

Carbonyl Sulfide (COS) Removal from Propane

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Foreword

This report is for Phase I of GPA Project 991, **Carbonyl Sulfide (COS) Removal from Propane**. This work was completed by Pearl Development Company with funding provided by the Propane Education and Research Council (PERC), and significant in-kind funding from Pearl Development Company. GPA's Research Steering Committee provided overall management of the project.

This report compares a number of commercially available sorbent materials based on designs provided by the manufacturers. A follow-up Phase II will conduct testing of sorbent materials and provide design information for the practicing engineer. Because this report provides relative capital and operating costs for materials from different manufacturers, it could be used to make a tentative selection of a sorbent product. That is not the intent of this work. This report is intended solely to illustrate the approximate relative costs of different methods of COS removal. The data provided in this report are only valid given the assumptions contained in the report. In fact, since the work was initiated, natural gas prices have increased significantly from the basis used in this work. The comparisons shown in this report are valid only for the product rates, utility costs, and other assumptions used in preparation of the economic analysis provided in this research report.

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This report should be considered as a whole. Sections or parts thereof should not be relied upon out of context.

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1. INTRODUCTION

With millions of gallons of propane traded commercially every day across the world, a detailed understanding of the allowable limits for carbonyl sulfide (COS) contaminant in the propane is important to all participants in the delivery chain. When COS concentrations in propane exceed allowable limits, removal systems may need to be installed. As GPA project 982 is being conducted by the National Institute of Standards and Technology (NIST) to help establish these limits, this project (GPA 991) is being conducted to examine technological merit and commercial requirements of sorbent technologies capable of reducing the COS contaminant from propane.

COS contained in the inlet gas to a Natural Gas Liquids (NGL) recovery plant will tend to concentrate in the propane product stream. Due to the hydrolysis of COS in the presence of water to form H₂S and CO₂, operating companies are tightening COS specifications to maintain allowable corrosivity specifications.

Various technologies are available to remove COS from liquid propane streams, including amine treating and sorbent treating. When the only contaminant to be removed from the propane stream is trace amounts of COS, a process based on a sorbent material may be a more economical solution. Pearl Development Company (Pearl) has compiled and analyzed the designs from major manufacturers of catalysts and molecular sieve materials to compare the technical and economical merits of available technologies to remove COS. This evaluation has identified the advantages and limitations of specific materials as presented by the sorbent suppliers.

2. RESULTS AND CONCLUSION

The materials reviewed within this study are commonly used to minimize COS production, in the polymerization industry. Carbonyl Sulfide can degenerate a range of expensive catalyst beds used for polymerization of propane and propylene. As a result, all the materials used are commonly designed to achieve COS levels considerably lower than the 2ppm_w outlet specification used in this work.

Due to the low polarity of COS it is a difficult molecule to adsorb on most molecular sieve materials. Refer to Table X for adsorption preference summary information. Furthermore, more polar molecules such as H₂O, CO₂, and H₂S displace COS from the bed. To remove COS there are three commonly used techniques:

1. Use a selective adsorbent material, which is sufficiently large or preceded by other materials, to remove the more polar compounds, (i.e. H₂O, CO₂ and H₂S) first.
2. Use a chemically reactive adsorbent material that bonds with the sulfur in a non-reversible reaction. (i.e., $\text{CuO} + \text{COS} \rightarrow \text{CuS} + \text{CO}_2$)
3. Hydrolyze the COS to H₂S and remove the H₂S in a molecular sieve that will minimize reverse hydrolysis back to COS.
4. Hydrolyze the COS to H₂S and remove the H₂S by a chemically reactive adsorbent material.

A number of the regenerable materials are similar to industry standard molecular sieves. As a result, they degrade in a similar manner. The presence of olefins and diolefins can have a

significant effect on molecular sieve bed life. The effectiveness of catalysts and adsorbents is also reduced as the bed acts as a filter in removing particles, which adhere to and block active sites for the adsorption process.

The life of non-regenerable beds is reduced if there are other sulfur species present, which co-load with the COS, such as H₂S and mercaptans.

2.1. Formation of COS

COS can form naturally from the hydrolysis reaction: $\text{H}_2\text{S} + \text{CO}_2 \rightarrow \text{COS} + \text{H}_2\text{O}$.

However, most sources of natural gas are water saturated, which promotes the formation of H₂S and CO₂, commonly known as “sour gas”. It has been found that the use of adsorbent materials for dehydration is a major cause of COS formation.

In the presence of H₂S and CO₂, molecular sieves have a relatively strong affinity for H₂O. As the sieve material removes water formed by the hydrolysis reaction, the equilibrium point is shifted and the reaction favors the production of COS. The molecular sieve crystal accelerates the formation of COS due to:

- The high surface area of the zeolite crystals,
- The basicity of the crystal structure and
- The concentrations of H₂S and CO₂ as these materials are adsorbed together.

Two techniques are used to minimize the formation of COS in molecular sieves;

1. The use of a small pore size sieve, such as Grade 3A for dehydration, minimizes adsorption of H₂S and CO₂ thereby reducing the exposure of reactants in the bed.
2. Changing the structure of the zeolite crystal reduces the basicity of the structure, which can significantly reducing the formation of COS.

The sodium cat ions of the standard 4A molecular sieve are exchanged with divalent calcium to form the standard 5A molecular sieve. The application of 5A molecular sieve can reduce COS formation by more than 50% when compared to a 4A sieve.

High purity applications have created the requirement for deep exchanged 5A molecular sieve. With deep exchanged molecular sieve material the COS formation is less than 10% of a comparable 4A sieve.

2.2. Equipment Design

The use of adsorbent materials to remove COS may be assimilated to the use of more familiar molecular sieve materials. Adsorbent materials are supported on various combinations of ceramic balls and Johnson screens, while vessels are provided with manways for removal and replacement of the processing media.

In liquid service the flow directions is normally from top to bottom during adsorption to prevent fluidization of the bed. Regeneration cycles would flow in reverse and cooling cycles are from bottom to top with liquid product, allowing vapors to vent without flow restriction. Most suppliers have designed the bed velocity below that of fluidization, enabling adsorption flow in either direction.

It is important to avoid fluidization of the bed as this increases bed degradation. Generally the adsorbents and catalysts exhibit levels of attrition below 5% volume per adsorbent life. If the small amount of dust generated is likely to lead to complications downstream then filtration may be required on an application specific basis.

2.3. Economic Analysis

Appendix A.1 includes the economic analysis summaries for design flows of 50,000 and 300,000 gallons of treated propane per day and two regeneration options. Each table provides a comparison of capital and operating costs with a pre-tax net present value calculation based on a 10% interest rate and a 10 year evaluation period. While this table gives the reader an overview of the different technologies presented, it is important to maintain a perspective of the approaches adopted in assembling this economic model.

2.3.1. CONSISTENCY CHECKING

Since this evaluation has been based on data provided by sorbent suppliers it should be expected that not all vendors apply the same design factors to their designs. Pearl noted design differences between similar materials submitted by different suppliers.

An example is illustrated in the submissions for non-regenerable copper-zinc adsorbents. Multiple vendors provided designs with widely varying design bed loading, therefore specifying significantly different bed sizes. Although the actual performance of these materials may or may not be similar, **the economic comparisons provided in this report use the manufacturer's predicted performance as a basis** and therefore show different removal costs. In reality, an alternate adsorbent may well operate at similar design loadings. This would change bed life and adsorbent replacement costs, thereby equalizing the removal cost.

These differences highlight the need to perform laboratory, pilot plant, or full scale tests. Designs should be tested to verify vendor designs and design factors under similar conditions.

2.3.2. REGENERATION ECONOMICS

For the purposes of this investigation, systems have been compared as a wholly independent or stand-alone system. To maintain this isolation the treated propane has been vaporized and heated for regeneration purposes. The regeneration loop cannot generally be a closed loop. As a result, the COS rich regeneration gas is a revenue stream of considerable value.

Typically, treated propane would not be the most economic medium for regeneration. In reality there are often different mediums available for regeneration. The use of fuel gas for example may reduce the regeneration costs and change the economic comparison. Another option may be to recycle the sulfur rich regeneration gas upstream of an amine train or sulfur removal unit, therefore enabling regeneration gas to be recycled.

Non-regenerable systems have to overcome the cost of bed replacement and disposal, while regenerable designs have to balance the increased capital expense with reduced operating costs to recharge the beds. When long project life and high sulfur rates are present the regenerable systems have improved economics.

The results from this report indicate that the non-regenerable systems have an economic advantage when a small amount of COS is present. The economics for regenerable systems are greatly dependent on what is done with the regeneration propane. For this reason the economic comparisons have been split into two cases. In Case A the propane used for regeneration is recovered as fuel gas with the associated value. In Case B, it is assumed that there is an adjacent process to this plant, which is able to recycle the propane, i.e. an Amine train or Sulfur Recovery Unit.

The treating cost differences between the cases, highlight the need to carefully examine the regeneration issues when incorporating new equipment into a prospective plant.

2.3.3. DEHYDRATION ECONOMICS

To maintain each design as a wholly independent system, when the propane has been treated by hydrolysis of the COS to H₂S, the excess water has been removed by an additional dehydration bed so as the final product meets the HD-5 propane specification.

With integration of this equipment into a plant, hydrolysis beds should be installed upstream of the propane product dryers.

It should be noted that if downstream dehydration beds are used for H₂O and H₂S removal, the molecular sieve in the product dryers must be changed to an acceptable material, such as a low sodium zeolite molecular sieve, that will not re-hydrolyze the H₂S and CO₂ back to COS and H₂O.

3. DISCUSSION OF RESULTS

Tables I, to V, of Appendix A.1 represent the summary of findings from the economic analysis.

Figures i to xiv of Appendix A.2 represent the flow diagrams of each of the process designs compared. The 300,000gpd cases have been completed with an economizer to improve the system efficiency by cross exchange where significant heating and cooling loads exist.

3.1. Design Basis

The design basis compares proposals on the basis of two propane flow rates:

- 50,000 gallons/day, representing a treating facility for local sale
- 300,000 gallons/day representing a large scale fractionation or storage center.

Each design operates with a 98% production or on-stream factor. This downtime allows for routine maintenance and vessel inspections where there is no standby unit. Where replacement of catalysts or adsorbents exceeds this on-stream factor a parallel or stand-by unit has been provided so as there is no interruption to production.

Untreated liquid propane enters the system at 400 psig and 80°F. The propane inlet composition meets a typical HD-5 specification, with the following composition:

- 5% Ethane
- 1% Iso Butane
- 0.5% N- Butane

- 94.5% Propane, (may contain up to 5% Propylene)
- Water content meets HD-5 specification, approximately 10ppm_w H₂O
- Minimum copper strip is No 1
- COS concentration is 30ppm_w average. 50ppm_w maximum, 10ppm_w minimum

The treated propane composition shall meet the same HD-5 composition, with a COS concentration of less than 2ppm_w.

3.2. Economic Analysis

The economic analysis calculates the before tax, net present value for each design based on a 10% interest rate over a 10 year period.

Flat pricing without escalation has been applied to the economic analysis.

3.2.1. CAPITAL COSTS

The total installed cost has been assumed at 3.5 times the total major equipment cost, excepting the cost of adsorbent or catalyst materials. The total installed cost would include the cost of all major equipment, land, taxes, construction permits and site fees, on-site fabrications, erections, catalyst and adsorbent material loading, testing and commissioning to a point where the plant is operable.

The major equipment cost includes the key capital equipment items excepting the cost of the adsorbent or catalyst. Transportation of the major equipment is based on a nominal ratio, which also contributes to the total major equipment cost.

3.2.2. EQUIPMENT ESTIMATES

Vessel estimates have been developed from the vendor's specified bed diameter and height, with additional height for manway nozzles, and support media. Basic vessel design has been used to establish vessel weight. Carbon Steel has been used for vessel construction. Unless significantly higher levels of H₂S, CO₂, and H₂O are present then this material is adequately protected against corrosion.

A cost per weight relationship dependant on vessel size, shell wall thickness, and total fabricated weight has been used to establish the vessel unit cost. Allowances have been made for special internals such as screens to support sorbent materials.

Heater and cooler estimates have been calculated using Pearl project estimation formulae, which have been adjusted to reflect actual budget quotations and recent Pearl projects.

Heater costs have been estimated based on cabin-type fired heaters at a cost per duty relationship applied to requirements specified in the process model. A more integrated plant design may use a hot oil system for propane pre-heating, vaporization and regeneration heat, providing sufficient temperature and heat energy is available in the plant hot oil system.

Air coolers have been designed on ACX (Air Cooled Exchanger) software, to meet the process simulation duty requirements. A preliminary sizing has enabled coolers to be estimated on a cost per square foot by ratio to budget quotations and recent Pearl projects.

Economizer heat exchangers have been designed on STX (Shell and Tube Exchanger) software, to meet the process simulation requirements. This preliminary sizing has enabled estimation on a cost per surface area.

3.2.3. DEHYDRATION ESTIMATES

To ensure that the treated product still meets the Propane HD-5 moisture specification, dehydration beds have been sized by Zeochem to remove any excess water, which has been added for the hydrolysis reaction. Regeneration requirements have been built into the process and economic model. Where the molecular sieves are removing water only, the regeneration system is a closed loop design, recycling the propane to upstream of the dehydration beds.

3.2.4. OPERATING COSTS

The base operating cost has been assumed at 2% of the total installed cost. This would include expenses associated with the day-to-day operation of the plant, including on-site labor and supervision services, administration, insurance, and site fees. This does not include the cost of utilities (water, electricity, and gas), these are detailed in following sections.

3.2.5. ADSORBENT COSTS

The selection of suitable materials and costing of catalysts and/or sorbent materials has been specified by the vendor from their process design and field experience with their products.

A nominal 48 labor hours has been applied for every bed change, based on three to four people working for 16 to 12 hours. Wherever possible the vendor has proposed a system with minimum impact to production. This has been achieved through the use of parallel or lead-lag beds.

3.2.6. TRANSPORTATION AND DISPOSAL

Due to the ambiguity of site locations, a nominal site transportation fee of 3% of cost has been applied for new equipment and materials. While a spent media transportation fee of 1.5% of cost has been used due to a typically reduced transportation distance.

Where spent media is to be disposed instead of recycled, an additional fee of US\$500 would be added to allow for material testing. If the inlet gas contains benzene or mercury products these components may accumulate on the beds resulting in additional disposal costs. Disposal cost of hazardous waste is ultimately dependent on the contaminant and its concentration. Non-hazardous waste can be disposed of in landfills at US\$40/ton plus haulage costs. Hazardous waste can be as high as US\$370 per cubic foot for mercury contaminated material.

3.2.7. UTILITIES

Fuel, electricity, and water consumption costs have been based on vendor data and the process models and merged with fixed rates for fuel (US\$/MMBtu), electricity

(US\$/kWh), and water (US\$/1000 gal). Refer to Table VI, Economic analysis assumptions table.

3.3. Cost of Regeneration

All designs requiring regeneration have been evaluated utilizing the treated propane stream as the regeneration medium. Liquid propane is heated and vaporized by the regeneration heater to a regeneration temperature of 550°F. An economizer heat exchanger has been utilized in the process design for all of the large scale (300,000 gpd) comparisons. Normally propane used for the regeneration of dehydration beds can be cooled, flashed, and recycled without propane losses. Unfortunately, systems using propane to regenerate beds in H₂S or COS removal service cannot directly recycle the propane. In these cases the regeneration gas is contaminated and must be either regenerated externally or traded as a reduced revenue stream.

The economic analysis has been run for two different regeneration gas cases:

- ◆ Case A – The regeneration propane is burned as fuel gas in the plant. This results in recovering the regeneration propane at its gas heating value versus its value as HD-5 Propane.
- ◆ Case B – The regeneration gas is cooled and recycled in external plant, such as an amine train or sulfur removal unit. The costs of recycling are assumed to be negligible.

When propane is burned as fuel the calorific value of propane gas, 2314.90 Btu/scf has been used.

3.4. Syntex/ICI Chemicals, PURASPEC 5030 : Dry Chemical Adsorption

REFERENCE: Figures i and ii

COMPANY: Syntex / ICI Chemicals

PRODUCT: PURASPEC 5030, Sulfur Adsorbent

PURASPEC 5030 is a non-regenerable product consisting of a proprietary blend of copper and zinc oxides, which chemically react with sulfur to form stable metal sulfides. This method of sulfur control ensures that high propane purity can be achieved with little or no auxiliary equipment. By forming a stable metal sulfide the spent media can be disposed of as non-hazardous waste.

3.4.1. PROCESS DESIGN

Syntex has specified the bed materials, dimensions, and feed requirements. This particular design uses a product heater to warm the incoming propane to 168°F to increase the sulfur loading capacity and efficiency of the PURASPEC 5030 adsorbent. This particular adsorbent is more suited to applications with elevated inlet temperatures. For straight COS adsorption Syntex has experienced their best results with the PURASPEC 5030 operating at a slightly elevated temperature.

The 50,000 gpd design uses a fired heater and air cooler to meet the required treating temperatures. The 300,000 gpd case uses an additional shell and tube economizer to reduce heater and cooler duties by approximately 45%.

3.4.2. ECONOMIC ANALYSIS

Refer to Summary Tables I to V for results of the economic analysis.

If the low temperature adsorbent PURASPEC 5038, were used instead of warming the product stream the adsorbent costs would increase by US\$8060 and US\$48,360 per year for the 50,000 and 300,000 gpd cases respectively. The annual fuel and cooling cost required when using PURASPEC 5030, are approximately US\$28,000 and US\$113,000 for the 50,000 and 300,000 cases respectively, highlighting the need to further evaluate the use of this material in this application.

3.4.3. DESIGN LIMITATIONS

If other sulfur species such as H₂S are present, these molecules will co-load with the COS, reducing the estimated bed life of 6 months. Designers can avoid this problem if the non-regenerable beds are placed downstream of product dryers. Industry Standard 5A or 13X molecular sieve in product dryers will adsorb H₂S, while the more expensive non-regenerable bed is able to remove the non-polar COS contaminant.

3.4.4. DESIGN ADVANTAGES

PURASPEC 5030 like most non-regenerable products has the advantage of simplicity. Without regeneration the only auxiliary systems are for pre-heating and post-cooling. The main concern is timely monitoring of the outlet specification to establish when breakthrough of the bed has developed. The design includes a lead-lag arrangement that allows for full breakthrough and saturation of the sorbent material before replacement of that bed is necessary.

Due to the elevated treating temperature requirement of PURASPEC 5030, this material lends itself specifically to higher temperature applications where heating and cooling costs can be reduced or eliminated.

3.5. Syntex/ICI Chemicals, PURASPEC 5312/5038: Hydrolysis & Adsorption

REFERENCE: Figure iii and iv

COMPANY: Syntex / ICI Chemicals

PRODUCTS: PURASPEC 5312, Hydrolysis Catalyst

PURASPEC 5038, Sulfur Adsorbent

Zeochem 4A Z4-01 Dehydration Molecular Sieve

PURASPEC 5312 is an activated alumina hydrolysis catalyst for the conversion of COS to H₂S and CO₂. Catalyst degradation is by trace metal contamination. The granulated bed acts as a filter collecting small particles, which block active sites. Over time sufficient

de-activation of the catalyst will necessitate its replacement. Estimated catalyst life under normal operation is 5 or more years.

PURASPEC 5038 is a direct adsorbent, which uses a combination of copper and zinc metal oxides to remove the sulfur from the propane stream in stable metal sulfides. PURASPEC 5030 is similar to PURASPEC 5038, in that they are both copper-zinc sulfur adsorbents. PURASPEC 5038 contains a higher concentration of copper oxide and some proprietary promoters, making the adsorbent more suited to sulfur removal at ambient temperatures. The use of a hydrolysis bed upstream of the ambient temperature bed ensures a more efficient operation, ensuring a purer product stream. The spent media may be recycled for copper recovery or it may be disposed of as non-hazardous waste.

Zeochem Z4-01 (4A) is a standard 4A grade molecular sieve, commonly used for dehydration, but can also be used to remove ammonia and methanol. With the use of a sulfur adsorbent upstream, the 4A sieve removes excess H₂O and CO₂ from the hydrolysis reaction to meet the HD-5 specification.

3.5.1. PROCESS DESIGN

Syntex/ICI Chemicals has specified bed materials, dimensions, and feed requirements. This particular design requires excess water injection of 3 times the molar requirements before the hydrolysis bed in order to ensure complete hydrolysis of the COS. Care should be taken to ensure the propane and water mix thoroughly before the bed.

The beds operate at ambient temperature, which eliminates any requirement for feed preheating. Zeochem has designed the dehydration molecular sieves, which use vaporized propane for regeneration in a closed loop system. The regeneration gas from the 4A sieve beds is cooled and liquids removed, before recycling upstream of the dehydration bed. The 50,000 gpd design uses a fired heater and air cooler to meet the required regeneration temperatures. The 300,000 gpd case has an added shell and tube economizer to reduce heater and cooler duties by approximately 60%.

3.5.2. ECONOMIC ANALYSIS

Refer to Summary Tables I to V for results of the economic analysis

The use of vaporized treated propane for regeneration has been a philosophy adopted for all regenerable systems, which allows the COS purification plant to become a stand-alone unit.

By using a separate bed for dehydration it has been possible to recycle the propane used for regeneration. This has a considerable benefit for the long term operating costs of this plant.

In reality the dehydration beds may be part of downstream equipment such as propane product dryers, significantly effecting the operating and capital costs. However, for a consistent approach on all designs the dehydration beds have been included.

3.5.3. DESIGN LIMITATIONS

The disadvantage of this design is complexity and the amount of equipment installed.

Replacement rates of the PURASPEC 5038 are estimated at 6 month intervals. If the inlet gas contains benzene or mercury products these components may accumulate on the beds, adding to the cost of disposal.

Replacement rates of the catalyst and dehydration bed are comparable with other materials at 5 or more years. Replacement of the catalyst bed requires a temporary bypass operation or a plant shutdown. The vendor has designed bed change-outs to meet the 98% on-stream factor.

3.5.4. DESIGN ADVANTAGES

The use of a three bed system to differentiate between sulfur removal and water removal, has the distinct advantage of minimizing COS production from reverse hydrolysis by separating the reactants into separate beds. COS formation is a common problem resulting from 4A or 13X dehydration beds when H₂S and CO₂ are present.

The second advantage in a three bed design, is the reduced long term operating expense. The 10 year horizon NPV calculation illustrates these benefits. Longer life cycle comparisons will enhance this advantage.

3.6. Sud Chemie, G-132D : Dry Chemical Adsorption

REFERENCE: Figures v and vi

COMPANY: Sud Chemie

PRODUCT: G-132D, Sulfur Adsorbent

G-132D, is a non-regenerable product consisting of a blend of mixed metal oxides including copper and zinc oxides in an alumina binder. The product reacts with a range of sulfur species including COS to form metal sulfides within the bed. G-132D has been developed as a finishing product to ensure high purity upstream of a polymerization plant.

The spent adsorbent may be recycled for metals recovery or disposed of as non-hazardous waste.

3.6.1. PROCESS DESIGN

Sud Chemie has specified bed materials, dimensions, and feed requirements. This particular product treats the feed stream at ambient temperatures.

3.6.2. ECONOMIC ANALYSIS

Refer to Summary Tables I to V for results of the economic analysis

3.6.3. DESIGN LIMITATIONS

The largest design limitation on G-132D is the design sulfur loading of 5% wt sulfur. As a result bed sizes are considerably larger and require more frequent change out. Estimated bed life is 3 months, thereby significantly increasing the plant long term operating costs.

When queried, Sud Chemie, prefer to specify larger than necessary bed sizes to ensure that the design meets or exceeds the required contaminant specifications, with allowances for additional capacity. If the bed is oversized this leads to improved specifications, thereby

allowing bypass of a portion of untreated gas to regulate to the 2ppm_w specification. Bed life would therefore be wholly dependant on the maximum sulfur loading, which has not been specified and would require laboratory or pilot plant testing to determine.

It should be noted that G-132D will co-load with other sulfur species such as H₂S, thereby reducing the estimated bed life of 6 months. Designers can avoid this problem if the non-regenerable beds are placed downstream of product dryers. Industry standard 5A or 13X molecular sieve in product dryers will adsorb H₂S, while the more expensive non-regenerable G-132D is able to remove the COS contaminant.

3.6.4. DESIGN ADVANTAGES

The ability to treat the propane at ambient temperatures, eliminates the need for additional capital equipment as required for other designs and the high copper concentration in spent material may be recycled for metals recovery under certain circumstances.

When installed in a lead-lag arrangement full breakthrough of the first adsorbent bed can occur to fully saturate the adsorbent before replacement.

3.7. Sud Chemie, C53-2-01 : Hydrolysis and Adsorption

REFERENCE: Figure vii and viii

COMPANY: Sud Chemie / Zeochem

PRODUCTS: Sud Chemie; C-53-2-01, Hydrolysis Catalyst

Zeochem; 5A Z5-01, H₂O, H₂S and CO₂ Adsorbent Molecular Sieve

Sud Chemie C53-2-01 is a platinum on alumina, hydrogenation catalyst for the conversion of COS to H₂S and CO₂. The design requires water injection at a minimum of 5 times the molar requirement upstream of the hydrolysis bed in order to enhance the hydrolysis reaction. Care should be taken to ensure proper mixing of the water and propane. This particular catalyst has been used in the syn-gas industry for over 30 years. Catalyst degradation in this application is commonly by trace metal contamination. The granulated bed acts as a filter, collecting small particles, which block active sites. Over time sufficient de-activation of the catalyst will necessitate its replacement. Estimated catalyst life under normal operation is 5 or more years.

Zeochem 5A Z5-01 is a standard 5A grade molecular sieve. This sieve has been installed to cost effectively remove H₂S, CO₂ and excess water from the treated stream by Adsorption. The 5A molecular sieve unlike 4A or 13X molecular sieve is able to reach the 2ppm_w COS specification at the given regeneration frequencies. If tighter COS specifications are required a low-sodium 5A molecular sieve, such as Zeochem's Z5-03 or Grace Davison's SZ-5 could be used to minimize COS formation due to reverse hydrolysis of H₂S and CO₂ back to COS and H₂O.

3.7.1. PROCESS DESIGN

Sud Chemie has specified bed materials, dimensions and feed requirements for the hydrolysis catalyst. Zeochem has designed the 5A Z5-01 sieve, which uses vaporized treated propane for regeneration. A fired heater provides regeneration fluid vaporization

and heating. Outlet regeneration gas is cooled in an air cooler to ambient temperatures. The 300,000 gpd case has a shell and tube economizer to reduce heater and cooler duties by approximately 60%.

3.7.2. ECONOMIC ANALYSIS

Refer to Summary Tables I to V for results of the economic analysis

The use of propane for regeneration is a high operating cost option. The cost varies depending on the use of the propane after regeneration. For this reason the economic analysis has been completed from two perspectives. Case A, involves the recycling of rich regen gas to the fuel system where it is recovered at the heating value of fuel gas. Case B, recycles the COS rich regen gas in an external plant, either amine train or sulfur removal unit, where the cost of processing is assumed negligible.

The cost of the platinum hydrogenation catalyst is also a large factor in the initial capital and ongoing maintenance considerations. The use of this catalyst is one aspect the end user should consider carefully. Sud Chemie anticipates improved performance and reliability to accompany the more expensive platinum catalyst. Unfortunately it has not been possible to quantify these benefits as part of this economic analysis.

3.7.3. DESIGN LIMITATIONS

The main disadvantage of this design is complexity and the amount of capital equipment.

3.7.4. DESIGN ADVANTAGES

If a cost effective regeneration gas system can be implemented the 2 bed hydrolysis system provides the reliability to handle considerably higher concentrations of COS and H₂S in the feed stream. The same design provides less concern with the co-loading of CO₂ and other compounds, as the bed loading is a function of the regeneration / processing ratio. The regeneration frequency and cycle times being adjusted to accommodate variable process loads.

The major advantage of regenerable designs is the reduced long term operating expense. The 10 year NPV analysis illustrates the long-term benefits of this design.

3.8. BASF, R 3-12 : Dry Chemical Adsorption

REFERENCE: Figures ix and x

COMPANY: BASF

PRODUCT: R 3-12, Sulfur Adsorbent

R 3-12 is a non-regenerable adsorbent consisting of a blend of copper and zinc oxides in an alumina binder. The product reacts with a range of sulfur species including COS to form metal sulfides within the bed. R 3-12 has been used extensively for propane and propylene purification where removal of COS and Arsine is required upstream of polymerization plants to the parts per billion range is required.

3.8.1. PROCESS DESIGN

BASF has specified bed materials, dimensions, and feed requirements. This particular product treats the feed stream at ambient temperatures.

3.8.2. ECONOMIC ANALYSIS

Refer to Summary Tables I to V for results of the economic analysis

3.8.3. DESIGN LIMITATIONS

R 3-12 will also remove H₂S, however, any H₂S will co-load with COS for the 20%wt sulfur loading capacity. Designers can avoid this problem if the non-regenerable beds are placed downstream of product dryers. Industry standard 5A or 13X molecular sieve in product dryers will adsorb H₂S, while the more expensive non-regenerable R 3-12 is able to remove the remaining COS contaminant.

When shipped the adsorbent contains up to 6-8 %wt water, which may also require drying prior to placing on line. No cost impact for bed drying has been included in the model.

3.8.4. DESIGN ADVANTAGE

Simplistic design of the direct adsorbent system provides an economically viable design with low capital costs, low operating costs and a high operability factor. A lead-lag arrangement allows fully saturating the adsorbent before replacement, thus maximizing the utilization of the adsorbent.

According to BASF, the bed design is capable of handling an additional 33% flowrate. However, as sulfur loadings increase so will the change out frequency. In the lead lag arrangement BASF has been able to accurately predict efficient operation with space velocities up to 10 hr⁻¹ (Design is 7.5⁻¹hr).

BASF encourages the user to recycle the spent adsorbent for metals recovery. If recycling is uneconomic the material may generally be disposed of as non-hazardous waste, depending on the levels of contaminants such as benzene, mercury and arsine from feed stream.

3.9. UOP, RK-29II : Dehydration and Adsorption

REFERENCE: Figures xi and xii

COMPANY: UOP

PRODUCT: 3A dehydration molecular sieve
RK-29II, molecular sieve

3A-DG molecular sieve is a preferred molecular sieve for dehydration. This material will adsorb Water, while H₂S, CO₂ and mercaptans are too large.

RK-29II is an A-type crystalline zeolite of nominal pore size 5 angstroms. It is used for the removal of H₂S, Methyl mercaptans and COS.

3.9.1. PROCESS DESIGN

UOP has specified bed materials, dimensions, and regeneration requirements. The design removes COS in a molecular sieve, by a two stage approach.

3A molecular sieve is designed to dehydrate the product stream, forcing the hydrolysis reaction to minimize further production of COS. Breakthrough of H₂O would displace COS in the downstream bed of RK-29II.

The combination of 3A and RK-29II in this manner, provides a regenerable design to remove COS.

Open loop regeneration is provided by vaporization and heating a slipstream of treated propane to regeneration temperatures. The 50,000 gpd case uses a fired heater and air cooler to meet the required regeneration conditions. The 300,000 gpd case has added a shell and tube economizer to reduce heater and cooler duties by approximately 60%.

3.9.2. ECONOMIC ANALYSIS

Refer to Summary Tables I to V for results of the economic analysis

The use of vaporized treated propane for regeneration has been a philosophy adopted for all regenerable systems to allow the COS purification plant to become a stand-alone unit. This approach results in high operating expenses. Use of an alternative regeneration may significantly affect the economics on this design.

For this reason the economic analysis has been completed from two perspectives. Case A, involves the recycling of rich regen gas to the fuel system where it is recovered at the heating value of fuel gas. Case B, recycles the COS rich regen gas in an external plant, either amine train of sulfur removal unit, where the cost of processing is assumed negligible

3.9.3. DESIGN LIMITATIONS

Replacement rates of the 3A and RK-29II materials are estimated at 3 or more years depending on contaminants within the feed stream. Performance is significantly reduced with the presence of olefins and diolefins. Performance is further reduced as the feed stream temperature increases.

RK-29II will adsorb H₂O, CO₂, and H₂S. However, the hydrolysis of H₂S and CO₂ to form COS is minimized in a similar manner as a "low-sodium" molecular sieve. These contaminants are adsorbed more strongly, forcing the COS to breakthrough first. If these contaminants are present larger bed sizes may be required.

3.9.4. DESIGN ADVANTAGES

The two adsorbent materials share the same processing / regeneration cycles, enabling assembly within the same vessel, reducing capital equipment and costs.

3.10. ALCOA, Selexsorb COS : Direct Adsorption

REFERENCE: Figures xiii and xiv

COMPANY: ALCOA

PRODUCT: SelexsorbCOS : regenerable adsorbent

SelexsorbCOS is a unique material for the selective removal by chemisorption of CO₂, COS, H₂S and CS₂ to concentrations to protect polymerization catalyst beds from COS degradation. Specific details such as composition are proprietary to Alcoa.

3.10.1. PROCESS DESIGN

Alcoa has provided the bed sizing and regeneration requirements for Selexsorb COS adsorbent. It should be noted that the bed sizing would increase with the presence of CO₂ and H₂S.

Regeneration is provided by vaporization and heating of a slipstream of the treated propane to regeneration temperatures. The 50,000 gpd case uses a fired heater and air cooler to meet the required regeneration conditions. The 300,000 gpd case has added a shell and tube economizer to reduce the heater and cooler duties by approximately 60%.

3.10.2. ECONOMIC ANALYSIS

Refer to Summary Tables I to V for results of the economic analysis

The use of vaporized treated propane for regeneration has been a philosophy adopted for all regenerable systems. It allows the COS purification plant to operate as a stand-alone unit. This approach results in a high operating expense.

For this reason the economic analysis has been completed from two perspectives. Case A, involves the recycling of rich regen gas to the fuel system where it is recovered at the heating value of fuel gas. Case B, recycles the COS rich regen gas in an external plant, either amine train of sulfur removal unit, where the cost of processing is assumed negligible

3.10.3. DESIGN LIMITATIONS

Performance of SelexsorbCOS will start to decline slowly above 120°F as the sulfur loading ability is reduced. Maximum recommended inlet temperatures are between 104 to 122°F

3.10.4. DESIGN ADVANTAGES

The Selexsorb COS is presently the only direct Adsorption product on the market to remove COS from propane. As a result the system is the simplest regenerable design to reach product specification suitable for polymerization feed streams.

3.10.5. OTHER ALCOA PRODUCTS

Alcoa also makes a desiccant suitable for dehydrating propane as well as a non-regenerative COS adsorption (via CuO-promoted alumina) product. In this study, Selexsorb was the only product for which Pearl requested a design from Alcoa, but it may be that another of the Alcoa products could be used for COS removal in a manner similar to other materials discussed in this report.

3.11. 13X Molecular Sieve

13X molecular sieve has not been economically evaluated in this study because it is unsuitable for the removal of COS. While 13X is an inefficient material for removing COS, it is utilized frequently as a material to treat liquid streams contaminated with H₂S.

13X is similar to the 4A, sodium aluminosilicate crystal, excepting its body centered cubic design (X-Type), rather than the cubic design (A-Type). 13X has a pore size of approximately 10 Angstroms, making it suitable for the Adsorption of H₂O, CO₂, H₂S, and also much larger molecules such as Benzene and Carbon Tetrachloride.

For some time, the reverse hydrolysis of H₂S and CO₂ to form COS on a molecular sieve was not commonly understood. There have been a number of reports written and tests performed, demonstrating the COS breakthrough well before H₂S or CO₂.

When sufficient concentrations of both H₂S and CO₂ combine on the molecular sieve, the equilibrium point of the hydrolysis reaction will move to generate COS and H₂O. The H₂O is adsorbed on the bed and COS is displaced by H₂O, CO₂ or H₂S. This reaction is catalyzed by the large surface area of the 13X sieve and the basicity of the sodium cation crystal.

The hydrolysis of H₂S and CO₂ to form COS has been the motivation behind the low sodium or “deep sodium exchange” series of molecular sieves. The multiple exchange sieves exchange the sodium cations with divalent calcium to reduce the basicity.

Grace Davison have developed SZ-5 a “deep sodium exchanged” 5A sieve to minimize the COS formation experienced when using standard 5A or 4A sieve. In a similar manner they have also developed SZ-9 a low-sodium 13X molecular sieve.

4. METHODS AND LIMITATIONS

The process models conducted by Pearl Development Company have been performed using HYSYS™ software for steady state analysis. Analysis of Air Coolers has been performed using ACX™, (Air Cooled Exchanger) software. The Economizer Heat Exchangers were evaluated using STX™, (Shell and Tube Exchanger) software.

As discussed in previous sections the accuracy of the conclusions in this report are limited by the design factors individual vendors place on a process design. This emphasizes the need to conduct experimental loading tests with these materials.

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- 7) Trent, Robert and Mike Schneider, Zeochem; Ph (502) 634.7667; fax (502) 634.8123; P.O. Box 35940, Louisville, KY, 40232

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APPENDIX A.1

DATA TABLES

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TABLE I : Treating Cost Comparison
 (US Dollars)

Client: Gas Processors Association
 Project: COS Removal from Liquid Propane
 Location: -
 Project No.: 0004.168

Rev. 0
 Date 10/29/2000
 By SJW/PJA

Vendor	Synetix / ICI Chemicals	Synetix / ICI Chemicals	Sud Chemie	Sud Chemie	BASF	UOP	ALCOA
Design	Single Stage, Dry Adsorption	3 Stage, Hydrolysis, Adsorption and Dehydration	Single Stage, Dry Adsorption	2 Stage, Hydrolysis and Adsorption	Single Stage, Dry Adsorption	2 Stage, Dehydration + Sulfur Adsorption in single vessel	Single Stage, Dry Adsorption
Regeneration Media	Non-Regenerable	Vaporized Treated Propane	Non-Regenerable	Vaporized Treated Propane	Non-Regenerable	Vaporized Treated Propane	Vaporized Treated Propane
Product/s	Puraspec 5030	Puraspec 5312, Puraspec 5038	G132D	C53-2-01, 5A Molecular Sieve	R3-12	3A + RK29II	Selexsorb COS

NPV(10) Based Treating Cost								
50,000 gpd case with Regen Propane recovered as fuel	US Cents/gallon Propane	(0.5074)	(0.5788)	(2.7781)	(0.4925)	(0.3718)	(1.9288)	(1.0121)
50,000 gpd case with Regen Propane recycled	US Cents/gallon Propane	(0.3998)	(0.4972)	(1.4943)	(0.3914)	(0.2379)	(0.6201)	(0.4828)
300,000 gpd case with Regen Propane recovered as fuel	US Cents/gallon Propane	(0.3391)	(0.3140)	(2.6060)	(0.2291)	(0.2715)	(1.5568)	(0.7042)
300,000 gpd case with Regen Propane recycled	US Cents/gallon Propane	(0.2497)	(0.2442)	(1.3580)	(0.1269)	(0.1555)	(0.2481)	(0.1999)

NOTES:
 1 Net Present Value calculations are based on an "end of year" convention, excepting capital expenses, which are assumed to be spent on day 1 of the project due to the size of each installation.
 2 Prices expressed as "US Cents/gallon Propane", are based on Treated or "Sales Propane" flow rates.
 3 Capital and operational expenses are based on "flat prices" with no escalation.

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TABLE II : Economic Analysis - Summary Sheet : CASE A1

(US Dollars)

Client: Gas Processors Association
 Project: COS Removal from Liquid Propane
 Location: -
 Project No.: 0004.168

CASE DESCRIPTION:
50,000 gal/day Propane - Regeneration Gas Recovered for Fuel Gas

Rev. 0
 Date 10/29/2000
 By SJW/PJA

Vendor Design	Synetix / ICI Chemicals Single Stage, Dry Adsorption	Synetix / ICI Chemicals 3 Stage, Hydrolysis, Adsorption and Dehydration	Sud Chemie Single Stage, Dry Adsorption	Sud Chemie 2 Stage, Hydrolysis and Adsorption	BASF Single Stage, Dry Adsorption	UOP 2 Stage, Dehydration + Sulfur Adsorption in single vessel	ALCOA Single Stage, Dry Adsorption
Regeneration Media Product/s	Non-Regenerable Puraspec 5030	Vaporized Treated Propane Puraspec 5312, Puraspec 5038	Non-Regenerable G132D	Vaporized Treated Propane C53-2-01, 5A Molecular Sieve	Non-Regenerable R3-12	Vaporized Treated Propane 3A + RK29II	Vaporized Treated Propane Selexsorb COS

Gross Production							
PROPANE							
Gross Inlet Propane (gpd)	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Gross Propane Used for Regen (gpd)	-	-	-	(387)	-	(4,588)	(1,927)
Gross Propane Sales (gpd)	50,000	50,000	50,000	49,613	50,000	45,412	48,073
FUEL GAS							
Regen Gas, Recovered for Fuel Gas (MMBtu/d)	-	-	-	33	-	386	162
Fuel Gas Usage (MMBtu/d)	(33)	(6)	-	(7)	-	(35)	(18)
Total Fuel Gas (MMBtu/d)	(33)	(6)	-	26	-	351	144

Net Revenue							
Incremental Propane Revenue	-	-	-	(553,906)	-	(6,564,808)	(2,757,220)
Net Fuel Gas Revenue	(268,683)	(50,607)	-	207,720	-	2,826,615	1,155,431
Total Net Revenue	US Dollars (268,683)	(50,607)	-	(346,186)	-	(3,738,193)	(1,601,789)
	US Dollars/gallon Propane (0.0015)	(0.0003)	-	(0.0020)	-	(0.0230)	(0.0093)

Net Operating Costs							
Base Operating Costs	(29,680)	(19,110)	(61,320)	(29,680)	(32,060)	(54,600)	(54,180)
Chemical Make-Up Costs	(274,324)	(285,259)	(3,466,024)	(96,175)	(339,512)	(88,636)	(91,051)
Disposal Costs	1,997	(3,962)	(159)	24,369	1,988	(1,173)	(1,723)
Utilities	(11,830)	(3,874)	-	(7,025)	-	(20,352)	(18,395)
Total Net Operating Costs	US Dollars (313,837)	(312,204)	(3,527,503)	(108,511)	(369,584)	(164,761)	(165,349)
	US Dollars/gallon Propane (0.0018)	(0.0017)	(0.0197)	(0.0006)	(0.0021)	(0.0010)	(0.0009)

Total Gross Profit	US Dollars (582,519)	(363,035)	(3,527,503)	(452,128)	(369,584)	(3,896,942)	(1,757,961)
	US Dollars/gallon Propane (0.0033)	(0.0020)	(0.0197)	(0.0025)	(0.0021)	(0.0240)	(0.0102)

Net Capital Costs							
Total Equipment Costs	(94,869)	(178,199)	(90,228)	(159,504)	(47,174)	(204,708)	(179,244)
Total Initial Chemical Fill	(38,265)	(51,747)	(271,627)	(46,823)	(49,769)	(25,197)	(35,965)
Total Installation Cost	(237,173)	(445,498)	(225,570)	(398,759)	(117,935)	(511,771)	(448,109)
Total Net Capital Costs	US Dollars (370,307)	(677,801)	(587,425)	(605,086)	(214,878)	(741,676)	(663,318)
	US Dollars/gallon Propane (0.0021)	(0.0038)	(0.0033)	(0.0034)	(0.0012)	(0.0046)	(0.0039)

Total Taxable Income	US Dollars (952,827)	(1,040,836)	(4,114,929)	(1,057,214)	(584,462)	(4,638,618)	(2,421,279)
	US Dollars/gallon Propane (0.0053)	(0.0058)	(0.0230)	(0.0060)	(0.0033)	(0.0286)	(0.0141)

Total BT Cash Flow	US Dollars (952,827)	(1,040,836)	(4,114,929)	(1,057,214)	(584,462)	(4,638,618)	(2,421,279)
	US Dollars/gallon Propane (0.0053)	(0.0058)	(0.0230)	(0.0060)	(0.0033)	(0.0286)	(0.0141)

Present Value							
PV(10) of Propane Revenue	-	-	-	(340,351)	-	(4,033,791)	(1,694,192)
PV(10) of Fuel Gas Revenue	(165,094)	(31,096)	-	127,635	-	1,736,833	709,962
PV(10) of Operating Expense	(179,728)	(180,332)	(2,085,211)	(56,141)	(210,574)	(94,446)	(92,761)
PV(10) of Capital Expense	(370,307)	(677,801)	(587,425)	(605,086)	(214,878)	(741,676)	(663,318)
NPV(10)	US Dollars (715,129)	(889,229)	(2,672,637)	(873,943)	(425,453)	(3,133,080)	(1,740,308)
	US Dollars/gallon Propane (0.0040)	(0.0050)	(0.0149)	(0.0049)	(0.0024)	(0.0193)	(0.0101)

NOTES:
 1 Net Present Value calculations are based on an "end of year" convention, excepting capital expenses, which are assumed to be spent on day 1 of the project due to the size of each installation.
 2 Prices expressed as "US Dollars/gallon Propane", are based on Treated or "Sales Propane" flow rates.
 3 Capital and operational expenses are based on "flat prices" with no escalation.

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TABLE III : Economic Analysis - Summary Sheet : CASE A2
(US Dollars)

Client: Gas Processors Association
Project: COS Removal from Liquid Propane
Location: -
Project No.: 0004.168

CASE DESCRIPTION:
300,000 gal/day Propane - Regeneration Gas Recovered for Fuel Gas

Rev. 0
Date 10/29/2000
By SJW/PJA

Vendor Design	Synetix / ICI Chemicals Single Stage, Dry Adsorption	Synetix / ICI Chemicals 3 Stage, Hydrolysis, Adsorption and Dehydration	Sud Chemie Single Stage, Dry Adsorption	Sud Chemie 2 Stage, Hydrolysis and Adsorption	BASF Single Stage, Dry Adsorption	UOP 2 Stage, Dehydration + Sulfur Adsorption in single vessel	ALCOA Single Stage, Dry Adsorption
Regeneration Media Product/s	Non-Regenerable Puraspec 5030	Vaporized Treated Propane Puraspec 5312, Puraspec 5038	Non-Regenerable G132D	Vaporized Treated Propane C53-2-01, 5A Molecular Sieve	Non-Regenerable R3-12	Vaporized Treated Propane 3A + RK29II	Vaporized Treated Propane Selexsorb COS

Gross Production							
PROPANE							
Gross Inlet Propane (gpd)	300,000	300,000	300,000	300,000	300,000	300,000	300,000
Gross Propane Used for Regen (gpd)	-	-	-	(2,349)	-	-	(11,241)
Gross Propane Sales (gpd)	300,000	300,000	300,000	297,651	300,000	272,471	288,759
FUEL GAS							
Regen Gas, Recovered for Fuel Gas (MMBtu/d)	-	-	-	197	-	2,315	945
Fuel Gas Usage (MMBtu/d)	(139)	(10)	-	(9)	-	(51)	(26)
Total Fuel Gas (MMBtu/d)	(139)	(10)	-	189	-	2,264	919

Net Revenue							
Incremental Propane Revenue	-	-	-	(3,360,361)	-	(39,388,851)	(16,083,781)
Net Fuel Gas Revenue	(1,118,192)	(77,456)	-	1,518,366	-	18,221,013	7,394,755
Total Net Revenue	(1,118,192)	(77,456)	-	(1,841,995)	-	(21,167,838)	(8,689,026)
US Dollars							
US Dollars/gallon Propane	(0.0010)	(0.0001)	-	(0.0017)	-	(0.0217)	(0.0084)

Net Operating Costs							
Base Operating Costs	(102,620)	(57,750)	(177,660)	(32,620)	(68,890)	(166,740)	(147,000)
Chemical Make-Up Costs	(1,354,695)	(1,395,420)	(20,186,576)	(411,509)	(1,743,455)	(333,688)	(381,218)
Disposal Costs	11,950	(25,896)	(955)	144,627	11,928	(6,882)	(9,201)
Utilities	(15,299)	(22,961)	-	(38,092)	-	(120,545)	(106,490)
Total Net Operating Costs	(1,460,663)	(1,502,027)	(20,365,191)	(337,594)	(1,800,408)	(627,855)	(643,910)
US Dollars							
US Dollars/gallon Propane	(0.0014)	(0.0014)	(0.0190)	(0.0003)	(0.0017)	(0.0006)	(0.0006)

Total Gross Profit	US Dollars	(2,578,511)	(1,581,104)	(20,365,191)	(2,164,031)	(1,800,408)	(21,761,187)	(9,280,220)
US Dollars/gallon Propane		(0.0024)	(0.0015)	(0.0190)	(0.0020)	(0.0017)	(0.0223)	(0.0090)

Net Capital Costs							
Total Equipment Costs	(267,317)	(365,265)	(261,414)	(248,572)	(101,352)	(476,274)	(401,429)
Total Initial Chemical Fill	(228,217)	(317,958)	(1,627,959)	(278,287)	(297,217)	(146,519)	(179,443)
Total Installation Cost	(668,294)	(981,689)	(653,535)	(621,431)	(253,380)	(1,190,686)	(1,003,573)
Total Net Capital Costs	(1,163,828)	(1,678,853)	(2,542,908)	(1,148,290)	(651,949)	(1,813,480)	(1,584,446)
US Dollars							
US Dollars/gallon Propane	(0.0011)	(0.0016)	(0.0024)	(0.0011)	(0.0006)	(0.0019)	(0.0015)

Total Taxable Income	US Dollars	(3,742,338)	(3,287,368)	(22,908,099)	(3,312,321)	(2,452,357)	(23,574,666)	(10,864,666)
US Dollars/gallon Propane		(0.0035)	(0.0031)	(0.0213)	(0.0031)	(0.0023)	(0.0242)	(0.0105)

Total BT Cash Flow	US Dollars	(3,742,338)	(3,287,368)	(22,908,099)	(3,312,321)	(2,452,357)	(23,574,666)	(10,864,666)
US Dollars/gallon Propane		(0.0035)	(0.0031)	(0.0213)	(0.0031)	(0.0023)	(0.0242)	(0.0105)

Present Value							
PV(10) of Propane Revenue	-	-	-	(2,064,797)	-	(24,202,744)	(9,882,787)
PV(10) of Fuel Gas Revenue	(687,080)	(47,594)	-	932,970	-	11,196,023	4,543,757
PV(10) of Operating Expense	(828,242)	(866,963)	(12,029,547)	(159,341)	(1,016,776)	(352,839)	(349,796)
PV(10) of Capital Expense	(1,163,828)	(1,706,264)	(2,542,908)	(1,148,290)	(651,949)	(1,813,480)	(1,584,446)
NPV(10)	(2,679,150)	(2,620,821)	(14,572,456)	(2,439,458)	(1,668,725)	(15,173,039)	(7,273,272)
US Dollars							
US Dollars/gallon Propane	(0.0025)	(0.0024)	(0.0136)	(0.0023)	(0.0016)	(0.0156)	(0.0070)

NOTES:
1 Net Present Value calculations are based on an "end of year" convention, excepting capital expenses, which are assumed to be spent on day 1 of the project due to the size of each installation.
2 Prices expressed as "US Dollars/gallon Propane", are based on Treated or "Sales Propane" flow rates.
3 Capital and operational expenses are based on "flat prices" with no escalation.

PEARL DEVELOPMENT COMPANY

BUSINESS DEVELOPMENT, ENGINEERING, AND CONSTRUCTION MANAGEMENT

TABLE IV : Economic Analysis - Summary Sheet : CASE B1
(US Dollars)

Client: Gas Processors Association
Project: COS Removal from Liquid Propane
Location: -
Project No.: 0004.168

CASE DESCRIPTION:
50,000 gal/day Propane - Regeneration Gas Recycled

Rev. 0
Date 10/29/2000
By SJW/PJA

Vendor	Synetix / ICI Chemicals	Synetix / ICI Chemicals	Sud Chemie	Sud Chemie	BASF	UOP	ALCOA
Design	Single Stage, Dry Adsorption	3 Stage, Hydrolysis, Adsorption and Dehydration	Single Stage, Dry Adsorption	2 Stage, Hydrolysis and Adsorption	Single Stage, Dry Adsorption	2 Stage, Dehydration + Sulfur Adsorption in single vessel	Single Stage, Dry Adsorption
Regeneration Media Product/s	Non-Regenerable Puraspec 5030	Vaporized Treated Propane Puraspec 5312, Puraspec 5038	Non-Regenerable G132D	Vaporized Treated Propane C53-2-01, 5A Molecular Sieve	Non-Regenerable R3-12	Vaporized Treated Propane 3A + RK29II	Vaporized Treated Propane Selexsorb COS

Gross Production							
PROPANE							
Gross Inlet Propane (gpd)		50,000	50,000	50,000	50,000	50,000	50,000
Gross Propane Used for Regen (gpd)		-	-	-	(387)	-	(4,588)
Gross Propane Sales (gpd)		50,000	50,000	50,000	49,613	50,000	45,412
FUEL GAS							
Regen Gas, Recovered for Fuel Gas (MMBtu/d)		-	-	-	-	-	-
Fuel Gas Usage (MMBtu/d)		(33)	(6)	-	(7)	-	(35)
Total Fuel Gas (MMBtu/d)		(33)	(6)	-	(7)	-	(35)

Net Revenue							
Incremental Propane Revenue		-	-	-	-	-	-
Net Fuel Gas Revenue		(268,683)	(50,607)	-	(54,277)	-	(278,534)
Total Net Revenue	US Dollars	(268,683)	(50,607)	-	(54,277)	-	(278,534)
	US Dollars/gallon Propane	(0.0015)	(0.0003)	-	(0.0003)	-	(0.0017)

Net Operating Costs							
Base Operating Costs		(29,680)	(19,110)	(61,320)	(29,680)	(32,060)	(54,600)
Chemical Make-Up Costs		(274,324)	(285,259)	(3,466,024)	(96,175)	(339,512)	(88,636)
Disposal Costs		1,997	(3,962)	(159)	24,369	1,988	(1,173)
Utilities		(11,830)	(3,874)	-	(7,025)	-	(20,352)
Total Net Operating Costs	US Dollars	(313,837)	(312,204)	(3,527,503)	(108,511)	(369,584)	(164,761)
	US Dollars/gallon Propane	(0.0018)	(0.0017)	(0.0197)	(0.0006)	(0.0021)	(0.0010)

Total Gross Profit	US Dollars	(582,519)	(363,035)	(3,527,503)	(160,220)	(369,584)	(437,283)
	US Dollars/gallon Propane	(0.0033)	(0.0020)	(0.0197)	(0.0009)	(0.0021)	(0.0027)

Net Capital Costs							
Total Equipment Costs		(94,869)	(178,199)	(90,228)	(159,504)	(47,174)	(204,708)
Total Initial Chemical Fill		(38,265)	(51,747)	(271,627)	(46,823)	(49,769)	(25,197)
Total Installation Cost		(237,173)	(445,498)	(225,570)	(398,759)	(117,935)	(511,771)
Total Net Capital Costs	US Dollars	(370,307)	(677,801)	(587,425)	(605,086)	(214,878)	(741,676)
	US Dollars/gallon Propane	(0.0021)	(0.0038)	(0.0033)	(0.0034)	(0.0012)	(0.0046)

Total Taxable Income	US Dollars	(952,827)	(1,040,836)	(4,114,929)	(765,306)	(584,462)	(1,178,959)
	US Dollars/gallon Propane	(0.0053)	(0.0058)	(0.0230)	(0.0043)	(0.0033)	(0.0073)

Total BT Cash Flow	US Dollars	(952,827)	(1,040,836)	(4,114,929)	(765,306)	(584,462)	(1,178,959)
	US Dollars/gallon Propane	(0.0053)	(0.0058)	(0.0230)	(0.0043)	(0.0033)	(0.0073)

Present Value							
PV(10) of Propane Revenue		-	-	-	-	-	-
PV(10) of Fuel Gas Revenue		(165,094)	(31,096)	-	(33,351)	-	(171,147)
PV(10) of Operating Expense		(179,728)	(180,332)	(2,085,211)	(56,141)	(210,574)	(94,446)
PV(10) of Capital Expense		(370,307)	(677,801)	(587,425)	(605,086)	(214,878)	(741,676)
NPV(10)	US Dollars	(715,129)	(889,229)	(2,672,637)	(694,578)	(425,453)	(1,007,270)
	US Dollars/gallon Propane	(0.0040)	(0.0050)	(0.0149)	(0.0039)	(0.0024)	(0.0062)

NOTES:
 1 Net Present Value calculations are based on an "end of year" convention, excepting capital expenses, which are assumed to be spent on day 1 of the project due to the size of each installation.
 2 Prices expressed as "US Dollars/gallon Propane", are based on Treated or "Sales Propane" flow rates.
 3 Capital and operational expenses are based on "flat prices" with no escalation.

PEARL DEVELOPMENT COMPANY
BUSINESS DEVELOPMENT, ENGINEERING, AND CONSTRUCTION MANAGEMENT

TABLE V : Economic Analysis - Summary Sheet : CASE B2
(US Dollars)

Client: Gas Processors Association
Project: COS Removal from Liquid Propane
Location: -
Project No.: 0004.168

CASE DESCRIPTION:
300,000 gal/day Propane - Regeneration Gas Recycled

Rev. 0
Date 10/29/2000
By SJW/PJA

Vendor Design	Synetix / ICI Chemicals Single Stage, Dry Adsorption	Synetix / ICI Chemicals 3 Stage, Hydrolysis, Adsorption and Dehydration	Sud Chemie Single Stage, Dry Adsorption	Sud Chemie 2 Stage, Hydrolysis and Adsorption	BASF Single Stage, Dry Adsorption	UOP 2 Stage, Dehydration + Sulfur Adsorption in single vessel	ALCOA Single Stage, Dry Adsorption
Regeneration Media Product/s	Non-Regenerable Puraspec 5030	Vaporized Treated Propane Puraspec 5312, Puraspec 5038	Non-Regenerable G132D	Vaporized Treated Propane C53-2-01, 5A Molecular Sieve	Non-Regenerable R3-12	Vaporized Treated Propane 3A + RK29II	Vaporized Treated Propane Selexorb COS

Gross Production							
PROPANE							
Gross Inlet Propane (gpd)	300,000	300,000	300,000	300,000	300,000	300,000	300,000
Gross Propane Used for Regen (gpd)	-	-	-	(2,349)	-	-	(11,241)
Gross Propane Sales (gpd)	300,000	300,000	300,000	297,651	300,000	272,471	288,759
FUEL GAS							
Regen Gas, Recovered for Fuel Gas (MMBtu/d)	-	-	-	-	-	-	-
Fuel Gas Usage (MMBtu/d)	(139)	(10)	-	(9)	-	(51)	(26)
Total Fuel Gas (MMBtu/d)	(139)	(10)	-	(9)	-	(51)	(26)

Net Revenue							
Incremental Propane Revenue	-	-	-	-	-	-	-
Net Fuel Gas Revenue	(1,118,192)	(77,456)	-	(71,082)	-	(409,881)	(212,860)
Total Net Revenue	(1,118,192)	(77,456)	-	(71,082)	-	(409,881)	(212,860)
US Dollars							
US Dollars/gallon Propane	(0.0010)	(0.0001)	-	(0.0001)	-	(0.0004)	(0.0002)

Net Operating Costs							
Base Operating Costs	(102,620)	(57,750)	(177,660)	(32,620)	(68,890)	(166,740)	(147,000)
Chemical Make-Up Costs	(1,354,695)	(1,395,420)	(20,186,576)	(411,509)	(1,743,455)	(333,688)	(381,218)
Disposal Costs	11,950	(25,896)	(955)	144,627	11,928	(6,882)	(9,201)
Utilities	(15,299)	(22,961)	-	(38,092)	-	(120,545)	(106,490)
Total Net Operating Costs	(1,460,663)	(1,502,027)	(20,365,191)	(337,594)	(1,800,409)	(627,855)	(643,910)
US Dollars							
US Dollars/gallon Propane	(0.0014)	(0.0014)	(0.0190)	(0.0003)	(0.0017)	(0.0006)	(0.0006)

Total Gross Profit	US Dollars	(2,578,511)	(1,581,104)	(20,365,191)	(393,118)	(1,800,409)	(1,003,230)	(804,054)
US Dollars/gallon Propane		(0.0024)	(0.0015)	(0.0190)	(0.0004)	(0.0017)	(0.0010)	(0.0008)

Net Capital Costs							
Total Equipment Costs	(267,317)	(365,265)	(261,414)	(248,572)	(101,352)	(476,274)	(401,429)
Total Initial Chemical Fill	(228,217)	(317,958)	(1,627,959)	(278,287)	(297,217)	(146,519)	(179,443)
Total Installation Cost	(668,294)	(981,689)	(653,535)	(621,431)	(253,380)	(1,190,686)	(1,003,573)
Total Net Capital Costs	(1,163,828)	(1,678,853)	(2,542,908)	(1,148,290)	(651,949)	(1,813,480)	(1,584,446)
US Dollars							
US Dollars/gallon Propane	(0.0011)	(0.0016)	(0.0024)	(0.0011)	(0.0006)	(0.0019)	(0.0015)

Total Taxable Income	US Dollars	(3,742,338)	(3,287,368)	(22,908,099)	(1,541,408)	(2,452,357)	(2,816,710)	(2,388,500)
US Dollars/gallon Propane		(0.0035)	(0.0031)	(0.0213)	(0.0014)	(0.0023)	(0.0029)	(0.0023)

Total BT Cash Flow	US Dollars	(3,742,338)	(3,287,368)	(22,908,099)	(1,541,408)	(2,452,357)	(2,816,710)	(2,388,500)
US Dollars/gallon Propane		(0.0035)	(0.0031)	(0.0213)	(0.0014)	(0.0023)	(0.0029)	(0.0023)

Present Value							
PV(10) of Propane Revenue	-	-	-	-	-	-	-
PV(10) of Fuel Gas Revenue	(687,080)	(47,594)	-	(43,677)	-	(251,854)	(130,793)
PV(10) of Operating Expense	(828,242)	(866,963)	(12,029,547)	(159,341)	(1,016,776)	(352,839)	(349,796)
PV(10) of Capital Expense	(1,163,828)	(1,706,264)	(2,542,908)	(1,148,290)	(651,949)	(1,813,480)	(1,584,446)
NPV(10)	(2,679,150)	(2,620,821)	(14,572,456)	(1,351,308)	(1,668,725)	(2,418,173)	(2,065,035)
US Dollars							
US Dollars/gallon Propane	(0.0025)	(0.0024)	(0.0136)	(0.0013)	(0.0016)	(0.0025)	(0.0020)

NOTES:
1 Net Present Value calculations are based on an "end of year" convention, excepting capital expenses, which are assumed to be spent on day 1 of the project due to the size of each installation.
2 Prices expressed as "US Dollars/gallon Propane", are based on Treated or "Sales Propane" flow rates.
3 Capital and operational expenses are based on "flat prices" with no escalation.

PEARL DEVELOPMENT COMPANY

BUSINESS DEVELOPMENT, ENGINEERING, AND CONSTRUCTION MANAGEMENT

**TABLE VII : Utility Consumption Comparison
50,000 gpd Cases**

Client: Gas Processors Association
Project: COS Removal from Liquid Propane
Pearl Project No.: 0004.168
GPA Project No.: 991

Rev. 0
Date 09/28/2000
By PJA

Vendor Design	Synetix / ICI Chemicals Single Stage, Dry Absorbtion	Synetix / ICI Chemicals 3 Stage, Hydrolysis, Absorbtion and Dehydration	Sud Chemie Single Stage, Dry Absorbtion	Sud Chemie 2 Stage, Hydrolysis and Adsorbtion	BASF Single Stage, Dry Absorbtion	UOP 2 Stage, Dehydration + Sulfur Adsorbtion in single vessel	ALCOA Single Stage, Dry Adsorbtion
Regeneration Media	Non-Regenerable	Vaporized Treated Propane	Non-Regenerable	Vaporized Treated Propane	Non-Regenerable	Vaporized Treated Propane	Vaporized Treated Propane
Product/s	Puraspec 5030	Puraspec 5312, Puraspec 5038	G132D	C53-2-01, 5A Molecular Seive	R3-12	3A + RK29II	Selexsorb COS
Units							

Main Stream Energy Requirements

		Synetix / ICI Chemicals	Sud Chemie	Sud Chemie	BASF	UOP	ALCOA
Untreated Propane Pre-Heating	MMBtu/h	1.391	NA	NA	NA	NA	NA
Treated Propane Cooling	MMBtu/h	0.479	NA	NA	NA	NA	NA
Treated Propane Cooling	hp	4.6	NA	NA	NA	NA	NA
Propane Economizer	MBtu/h-F	NA	NA	NA	NA	NA	NA
Water addition	Bpd	NA	0.01	NA	0.15	NA	NA

Regeneration Energy Requirements

		Synetix / ICI Chemicals	Sud Chemie	Sud Chemie	BASF	UOP	ALCOA
Heating	MMBtu/h	NA	0.262	NA	0.281	NA	1.442
Cooling	MMBtu/h	NA	0.260	NA	0.278	NA	1.392
Cooling	hp	NA	1.6	NA	1.7	NA	5.6
Economizer	MBtu/h-F	NA	NA	NA	NA	NA	NA
Pump	hp	NA	0.01	NA	NA	NA	NA

Regeneration Medium

		Synetix / ICI Chemicals	Sud Chemie	Sud Chemie	BASF	UOP	ALCOA
Peak Open loop Propane use	Bpd	NA	NA	NA	98	NA	492
Peak Open loop Propane use	MMBtu/d	NA	NA	NA	378	NA	378

NOTES:

- 1 Values based on Hysys simulation data
- 2 Propane outlet and regeneration return temperatures of 100°F are utilized
- 3 Economizer exchangers were not utilized for the 50,000 gpd cases due to scale

PEARL DEVELOPMENT COMPANY

BUSINESS DEVELOPMENT, ENGINEERING, AND CONSTRUCTION MANAGEMENT

**TABLE VIII : Utility Consumption Comparison
300,000 gpd Cases**

Client: Gas Processors Association
 Project: COS Removal from Liquid Propane
 Pearl Project No.: 0004.168
 GPA Project No.: 991

Rev. 0
 Date 09/28/2000
 By PJA

Vendor	Synetix / ICI Chemicals	Synetix / ICI Chemicals	Sud Chemie	Sud Chemie	BASF	UOP	ALCOA
Design	Single Stage, Dry Absorbtion	3 Stage, Hydrolysis, Absorbtion and Dehydration	Single Stage, Dry Absorbtion	2 Stage, Hydrolysis and Adsorbtion	Single Stage, Dry Absorbtion	2 Stage, Dehydration + Sulfur Adsorbtion in single vessel	Single Stage, Dry Adsorbtion
Regeneration Media	Non-Regenerable	Vaporized Treated Propane	Non-Regenerable	Vaporized Treated Propane	Non-Regenerable	Vaporized Treated Propane	Vaporized Treated Propane
Product/s	Puraspec 5030	Puraspec 5312, Puraspec 5038	G132D	C53-2-01, 5A Molecular Seive	R3-12	3A + RK29II	Selexsorb COS
Units							

Main Stream Energy Requirements

		Synetix / ICI Chemicals	Synetix / ICI Chemicals	Sud Chemie	Sud Chemie	BASF	UOP	ALCOA
Untreated Propane Pre-Heating	MMBtu/h	5.789	NA	NA	NA	NA	NA	NA
Treated Propane Cooling	MMBtu/h	0.304	NA	NA	NA	NA	NA	NA
Treated Propane Cooling	hp	5.1	NA	NA	NA	NA	NA	NA
Economizer	MBtu/h-F	106.6	NA	NA	NA	NA	NA	NA
Water addition	Bpd	NA	0.1	NA	0.90	NA	NA	NA

Regeneration Energy Requirements

		Synetix / ICI Chemicals	Synetix / ICI Chemicals	Sud Chemie	Sud Chemie	BASF	UOP	ALCOA
Heating	MMBtu/h	NA	0.401	NA	0.368	NA	2.122	1.102
Cooling	MMBtu/h	NA	1.579	NA	1.446	NA	8.352	3.943
Cooling	hp	NA	9.7	NA	9.0	NA	33.6	19.1
Economizer	MBtu/h-F	NA	19.80	NA	21.85	NA	108.3	57.0
Pump	hp	NA	0.1	NA	NA	NA	NA	NA

Regeneration Medium

		Synetix / ICI Chemicals	Synetix / ICI Chemicals	Sud Chemie	Sud Chemie	BASF	UOP	ALCOA
Peak Open loop Propane use	Bpd	NA	NA	NA	513	NA	2952	1533
Peak Open loop Propane use	MMBtu/d	NA	NA	NA	1962	NA	11322	5882

NOTES:

- 1 Values based on Hysys simulation data
- 2 Propane outlet and regeneration return temperatures of 100°F are utilized
- 3 Economizer exchangers were utilized for the 300,000 gpd cases due to scale

Carbonyl Sulfide (COS) Removal from Propane

TABLE IX b INDEX OF SORBENT MATERIALS (Continued)

SULFUR CHEM-ADSORBENTS (Non Regenerable)	
Puraspec 5030	Is a combination of copper, zinc and aluminum oxides, used to remove sulfur compounds by forming stable metal sulfides at temperatures slightly above ambient.
Puraspec 5038	Is a combination of copper, zinc and aluminum oxides, used to remove sulfur compounds by forming stable metal sulfides. Similar to Puraspec 5030, this material has additional activators to enable efficient operation at ambient temperatures.
Sud Chemie's G132D	Is a combination of copper, zinc and aluminum oxides, used to remove sulfur compounds by forming stable metal sulfides.
BASF's R 3-12	Is a combination of copper, zinc and aluminum oxides, used to remove sulfur compounds by forming stable metal sulfides. R3-12 is also used for Arsine removal
Alcoa's SelexsorbAS	Is a copper-zinc, non regenerable adsorbent used for the removal of Arsine and COS.
SULFUR ADSORBENTS (Regenerable)	
Alcoa's SelexsorbCOS	is an activated alumina, regenerable, sulfur absorbent, which is used for the removal of COS, CO ₂ , H ₂ S and CS ₂ from hydrocarbon streams.
HYDROLYSIS CATALYSTS	
Puraspec 5312	is an activated alumina hydrolysis catalyst for the hydrolysis of COS to H ₂ S and CO ₂ in the presence of water. No catalyst is consumed in the reaction.
Sud Chemie's G52-2-01	Is a platinum on alumina hydrolysis catalyst for the hydrolysis of COS to H ₂ S and CO ₂ in the presence of water. No catalyst is consumed in the reaction.
Alcoa's SelectaCAT	is an activated alumina hydrolysis catalyst for the hydrolysis of COS to H ₂ S and CO ₂ in the presence of water.

Carbonyl Sulfide (COS) Removal from Propane

TABLE X INDEX OF ADSORPTION PREFERENCE

Providing that the molecule is small enough to enter the pore opening of the molecular sieve, the adsorption is;		
<ul style="list-style-type: none"> - Directly Proportional to Molecular Weight - Inversely Proportional to Vapor Pressure - Directly Proportional to dipole moment (ie. polarity) 		
MOLECULE COMPONENT		
Water	Strongest Retention	Decreasing Adsorption Preference 
Methanol	Coadsorbs with H ₂ O	
Heavier Mercaptans		
Lighter Mercaptans		
H ₂ S		
CO ₂	Similar to H ₂ S	
COS	Weakest Retention	
CS ₂	Not Adsorbed	

Reference : Gas Conditioning and Processing Vol. 4, Pg 262.

APPENDIX A.2

FIGURES

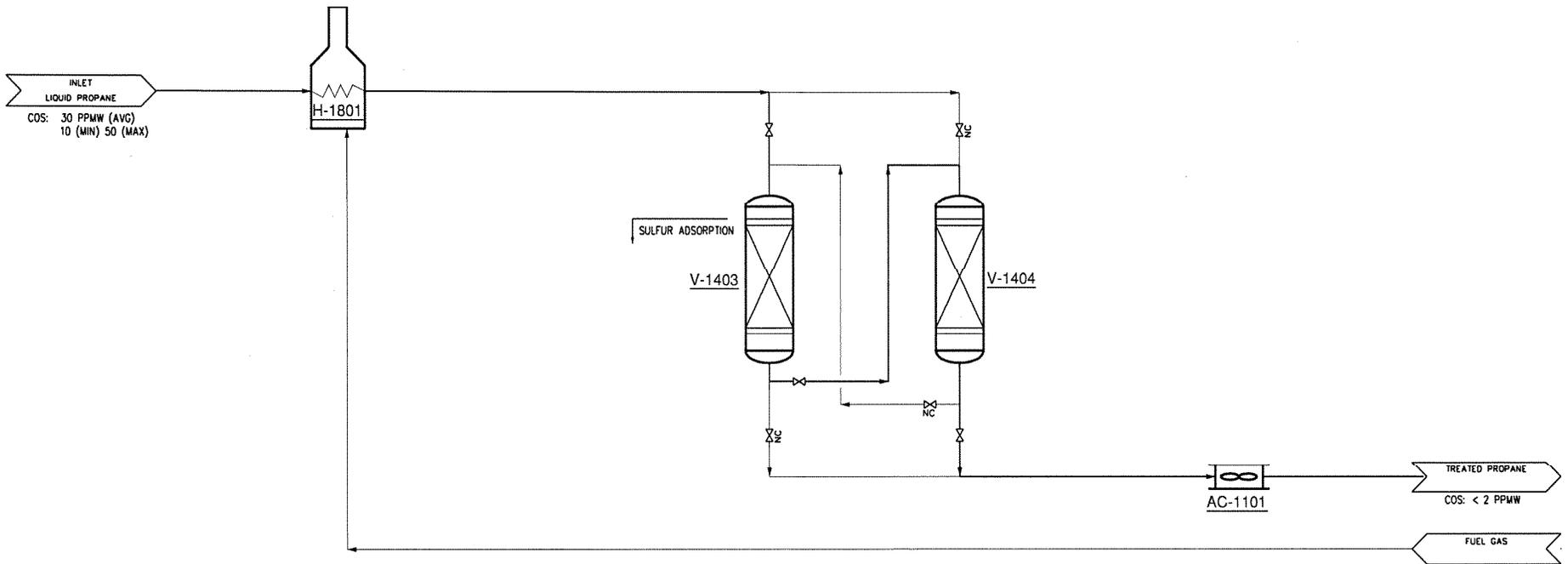
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- Figure viii: Block Flow Diagram, 300,000 gpd Sud Chemie, Hydrolysis and combined Adsorption/Dehydration.
- Figure ix: Block Flow Diagram, 50,000 gpd BASF Dry Adsorption
- Figure x: Block Flow Diagram, 300,000 gpd BASF Dry Adsorption
- Figure xi: Block Flow Diagram, 50,000 gpd UOP, Dehydration and Adsorption
- Figure xii: Block Flow Diagram, 300,000 gpd UOP, Dehydration and Adsorption
- Figure xiii: Block Flow Diagram, 50,000 gpd ALCOA, Adsorption
- Figure xiv: Block Flow Diagram, 300,000 gpd ALCOA, Adsorption

H-1801
 REGEN GAS HEATER
 DUTY: 1.391 MMBTU/HR

V-1403 & V-1404
 COMPANY: SYNETIX
 PRODUCT NO: PURASPEC 5030
 TYPE: SULFUR ADSORBENT
 SIZE: 40.3 CUBIC FEET

AC-1101
 REGEN GAS COOLER
 DUTY: 0.470 MMBTU/HR
 DESIGN HP: 4.6 HP



DESIGNER: SYNETIX
 PRODUCT: PURASPEC 5030
 DESCRIPTION: DIRECT SULFUR ADSORPTION
 INLET: 400 PSIG @ 80F
 HD-5 PROPANE LIQUID

THIS DRAWING HAS NOT BEEN PUBLISHED BUT RATHER HAS BEEN PREPARED BY PEARL DEVELOPMENT COMPANY FOR USE BY THE CLIENT NAMED IN THE TITLE BLOCK SOLELY IN RESPECT OF THE CONSTRUCTION, OPERATION AND MAINTENANCE OF THE FACILITY NAMED IN THE TITLE BLOCK AND SHALL NOT BE USED FOR ANY OTHER PURPOSE OR FURNISHED TO ANY OTHER PARTY WITHOUT THE EXPRESS CONSENT OF PEARL DEVELOPMENT COMPANY.

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PROJ. NUMBER	DRAWING NUMBER	SCALE	REVISION
0004-168	168-2415	NONE	1



GPA COS REMOVAL
 SINGLE STAGE DRY ADSORPTION
 DESIGN: 50,000 GPD

PLOT DATE: 9/28/00

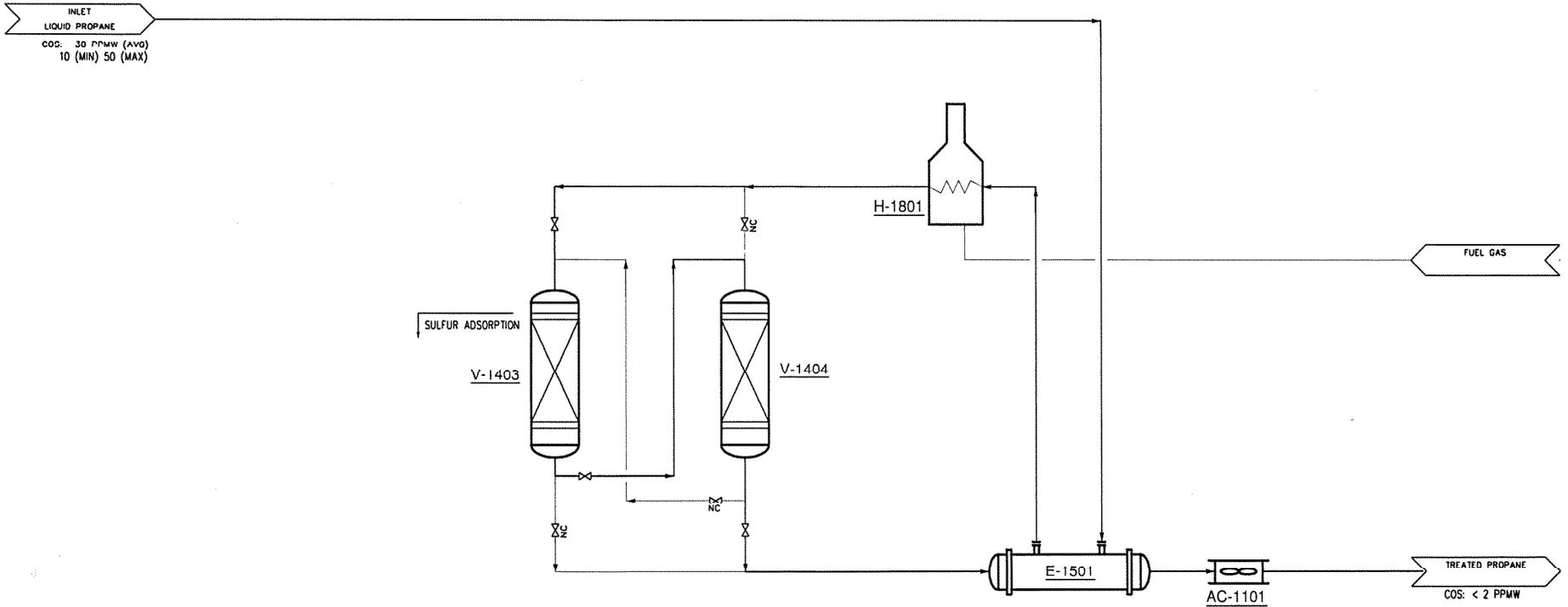
FIGURE i

V-1403 & V-1404
 COMPANY: SYNTEX
 PRODUCT NO. PURASPEC 5030
 TYPE: SULFUR ADSORBENT
 SIZE: 241.8 CUBIC FEET

H-1801
 REGEN GAS HEATER
 DUTY: 5.789 MMBTU/HR

E-1501
 REGEN GAS EXCHANGER
 UA: 106.6 MBTU/HR-F

AC-1101
 REGEN GAS COOLER
 DUTY: 0.304 MMBTU/HR
 DESIGN I/P: 5.1 I/P



DESIGNER: SYNTEX
 PRODUCT: PURASPEC 5030
 DESCRIPTION: DIRECT SULFUR ADSORPTION
 INLET: 400 PSIG @ 80°F
 HD-5 PROPANE LIQUID

THIS DRAWING HAS NOT BEEN PUBLISHED BUT RATHER HAS BEEN PREPARED BY PEARL DEVELOPMENT COMPANY FOR USE BY THE CLIENT NAMED IN THE TITLE BLOCK SOLELY IN RESPECT OF THE CONSTRUCTION, OPERATION AND MAINTENANCE OF THE FACILITY NAMED IN THE TITLE BLOCK AND SHALL NOT BE USED FOR ANY OTHER PURPOSE OR FURNISHED TO ANY OTHER PARTY WITHOUT THE EXPRESS CONSENT OF PEARL DEVELOPMENT COMPANY.

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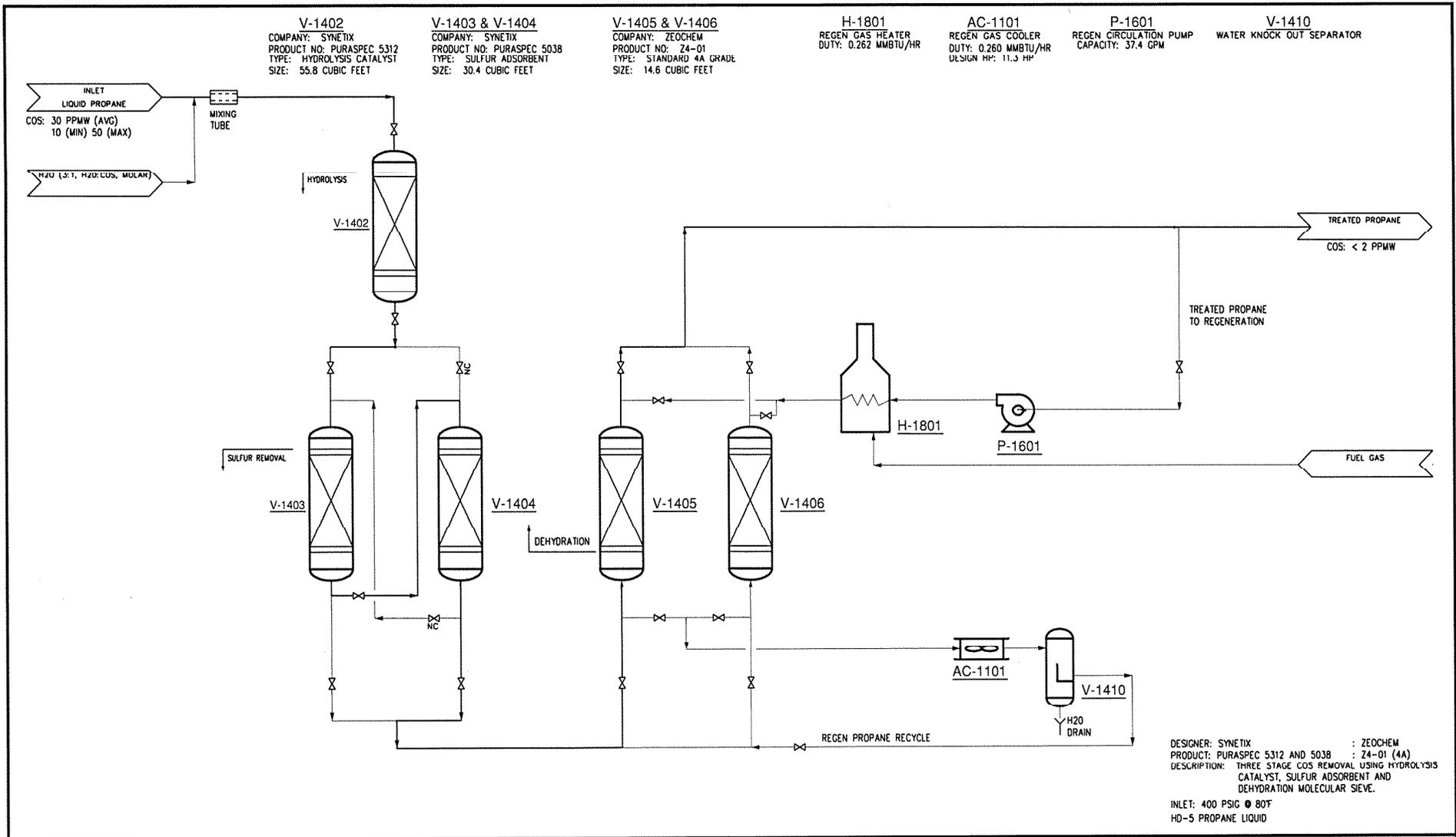
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GPA COS REMOVAL
 SINGLE STAGE DRY ADSORPTION
 DESIGN: 300,000 GPD

PROJ. NUMBER 0004-168	DRAWING NUMBER 168-2411	SCALE NONE	REVISION 0
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PL01 DATE: 9/28/00

FIGURE ii



THIS DRAWING HAS NOT BEEN PUBLISHED BUT RATHER HAS BEEN PREPARED BY PEARL DEVELOPMENT COMPANY FOR USE BY THE CLIENT NAMED IN THE TITLE BLOCK SOLELY IN RESPECT OF THE CONSTRUCTION, OPERATION AND MAINTENANCE OF THE FACILITY NAMED IN THE TITLE BLOCK AND SHALL NOT BE USED FOR ANY OTHER PURPOSE, BE FURNISHED TO ANY OTHER PARTY WITHOUT THE EXPRESS CONSENT OF PEARL DEVELOPMENT COMPANY.

No	REVISIONS	BY	CHKD	PM	DATE	BY	DATE
1	ISSUED FOR REPORT	SLD	SJW	PJA	9/28/00		



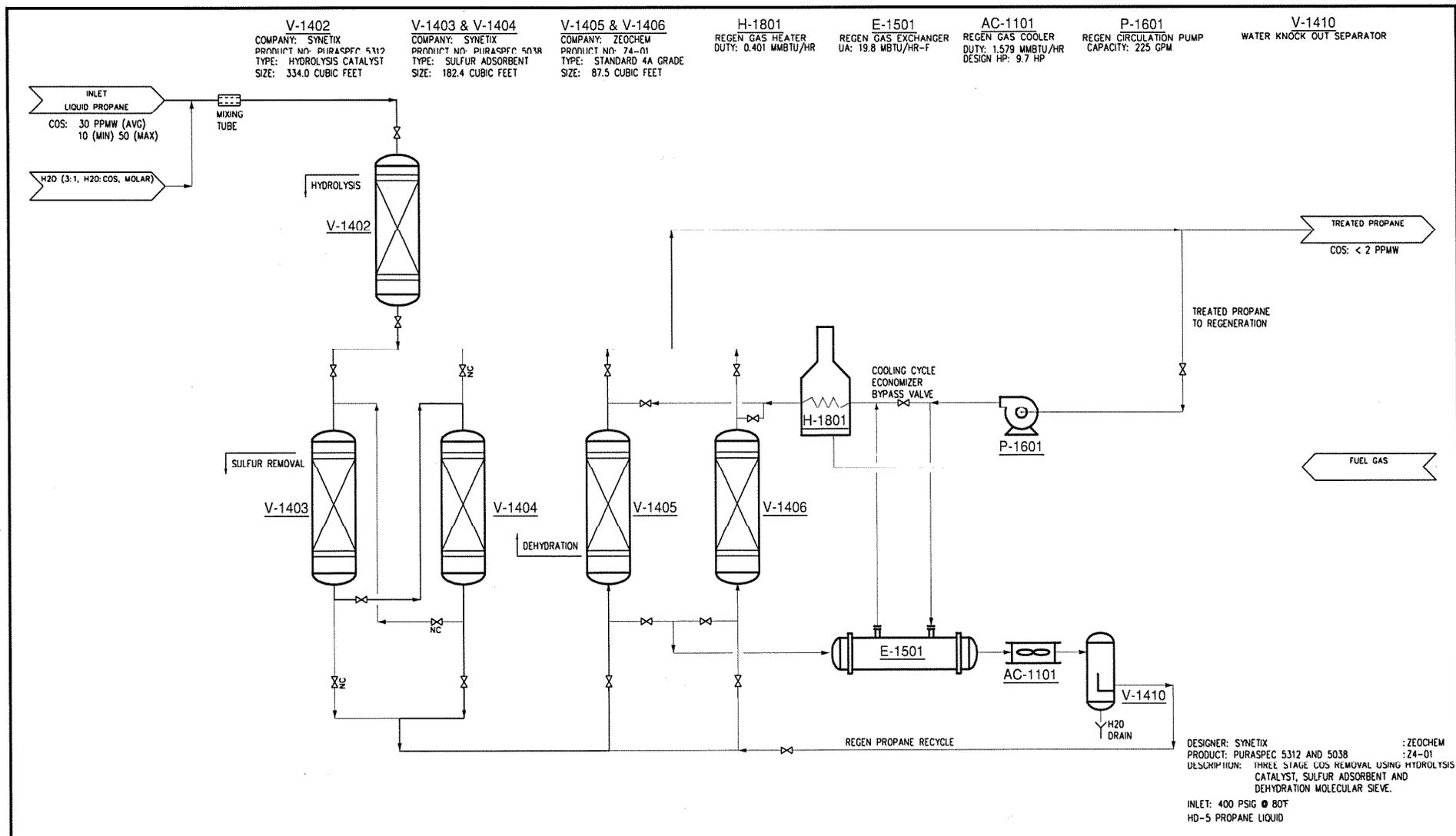
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GPA
 CPA COS REMOVAL
 3 STAGE HYDROLYSIS, ADSORPTION & DEHYDRATION
 DESIGN: 50,000 GPD

PROJ NUMBER 0004-168	DRAWING NUMBER 168-2409	SCALE NONE	REVISION 0
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FIGURE iii

PL01 DATE: 9/28/00



THIS DRAWING HAS NOT BEEN PUBLISHED BUT RATHER HAS BEEN PREPARED BY PEARL DEVELOPMENT COMPANY FOR USE BY THE CLIENT NAMED IN THE TITLE BLOCK SOLELY IN RESPECT OF THE CONSTRUCTION, OPERATION AND MAINTENANCE OF THE FACILITY NAMED IN THE TITLE BLOCK AND SHALL NOT BE USED FOR ANY OTHER PURPOSE OR SUPPLIED TO ANY OTHER PARTY WITHOUT THE EXPRESS CONSENT OF PEARL DEVELOPMENT COMPANY.

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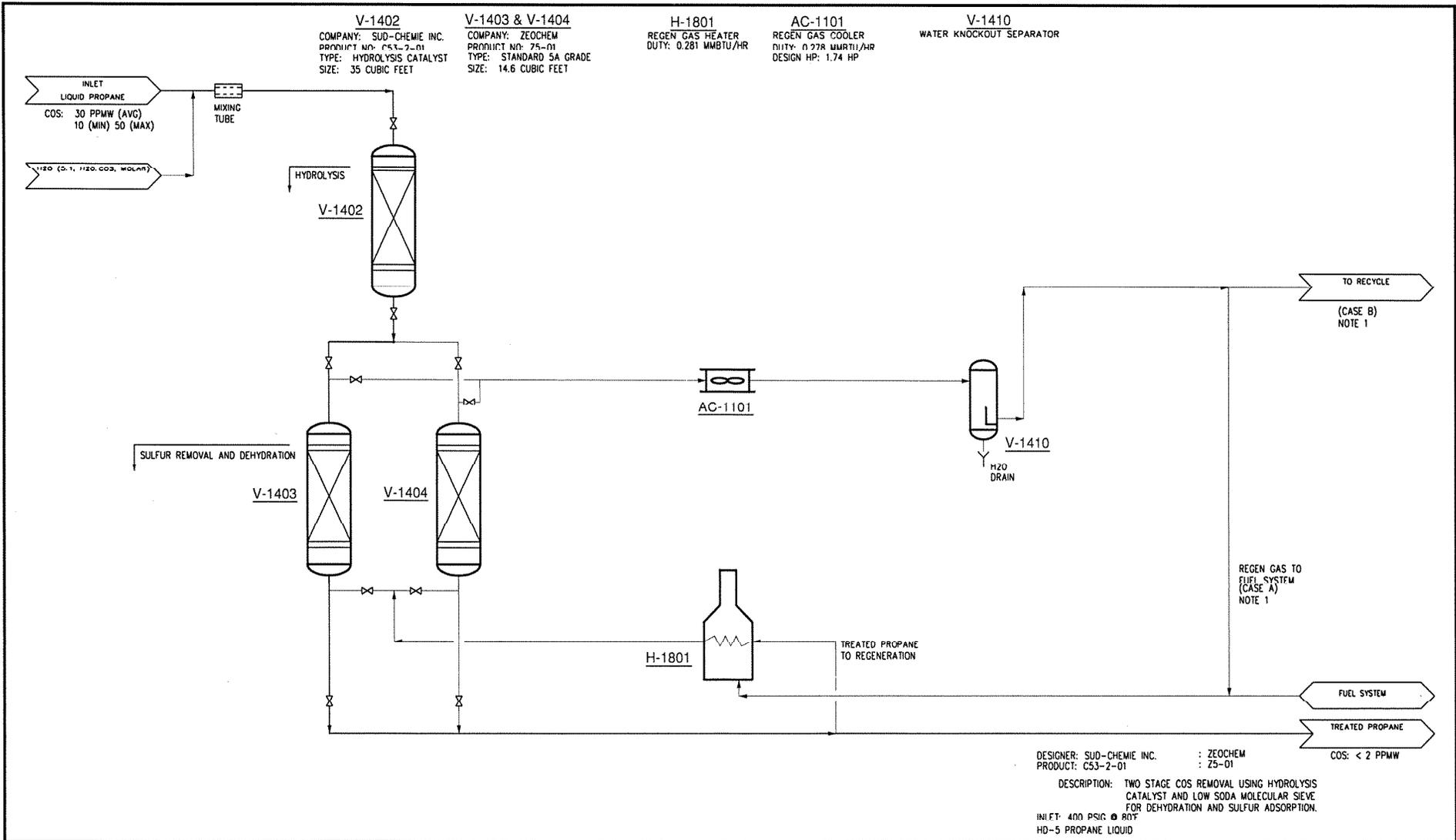


GPA COS REMOVAL
 3 STAGE HYDROLYSIS, ADSORPTION & DEHYDRATION
 DESIGN: 300,000 GPD

PROJ. NUMBER	DRAWING NUMBER	SCALE	REVISION
0004-168	168-2407	NONE	0

PLOT DATE: 9/28/00

FIGURE iv



THIS DRAWING HAS NOT BEEN PUBLISHED BUT RATHER HAS BEEN OBTAINED BY PEARL DEVELOPMENT COMPANY FOR USE BY THE CLIENT NAMED IN THE TITLE BLOCK SOLELY IN RESPECT OF THE CONSTRUCTION, OPERATION AND MAINTENANCE OF THE FACILITY NAMED IN THE TITLE BLOCK AND SHALL NOT BE USED FOR ANY OTHER PURPOSE OR FURNISHED TO ANY OTHER PARTY WITHOUT THE EXPRESS CONSENT OF PEARL DEVELOPMENT COMPANY.

NOTE:
 1. CASE A, REGEN GAS RECOVERED AS FUEL GAS.
 CASE B, REGEN GAS IS RECYCLED.

No	REVISIONS	BY	CHKD	PM	DATE	BY	DATE
1	ISSUED FOR REPORT	SLD	SJW	PJA	9/28/00		

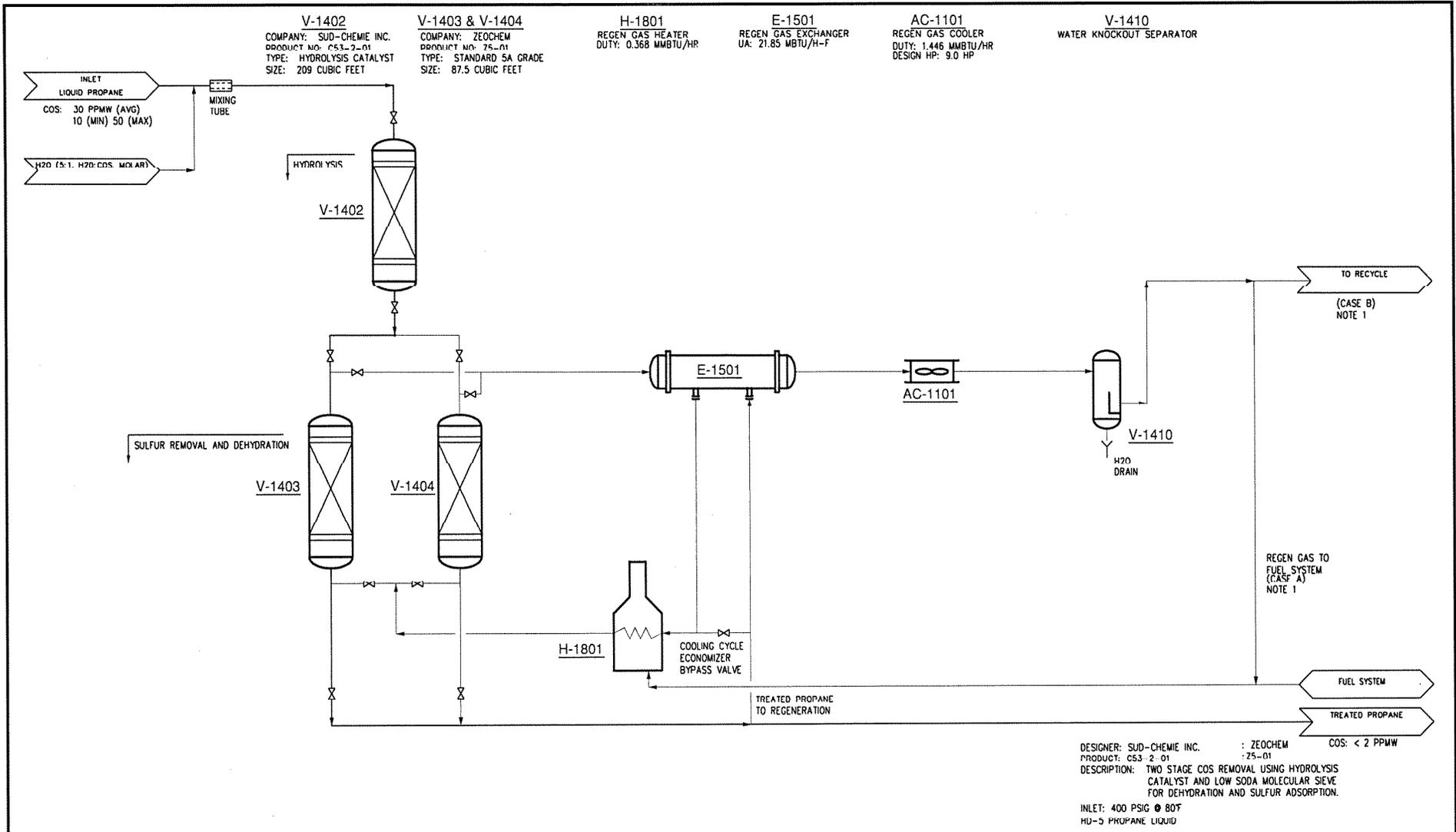
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GPA COS REMOVAL
 2 STAGE HYDROLYSIS & ADSORPTION
 DESIGN: 50,000 GPD

PROJ. NUMBER 0004-168	DRAWING NUMBER 168-2405	SCALE NONE	REVISION 0
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PLOT DATE: 9/28/00

FIGURE vii



THIS DRAWING HAS NOT BEEN PUBLISHED BUT RATHER HAS BEEN PREPARED BY PEARL DEVELOPMENT COMPANY FOR USE BY THE CLIENT NAMED IN THE TITLE BLOCK SOLELY IN RESPECT OF THE CONSTRUCTION, OPERATION AND MAINTENANCE OF THE FACILITY NAMED IN THE TITLE BLOCK AND SHALL NOT BE USED FOR ANY OTHER PURPOSE OR REFERRED TO ANY OTHER PARTY WITHOUT THE EXPRESS CONSENT OF PEARL DEVELOPMENT COMPANY.

NOTE:
 1. CASE A, REGEN GAS RECOVERED AS FUEL GAS
 CASE B, REGEN GAS IS RECYCLED.

No	REVISIONS	BY	CHKD	PM	DATE	BY	DATE	
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Phone (303)838-8090

GPA

GPA COS REMOVAL
 2 STAGE HYDROLYSIS & ADSORPTION
 DESIGN: 300,000 GPD

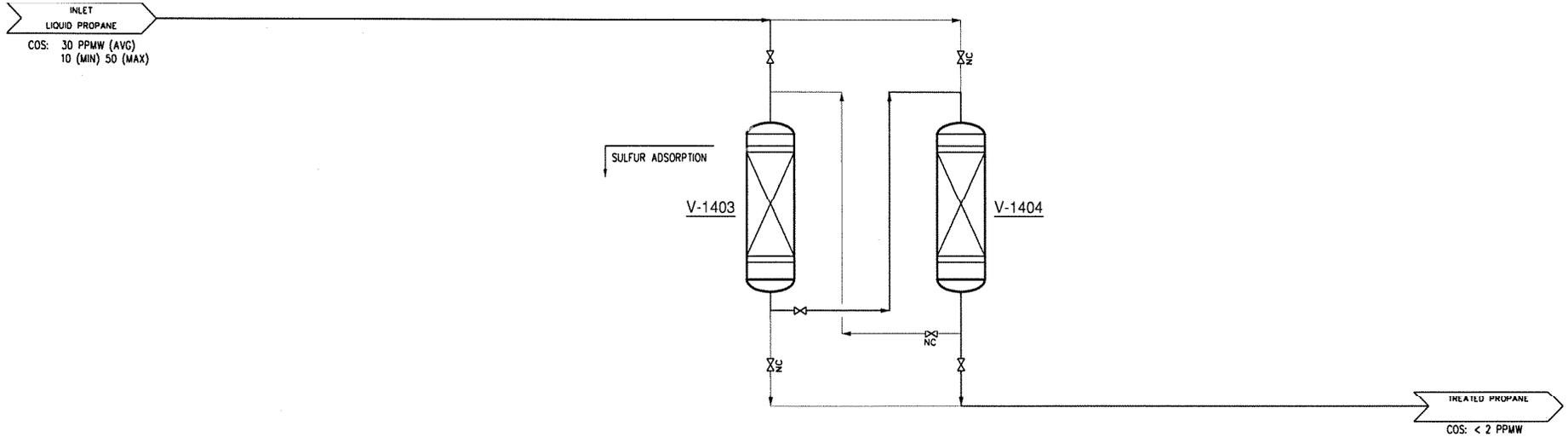
PROJ. NUMBER 0004-168	DRAWING NUMBER 168-2404	SCALE NONE	REVISION 0
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FIGURE viii

PLOT DATE: 9/28/00

V-1403 & V-1404

COMPANY: BASF
 PRODUCT NO: R 3-12
 TYPE: SULFUR ADSORBENT
 SIZE: 37.1 CUBIC FEET



DESIGNER: BASF
 PRODUCT: R 3-12
 DESCRIPTION: DIRECT SULFUR ADSORPTION
 INLET: 400 PSIG @ 80F
 HU-3 PROPANE LIQUID

THIS DRAWING HAS NOT BEEN PUBLISHED BUT RATHER HAS BEEN ORDERED BY PEARL DEVELOPMENT COMPANY FOR USE BY THE CLIENT NAMED IN THE TITLE BLOCK SOLELY IN RESPECT OF THE CONSTRUCTION, OPERATION AND MAINTENANCE OF THE FACILITY NAMED IN THE TITLE BLOCK AND SHALL NOT BE USED FOR ANY OTHER PURPOSE OR FURNISHED TO ANY OTHER PARTY WITHOUT THE EXPRESS CONSENT OF PEARL DEVELOPMENT COMPANY.

No	REVISIONS	BY	CHKD	PM	DATE	BY	DATE
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GPA COS REMOVAL
 SINGLE STAGE DRY ADSORPTION
 DESIGN: 50,000 CPD

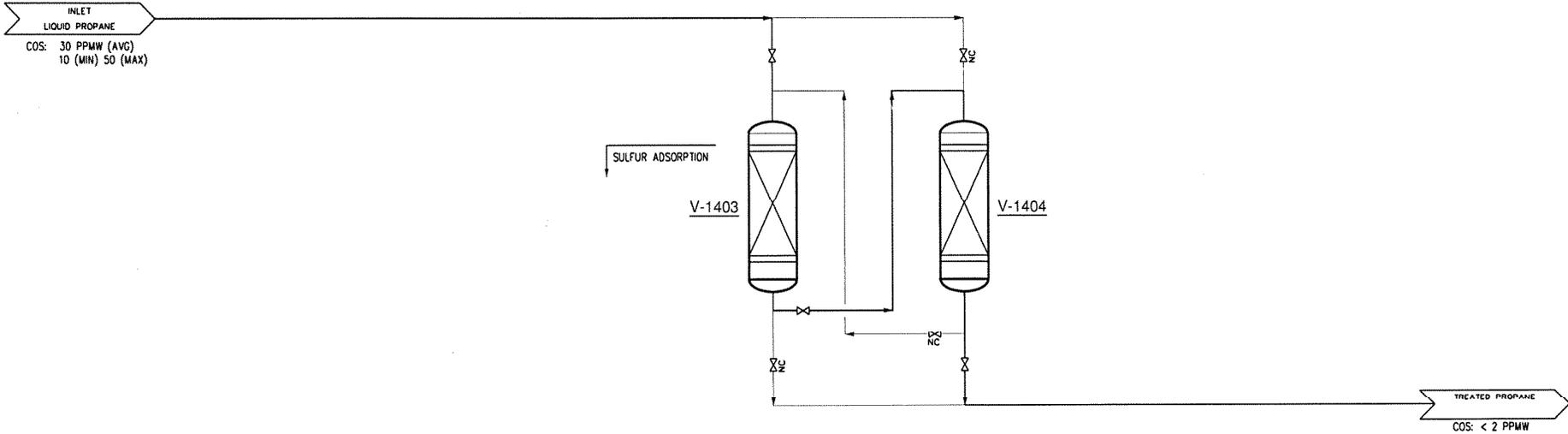
PROJ NUMBER 0004-168	DRAWING NUMBER 168-2416	SCALE NONE	REVISION 1
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PLOT DATE 9/29/00

FIGURE ix

V-1403 & V-1404

COMPANY: BASF
 PRODUCT NO: R 3-12
 TYPE: SULFUR ADSORBENT
 SIZE: 222.8 CUBIC FEET



DESIGNER: BASF
 PRODUCT: R 3-12
 DESCRIPTION: DIRECT SULFUR ADSORPTION
 INLET: 400 PSIG @ 80F
 HD-3 PROPANE LIQUID

THIS DRAWING HAS NOT BEEN PUBLISHED BUT RATHER HAS BEEN PREPARED BY PEARL DEVELOPMENT COMPANY FOR USE BY THE CLIENT NAMED IN THE TITLE BLOCK SOLELY IN RESPECT OF THE CONSTRUCTION OPERATION AND MAINTENANCE OF THE FACILITY NAMED IN THE TITLE BLOCK AND SHALL NOT BE USED FOR ANY OTHER PURPOSE OR FOR ANY OTHER PARTY WITHOUT THE EXPRESS CONSENT OF PEARL DEVELOPMENT COMPANY.

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0004-168

DRAWING NUMBER
168-2413

SCALE
NONE

REVISION
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PLOT DATE: 9/28/00

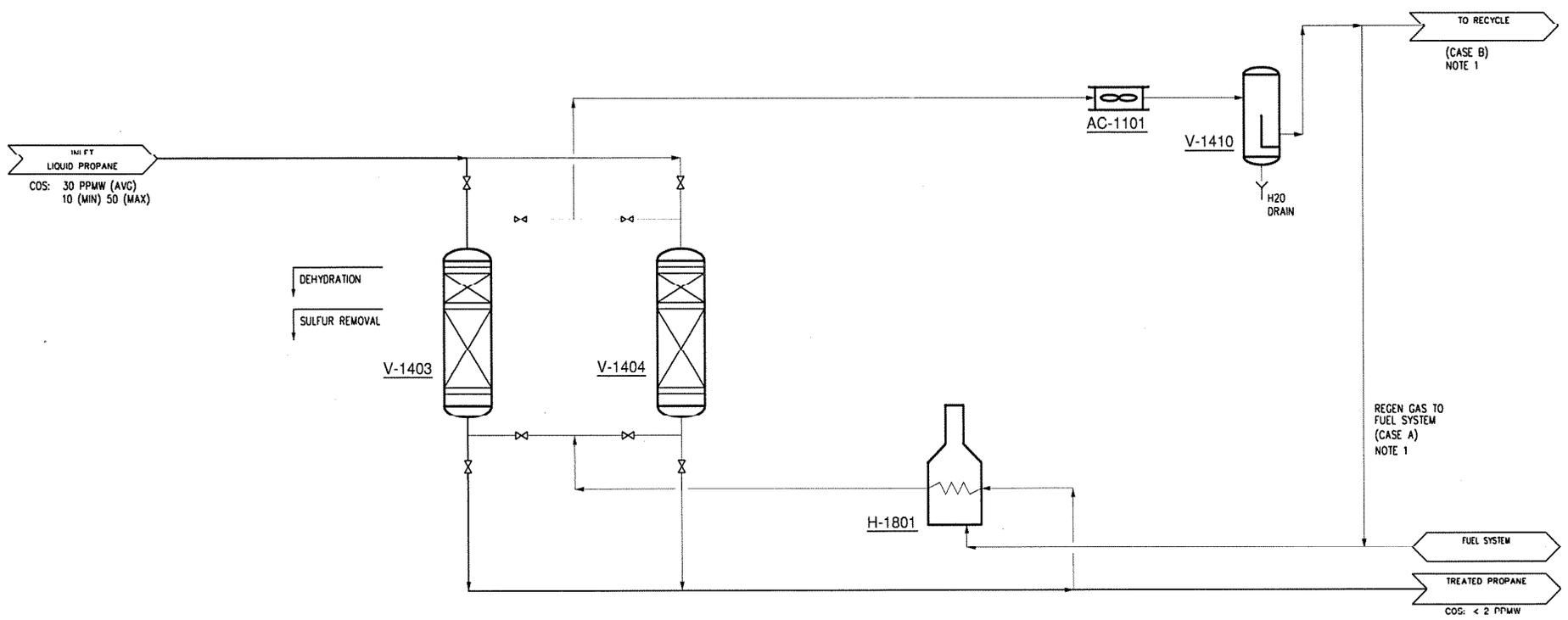
FIGURE X

V-1403 & V-1404
 COMPANY: UOP
 PRODUCT NO: 3A-DG
 TYPE: DEHYDRATION MOLECULAR SIEVE
 SIZE: 7.1 CUBIC FEET (300 LBS)
 PRODUCT NO: RK-29 II
 TYPE: SULFUR ADSORBENT
 SIZE: 86.7 CUBIC FEET (4,000 LBS)

H-1801
 REGEN GAS HEATER
 DUTY: 1.442 MMBTU/HR

AC-1101
 REGEN GAS COOLER
 DUTY: 1.392 MMBTU/HR
 DESIGN HP: 5.6 HP

V-1410
 WATER KNOCKOUT SEPARATOR



DESIGNER: UOP : UOP
 PRODUCT: 3A-DG : RK-29 II
 DESCRIPTION: DEHYDRATION AND SULFUR ADSORPTION.
 INLET: 400 PSIG @ 80F
 HD-5 PROPANE LIQUID

THIS DRAWING HAS NOT BEEN PUBLISHED BUT RATHER HAS BEEN OBSOLETE BY PEARL DEVELOPMENT COMPANY FOR USE BY THE CLIENT NAMED IN THE TITLE BLOCK SOLELY IN RESPECT OF THE CONSTRUCTION, OPERATION AND MAINTENANCE OF THE FACILITY NAMED IN THE TITLE BLOCK AND SHALL NOT BE USED FOR ANY OTHER PURPOSE OR FURNISHED TO ANY OTHER PARTY WITHOUT THE EXPRESS CONSENT OF PEARL DEVELOPMENT COMPANY.

NOTE:
 1. CASE A, REGEN GAS RECOVERED AS FUEL GAS.
 CASE B, REGEN GAS IS RECYCLED.

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GPA
 GPA COS REMOVAL
 DEHYDRATION AND SULFUR REMOVAL
 DESIGN: 50,000 GPD

PROJ. NUMBER 0004-168	DRAWING NUMBER 168-2406	SCALE NONE	REVISION 0
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FIGURE xi

PLOT DATE 9/29/00

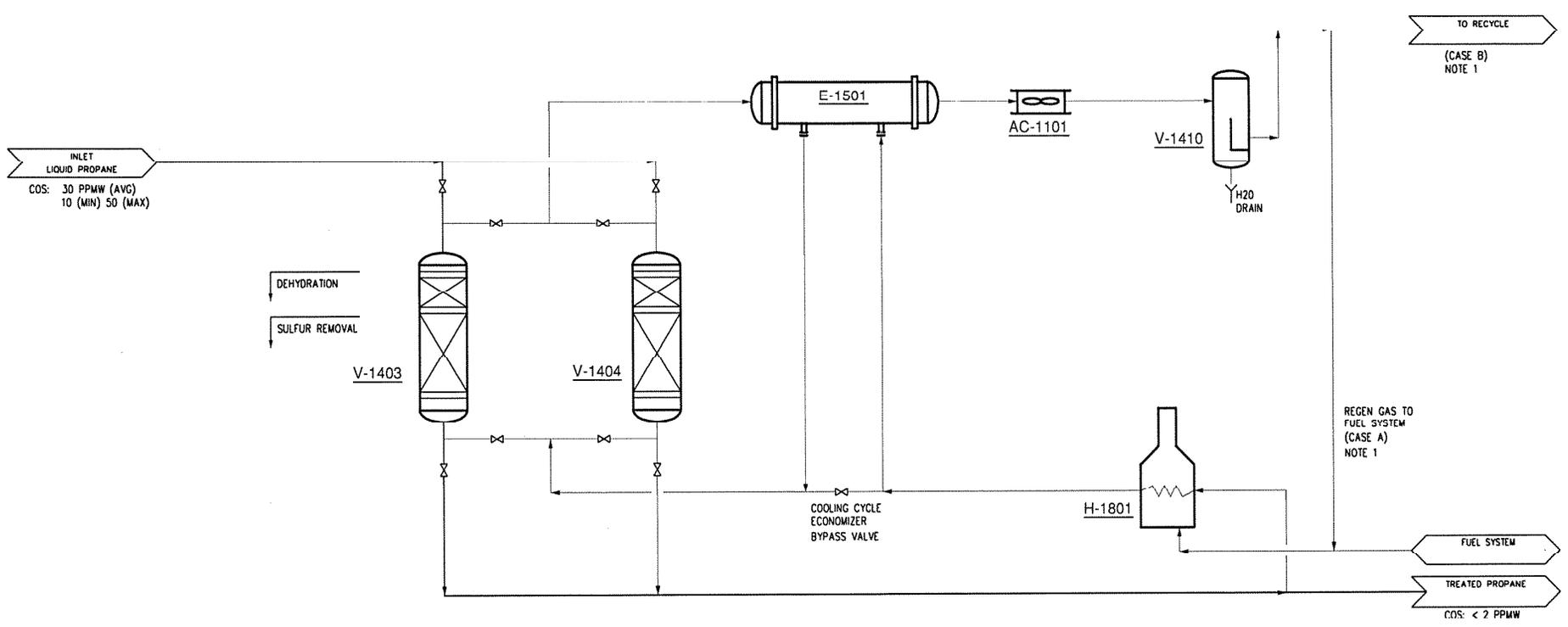
V-1403 & V-1404
 COMPANY: UOP
 PRODUCT NO: 3A-DG
 TYPE: DEHYDRATION MOLECULAR SIEVE
 SIZE: 28.6 CUBIC FEET (1,200 LBS)
 PRODUCT NO: RK-29 II
 TYPE: SULFUR ADSORBENT
 SIZE: 520 CUBIC FEET (24,000 LBS)

E-1501
 REGEN GAS EXCHANGER
 UA: 108.3 MBTU/H-F

AC-1101
 REGEN GAS COOLER
 DUTY: 8.352 MMBTU/HR
 DESIGN HP: 33.6 HP

H-1801
 REGEN GAS HEATER
 DUTY: 2.122 MMBTU/HR

V-1410
 WATER KNOCKOUT SEPARATOR



DESIGNER: UOP
 PRODUCT: 3A-DG
 DESCRIPTION: DEHYDRATION AND SULFUR ADSORPTION
 INLET: 400 PSIG @ 80"
 HD-3 PROPANE LIQUID

: UOP
 : RK-29 II

THIS DRAWING HAS NOT BEEN PUBLISHED BUT RATHER HAS BEEN PREPARED BY PEARL DEVELOPMENT COMPANY FOR USE BY THE CLIENT NAMED IN THE TITLE BLOCK SOLELY IN RESPECT OF THE CONSTRUCTION, OPERATION AND MAINTENANCE OF THE FACILITY NAMED IN THE TITLE BLOCK AND SHALL NOT BE USED FOR ANY OTHER PURPOSE OR FURNISHED TO ANY OTHER PARTY WITHOUT THE EXPRESS CONSENT OF PEARL DEVELOPMENT COMPANY.

NOTES:
 1. CASE A, REGEN GAS RECOVERED AS FUEL GAS.
 CASE B, REGEN GAS IS RECYCLED.

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GPA
 GPA COS REMOVAL
 DEHYDRATION AND SULFUR ADSORPTION
 DESIGN: 300,000 GPD

PROJ. NUMBER 0004-168	DRAWING NUMBER 168-2408	SCALE NONE	REVISION 0
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FIGURE xii

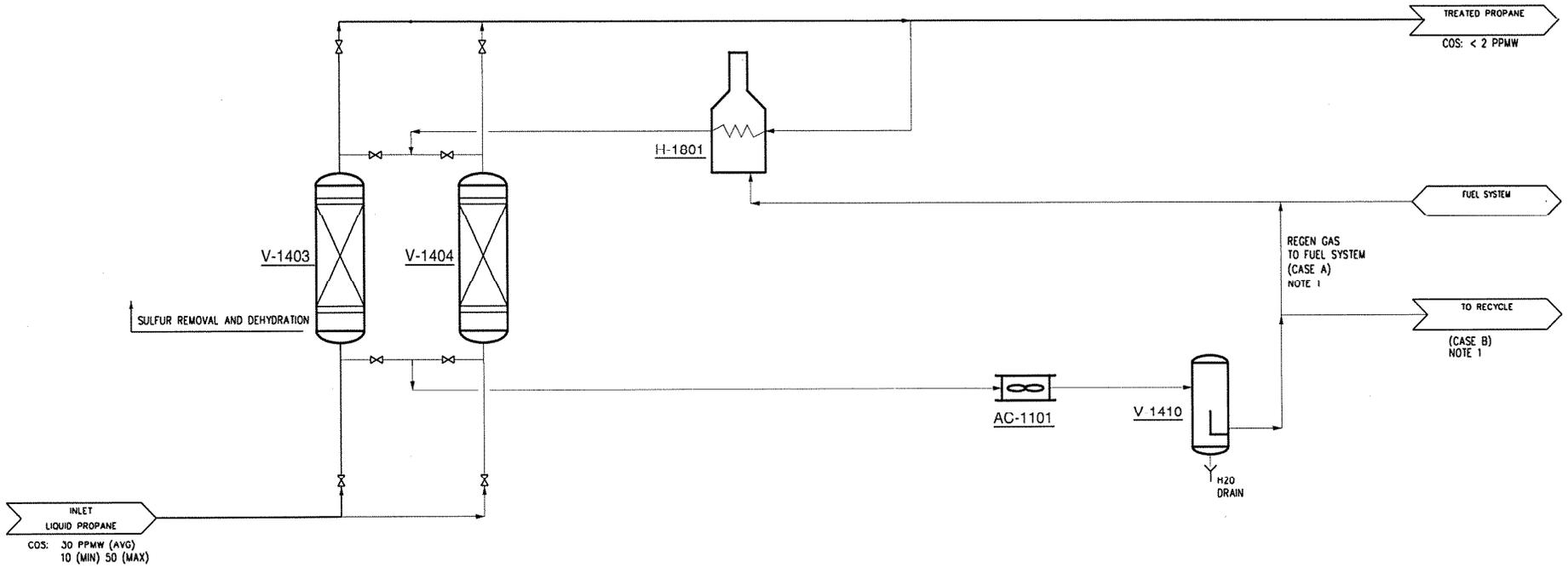
PLOT DATE: 9/28/00

V-1403 & V-1404
 COMPANY: ALCOA
 PRODUCT NO: SELEXSORB-COS
 TYPE: ACTIVATED ALUMINA ADSORBENT
 SIZE: 129.0 CUBIC FEET

H-1801
 REGEN GAS HEATER
 DUTY: 0.770 MMBTU/HR

AC-1101
 REGEN GAS COOLER
 DUTY: 0.743 MMBTU/HR
 DESIGN HP: 3.5 HP

V-1410
 WATER KNOCK SEPARATOR



DESIGNER: ALCOA
 PRODUCT: SELEXSORB-COS
 DESCRIPTION: DIRECT COS ADSORPTION
 INLET: 400 PSIG @ 80F
 HD-5 PROPANE LIQUID

THIS DRAWING HAS NOT BEEN PUBLISHED BUT RATHER HAS BEEN PREPARED BY PEARL DEVELOPMENT COMPANY FOR USE BY THE CLIENT NAMED IN THE TITLE BLOCK SOLELY IN RESPECT OF THE CONSTRUCTION, OPERATION AND MAINTENANCE OF THE FACILITY NAMED IN THE TITLE BLOCK AND SHALL NOT BE USED FOR ANY OTHER PURPOSE OR FURNISHED TO ANY OTHER PARTY WITHOUT THE EXPRESS CONSENT OF PEARL DEVELOPMENT COMPANY.

NOTE:

- 1 CASE A, REGEN GAS RECOVERED AS FUEL GAS.
- CASE B, REGEN GAS IS RECYCLED.

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FIGURE xiii

PLOT DATE 9/29/00

