases the amount of energy required to reheat the gas to each converter.

6.3 Waste Heat Boiler Performance

The waste heat boiler will have a larger heat duty as the throughput is increased by oxygen enrichment. However, in many cases the existing waste heat boiler is adequate for the expanded capacity. Heat transfer in the waste heat boiler is improved significantly during oxygen-enriched operation. One reason for this is that there is more radiant heat transfer due to the higher operating temperature. Also, a non-radiating molecule (nitrogen) is replaced in the combustion gases by a radiating molecule (water vapor, a product of combustion and the Claus reaction). Convective heat transfer is improved in the COPE Phase II process as the mass flow through the thermal section of the SRU is increased. All of these factors result in a considerable increase in the heat-exchange capability of the waste heat boiler when operating with oxygen enrichment.

6.4 Effects on Tail Gas Cleanup Unit and Incinerator

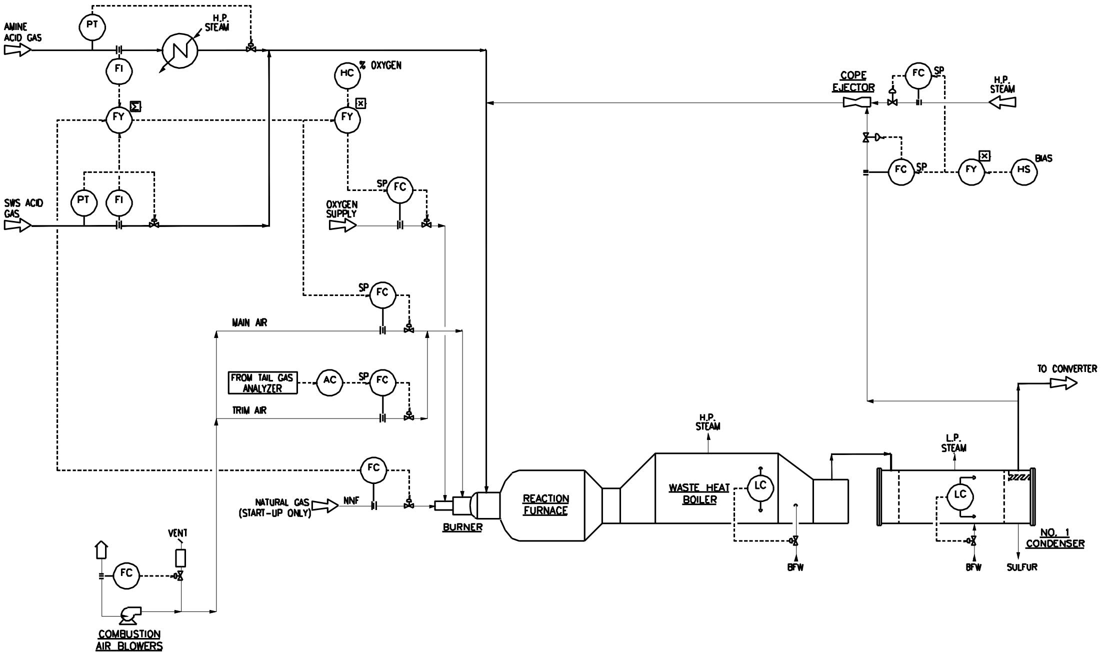
The SRU tail gas flow to the TGCU when operating the COPE Process is equal to or less than the flow with air-only operation. Operation of the hydrogenation portion of the TGCU is relatively unchanged. This is not true of the quench section, where the condensing load on the quench tower and cooler increases more or less in direct proportion to the increase in sulfur throughput. Usually this section will have to be debottlenecked if the increase in SRU capacity is more than a modest amount. After the quench section, where the water formed in the Claus reaction is condensed and removed, the flow of tail gas is greatly reduced compared to air-based operation. The amine absorber will have a lower feed gas flow and a higher partial pressure of H_2S, resulting in a lower quantity of H_2S in the absorber vent gas. Thus, there is less incineration fuel consumed, reducing operating cost as well as CO_2 emissions.

6.5 Simple Process Control

The key process control feature is that the total flow of all feed components is fed to one burner location. There are no manifolds or split flows of the feed stream components - this includes the acid gases (amine and sour water), combustion air (if any), pure oxygen, fuel gas (when necessary) and recycle gas (when necessary). All SRU feed streams are fed to only one burner that generates only one flame. Furthermore, the air/oxygen control scheme is independent and decoupled from the flame moderation recycle stream (Refer to Figure 6).

For retrofit applications, the simple and understandable control scheme means the operating and maintenance requirements are similar to the familiar air-based SRU. This key feature facilitates an easy and safe transition to and from oxygen-enriched operation.

Figure 6. COPE Phase II – Process Control



The recycle is a simple, but powerful tool for independently controlling the furnace temperature to a desired setpoint. The recycle is utilized only as necessary for the required flame moderation and additional operating flexibility. During upset or abnormal operation, the availability of the on-line recycle can be beneficial for maintaining a high on-stream factor by protecting the reaction furnace and waste heat boiler from temperature excursions. The mechanical features of the ejector and the associated steam jacketed piping system allow for on/off or continuous operation on demand.

The key feature is the simplicity of the process scheme, the associated control loops and thus, the ability for operating personnel to ensure a safe, reliable and optimized operation.

6.6 Safe start-ups and shutdowns

Start-ups and shutdowns of SRUs, whether scheduled or unscheduled, often present the most hazard to both personnel and equipment. Fuel gas firing the main burner is frequently the most difficult step due to concerns with high flame temperature and turndown operation that may result in oxygen-breakthrough or soot formation due to metering difficulties and/or burner limitations. Traditionally nitrogen or steam is used for the fuel gas flame temperature moderation. The steam driven ejector stream has proven to provide several benefits for start-ups and shutdowns that include:

- The recycle stream is indigenous to the process that includes permanent process piping, pressure and flow measurement and control valves. This minimizes the risk associated with introducing a moderating stream, such as steam or nitrogen, which is used on an irregular basis.
- High volumes of recycle gas can be utilized thus allowing the main burner to operate closer to design conditions. This ensures better mixing in the burner and thus reduces the risk of oxygen breakthrough or soot formation often associated with turndown fuel gas fired operation.
- The mechanical features of the ejector and the associated steam jacketed piping system allow for on/off or continuous operation on demand. This would include full availability for fuel gas fired temperature moderation for unscheduled shutdowns.

7. COPE PROCESS INVESTMENT COSTS

The obvious economic advantage of the COPE Process is that it is much less expensive to modify a portion of an existing SRU than to install a new SRU in order to obtain the necessary increase in acid gas processing capacity. In this section we present some approximate costs to modify a 100 MTPD SRU with COPE oxygen-enrichment technology to give capacity increases of 50% and 100%, respectively. Also, the estimated cost of a new SRU incorporating the COPE Phase II Process is shown.

7.1 50% Capacity Increase

To increase the capacity from 100 MTPD to 150 MTPD in a typical refinery SRU, the COPE Phase I Process would be employed. A new burner, new oxygen piping and controls, and probably larger acid gas piping and controls would be required. Some debottlenecking of the

TGCU quench system (if applicable) would also be required. Including engineering and license fees, the installed cost for a revamp of this scope would be approximately $ 2.5 – 4.0 MM U.S. This compares to the approximate installed cost of a new 50 MTPD SRU and TGCU of about $ 30 MM U.S. (Gulf Coast Basis)

7.2 100% Capacity Increase

Using the COPE Phase II Process, the capacity of a 100 MTPD can be increased to 200 MTPD or more. Because recycle is required and sometimes the WHB or No.1 Sulfur Condenser must be replaced, the cost can be significantly more than for a COPE Phase I revamp. The use of an ejector instead of a blower to provide the necessary recycle will help to reduce the investment cost for this case. The installed cost for a COPE Phase II revamp, including engineering and license fees, would be in the range of $ 4.5 – 6.5 MM U.S. A new 100 MTPD SRU with TGCU would be expected to cost about $ 44 MM U.S.

7.3 New SRU with COPE Phase II

There are some savings to be achieved by installing a new SRU with oxygen enrichment, especially if the maximum required capacity will only be needed for a small fraction of the time. A new SRU and TGCU with an air-based capacity of 100 MTPD would have an installed cost of about $44 MM U.S. A 50 MTPD (air-only) SRU and TGCU to operate when needed on high-level oxygen enrichment at a capacity of 100 MTPD could be installed for about 75% of the cost of the larger unit.

7.4 New Redundant SRUs with COPE Phase II

The need for redundant SRU capacity is seen more frequently as refiners seek flexibility and to eliminate reductions in feed rates to their refining units. One way to achieve this redundancy is to build two SRUs that incorporate the COPE Phase II Process. Normally, both units would operate in the air-only mode at 50 MTPD. When one of the units needs to be shut down for maintenance, the second unit can switch to oxygen enrichment and operate at 100 MTPD. So, total redundancy can be achieved for about 150% of the cost of one 100 MTPD unit, compared to 200% if two full-sized 100 MTPD units were installed.

8. IMPLEMENTATION

Air Products works closely with a company to help evaluate the technical and economic merits of oxygen enrichment of the SRU versus other capacity increase options. Once oxygen enrichment has been chosen as the preferred solution, Air Products and GAA can assist, on a case-specific basis, with several aspects of the project for the timely installation and start-up of the oxygen-based solution:

- Calculating the expected oxygen requirement, using process simulation software and incorporating heat transfer and other limitations.
- Determining the best means of oxygen supply.
- Designing, procuring and installing the appropriate equipment for the applicable oxygen enrichment technology, along with the oxygen storage and supply system.

This includes design and fabrication of a flow control skid with the necessary interlocks for reliable operation and safe start-up and shut-down.

- Consulting on oxygen material compatibility and cleaning procedures for piping within the refinery.
- Collaborating on Hazops and operator safety training for oxygen-based operations prior to commissioning of oxygen enrichment.
- Assisting with the start-up of the oxygen enrichment technology by trained engineers until the system has reached the desired operating rates.
- Ongoing technical support and equipment maintenance.

9. OXYGEN SUPPLY ALTERNATIVES

Oxygen for SRU oxygen enrichment can either be delivered to the refinery or generated on-site. The common mode of supply for delivered oxygen is via on-road liquid oxygen tankers from a central manufacturing facility. The oxygen is stored as liquid at the refinery in an insulated tank and vaporized at the time of use. Oxygen can also be generated on-site using cryogenic or adsorption technologies. At locations in the vicinity of an oxygen pipeline, supply via pipeline could be the most cost-effective and flexible source of oxygen. Evaluating the optimal mode of supply requires the review of a host of factors:

- Size of the oxygen requirement (average and peak demand).
- Expected use pattern: is the demand continuous or seasonal or erratic?
- Need for co-product nitrogen for inerting, blanketing, etc., in the refinery.
- Presence of other oxygen-consuming applications in the vicinity
- Power availability and cost.
- Proximity of delivered oxygen source.

In general, relatively small oxygen requirements or non-steady use patterns are best served by delivered oxygen while large, relatively steady requirements are best suited for on-site oxygen production. Air Products works closely with a company considering SRU enrichment to jointly determine the best mode of oxygen supply.

10. CONCLUSION

With its versatility and proven track record, oxygen enrichment has established itself as one of the leading technologies for achieving SRU capacity increases and redundancy requirements. It has helped operators in petroleum refining, natural-gas processing, and coal gasification meet the challenging mandates for clean air and clean fuels while conserving capital for other pressing investments.

The appeal of oxygen enrichment to debottleneck existing facilities is increasing as steeply rising construction costs and a tight labor market for engineers and skilled labor give planners pause, despite strong refining margins, as they consider building new facilities to meet increasing demand. Thus the array of oxygen enrichment technologies offered by GAA and Air Products through their combined know-how in sulfur plant design, equipment, operations, and oxygen manufacture, delivery and safety is particularly relevant for companies striving to environmentally and profitably meet the world’s growing energy needs.