GOAR, ALLISON & ASSOCIATES, INC.

# The COPE™ Process— Increase Sulfur Recovery Capacity to Meet Changing Needs

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## I. 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 and Asia all require progressively cleaner motor transportation fuels. Product demand is away 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).

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 acceptance as a proven measure to handle 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. This paper describes how today the COPE Process is a proven technology providing all the advantages obtainable with oxygen enrichment in a simple, easy to operate and economical process.

## II. FUNDAMENTALS OF OXYGEN ENRICHMENT

The concept of increasing SRU capacity by enriching the combustion air with oxygen has been of interest for many years. Initial methods of enrichment were by injection of the oxygen directly into the combustion air stream. This had a limit of no more than about 28% oxygen in the mixed stream, and yielded capacity increases of only 15-25%. Injection of oxygen directly into the combustion chamber required the development of new burner designs, the first of which was applied on a commercial scale in 1985. This technique allowed the use of up to 100% oxygen and has provided capacity increases of 100-150% above the original air-based design.

The typical SRU reaches its limiting capacity when the maximum allowable front-end pressure prevents a further increase in feed rate. Usually the front-end pressure limit is set by either the combustion air blower discharge pressure, the depth of the sulfur seal leg, or the operating pressure of an upstream amine unit regenerator. Oxygen enrichment reduces the process flow rate through the SRU by decreasing the amount of nitrogen that enters with the combustion air, thereby reducing the unit pressure drop. This reduction in process flow rate in the SRU allows a corresponding increase in the acid gas feed rate.

From a technical point of view, the commercial application of oxygen enrichment has been limited by one major obstacle - the maximum allowable operating temperature in the SRU reaction furnace and at the inlet to the waste heat boiler. The maximum demonstrated temperature for commercially available refractory materials is about $2800^{O}F$ ($1540^{O}C$). Current design philosophy is to limit the calculated bulk temperature to this value, although some refractory manufacturers claim that their products can operate continuously at up to $3000^{O}F$ ($1650^{O}C$). The temperature resulting from the addition of oxygen to an SRU burner can be in excess of this limit, in some cases at enrichment levels as low as 30% oxygen.

This problem has been addressed with various processing techniques to reduce the reaction furnace operating temperature below the limit set by the refractory. These innovations include at least three different approaches:

- "shaped" burning to achieve a high degree of $H_2S$ dissociation in high temperature zone(s) within the combustion chamber
- recycle of an internal process stream to dilute and cool the combustion products
- dual combustion stages with intermediate cooling to limit the temperature by distributing the heat release over two stages

Furthermore, the increase in furnace temperature is somewhat 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 oxidation is required, ultimately decreasing the heat release and temperature.

The COPE Phase I Process utilizes the shaped burning technique for moderation of flame temperature; the COPE Phase II Process uses both shaped burning and recycle to achieve high level oxygen enrichment without exceeding the temperature limitations of commercially available refractory materials.

## III. THE COPE PROCESS

The COPE Process was first implemented in 1985, when Conoco, Inc. installed it on two existing Claus SRU's at their refinery located at Lake Charles, Louisiana. Using an oxygen-enrichment level of 55-65%, the capacity of each SRU was increased from 108 LTPD (with air only) to more than 200 LTPD. This first application of high level oxygen enrichment was a significant breakthrough, which has lead to a current 17 COPE units operating at 11 locations throughout North America. A list of these units is given in Table 3 at the end of the paper. After the successful implementation of the COPE Process, competing processes have also been developed to utilize oxygen enrichment for capacity expansion of SRU's. Figure 1 below provides a summary of COPE operating history.

Figure 1

| COPE™ SRU $O_2$ Enrichment Technology | |
|---|---|
| Successful Technology First Introduced in 1985 | |
| 17 SRU Trains with over 125 Train Years in Operation | |
| Two Versions: | COPE Phase I with COPE® Burner<br>Mid Level Enrichment<br>11 SRU Trains in operation |
| | COPE Phase II with Gas Recycle<br>High Level Enrichment<br>6 SRU Trains in Operation |
| SRU Capacity increase of up to 150% documented | |

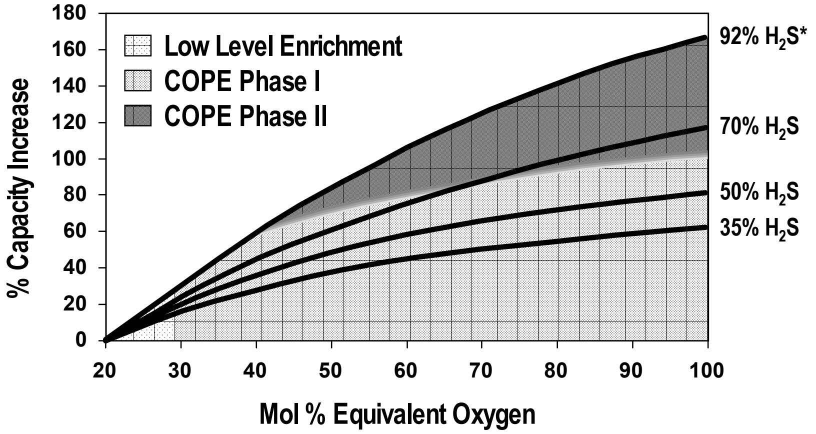
The process was developed and patented jointly by Goar, Allison & Associates, Inc. of Tyler, Texas, USA, and Air Products and Chemicals, Inc. of Allentown, Pennsylvania, USA.

The COPE Process uses a proprietary burner design in which oxygen is brought into the combustion chamber separately from the air and other gas streams. As more oxygen is introduced, it decreases the amount of air required, reducing the amount of inert nitrogen which enters the burner. The resulting reduction in flow decreases the hydraulic pressure drop through the equipment and piping, allowing more acid gas feed to be charged to the SRU.

Oxygen enrichment can be implemented in three or more steps. Figure 2 below illustrates the capacity increases that can be obtained in each step. The first is low-level enrichment (LLE), in which the oxygen is injected through a diffuser directly into the combustion air stream. This method is limited to 28% oxygen content in the mixture, and typically yields 15-25% increased capacity.

Figure 2

**COPE™ Capacity Expansions**
**for Claus Sulfur Recovery Units**



***Other Amine Acid Gas Components Are:**
**$H_2O$ 7.0%, $C_1$ 0.5%, $C_2$ 0.5%, $CO_2$ Balance**

The second step, the COPE Phase I Process, introduces oxygen using the special burner and allows enrichment up to the temperature limit of the reaction furnace refractory, usually about 2800$^{o}$F (1540$^{o}$C). Enrichment levels of 40-50% oxygen and capacity increases of 50-60% are typical, depending upon the feed gas composition and the specific design of the SRU. The only new equipment required for COPE Phase I is the COPE burner. Of the 17 COPE units operating, 11 utilize the Phase I Process. This process is shown on Figure 3.

The third step, the COPE Phase II Process, uses a relatively cool recycle stream to moderate the reaction furnace temperature so that, as more oxygen is added, the temperature does not rise above the limit of the refractory. The recycle is taken from the outlet of the first sulfur condenser as shown in Figure 4. The flow of recycle gas is controlled to maintain the desired temperature in the reaction furnace. A mechanical blower is used to provide the necessary head so that the recycle flows back to the burner. Six SRU trains operate using the COPE Phase II Process.

A new modification of the COPE Phase II Process (Figure 5) utilizes an ejector in place of the blower. The ejector provides the necessary head, and the motive gas becomes part of the recycle stream to the burner. The motive gas would typically be medium or high-pressure steam, although air or other suitable compressed gases could also be used. An ejector offers several process, mechanical, and economic advantages (Ref. 1). The first installation of an ejector system is scheduled to be installed at an existing COPE Phase II location during the next turnaround.

## IV. PROCESS CONSIDERATIONS

### Combustion and Enhanced Dissociation in the COPE Burner

The main feature of the COPE Process is the proprietary COPE Burner, which is manufactured by LD Duiker, b.v. The design of the burner has been updated over the years to incorporate various improvements. The burner allows for the safe and effective introduction of the separate inlet streams: air, acid gases, startup fuel gas, high purity oxygen, and, when necessary, recycle gas. The COPE burner is a high intensity, swirl vane burner that has its own small combustion chamber. The combined geometry of the burner injection nozzle, the mixing throat, and the combustion chamber produces a short, highly turbulent flame. Rotation is induced in both the air and mixed acid gas streams, and then the air is injected at right angles to the high velocity acid gas stream to achieve a high degree of mixing. Multiple vortices created by expanding gases from the burner nozzle produce further rapid mixing and high intensity burning. Combustion is essentially complete as the gases leave the burner chamber and enter the reaction furnace, so that the full volume of the furnace may be utilized for the desired reactions to destroy ammonia, consume hydrocarbons, and form sulfur. The high-efficiency mixing also eliminates non-uniform heating and hot spots at the burner, furnace, and waste heat boiler tubesheet.

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. In addition to dissociation, ammonia is converted by at least two other reactions: oxidation by oxygen (air) to nitrogen and water vapor, and, as shown by Clark (Ref.3), oxidation by $SO_2$ to form nitrogen, water vapor, hydrogen, and sulfur. Both of these reactions are enhanced by higher temperatures. 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 destroys any $CS_2$ that may be formed from the hydrocarbons.

### Improved SRU Recovery

One of the unexpected results of oxygen enrichment is that the overall sulfur recovery of the SRU is increased by 0.5-1.0%. 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.

## 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 actually improved during COPE 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 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.

## 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. Table 1 gives some comparative values for operation at 100 t/d with air only and 200 t/d with 65% oxygen equivalent. 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. The vent gas flow to the incinerator decreases to less than 40% of the air-only case, while the amount of sulfur processed in the SRU has doubled. Thus, there is less incineration fuel consumed, reducing operating cost as well as $CO_2$ emissions. The sulfur emissions from the incinerator will also be greatly reduced as shown by the values for the contained $H_2S$ in the absorber vent gas.

## TABLE 1

Comparison of Operation
Air-Only vs. COPE™ Phase II
Rich Acid Gas Feed (1)

| Item | Units | Air-Only Operation 21% $O_2$, 100 MTPD | COPE Operation 65% $O_2$, 200 MTPD |
|---|---|---|---|
| SRU Acid Gas Feed | Kmol/h | 151 | 302 |
| Contained Sulfur in Acid Gas Feed | MTPD | 100 | 200 |
| SRU Tail Gas Flow | Kmol/h | 416 | 380 |
| Percent Water Vapor in SRU Tail Gas | % | 35 | 72 |
| Feed Gas to TGCU Absorber | Kmol/h | 303 | 123 |
| Contained Sulfur in TGCU Absorber Feed Gas | MTPD | 2.7 | 4.2 |
| Absorber Vent Gas to Incinerator | Kmol/h | 300 | 116 |
| $H_2S$ Content of Absorber Vent Gas | ppmv | 80 | 80 |
| Contained $H_2S$ in Absorber Vent Gas | Kmol/h | 0.024 | 0.009 |

(1) Acid Gas Feed: 86% $H_2S$ (wet)

## V. RECYCLE GAS FOR COPE PHASE II

As the capacity of an SRU is increased further and further using oxygen enrichment, eventually the temperature reaches the limit of the refractory material. At this point some adjustment must be made to the process to allow for more oxygen, and therefore, more acid gas feed. The COPE Phase II Process utilizes the recycle of a relatively cool and inert stream from the first sulfur condenser to essentially dilute the combustion products to a level such that the burner temperature is maintained below the required limit. Recycle is a simple but powerful tool for controlling the temperature in the burner and reaction furnace. It provides stability and flexibility to the operation of the SRU. During upset or abnormal operation, the availability of recycle gas is beneficial for maintaining operation by protecting against temperature excursions or variations in feed gas flow and composition. The use of recycle, even when not required for temperature moderation, can be beneficial when dealing with common operating problems such as sudden large changes in the hydrocarbon content of the acid gas feed, and similar rapid changes in the flow rate from the amine regenerator overhead. Over the years, the COPE Phase II operating units have demonstrated these advantages.

All of the COPE Phase II units installed to date use a single stage centrifugal blower, properly designed for the service. Recycle blowers for service in sulfur-containing process gas have been in use since at least 1981. In addition to the COPE units, at least 12 Recycle Selectox units (UOP-licensed process) have been installed with blowers in similar service recycling gas from the No. 1 Sulfur Condenser outlet. All of the blowers have provided good performance and high on-stream factor, typically in the range of 99 percent. Some plant engineering and operations personnel nevertheless have felt that the use of a blower in this service could be troublesome to operate and maintain, and have elected to increase plant capacity by using other technology or by installing new capacity at a much greater cost.

### Recycle Ejector

A new version of COPE Phase II has been developed which uses an ejector instead of a blower to recycle the gas from the outlet of the No.1 Sulfur Condenser to the COPE burner. The ejector maintains all of the benefits of recycle with added advantages over a mechanical blower.

The most likely motive fluid for a recycle ejector is medium or high pressure steam. Steam is usually readily available, since it is produced in the waste heat boiler of most sulfur recovery units. The steam becomes part of the recycle stream that is injected into the burner. The presence of the additional steam helps in the conversion of undesirable hydrocarbons, increases the amount of radiant heat transfer in the waste heat boiler, and provides the same amount of temperature moderation at a decreased mass flow rate. There is also a small increase in flow through the catalytic stages, which can be helpful if the mass velocity in the sulfur condensers is approaching the lower limit (Ref. 1).

A steam or gas-powered ejector is a simple device with no moving parts, requiring little, if any, maintenance. It should be located at an elevation above the first condenser and the burner, so that all piping can be self-draining. The ejector requires very little space on a platform or pipe rack. Fully or partially spared configurations can be attractive options due to the small space requirement, simplicity of installation, and low initial cost of ejectors.

An ejector system will be installed at the Conoco Lake Charles refinery, the site of the first COPE Phase II units during the next scheduled shutdown of the SRU. It will be installed in parallel with the one of the existing recycle blowers. We are confident that this installation will prove to be a success, and believe that the change from blower to ejector will stimulate new interest in the COPE Process.

## VI. TYPICAL COPE RETROFIT MODIFICATIONS

The large increases in SRU capacity achieved with $O_2$ 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. Seventeen COPE Process trains are in operation; all units that have started-up remain in operation. Fourteen of the seventeen units are retrofits. Although process conditions are altered substantially by a COPE retrofit, the existing equipment is entirely adequate in most cases, in both the SRU and the associated SCOT type tail gas cleanup unit. Required replacement of major equipment in the fourteen COPE Retrofits is shown in Table 2.

Table 2

Equipment Replacements Required
In Making COPE Process Retrofits(1)

| Retrofit Type: | COPE Phase I | COPE Phase II |
|---|---|---|
| Units in Operation | 10 | 4 |
| Furnaces | 1(2) | 2 |
| WHB's | 3 | 2 |
| WHB Steam Drum (only) | 3 | |
| No. 1 Sulfur Condenser | --- | 2 |

(1) Of 17 COPE Process units in operation, 14 are retrofits to existing SRU's.

(2) 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, since quench water cooling duty increases in direct proportion to increase SRU capacity.

## VII. 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.

### 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 $ 1.0 - 1.5 MM U.S. This compares to the approximate installed cost of a new 50 MTPD SRU and TGCU of about $ 9.5 MM U.S. (ca. $ 5.2 MM U.S. for SRU only).

### 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 $ 2.0 - 3.0 MM U.S. A new 100 MTPD SRU with TGCU would be expected to cost about $ 14.5 MM U.S. (ca. $ 8 MM U.S. for SRU only).

### 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 $14.5 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 would could be installed for about 75% of the cost of the larger unit (Ref. 4).

### New Redundant SRU's with COPE Phase II

The need for redundant SRU capacity is seen more frequently as refiners seek to eliminate reductions in feed rates to their refining units. One way to achieve this redundancy is to build two SRU's 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.

## VIII. OXYGEN SUPPLY

Oxygen for SRU oxygen enrichment can either be delivered to the refinery or generated on-site. Delivery to the refinery can be by liquid tanker (LOX) or by oxygen pipeline (GOX) from a distant plant which is dedicated or servicing a network of customers. Oxygen may be generated at the refinery using membrane, adsorption (Vacuum Swing Adsorption-VSA and Pressure Swing Adsorption-PSA), or cryogenic gas separation technologies (ASU''). Evaluation of the optimal mode of supply requires the review of several factors. The major factors normally considered are:

- Size of the oxygen requirement (average and peak demand)
- Oxygen purity required. Most often VSA purity (90+% purity) is satisfactory.
- Expected oxygen use patter. Is oxygen demand steady or erratic? What percentage of time during the year would the oxygen generating unit be utilized?
- Need for co-product nitrogen for inerting, blanketing and other refinery uses
- Presence of other oxygen-consuming applications in the area
- Power Cost
- Proximity of a delivered oxygen source: LOX by truck or gaseous oxygen by pipeline

The size of the needed SRU capacity expansion will determine which oxygen supply mode is favored. Historically, Low Level Enrichment (LLE) with its smaller oxygen volume (2-30 STPD, 53-795 $Nm^3/h$) and somewhat erratic demand pattern have made LOX the preferred mode of supply. VSA supply could handle many LLE and Mid-Level Enrichment scenarios. On-site cryogenic generation, typically competitive above a requirement of 100-200 STPD (2650-5300 $Nm^3/h$), is more likely to find use in medium to high level oxygen enrichment projects. Air Products works closely with the operating company considering SRU enrichment to help determine the best mode of oxygen supply (Ref. 2).

## IX. SUMMARY: BENEFITS OF THE COPE PROCESS

The COPE Process is a time-proven oxygen-enrichment process for increasing the capacity of a sulfur recovery unit. Capacity increases of up to 150% have been achieved at a fraction of the cost of a new unit.

The COPE Phase I mid-level enrichment technology can provide increased throughput of 50-60%, with just the addition of a new burner and the oxygen system. For greater capacity expansion, the COPE Phase II high-level enrichment technology is used. It requires a new burner, a recycle blower or recycle ejector, and possibly some replacement equipment items, depending on the specifics of the particular SRU.

The COPE Process uses a special burner design to introduce oxygen into the combustion chamber. A shaped flame with high temperature combustion zone promotes dissociation of $H_2S$, moderating the temperature and reducing the amount of oxygen required. The high degree of mixing achieved with this burner also improves the destruction of ammonia and hydrocarbons, as well as eliminating hot spots throughout the refractory-lined furnace and waste heat boiler tubesheet.

Other process benefits include a higher sulfur recovery within the SRU, and lower emissions of sulfur compounds from the TGCU. Also, a significant decrease in incinerator fuel usage can be realized when operating the COPE Process.

The recycle system is a powerful tool for controlling the furnace temperature and also for providing stability and flexibility to the SRU. Centrifugal blowers have been used very successfully in this service for many years. A recent development is the use of an ejector to recycle the gas to the burner. An installation of a recycle ejector system is pending at an existing COPE Phase II location.

The capacity increases that can be obtained using the COPE Process can be implemented for about 10-20% of the cost of a new facility with equivalent incremental capacity. Cost savings for new plant redundancy can be achieved using COPE Phase II, by installing two smaller oxygen-enrichment units instead of two full-sized air-based units.

The COPE Process is an oxygen-enrichment technology that provides proven solutions at minimum cost to the heightened need for increased sulfur recovery capacity.

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## TABLE 3

## COPE$^{TM}$ PROCESS UNITS

| Client | SRU Train | Location | Project Type | Air Based Capacity, LTPD | COPE Capacity LTPD | Start-up Date |
|---|---|---|---|---|---|---|
| COPE$^{TM}$ Units in Operation | | | | | | |
| Conoco, Inc. | 2 | Lake Charles, LA | Phase II Revamp | 108 | 190 | March 1985 |
| Conoco, Inc. | 1 | Lake Charles, LA | Phase II Revamp | 108 | 190 | May 1985 |
| CITGO (Champlin Refining Co.) | A | Corpus Christi, TX | Phase I Revamp | 70 | 87 | April 1986 |
| CITGO (Champlin Refining Co.) | B | Corpus Christi, TX | Phase I Revamp | 70 | 87 | June 1986 |
| Ultramar Diamond Shamrock (Champlin) | 1 | Wilmington, CA | Phase I Revamp | 58 | 90 | Dec. 1987 |
| Ultramar Diamond Shamrock (Champlin) | 2 | Wilmington, CA | Phase I Revamp | 58 | 90 | Jan. 1988 |
| Ultramar Diamond Shamrock (Total) | 1 | Ardmore, OK | Phase I Revamp | 60 | 85 | June 1994 |
| Clark Oil (Chevron USA) | A | Port Arthur, TX | Phase I Revamp | 100 | 160 | Nov. 1994 |
| Clark Oil (Chevron USA) | B | Port Arthur, TX | Phase I Revamp | 100 | 160 | Nov. 1994 |
| Dynegy (Dow/Destec) | 1 | Terre Haute, IN Coal Gas Facility | Phase I New Plant | --- | 120 | Aug. 1995 |
| Ultramar Diamond Shamrock | 1 | Wilmington, CA | Phase II Revamp | 58 | 150 | Sept. 1995 |
| Ultramar Diamond Shamrock | 2 | Wilmington, CA | Phase II Revamp | 58 | 150 | Oct. 1995 |
| Valero Energy Co. (Phibro Energy) | A | Texas City, TX | Phase I Revamp | 206 | 330 | May 1996 |
| Valero Energy Co. (Phibro Energy) | B | Texas City, TX | Phase I Revamp | 206 | 330 | July 1996 |
| Excel Paralubes, Inc. (Conoco/Pennzoil joint venture) | A | Lake Charles, LA | Phase II New Plant | 90 | 180 | Oct. 1996 |
| Excel Paralubes, Inc. (Conoco/Pennzoil joint venture) | B | Lake Charles, LA | Phase II New Plant | 90 | 180 | Jan. 1997 |
| Mobil Mary Ann Gas Plant | --- | Coden, AL | Phase I Revamp | 280 | 470 | June 1997 |
| Chevron Canada | --- | Burnaby, BC | Phase I Revamp | 12 | 20 | Mar. 1998 |
| Pacific Offshore Pipeline Company | --- | Goleta, CA | Phase I Revamp | 30 | 60 | April 1998 |

Total COPE$^{TM}$ Trains 17

Total Train-Operating Years > 125

NONE: If a refinery has been sold or changed names, the current owner/name is shown with the original licensee shown in parentheses.