Cost Effective Options to Expand SRU Capacity Using Oxygen

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Expansion demand in sulfur recovery processing capacity for refineries and gas plants worldwide is on the rise due to the expansion activities of overall plant capacity; the need for processing more sour crudes; and the tightening of sulfur emissions. WorleyParsons/BOC's proprietary SURE Oxygen Enrichment Technology provides cost effective solutions to this demand.

WorleyParsons/BOC's SURE Oxygen Enrichment Technology is a proven technology being employed worldwide. Various configurations and levels of oxygen enrichment are used in these licensed units depending on existing sulfur plant configurations, sulfur processing capacity expansion requirements, plot space available and concentration levels of hydrogen sulfide in the acid gas feeds. Significant operating and capital cost savings are realized in employing SURE Technology in these licensed units which consist of a number of revamped units and some new units.

In general, commercially available technologies offer three levels of oxygen enrichment: low-level, medium-level, and high-level providing additional capacity of about 25%, 75% and 150% respectively.

All of the existing major equipment can be reused for low-level oxygen enrichment. For medium-level oxygen enrichment a specially designed burner such as WorleyParsons/BOC's SURE direct oxygen injection burner is needed. High-level oxygen enrichment requires the implementation of technology such as WorleyParsons/BOC's Double Combustion SURE process. The process involves the addition of a new reaction furnace burner, reaction furnace and waste heat boiler upstream of the existing equipment. When multiple sulfur trains are involved either a common set of new equipment is shared by the various trains or each sulfur train will have its own set of new equipment. The selection of different oxygen enrichment configurations depends on the overall sulfur plant capacity requirement, desired operating scenario, existing equipment conditions, plot space available and existing facility layout. Details of selecting the optimum oxygen enrichment configuration are discussed in this paper.

With the sulfur content of crude oil and natural gas on the increase and with the ever-tightening sulfur content in fuels, the refiners and gas processors will require additional sulfur recovery capacity. At the same time, environmental regulatory agencies of many countries continue to promulgate more stringent standards for sulfur emissions from oil, gas and chemical processing facilities. It is necessary to develop and implement reliable and cost-effective technologies to cope with the changing requirements. In response to this trend, several new technologies are now emerging to comply with the most stringent regulations. These advances are not only in the process technology but also in the manner in which the traditional modified Claus process is viewed and operated.
Abstract

Typical sulfur recovery efficiencies for Claus plants are 90% to 96% for a two-stage plant and 95% to 98% for a three-stage plant. Most countries require a sulfur recovery efficiency in the range of 98.0% to >99.9%. Therefore, the sulfur constituents in the Claus tail-gas must be reduced further.

The following key parameters affect the selection of the tail-gas cleanup process:

1. Required sulfur recovery efficiency established by the environmental agency for different countries (e.g., the EPA or EU).
2. Feed gas composition, including H₂S content, hydrocarbons and other contaminants
3. Existing equipment and process configuration/modifications
4. Concentration of sulfur species in the stack gas
5. Ease of operation
6. Remote location
7. Sulfur product quality
8. Minimum unit modification for existing units
9. Costs (capital and operating)

Depending on the process route selected, an overall sulfur recovery efficiency of 98.0% to >99.9% is achievable. The latter recovery corresponds to less than 250 ppmv of SO₂ in the offgas going to the thermal oxidizer before the offgas is vented to the atmosphere.

In United States, oil and gas refineries are required to reduce the emissions of sulfur levels to achieve 99.9% or higher sulfur recovery. The sulfur recovery requirements in Canada increase from 98.5% for plants with a capacity of 50 tpd up to 99% for plants with a capacity of 2,000 tpd. In South America, the sulfur recovery requirements vary from 99.0% to 99.9%, depending on where the plant is located.

The European countries are required to reduce the maximum levels of sulfur in diesel and gasoline by environmental regulation agencies. However, the overall sulfur recovery in most European countries is at least 98.5%. Germany requires sulfur recoveries of 99.5% for plants with a high capacity and 99.8% for plants with lower capacity.

This paper presents ways to increase sulfur recovery, the capacity and the key parameters to improve the existing plants, as well as the design criteria for the new
Abstract

plants to achieve the emission requirements established by environmental regulatory agencies.

The major impacts of the new regulations on the sulfur recovery units worldwide are not more than a 15% to 30% capacity increase, and that could be corrected by the minimum modifications in sulfur plants. Oxygen enrichment seems to be the most cost-effective process to increase the capacity in existing sulfur plants.
Oxygen enrichment technologies in Claus sulfur recovery plants have gradually gained worldwide acceptance as a cost-effective method to expand SRU capacity. This paper is written with the intention of introducing the different options of these superb technologies and how to select the optimum configuration to suit the requirement of various facilities.

In general, commercially available technologies offer the following three levels of oxygen enrichment, and these also represent the three incremental steps for capacity expansion, equipment modifications and capital investments.

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

- **Medium-level oxygen enrichment**
  
  Oxygen is introduced into the combustion air to attain an oxygen concentration between 28% and 45%. An additional capacity of up to 75% of the original design capacity is achievable via a specially designed burner such as WorleyParsons/BOC's SURE direct oxygen injection burner.

- **High-level oxygen enrichment**
  
  Oxygen is introduced into the combustion air to attain an oxygen concentration between 45% and 100%. An additional capacity of up to 150% of the original design capacity is achievable. A number of different technologies are commercially available such as WorleyParsons/BOC's Double Combustion SURE process. The SURE process can be configured in various ways to fit the needs of different facilities depending on the overall sulfur plant capacity requirement, desired operating scenario, existing equipment conditions, plot space available and existing facility layout.

WorleyParsons/BOC's unique Double Combustion design offers distinct advantages for SURE process in cost, schedule, unit downtime, staged investment, reliability and safety as compared to other competing processes. State-of-the-art combustion simulation, pilot plant testing and actual operating experience ensure cost-effective and reliable SURE sulfur plant designs. The Double Combustion design does not require partial shutdown of the unit when oxygen is not in use. Furthermore, simple burner design and absence of a recycle gas blower lower the cost and improve the reliability and safety of the SURE design. When multiple sulfur trains are involved, installing a common set of new equipment shared by the various trains to achieve the required capacity can further
reduce capital investment. The existing furnace and Waste Heat Boiler (WHB) can be used for medium-level oxygen enrichment. Most of the onsite installation can be performed while the sulfur plant is operating and the tie-in work can be accomplished within a routine maintenance shutdown when the Double Combustion process is installed for high-level oxygen enrichment. Therefore, short downtime and schedule, reduced up-front investment, simple operation, improved reliability and safety make the WorleyParsons/BOC's SURE design an extremely attractive route to implement sulfur plant oxygen enrichment for SRU capacity expansion.

When crude oil is processed in refineries, sulfur contained in the oil is mainly recovered as H₂S, which is converted to sulfur in the refinery Claus plant. Part of the sulfur in the crude oil accumulates in the refinery residues.

Combustion of refinery residues, as well as incineration of Claus tail gases, results in off-gases containing SO₂. The environmental regulations in many countries require that most of the SO₂ is removed from these flue gas flows. In response to this trend, several new technologies are now emerging to comply with the most stringent regulations.

Whether the initiative arose from government inducement, public pressure, or internally from corporate philosophy, there has been a considerable increase in demand from industries for what are regarded as the key elements for achieving higher sulfur recovery efficiencies. These are:

1. Process knowledge
2. Existing process evaluation
3. Process modifications/optimization/converting to a suitable process in order to meet the new emission requirements for any unit involved with the emission requirements
4. Selection of a new technology for the new plant
5. Evaluation of the existing process control/possibilities of additional new controls
6. Process monitoring
7. Capital and operating costs

To achieve the higher recovery expected of a modern sulfur recovery unit, advances in to modified Claus sulfur recovery process itself are being implemented.
Section 2 | Evaluation of Key Elements for High Sulfur Recovery

The major impacts on the sulfur recovery units worldwide are not more than 15% to 30% capacity increases. To achieve the higher sulfur recovery in existing plants (with the possibility of additional changes), the actual performance test of the unit should be evaluated to determine how much improvement is required. The following key elements for higher sulfur recovery should be evaluated in a step-by-step process to maintain the capital and operating costs within an acceptable range.

2.1 Process Knowledge

The education of operators has taken a major step forward with the introduction in annual training and seminars on the subject of optimizing sulfur plants. These meetings not only deal intensively with the theoretical and practical aspects of sulfur plant operations but also provide opportunities for operators from diverse backgrounds to discuss and sometimes solve common problems.

The process knowledge could be gained from the experience of analyzing data obtained during detailed engineering evaluations of an operating plant. Most such tests are conducted on plants that are experiencing operational problems or have problems with low sulfur recoveries. Engineers and operators who have a hands-on understanding of the process are invaluable in conducting such troubleshooting activities. Based on the analysis of numerous detailed sulfur plant tests, it has been reported that the potential causes of recovery efficiency losses can be divided into the following categories:

- Poor reaction stoichiometry
- Catalyst deactivation
- Operating the first converter when it is too cold
- Operating the second and third converters when they are too hot
- Bypassing gases around the conversion stages
- High final condenser temperature
- Liquid sulfur entrainment

2.2 Existing Process Evaluation

The thermodynamic limitations of the Claus equilibrium reaction do not allow the attainment of sulfur recovery efficiencies greater than 90% to 96% for a two-stage reactor plant and 95% to 98% for a three-stage reactor plant. In most existing
Evaluation of Key Elements for High Sulfur Recovery

plants, the actual sulfur recovery efficiency is unknown because the feed compositions to the sulfur recovery unit could vary as the result of the upset upstream units or the variation of the summer and winter feed compositions. However, if the existing equipment, piping, catalysts and chemicals are not well maintained, the actual sulfur recovery efficiency will not be the same as had been originally designed. The test itself consists of collecting all operational data and stream compositions between all vessels in the process where a change in chemical composition has occurred. For the average sulfur plant, this process requires taking samples from eight process streams. An analysis of process streams of upstream and downstream units (such as amine, sour water and tail-gas cleanup units) often helps to identify process problems in the sulfur plant. Operational changes are accepted because they are usually simple and easy to implement without affecting operating costs. Indeed, the implementation of such changes has resulted in significant improvements in the sulfur recovery efficiencies of many plants. However, because modifications to process equipment could be expensive, the benefits from these modifications should be considered carefully. After the improved actual sulfur recovery efficiency takes place, a further evaluation could proceed.

2.3 Process Modifications/Optimizations

The acid gas composition leaving the acid gas removal system has an impact on sulfur recovery efficiency. To achieve the higher recovery expected of a modern sulfur recovery unit, advances are being implemented in the modified Claus sulfur recovery process itself. These advances are taking place in process technology as the result of evaluating the following key parameters:

- Corrections (i.e., those listed previously as deficiencies in the process design basis)
- Optimization of the feed to the Claus unit by improving the upstream units (such as gas treating to reduce impurities)
- Providing an additional process downstream of the Claus unit (such as tail-gas unit)
- Switching from air to oxygen in order to destroy more impurities and increase the capacity/recovery
- Providing an acid gas and air preheater upstream of the reaction furnace
- Changing the Claus catalyst or combining it with a high-performance catalyst such as hydrolysis catalyst (with a ratio of 30% to 100%) and an oxidation and reduction catalyst in order to increase the sulfur recovery
Section 2  Evaluation of Key Elements for High Sulfur Recovery

- Converting the modified Claus process to WorleyParsons Beaven’s Sulfur Removal BSR Hi-Activity process
- Converting any SuperClaus, cold bed adsorption (CBA), Sub-dewpoint process by Delta Engineering (MCRC), or Sulfreen process to the latest technology WorleyParsons PROClaus process
- Adding a new reactor with an additional heater and condenser
- Optimizing the Sulfur Recovery Unit (SRU) converter/condenser temperatures
- Converting the amine solvent in the gas treating unit and any tail-gas unit from a generic solvent to proprietary solvent to increase the volumetric rate and improve the emissions
- Optimizing the BSR reactor’s temperature and hydrogen consumption
- Optimizing the amine flow rate and temperature for amine absorbers
- Minimizing the steam consumption and stabilization of the acid gas’s quality for amine regenerators
- Minimizing the steam consumption stabilization of the acid gas’s quality for sour water strippers

2.4 Selection of New Technology to Increase Sulfur Recovery

Typical sulfur recovery efficiencies for Claus plants are 90% to 96% for a two-stage plant and 95% to 98% for a three-stage plant. Most countries require sulfur recovery efficiencies in the range of 98.5% to > 99.9%. Tail-gas processes include \( \text{H}_2\text{S} \) absorption, recycling technologies, catalytic oxidation of \( \text{H}_2\text{S} \) into elemental sulfur and a tail-gas incinerator process. Therefore, the sulfur constituents in the Claus tail-gas must be reduced further.

The increasing standards of efficiency required by the pressure from environmental protection has led to the development of a large number of Claus tail-gas treatment units, based on different concepts, in order to remove the last remaining sulfur species. The choice of the tail-gas treatment processes depends on several criteria, including the sulfur recovery efficiency required, acid gas composition, configuration and capacity of the existing Claus unit. Table 2-1 presents the typical amounts of sulfur-containing compounds to be treated in the Claus tail gas.
When building a new plant, the feasibility study should be based on all the selection criteria, including the required sulfur recovery efficiency, minimum capital cost and minimum unit modification.

### 2.5 Evaluation of Existing Process Control/Possibilities of Additional New Controls

To improve the higher sulfur recovery efficiency, the existing process control should be evaluated first; additional new controls, along with the new equipment, might then be required. Because of the shortcomings of feed forward control, it is widely accepted that a tail-gas analyzer in closed loop control contributes from 3% to 5% to the overall recovery efficiency on the conventional Claus SRU. By comparison, a third conversion stage only contributes an additional 2% recovery at a capital cost of 15%, and an enhanced Claus process contributes an additional 2% to 2.5% at a capital cost of 15% to 25%. Thus, the tail-gas analyzer is certainly worthy of attention and merit in the overall scheme to attain high recovery efficiencies. The achievement and maintenance of high sulfur recovery efficiencies in the existing plants is a long-term commitment from all who are involved in operating the plant. The key parameters for the process control in the existing plants follow:

- Provide good process design
- Provide well-maintained equipment
- Provide well-trained operators
- Maintain the correct operating temperatures throughout the unit
- Maintain the correct feed ratio (acid gas, air, oxygen) to the reaction furnace/reactors for the main and side streams
Section 2  Evaluation of Key Elements for High Sulfur Recovery

- Provide appropriate instrumentation, especially analyzers
- Use active catalyst
- Compare actual sulfur recovery versus calculated sulfur recovery
- Correct any of above deficiencies to improve the sulfur recovery efficiency
- The additional new control systems should be implemented in conjunction with the existing control systems to prevent any deficiencies.

2.6 Process Monitoring

Process monitoring is the final phase of the optimization process. Advances in process monitoring have given the operators and the regulatory authorities a better daily account of plant performance. Monitoring is essential for implementing good operating practices that emphasize preventive measures rather than corrective actions to keep the plant running at optimal efficiency.

The expected long-term efficiency is the goal for each plant. The thermodynamic capability of the process determines the allowances for feed composition, process configuration, types of reheaters used, operation above the sulfur dewpoint, sulfur fog/mist losses, fluctuations in the air-to-acid gas ratio and degradation of catalyst activity and plant equipment, plus an allowance for the effects of transitory upsets in upstream processes and equipment failures that occur from time to time. It is further assumed that the plant is optimized and a good operational practice has been established to maintain the optimal performance. Because the expected efficiency is not a thermodynamic limit, the efficiency can be exceeded at any time when circumstances result in the actual efficiency losses due to the factor being less than assessed in determining the expected efficiency.

2.7 Capital and Operating Costs

One of the main selection criteria for the chosen technology is to achieve minimum capital and operating costs. The easiest option is to select the technology with the minimum modifications and minimum changes to the operation procedures and, at the same time, to achieve the required sulfur recovery efficiency. Sometimes, revamping the SRU units can take place during general turnarounds to eliminate an additional plant shutdown. The existing plot plan should be evaluated to eliminate the need for designing long piping that contains the hot fluids and the need for new structures; and it should still be able to use the existing equipment as much as possible.
Expansion demand in sulfur recovery processing capacity for refineries and gas plants worldwide is on the rise due to the expansion activities of overall plant capacity, the need for processing more sour crudes and the tightening of sulfur emissions. WorleyParsons/BOC’s proprietary “SURE” Oxygen Enrichment Technology provides “cost effective” solutions to this demand.

In recent years, the drive towards clean air and clean fuels created great demand for additional hydrodesulfurization and sulfur recovery capacities in refineries and gas plants worldwide. For many operators, the most economical route to acquire incremental SRU capacities is to apply oxygen enrichment in their existing SRUs in lieu of building new SRUs. This technology application enables operators to realize significant cost savings in both capital investment and operating costs depending on the desired capacity expansion.

In addition, “SURE” Technology also enhances performance of Claus sulfur recovery units in processing dilute acid gas feeds with undesired high concentration of contaminants such as heavy hydrocarbons and ammonia. These contaminants often cause unscheduled shutdowns and poor plant performance. The key to improve contaminant destruction is the achievement of high-flame temperature, which would otherwise be unattainable in air-burning Claus units. The high-flame temperature, achieved via burning oxygen, ensures complete destruction of heavy hydrocarbons and ammonia present in the dilute acid gases; and relieves the Claus unit from operating problems caused by carbon lay down or deposition of ammonium salts as a result of incomplete destruction of contaminants in the acid gases.

### 3.1 Low-level Oxygen Enrichment (< 28% O2)

For a desired capacity increase of up to 20% to 25% of the original design sulfur processing capacity, low-level oxygen enrichment technology is adequate. Low-level oxygen enrichment is accomplished by injecting pure oxygen or oxygen-rich air into the combustion air; i.e., oxygen is premixed with combustion air upstream of the burner. No equipment modification is required in the existing SRU, other than providing the tie-in point for oxygen injection in the combustion air line. An SRU capacity increase of approximately 20% to 25% is achievable with low-level oxygen enrichment. The capital cost investment is mainly in the installation of an oxygen supply system, which is usually an oxygen supply line added to the reaction furnace burner.

### 3.2 Medium-level Oxygen Enrichment (28% to 45% O2)

For a desired capacity increase of up to 75% of the original design sulfur processing capacity, medium-level oxygen enrichment technology is required. The
Section 3  Oxygen Enrichment Configurations

Combustion air piping in a conventional SRU is not suitable for handling oxygen-rich air above 28% oxygen. The burner designed for air-only operation might not withstand the higher combustion temperature. In any case, direct injection of oxygen through separate nozzles from combustion air is recommended; hence, special burners designed for direct oxygen injection should be installed.

The SURE burner is designed for efficient combustion in SRUs with oxygen enrichment. It can be used in either end-firing or tangential-firing designs. The excellent mixing characteristics of the SURE burner, coupled with the higher combustion temperature attained in oxygen enrichment operation, allow the existing reaction furnace to be used with only minor modifications to accommodate the new burner.

Oxygen enrichment considerably raises the reaction furnace temperature, which ensures complete destruction of undesired heavy hydrocarbons and ammonia, reduces formation of COS and CS₂ and shortens gas residence time requirements for contaminant destruction.

The capital cost investment is mainly in the installation of an oxygen supply system and a new oxygen-compatible burner.

3.3 High-level Oxygen Enrichment (> 45% O₂)

For a capacity increase of up to 150% of the original design capacity, high-level oxygen enrichment is applicable. The thermal section of the existing SRU must be modified and/or have new equipment added, depending on which oxygen enrichment technology is chosen.

1. The “SURE” Double Combustion process divides the combustion in two stages with intermediate cooling of the combustion product.

2. The Lurgi process employs a multi-staged burner, which reportedly maintains the furnace temperature low enough for up to about 60% oxygen enrichment (for a rich acid gas feed).

3. The COPE process from GAA/Air Products recycles cooled acid gas from the first sulfur condenser to the furnace using a recycle acid gas blower, similar in concept to the WorleyParsons/UOP Recycle Selectox process.
4.1 Inexpensive Incremental Sulfur Recovery Unit (SRU) Capacity

In recent years, the drive towards clean air and clean fuels created great demand for additional hydrosulfurization and sulfur recovery capacities in refineries and gas plants worldwide. For many operators, the most economical route to acquire incremental SRU capacities is to apply oxygen enrichment in their existing SRUs in lieu of building new SRUs. This technology application enables operators to realize significant cost savings in both capital investment and operating costs depending on the desired capacity expansion. For a desired capacity increase of up to 20% to 25% of the original design sulfur processing capacity, low-level oxygen enrichment technology is adequate. The capital cost investment is mainly in the installation of an oxygen supply system, which is usually an oxygen supply line added to the reaction furnace burner. For a desired capacity increase of up to 75% of the original design sulfur processing capacity medium-level oxygen enrichment technology is required. The capital cost investment is mainly in the installation of an oxygen supply system and a new oxygen compatible burner. For capacity increase of up to 150% of the original design capacity, high-level oxygen enrichment is applicable. The thermal section of the existing SRU must be modified and/or have new equipment added, depending on which oxygen enrichment technology is chosen. The investment cost associated with an oxygen enrichment revamp is only 10–15% of a new air-based SRU.

4.2 Smaller Equipment for New SRU

Applying oxygen enrichment to a new SRU can cut the flow rate through the SRU by half at the same sulfur recovery capacity as compared to an air-only unit; this results in approximately 35% savings in investment cost, which excludes the cost of an on-site oxygen generation unit.

4.3 Sparing Requirements

If spare sulfur recovery capacity is required by law to handle unexpected Claus unit shutdown, then at least two units must be present at the same site to apply oxygen enrichment. In this case, oxygen is only used on an intermittent basis; the operating cost associated with oxygen usage is much reduced.
5.1 Lean Acid Gas Feed

Lean (low H₂S content) acid gas feed often poses processing problems in an air-only Claus SRU in terms of unstable flame and inadequate contaminant destruction. Oxygen enrichment raises the reaction furnace temperature and provides for a more stable SRU operation in addition to increasing SRU's capacity.

Acid gas fired direct reheat has been extensively used in Claus units. Acid gas fired burners are usually operated far away from stoichiometry to minimize oxygen slippage. When the acid gas is lean in hydrogen sulfide, the burner is usually designed for firing nearer to stoichiometry to reduce the amount of acid gas. Consequently, only an acid gas with stable composition should be used to avoid oxygen slippage.

5.2 Acid Gas Bypass

The quantity of combustion air used in the Claus process is fixed at about one third of complete hydrogen sulfide combustion, as dictated by the requirement of the Claus reaction. The acid gas bypass scheme takes advantage of the fact that the furnace operates far away from complete combustion in the straight-through configuration. By bypassing part of the feed gas, the furnace will then operate nearer to complete combustion. Consequently, the flame temperature is increased. However, the amount of acid gas bypass is limited to two thirds of total feed because it is undesirable to run the furnace under oxidizing conditions and operating beyond complete combustion will lower the flame temperature anyway.

Acid gas bypass is the most economical scheme since neither additional equipment nor operating cost is involved. The downside of this scheme is the contaminants in the feed gas, if present, will not be destroyed in the high temperature furnace zone. The detrimental effects of the contaminants on the back-end of the Claus plant, e.g. catalyst deactivation and equipment/line plugging, may jeopardize the smooth and continuous operation of the sulfur plant.

5.3 Feed Preheat

Both the combustion air and the acid gas can be preheated in order to raise the flame temperature. Usually, the combustion air is the first choice since it is more benign than the acid gas. Furthermore, there are the all important pressure drop considerations. The upstream amine unit often limits the available acid gas pressure.

The extent of combustion air preheat is basically an economic decision, i.e. available heating medium and metallurgy. Stream at a suitable pressure level is
Section 5  Acid Gas Feed Quality Considerations

preferred over a fired heater due to ease of operation and lower investment cost. It is also desirable to use carbon steel rather than more exotic and expensive piping and equipment material.

The extent of acid gas preheat is further complicated by the possibility of thermal cracking of its constituents.

When applying preheat, it is important to ensure that the burner is properly designed in terms of both process performance and mechanical integrity.

5.4 Oxygen Enrichment

Oxygen enrichment raises the flame temperature by eliminating the diluents effect of nitrogen in air. An economical source of oxygen is the key in this case. A perfect example is the IGCC plant, where lean acid gas and inexpensive oxygen are both present. Equipment sizes of a sulfur plant and, therefore, investment cost are lower when oxygen enrichment is used.

5.5 Fuel Gas Supplement

Fuel gas can be added to raise the flame temperature. Of course, this is against conventional wisdom. Fuel gas, if not completely combusted, causes catalyst deactivation even plugging and off-color sulfur products. Even when it is completely combusted, the equipment sizes, investment and operating costs will be bigger and the overall sulfur recovery efficiency will be lower.

Fuel gas supplement has been applied successfully for operating the Claus unit at greater than ten to one turndown. In any case, when contemplating fuel gas supplement, investing in a high performance, high intensity and high cost burner is a must.

The relationship of adiabatic flame temperature versus SRU capacity increase at various oxygen enrichment levels for a typical rich amine acid gas feed with no ammonia, for example 90% H₂S. The two major material limitations usually encountered in SRU oxygen enrichment revamping implementation are: (1) piping material and burner for handling oxygen/oxygen enriched air, and (2) refractory of the existing reaction furnace in handling high oxygen flame temperature. The most likely equipment limitation in determining achievable capacity expansion via oxygen enrichment is the heat removal capacity of the existing WHB and the No. 1 sulfur condenser. The ultimate capacity increase for each individual case is dependent on acid gas compositions and existing equipment sizes.
The Claus process is undoubtedly the technology of choice for gases containing higher concentration of hydrogen sulfide and/or larger quantities of sulfur. Only when the hydrogen sulfide content drops below 30% and/or the amount of sulfur is less than about 10, 30 tons/day (TPD) would other processes become economical.
6.1 The Effects of Oxygen Use on Ammonia and Hydrocarbon Destruction

If not properly destroyed, hydrocarbons in the acid gas feed often cause carbon laydown on catalyst, generation of undesired high concentration of COS and CS$_2$. Also, ammonia in the acid gas feed often causes deposition of complex ammonia/sulfur salts in cooler parts of the plant. These undesired phenomena would either cause unscheduled plant shutdown or reduce sulfur recovery or shorten catalyst life. Oxygen enrichment raises the reaction furnace temperature which ensures complete destruction of heavy hydrocarbons and ammonia; reduces formation of COS and CS$_2$; and shortens gas residence time requirements for contaminants destruction.

In the case of lean acid gas feed contaminated with high levels of heavy hydrocarbons, oxygen enrichment offers inexpensive and simple solutions to circumvent this otherwise unsolvable problem that requires costly processing technology.

Quantitatively, based practical experience, the WorleyParsons/BOC burner has proved to be very effective in destroying ammonia and hydrocarbons in Claus plants. Outside of their application in Claus plants, oxy-fuel burners are widely used in the metals and minerals and in the chemical and refining industries to burn a wide range of fuels, including gases, liquids, and pulverized solids. One of their most attractive features is their ability to burn heavy residual hydrocarbons cleanly.

Two major effects in using oxygen or oxygen-enriched air in place of air for combustion are higher temperatures and higher flame speeds. The degree of change depends on the degree of oxygen enrichment, but in the case of pure oxygen, temperatures may increase by 1,000°C and flame velocities by 10 times in round numbers. The combination of these two effects is to produce a hotter, shorter, more intense flame much better suited to the rapid destruction of combustible materials.

The destruction of individual feed components in a Claus unit cannot be considered in isolation, since there is considerable molecular interaction. Both hydrogen sulfide and ammonia dissociate quite readily and the higher the temperature, the higher the level of dissociation. The result is that when oxygen is used, the hydrogen level in the reaction furnace increases greatly over that achieved in air-based systems. Most of this hydrogen will subsequently recombine with sulfur in the Waste Heat Boiler (WHB), including hydrogen produced from ammonia dissociation. The ammonia must effectively be burned; therefore, even if the mechanism of destruction is initially dissociation, in order to preserve the Claus Stoichiometry downstream of the WHB.
It is possible to speculate that the hydrogen remaining in the gas after the WHB will be higher if the level in the reaction furnace before the boiler is higher. This must be true if the quench rate in the boiler remains constant. The effect may be small however, and in the case of up rating with oxygen, where the WHB sees a higher load, a fall in quench rate may reduce it still further.

Heavy hydrocarbons such as BTX can be present in the feed to Claus units in certain cases; and their propensity for cracking thermally to produce carbon is well understood. Little, if any, published data on the effect of oxygen on BTX destruction in a Claus environment is currently available; however, it is known that oxygen is very efficient in burning these materials in other environments.

It is also possible to design the WorleyParsons/BOX Claus burner so that feed stream contaminants are preferentially destroyed; and making use of the much higher reaction rates which are available even in plants operating with only moderate enrichment levels. Qualitatively, therefore, oxygen should have a beneficial effect on the destruction of heavy hydrocarbon contaminants such as BTX.

Three general parameters may be said to control the destruction of feed stream contaminants in Claus units, temperature, mixing and residence time. Temperature may be the most important parameter; and mixing is an essential parameter to ensure that all the contaminant molecules reach a high enough temperature and promote reaction where appropriate. A study of the Claus system using a kinetic CFD model indicates that residence time is important, particularly to sulfur forming reactions, but while oxygen is present, the system is dominated by hydrogen combustion. In such a system, molecules like ammonia compete poorly for oxygen and the initial step in its destruction is likely to be dissociation. The higher temperatures generated with oxygen use clearly favor this; and since the ammonia is often contained in a stream separate from the main Claus feed stream, it is possible to maximize the benefit through the burner design.

The key parameter considered when applying the Claus process is to maintain a stable flame at the burner. However, if the feed gas contains contaminants, a much higher flame temperature will be required to destroy the undesirable compounds in the furnace so that they do not cause operational difficulties downstream.

### 6.2 Others (Cyanide, Mercaptans)

These contaminants can be destroyed in the Claus furnace based on the same considerations as given for aromatic hydrocarbons above. They are detrimental to
the wet oxidization and non-regenerative processes due to spent chemical disposal and odor problems.

It cannot be over emphasized that a well-designed burner and reaction furnace, which promotes good mixing of the reactants, is essential for complete destruction of undesirable feed contaminants.
Section 7 Relevant Factors in Considering Oxygen Enrichment

The following factors should be investigated when considering application of oxygen enrichment.

7.1 Relief of Tight Pressure Profile

As oxygen enrichment offers the option of using oxygen without the burden of nitrogen, this advantage can be taken to reduce pressure drop across a SRU in the event that additional Claus stage or tail gas treatment needs to be added to increase the sulfur recovery to meet more stringent emissions requirements.

This technology also offers a solution to plant design with inadequate acid gas feed pressure. Oxygen enrichment reduces the total result of gas flow through a SRU; and this reduces the total pressure drop requirement of the otherwise air-base Claus operation. Implementation of oxygen enrichment in this case eliminates the need of an undesirable acid gas blower.

7.2 Fast Track Schedule and Short Unit Downtime

As mentioned above, the “SURE” process re-uses existing equipment with only minor modifications. The new equipment could be installed on-site while the SRU is in operation. Only a short downtime is needed to tie-in the new equipment for high-level oxygen enrichment. Typically the revamp tie in work has been accomplished within one to two weeks, which is normally within the schedule of a routine plant maintenance shutdown.

7.3 Plot Area and Site Location Requirement

It is obvious that oxygen enrichment reduces the plot area required for SRU capacity expansion. For operating facilities limited by plot space, oxygen enrichment may be the only viable option for SRU capacity expansion.

A more frequent encountered problem is inability to install a new SRU unit that is close to the upstream amine regeneration unit due to existing plot space constraints. It is undesirable to locate the SRU too far from the amine regeneration unit because of the pressure drop and safety considerations. Most operators shun at the idea of an acid gas booster blower. Operating the amine regenerator at higher pressure is equally unpalatable due to amine degradation and corrosion.
Safety concerns on SRU oxygen enrichment are two-fold: (1) the introduction of oxygen to a new plant area; and (2) changes in design and equipment from a conventional air-based SRU.

There is no doubt that the presence of oxygen requires operators to exercise additional safety precautions; but operators and designers are gaining more experience and higher comfort level in handling oxygen in hydrocarbon rich area. The necessary materials, safeguards and operating procedures for handling oxygen are well defined and understood. Furthermore, the oxygen distribution system is designed with minimum inventory near combustibles.

Different commercially available oxygen enrichment technologies employ very different approaches to circumvent the furnace refractory temperature limitation when high-level (>45%) oxygen enrichment is used. WorleyParsons/BOC’s “SURE” Double Combustion design employs simple burner design and does not require an acid gas recycle blower during oxygen operation or partial shutdown and isolation when oxygen is not in use. These features ensure safe operation of a “SURE” SRU.

“SURE” SRUs have been proven to be as reliable as conventional air-based SRUs. As it does not involve operation of recycle gas blowers in contrast to other competing oxygen enrichment technologies, it has been proven to be comparatively more reliable.

Simplicity of the “SURE” burner and “SURE” Double Combustion design and the absence of a recycle acid gas blower ensure the reliability of the “SURE” process. The simpler piping for “SURE” design and the absence of a recycle acid gas blower reduce the possibility of accidental H₂S emission and rotating equipment failure. The “SURE” Double Combustion design does not require shutting down and isolating a recycle loop when oxygen enrichment is not being used; this further improves the safety of the “SURE” process compared to other processes. Changing the mode of operation between air-only and oxygen enrichment is simple and smooth for the “SURE” process which involves only the oxygen supply system. The SRU itself is always ready to receive oxygen.

Increasing capacity by oxygen enrichment almost always requires less investment. However, oxygen enrichment often incurs higher operating cost.
Oxygen costs could be reduced if:

A cheap source is close-by, e.g. IGCC plant or oxygen pipeline or byproduct nitrogen commands a good market value or oxygen is being used on an intermittent basis for occasional capacity excursions.

On the positive side, oxygen enrichment reduces the number of operating facilities and may reduce the number of operating and maintenance personnel, thereby, saving operating costs.

### 7.7 Oxygen Supply

Oxygen can be made available in a number of ways to suit the requirements of a particular application. In general, oxygen for use in Claus units may be supplied either as liquid for subsequent vaporization or as gas either from a dedicated plant or by pipeline from a nearby air separation unit. A wide range of plant supply options are now available at the small end (5 – 150 tpd) including non-cryogenic plants such as pressure swing adsorption (PSA) and vacuum swing adsorption (VSA). A range of smaller cryogenic plants are also now available such as the BOC Improved Cryogenic Oxygen (ICO) range; and these generally become competitive with non-cryogenic units at the 70 – 100 tpd level, depending on the demand pattern for the oxygen and any requirements for the associated nitrogen. Where the oxygen use on the Claus unit is intermittent, liquid may still provide the most economical solution, but any demand from 10 tpd upwards one should consider the use of PSA or VSA alternatives. The latter will not match liquid oxygen purity, which gives a product containing 90 – 95% oxygen by volume in general, but this is not an issue in Claus plants unless absolute maximum up-rating is required.

The cost of on-site cryogenic generated oxygen is in the range of U.S.$25 per ton to U.S.$35 per ton when the associated nitrogen by-product can be used elsewhere and not discarded.

The location of the oxygen supply in a refinery or gas installation must be considered carefully. The oxygen inventory in a liquid installation is sometimes a concern to Claus plant operators, although much experience now exists in safe siting of liquid oxygen systems in hydrocarbon environments. In either the liquid or plant supply case; the oxygen requirement can be piped some distance to the point of use if necessary, in which case the oxygen inventory in the vicinity of the Claus plant is effectively limited to that contained in the supply pipe-work.

Non-cryogenic plants are particularly attractive for use in hydrocarbon environments because their oxygen inventory is very low, this being confined to
Section 7

Relevant Factors in Considering Oxygen Enrichment

the outlet of the adsorber bed and the delivery pipe-work. In the PS Claus TM process from WorleyParsons, the PSA plant is located between the air blower and the burner/reaction furnace, acting in this case as a ‘nitrogen rejection unit,’ and this optimizes the plant design and benefits the scale achieved by using oxygen.

### 7.8 Initial Investment Cost

As mentioned above, there are considerable cost savings when SRU capacity expansion is accomplished by oxygen enrichment, rather than building new air-based SRUs. An operating company will save substantial initial investment cost even for new SRUs if oxygen is available or can be imported across the fence.

### 7.9 Operating Cost

The main drawback of SRU oxygen enrichment could be the operating cost associated with oxygen usage. The economics of oxygen enrichment depends very much on the cost of oxygen, which varies significantly from site-to-site depending on oxygen availability and utility costs. Obviously, excess “free” oxygen on-site will give the best economics, although few operators enjoy the luxury. Pipeline and truck-delivered oxygen cost about U.S.$35 per ton and U.S.$80 per ton, respectively (U.S. Gulf Coast Basis). The economics of on-site oxygen generation will be very attractive if the co-produced nitrogen commands a premium or if cogen-power is available.

New Claus plants associated with integrated gasification combines cycle (IGCC) projects require only a small (5 to 10%) increase in the total project oxygen requirement. This inexpensive incremental oxygen makes oxygen-based Claus units a logical choice for IGCC projects. Furthermore, oxygen enrichment achieves better combustion performance for the lean acid gas feed usually encountered in IGCC projects.

### 7.10 Reduced Costs

Due to the staged incremental investment, limited up-front investment and complete re-use of existing equipment, the total project cost to the client based on the “SURE” process is lower than other competing technologies. The “SURE” process does not use a recycle acid gas blower, and this reduces the operating and maintenance costs associated with the blower. The “SURE” burner design is also simpler than others and is directly supplied by BOC, making the “SURE” process even more cost effective.

The table below compares the typical equipment changes required for upgrading an air-only SRU to high-level oxygen enrichment:
Table 7-1, Equipment Comparison for Various Technologies

<table>
<thead>
<tr>
<th>Existing Equipment</th>
<th>SURE</th>
<th>Lurgi</th>
<th>COPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burner</td>
<td>Remove</td>
<td>Remove</td>
<td>Remove</td>
</tr>
<tr>
<td>Furnace</td>
<td>No Change</td>
<td>Remove</td>
<td>Remove</td>
</tr>
<tr>
<td>WHB</td>
<td>No Change</td>
<td>Remove</td>
<td>Remove</td>
</tr>
<tr>
<td>No. 1 Sulfur condenser</td>
<td>No change</td>
<td>No Change</td>
<td>Remove</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>New Equipment</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Burner</td>
<td>New</td>
<td>New</td>
<td>New</td>
</tr>
<tr>
<td>Furnace</td>
<td>New</td>
<td>New</td>
<td>New</td>
</tr>
<tr>
<td>WHB</td>
<td>New</td>
<td>New</td>
<td>New</td>
</tr>
<tr>
<td>No. 1 Sulfur condenser</td>
<td>Not Required</td>
<td>Not Required</td>
<td>New</td>
</tr>
<tr>
<td>Recycle Acid gas blower</td>
<td>Not Required</td>
<td>Not Required</td>
<td>New</td>
</tr>
</tbody>
</table>

As mentioned previously, equipment limitation due to inadequate heat removal capacity of the existing WHB and No. 1 sulfur condenser normally restricts the revamp capacity before the refractory material limitation does. This means that even if special staged burner designs can circumvent the refractory temperature limit, the heat removal equipment (WHB and/or No. 1 sulfur condenser) must be replaced, resulting in a major revamp.

It is worthwhile to note that the new furnace and WHB added in “SURE” process are significantly small in size/duty than the other two competing process schemes.

The following tables compare the cost for building a new sulfur plant with oxygen enrichment versus new sulfur plant air based.

These tables are prepared as the results of the feasibility study for the actual project, having high the H₂S concentration and NH₃ from sour water stripper (typical refinery gas compositions) in order to select the technology to build a new sulfur plant/tail gas unit air based versus oxygen based.
### Table 7-2, Claus Sulfur Recovery Unit

<table>
<thead>
<tr>
<th>Item</th>
<th>OXYGEN-BASED SRU 72 MTPD</th>
<th>AIR-BASED SRU 72 MTPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost, $US</td>
<td>7,100,000</td>
<td>13,300,000</td>
</tr>
<tr>
<td>Operating Cost: $US/yr</td>
<td>(882,000)</td>
<td>(535,000)</td>
</tr>
<tr>
<td>Utilities</td>
<td>3,000</td>
<td>6,000</td>
</tr>
<tr>
<td>Catalysts &amp; Chemicals</td>
<td>321,000</td>
<td>507,000</td>
</tr>
<tr>
<td>Operations &amp; Maintenance</td>
<td>(558,000)</td>
<td>(22,000)</td>
</tr>
<tr>
<td>Total Operating Costs $US/yr</td>
<td>(558,000)</td>
<td>(22,000)</td>
</tr>
</tbody>
</table>

**Notes:**
1. Costs are based on 2-stage one train sulfur recovery unit.
2. Annual operating costs based on 8000 hr/year.
3. Value of sulfur product is not included.
4. The capital cost does not include any license fee, but includes the interconnecting facilities & utilities, start-up services, construction management and engineering.

### Table 7-3, Tail Gas Treating Unit

<table>
<thead>
<tr>
<th>Item</th>
<th>OXYGEN-BASED SRU 130 MTPD</th>
<th>AIR-BASED SRU 130 MTPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost, $US</td>
<td>6,700,000</td>
<td>9,900,000</td>
</tr>
<tr>
<td>Operating Cost: $US/yr</td>
<td>386,000</td>
<td>602,000</td>
</tr>
<tr>
<td>Utilities</td>
<td>33,000</td>
<td>61,000</td>
</tr>
<tr>
<td>Catalysts &amp; Chemicals</td>
<td>309,000</td>
<td>405,000</td>
</tr>
<tr>
<td>Operations &amp; Maintenance</td>
<td>728,000</td>
<td>1,068,000</td>
</tr>
<tr>
<td>Total Operating Costs $US/yr</td>
<td>728,000</td>
<td>1,068,000</td>
</tr>
</tbody>
</table>

**Notes:**
1. Costs are based on one common tail gas unit.
2. Annual operating costs based on 8000 hr/year.
3. The capital cost does not include any license fee, but includes the interconnecting facilities & utilities, start-up services, construction management and engineering.

Table 7-4, Claus Sulfur Recovery Unit  
(Utility Breakdown)

<table>
<thead>
<tr>
<th>Item, $US/yr</th>
<th>OXYGEN- BASED SRU 72 MTPD</th>
<th>AIR- BASED SRU 72 MTPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP Steam</td>
<td>71920</td>
<td>156,136</td>
</tr>
<tr>
<td>MP Steam</td>
<td>(1,172,718)</td>
<td>(1,124,496)</td>
</tr>
<tr>
<td>LP Steam</td>
<td>(148,120)</td>
<td>(201,480)</td>
</tr>
<tr>
<td>BFW</td>
<td>323,340</td>
<td>326,640</td>
</tr>
<tr>
<td>HP Condensate</td>
<td>(12,400)</td>
<td>(26,920)</td>
</tr>
<tr>
<td>LP condensate</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>54,458</td>
<td>208,535</td>
</tr>
<tr>
<td>Electricity</td>
<td>1,600</td>
<td>126,800</td>
</tr>
<tr>
<td>Total Utility, $US/yr</td>
<td>(882,000)</td>
<td>(535,000)</td>
</tr>
</tbody>
</table>

Table 7-5, Tail Gas Treating Unit  
(Utility Breakdown)

<table>
<thead>
<tr>
<th>Item</th>
<th>OXYGEN- BASED SRU 130 MTPD</th>
<th>AIR- BASED SRU 130 MTPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP Steam</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>MP Steam</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>LP Steam</td>
<td>248,952</td>
<td>325,956</td>
</tr>
<tr>
<td>BFW</td>
<td>35,076</td>
<td>73,152</td>
</tr>
<tr>
<td>HP Condensate</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>LP Condensate</td>
<td>(81,020)</td>
<td>(126,600)</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>96,298</td>
<td>225,803</td>
</tr>
<tr>
<td>Electricity</td>
<td>86,400</td>
<td>104,000</td>
</tr>
<tr>
<td>Total Utility, $US/yr</td>
<td>386,000</td>
<td>602,000</td>
</tr>
</tbody>
</table>
Salient Design Features of SURE Burner

Oxygen enrichment has been applied to Claus unit revamps because the economics are clearly favorable if an increase in sulfur production is required. New plants have been designed to use oxygen enrichment when a refiner sees a need for a “peak shaving” operation or the need to increase the capacity of a unit on a short-term basis to allow for the maintenance of a second unit. New Claus plants using oxygen without air are normally associated with gasification projects or gas plants, both of which can have a lean relatively constant composition feed.

The minimum modifications required for a typical revamp are listed below:

- New burner
- Revised control system
- Revised shutdown systems
- Oxygen storage (if not available)
- Oxygen transfer line

Normally the existing reaction furnace and Waste Heat Boiler (WHB) could be used for the oxygen-enriched operation if the design temperature of their refractory is suitable for the oxygen enrichment. For some of the revamps discussed here, a new combustion chamber was installed for each plant. There were various reasons for this, namely corrosion of the old combustion chamber, replacement of the WHB, and a requirement for ammonia burning, but the main determining factor is the time allowed for the work on site. The short time allowed for the mechanical implementation of a revamp (typically 3 weeks) means that operations such as re-bricking a combustion chamber on site are too time-consuming; therefore, provision of a new combustion chamber with its refractory is favored. In the case of employing WorleyParsons/BOC Gases Company (BOC) SURE Double Combustion technology, a new reaction furnace/WHB is installed upstream and in series of the existing reaction furnace/WHB. In this case, the preinstalled new reaction furnace/WHB could easily be tied in with its existing counter part within the plant shutdown schedule. Table 8-1 presents the plant comparison before and after revamp.
Section 8

Salient Design Features of SURE Burner

Table 8-1, Revamp Plants Comparison

<table>
<thead>
<tr>
<th>Refinery Item</th>
<th>Before Plant Revamp, metric tons per day (MTPD)</th>
<th>After Plant Revamp, MTPD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>NH₃</td>
</tr>
<tr>
<td>Refinery A</td>
<td>60</td>
<td>—</td>
</tr>
<tr>
<td>Refinery B</td>
<td>70</td>
<td>1.9</td>
</tr>
<tr>
<td>Refinery C</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Refinery D</td>
<td>32</td>
<td>0.3</td>
</tr>
<tr>
<td>Refinery E</td>
<td>42</td>
<td>0.3</td>
</tr>
<tr>
<td>Refinery F₁</td>
<td>48.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Refinery G</td>
<td>New</td>
<td>—</td>
</tr>
<tr>
<td>Refinery H</td>
<td>51</td>
<td>3.5</td>
</tr>
<tr>
<td>Refinery I</td>
<td>150</td>
<td>10.6</td>
</tr>
<tr>
<td>Refinery J</td>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>Refinery K</td>
<td>240 x 2</td>
<td>—</td>
</tr>
<tr>
<td>Refinery M₁</td>
<td>250</td>
<td>—</td>
</tr>
<tr>
<td>Refinery N₁</td>
<td>20</td>
<td>—</td>
</tr>
<tr>
<td>Refinery O</td>
<td>330</td>
<td>—</td>
</tr>
<tr>
<td>Refinery P</td>
<td>140</td>
<td>—</td>
</tr>
<tr>
<td>Refinery R</td>
<td>95/180</td>
<td>—</td>
</tr>
</tbody>
</table>

¹The sulfur production requirement decreased and sour water stripper (SWS) processing requirement significantly increased.

The SURE Double Combustion employs two combustion furnaces and WHBs arranged in series. All acid gas and combustion air are sent to the first furnace where the SURE burner is located. Part of the oxygen is injected directly into the first furnace through dedicated oxygen injection nozzles in the SURE burner. The combustion products from the first furnace are cooled in the first WHB and then flow into the second furnace. The remaining oxygen is injected into the second furnace by oxygen lances. The combustion products from the second furnace are cooled in the second WHB and then sent to the catalytic stages. The first WHB is designed to cool the combustion products to a temperature above 1,000 F (540 C), which is higher than the auto-ignition temperature of H₂S and sulfur.
(about 500 F or 260 C), so that no igniter is required in the second furnace and there is no danger from buildup of an explosive mixture of acid gas and oxygen.

There are two basic types of burners, tip-mixed, where the fuel and oxidant are mixed after leaving the burner, and pre-mixed, where a degree of mixing of fuel and oxidant occurs before they leave the burner tip. Both types of burners are in use in Claus plants. In order to provide a safe and economical solution at all oxygen concentrations including pure oxygen, BOC chose to design a tip-mixed burner system. Other basic requirements were that the design should be simple but flexible and the burners should be self-cooling and as far as possible, self-protecting in the highly reducing atmosphere within a Claus reaction environment. The features should also be capable of operating on any mixture of air and oxygen, from air-only right up to pure oxygen use.

The resulting “SURE” burner design has been in operation in Claus units for more than five years. Whilst a ‘standard’ range of burners, from 3 to 30 inches (for SRUs up to 600 tpd capacity), has been produced, these retain some features, which can be ‘fine-tuned’ to suit the particular requirements of a practical Claus installation and enable them to be used in either axial- or tangential-firing mode.

A feature of all tip-mixed, oxygen-fuel burners is the generation of hot zones within the flame. The size and number of these hot zones is a function of the burner design; and these are most obvious in systems operated under highly reducing conditions such as those found in a Claus reaction furnace. Oxygen leaving the burner tip travels some distance before mixing with the fuel and forms a gas envelope within the flame. Combustion occurs at the outer surface of this envelope and goes from super-stoichiometric through stoichiometric to sub-stoichiometric. Areas within the flame can be more than 1,000°C hotter than the average flame temperature. This is very beneficial in destroying feed contaminants such as ammonia and heavy hydrocarbons, but the burner design must always ensure that these hot zones are controlled well away from any refractory surface.

CFD models are capable of using kinetic information and can handle heat transfer calculations in a non-adiabatic system. The models are large and take several days to run, but the results are detailed three-dimensional profiles of gas velocity, temperature and molecular species concentrations, which has enabled BOC to optimize its’ burner design for both axial- and tangential-firing options. This in turn has produced a safe and economical solution to oxygen use in Claus plants where the maximum benefit in destruction of ammonia and other feed gas contaminants is combined with control or refractory temperatures to well within safe limits.
As mentioned in the previous section or burner design, it is critical that the high-temperature oxygen combustion product does not cause the refractory to exceed its temperature limit. Only by treating the burner and the combustion chamber as an integral unit through the use of a CFD model, it is possible to optimize and to ensure a safe design of the combustion process, especially in a revamp situation where existing combustion chamber is being reused.

The investment cost associated with an oxygen enrichment revamp is only 15% to 25% of a new air-based SRU. Oxygen enrichment also provides substantial cost savings for new SRUs by reducing the sizes of the equipment. Applying oxygen enrichment to a new SRU can cut the flow rate through the SRU by half at the same sulfur recovery capacity as compared to an air-only unit; this results in approximately 35% savings in investment cost, which excludes the cost of an onsite oxygen generation unit.

Using oxygen enrichment will improve the following factors in sulfur recovery units:

- Increase unit capacity.
- Eliminate the limitation of air blower discharge pressure and plant hydraulics.
- Increase processing SWS offgas.
- Increase combustion chamber temperature and increase the stability of the flame temperature for lean acid gases.
- Increase the tail gas unit capacity (cooling capacity of direct contact condenser should be evaluated and the amine circulation rate should be examined to ensure adequate amine circulation for H₂S absorption).
- Evaluate the existing degassing system and the sulfur rundown (required for large percentage of sulfur capacity).
- Evaluate the existing incinerator (required for large percentage of sulfur capacity).
- Facilitate the complete destruction of ammonia, heavy hydrocarbons [such as benzene, toluene, and xylene (BTX)], and other contaminants.
- Increase accuracy by Computational Fluid Dynamic (CFD) program (means of predicting flame patterns for specified operating conditions).
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Various configuration options for high-level oxygen enrichment with WorleyParsons/BOC’s SURE Double Combustion process are available to suit the requirements of the individual facility.

8.1 Conventional Configuration for High Capacity Expansion

The conventional configuration involves the addition of a new reaction furnace burner, reaction furnace and WHB boiler upstream of the existing reaction furnace (Figure 8-1). Gas effluent from the new waste boiler is routed to the existing reaction furnace, which serves as the second thermal stage. With this configuration the SURE Double Combustion technology allows SRU capacity to be expanded at considerably lower costs compared to building new air-based SRUs. The operator could save substantial initial investment cost even for new SRUs if oxygen is available or can be imported across the fence. Moreover, oxygen enrichment reduces the plot area required and, in fact, for operating facilities limited by plot space, oxygen enrichment might be the most viable option for SRU capacity expansion.

Occasionally, existing reaction furnaces and WHBs cannot be reused because of original design limitations. In these cases, a two-pass WHB with an extended head can be designed in which the extended head serves as the second-stage reaction furnace and the second pass serves as the second WHB (Figure 8-2). This two-pass WHB configuration effectively reduces capital cost and conserves plot space requirement. In addition, operators could realize the following benefits:

The new reaction furnace/WHB can be installed while the existing SRU is still in operation. The new equipment can be tied in with the existing reaction furnace/WHB during a short period shutdown or during the SRU turnaround time, thus minimizing the loss of plant throughput while the technology is implemented.

The simple piping for the SURE design reduces the possibility of accidental H₂S emission and equipment failure compared to other commercially available processes.

The SURE Double Combustion design does not require shutting down and isolating a recycle loop when oxygen enrichment is not being used; this further improves the safety of the SURE process.

Changing the mode of operation between air-only and oxygen enrichment is simple and smooth for the SURE process, which involves only the oxygen supply system. The SRU itself is always ready to receive oxygen.
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Figure 8-1—Conventional SURE Double Combustion Configuration
Reusing Existing Reaction Furnace and WHB

Figure 8-2—Conventional SURE Double Combustion Configuration
with New Two-pass WHBs
8.2 Innovative Configuration for High-capacity Expansion

When multiple SRU trains are involved, one set of common new equipment (burner, reaction furnace and WHB) can be shared by the various trains. The existing reaction furnaces and WHBs of the individual trains can be used as the second thermal stage. The effluent of the new WHB is split and routed to each of the existing reaction furnaces (Figure 8-3). The new equipment could be installed onsite while the SRU is in operation. Only a short downtime is needed to tie in the new equipment for high-level oxygen enrichment. Typically, the revamp tie-in work has been accomplished within 1 to 2 weeks, which is normally within the schedule of a routine plant maintenance shutdown.

Having the hot effluent (>1,000 F) from the first thermal stage travel a very long distance is undesirable. Therefore, if the individual trains are far away from each other, it might be necessary to install a new common second thermal stage. Depending on the required capacity, the second stage will either be a two pass WHB sharing a common shell with the first stage or an individual boiler. The relatively cool gas from the new second stage WHB is then split and tied into each of the existing number one sulfur condensers (Figure 8-4). Oxygen consumption can be reduced by treating part of the acid gas in the existing reaction furnaces and WHBs of the individual units using air. The effluent gas is also routed to the number one condenser and joins with the effluent of the new WHB for the remaining Claus process. This configuration can also be applied when the sizes of the existing reaction furnaces and WHBs are not adequate to handle the required capacity increase alone. It can effectively reduce the pressure drop across the SRUs and hence provides greater flexibility in the event that additional Claus stage or tail gas treatment needs to be added to increase the sulfur recovery to meet more stringent emissions requirements. These common equipment configurations could be cost effective for the following revamp situations.

8.2.1 Spare Train Capacity Requirement

Refer to the process configuration described in Figure 8-3; when no additional capacity is required during normal operation, existing reaction furnaces of both trains can be operated with air while the new reaction furnace/WHB can also be operated with air at reduced capacity. This operation mode will save oxygen cost.

When one of the two trains is down, the reaction furnace of the operating train can be operated with air at reduced rate while the new reaction furnace/WHB is operated with oxygen to provide the spare train capacity with one single train operation. This operation mode will ensure that refinery or gas plant throughput is maintained and thus will avoid any loss of income.
8.2.2 Normal Capacity Expansion with Added Spare Train Capacity

If additional sulfur processing capacity is required during normal operation, existing reaction furnaces of both trains can be operated with air at reduced capacity while the new reaction furnace/WHB operates with oxygen to provide the required additional capacity to both trains.

When one of the two trains is down, the reaction furnace of the operating train can be operated with air at reduced rate while the new reaction furnace/WHB is operated with oxygen to provide the spare (double) train capacity with one single train operation. This operation mode will ensure that refinery or gas plant throughput is maintained and thus avoids any loss of income.

Figure 8-3—Parallel SURE Double Combustion Configuration Using Existing Reaction Furnace and WHB as Second Thermal Stage Providing 150% Capacity Increase
8.2.2.1 Provide 300% Additional Capacity for Two Existing Parallel Trains

The new reaction furnace/WHB can be designed to provide up to 150% additional sulfur processing capacity for each of the two existing parallel SRUs resulting in a total additional capacity of 300%. This operation mode would require the reaction furnace/WHB to be operated with oxygen during normal operation. Figure 8-5 depicts the minimum cost configuration to double the sulfur processing capacity of both existing trains. Although this minimum cost configuration does not offer some desired operation flexibilities, it could be configured as described in Figure 8-6. If the new equipment is shut down, the existing reaction furnaces can be operated with up to 28% oxygen-enriched air and can still provide 125% of the original design capacity. This configuration and operation mode minimize the loss of sulfur processing capacity and still maintain more than half of the total required capacity if any one of the two trains is down or if the new equipment system is down.

8.3 Stage Wise Investment Option

Considering the fact that configurations described in Figures 8-3 and 8-5 offer limited plant operation flexibility as when the new reaction furnace/WHB is down, the sulfur processing complex may suffer reduced or total loss of capacity. However, this configuration does provide a viable option for stage wise investment.
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If the process configurations described in Figures 8-2 and 8-4 are the most desired configurations that fit well into the existing designed equipment, plot space availability, and/or budget target, such a configuration can be implemented as a first-stage investment to accommodate the immediate needs. A second reaction furnace/WHB can be considered to install for the second train at a later time when budget is available to provide the desired operating flexibility while achieving the required sulfur processing capacity.

Figure 8-5—Parallel SURE Double Combustion Configuration Using Existing Reaction Furnace and WHB as Second Thermal Stage Providing 300% Capacity Increase
Figure 8-6—Parallel SURE Double Combustion Configuration with New Reaction Furnace and WHBs Providing 300% Capacity Increase
The “SURE” process offers an inexpensive route for SRU capacity expansion by oxygen enrichment, up to 100% oxygen. State-of-the-art engineering tools produce a simple, efficient “SURE” burner and process design.

The “SURE” Double Combustion process for high-level oxygen enrichment is inherently suited for staged investment and SRU capacity expansion. Very little up-front investment is needed in order to achieve the final phase of expansion to 100% oxygen enrichment. The unique “SURE” design offers better economics, shorter downtime for implementation and ease of operation that is safe and reliable.

The “SURE” process undoubtedly offers viable technical solutions to process dilute acid gases especially those contaminated with ammonia or heavy hydrocarbons such as benzene, toluene and xylene (BTX).

Various levels and configuration for oxygen enrichment are available to meet specific requirements of individual facility. An optimum configuration is chosen based on sulfur processing capacity requirement, configuration of existing sulfur plant, plot area availability, existing equipment conditions, site location specifics and budget availability.

The SURE technology offers an inexpensive route for SRU capacity expansion by using oxygen-enriched air, up to 100% oxygen. State-of-the-art engineering tools produce a simple, efficient SURE burner and process design.

The SURE Double Combustion process for high-level oxygen enrichment is inherently suited for staged investment and SRU capacity expansion. Very little up-front investment is needed in order to achieve the final phase of expansion to 100% oxygen enrichment. The unique SURE design offers better economics, shorter downtime for implementation and ease of operation that is safe and reliable.
## Bibliography

1. PROClaus, New Performance in Sulfur Recovery, M. Rameshni, Brimstone, Canmore, Canada, 2001
