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Biotechnology for Removal of Carbon Disulfide Emissions: Final Report

Energy Systems Division
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Biotechnology for Removal of Carbon Disulfide Emissions: Final Report

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BIOTECHNOLOGY FOR REMOVAL OF CARBON DISULFIDE EMISSIONS: FINAL REPORT

by

M.J. McIntosh

ABSTRACT

Biological removal in a "biofilter" plant of carbon disulfide and hydrogen sulfide from the air effluent of a viscose plant at Teepak, Inc., is analyzed from process and economic standpoints by use of the Aspen Plus simulation program. The metabolic product from the biofilter, 3% sulfuric acid, must be transformed at the source into either a marketable or recyclable commodity (such as 95% sulfuric acid, high-quality sulfur, or high-quality gypsum) or a material with reasonable landfill costs (such as sulfur or gypsum). The simulations indicate that the total capital requirement for production of concentrated sulfuric acid is \$48.9 million; for high-quality gypsum, \$40.4 million; and for high-quality sulfur, \$29.4 million. Production of concentrated sulfur for landfill is not economically practical. The process to neutralize the 3% acid effluent with limestone and landfill the resulting low-quality gypsum requires the lowest total investment of the processes simulated, \$8.7 million, including the biofilter plant.

SUMMARY

A viscose plant operated by Teepak, Inc., produces approximately 644,000 m³/h of waste air contaminated with 293 mg of CS₂ and 146 mg of H₂S per cubic meter. The H₂S is currently being removed by alkali scrubbing, but the CS₂ is emitted to the atmosphere. Biological removal of these contaminants is analyzed from process and economic standpoints. A "biofilter" plant is estimated to consist of a field of 104 large porous beds or biofilters. One acre of area is required, assuming the biofilter units are double-stacked. Each biofilter treats a portion of the air by passing it through a bed of organic material and activated carbon that is saturated with the sulfur-metabolizing bacteria, thiobacillus. A recycling solution carries the metabolic product, 3% sulfuric acid, from the biofilter to other processing units.

The 3% sulfuric acid has no commercial value and cannot be disposed of at a reasonable cost. If the biofilter is to be used, the dilute acid must be transformed at the source, either into a marketable or recyclable commodity or into a material less costly to dispose of than acid. Possible marketable commodities are concentrated sulfuric acid (95%), high-quality sulfur, and high-quality gypsum. Possible materials with reasonable landfill costs are sulfur and gypsum.

The production of concentrated acid and high-quality gypsum requires acid concentration by evaporation. Budget estimates ($\pm 30\%$) indicate that the total capital requirements for these processes are \$48.9 million (acid) and \$40.4 million (gypsum). For comparison, a carbon adsorption plant for CS_2 removal would have a total capital requirement of \$31.6 million (calculated by using the same estimating methods).

It is possible for a marketable high-quality sulfur to be produced in a packed column containing surfaces saturated with thiobacillus. The total capital requirement is estimated to be \$29.4 million. Production of concentrated sulfur for landfill is not economically practical.

To neutralize the 3% acid effluent from a biofilter plant with powdered limestone, by using a simple stirred-tank reactor followed by a clarifier, may require a total investment as low as \$8.7 million, including the biofilter plant. The resulting low-quality gypsum product is sent to a landfill. Because of the relatively low estimated cost, this option is recommended for further, more detailed, process and economic study.

1 INTRODUCTION

A plant in Danville, Illinois, operated by Teepak, Inc., manufactures cellulose food casings by means of the viscose process (a well-known process for producing such cellulose polymeric materials as food casings, rayon, etc.). Approximately 644,000 m³ of ventilation air is emitted from the plant per hour. Prior to scrubbing, this airstream is contaminated with about 293 mg of CS₂ and 146 mg of H₂S per cubic meter. Caustic scrubbing removes the H₂S but not the CS₂. The Clean Air Act Amendments of 1990 require that these CS₂ emissions eventually be eliminated or greatly reduced.

Argonne National Laboratory has previously studied the possibility of using currently available, well-known, gas cleanup methods, including adsorption and absorption, to remove the CS₂ [1]. Common absorption and incineration were found to be either infeasible or very expensive. Carbon adsorption was found to be effective and less expensive and, therefore, was a possibility. This current study is a supplement to the previous study. Instead of focusing on well-known, proven methods, this study considers less well-known, bacterial-based methods, emphasizing comparative cost estimates.

In particular, two slightly different bacterial-based processes are under consideration for cleaning the Teepak airstream. Both use the sulfur-metabolizing bacteria, thiobacillus, to oxidize and thereby destroy the airborne sulfide contaminants H₂S and CS₂. In one case, certain conditions (discussed in Section 2.4) are controlled to force the reaction to near 100% oxidation of the sulfide, producing sulfate (i.e., sulfuric acid). In the other case, it is assumed that complete oxidation can be discouraged, and much less of the sulfide is converted to sulfate; most of the sulfur in the sulfides becomes elemental sulfur. Representative processes for these two cases are simulated in detail, and economic models of the processes are presented (see Appendix A for a detailed explanation of the costing application of Aspen Plus, a well-known simulator). In this report, the term "biofiltration" is used for the process that oxidizes to sulfate, and the term "biocolumn" is used for the process that produces mostly elemental sulfur.

Ancillary processes for sulfuric acid concentration and gypsum production are also evaluated in various combinations with the biological processes. Process simulation is used to select the most economically feasible means of removing sulfide gases from the Teepak air, while minimizing disposal costs of sulfur-based by-products.

2 BIOTECHNOLOGY FOR AIR PURIFICATION

2.1 BIOFILTRATION

Biofiltration is defined as the removal and oxidation of organic gases (or such inorganic gases as H_2S and CS_2) from contaminated air by microorganisms in a "filter" or bed of porous compost or soil. It is a relatively new technique for reducing industrial emissions of polluted air. The first biological air filters appeared in the 1950s and were used to treat odorous air from compost factories and sewage-water treatment plants. With the development of new biologically active materials in the late 1970s, the applicability of biofiltration has expanded [2].

Recently, a closed-type modular biofiltration unit, or "biofilter," has been developed. This unit is illustrated in Figure 1. Polluted air is conducted via a pressure chamber through a porous filter (i.e., a layer of biologically active material approximately 1-m thick). The filter material is continuously sprayed from above with a recycled-water solution to provide nutrients and to maintain filter moisture content between 60 and 70 wt%. The filter material comprises a mixture of selected tree bark, compost, microorganisms, and adsorbents (e.g., activated carbon). This mixture forms an optimal environment for selected microorganisms. Within the filter, the microorganisms attach to all surfaces, forming a layer of microbial life called the "biolayer."

Contaminants and oxygen are transported by diffusion through the biolayer from the gas/liquid interface to the microorganisms. Inorganic nutrients necessary for microbial life are also supplied. Contaminants (such as sulfides) are taken up by the microorganisms, which use the contaminants for growth and other metabolic activities, and the oxidized form is excreted.

The applicability of biofiltration is increasing continually. The number of contaminant chemicals that can be treated successfully, as well as the number of installations, is increasing yearly. This growth is not only due to increased applicability but also due to increasing knowledge of the biodegradation process.

2.2 BIOCOLUMN

In the biological trickle column (biocolumn) configuration, a vertical cylinder is filled with a relatively large-size plastic or ceramic packing, e.g., the packing rings shown in Figure 2. The microorganisms form a surface biolayer on the packing. A recycled-water solution of controlled pH, containing dissolved bacterial nutrients, flows downward. Contaminated air passes upward, where the biolayer removes the contaminants [3]. In the case of H_2S and CS_2 contaminants, autotrophic

FIGURE 1 Closed Modular Biofiltration Unit

FIGURE 2 Biological Trickle Column (Biocolumn)

bacteria of genus *Thiobacillus* are used. When the pH is maintained near neutral, large amounts of sulfur are produced, which exit the reactor as colloidal-sized particles [3]. This sulfur is carried through the column by the recycle liquid. If a favorable environment in the biocolumn is maintained, the biolayer can last for years with relatively little loss of microorganisms.

2.3 MICROORGANISMS

Many common soil bacteria can oxidize reduced sulfur compounds like CS₂ and H₂S. Some bacteria do this oxidation aerobically (in the presence of air), and others do it anaerobically (in the absence of oxygen). These microbes comprise both heterotrophic (obtaining nourishment from organic substances) and autotrophic (obtaining nourishment by synthesis of inorganic materials) types. Both types have been studied for biological removal of sulfur contaminants from water and air, but most of the work to date has been centered on autotrophic species, especially those of the genus *Thiobacillus*, which use reduced sulfur compounds as electron donors and carbon dioxide as a carbon source.

In some cases, the microbial population is composed of mixed cultures that have been enriched from common ditch mud [4]. In other cases, pure strains have been used [5]. Several studies have shown the applicability of mixed cultures grown from sewer sludge [3]. In particular, *Thiobacillus denitrificans* has been used to reduce H₂S under a variety of conditions [5]. This microbe has also shown a tolerance for CS₂. In only a few cases have these biological methods been directly applied in CS₂ removal from air emissions from a viscose plant [6].

2.4 BIOLOGICAL OXIDATION

The inorganic oxidation of sulfide in thiobacilli appears to proceed through three sequential reactions:

The economics of producing free sulfur, compared to the economics of producing sulfuric acid, depend on many variables, and separate evaluation of each individual case is necessary. Therefore, relative to the above three-stage reaction, two issues are pertinent: First, how can the three

reactions be controlled, thereby controlling the relative yields of free sulfur and sulfuric acid? Second, how can possible by-products, such as free sulfur or sulfuric acid, best be recovered from the reactor and prepared for potential users?

A small amount of work has been done to address the first issue. In one study, which used a water-based, stirred gas/liquid reactor, it was concluded for thiobacillus that the third reaction can be suppressed by controlling oxygen and sulfide concentrations [4]. At high sulfide concentrations (exceeding 20 mg/L), the second reaction was suppressed by the sulfide itself, so high oxygen concentration can be used to increase oxidation rates; at lower sulfide concentrations, the second reaction can be suppressed by increasing oxygen concentration.

Another study found that the relative rates of reactions 1 and 3 are different for different strains of thiobacillus [5], and these different strains require different acidities of the recycle solution to thrive [3]. The strains that favor reaction 1 thrive at neutral pH, so maintenance of the bioreactor at pH 6 or 7 will eventually eliminate strains that favor reaction 3, and the production of elemental sulfur will be enhanced.

Some aspects of the recovery of by-products are addressed in detail in Section 6, where it is assumed that sulfuric acid can be recovered from the biofilter in dilute solution and that elemental sulfur can be recovered from the biocolumn. However, the recovery of elemental sulfur is less certain. Some researchers have stated that it is impossible to separate biomass and sulfur in a stirred reactor [4]. However, nonstirred experiments indicate that colloidal sulfur is indeed excreted by the bacteria and can be recovered from a packed, washed column [3]. Furthermore, the bacteria will remain in the column as long as favorable conditions are maintained. Therefore, the removed sulfur is not highly contaminated with bacteria cells. This concept has been described and patented by Torres-Cardona, et al. [7] and discussed by Cork [8].

3 DISPOSAL OF BY-PRODUCTS

As mentioned in the Introduction, approximately 644,000 m³/h of sulfide-contaminated air is emitted at Teepak. The CS₂ levels are around 293 mg/m³. Caustic scrubbers currently remove about 9.4×10^7 mg of H₂S per hour from this air. If all sulfur, including that of the H₂S currently removed by caustic scrubbing, were collected as elemental sulfur, about 2,392 tons of sulfur would be produced per year. This section covers generalized possibilities for disposal of either recovered sulfur or compounds that can be made from it; that is, the scope of the disposal problem is estimated and discussed without regard to how the sulfides are recovered from air and how the resulting sulfur compounds are processed.¹ Also in this section, and in Appendix B, disposal costs are developed for possible sulfur compounds considered as wastes. Some possible forms of the recovered sulfur are (1) high-quality sulfur, (2) concentrated sulfuric acid, (3) dilute sulfuric acid, and (4) gypsum.

If all the sulfur were oxidized to sulfate, about 7,307 tons of sulfuric acid per year would be produced. Assuming 4% losses, collection possibilities for elemental sulfur and pure sulfuric acid become, respectively, 4.59 million pounds or 2,296 tons of sulfur per year and 14.0 million pounds or 7,015 tons of acid per year. If the sulfuric acid were obtained in a dilute form (such as 3%), about 233,830 tons of dilute acid per year would be produced. If the acid were obtained at 13%, about 53,961 tons of dilute acid per year would be produced. If the sulfur were contained in gypsum, about 12,351 tons of gypsum per year would be produced. Calculations to obtain these numbers are detailed in Appendix B. Table 1 summarizes the results.

Since sulfur is considered a nonhazardous waste and can be safely landfilled, it is possible that the sulfur recovered from the Teepak emissions could be disposed of in a relatively inexpensive, special-waste landfill. The costs for disposal of elemental sulfur, along with the other possible products, are estimated in Appendix B and summarized in Table 2.

The sulfuric acid produced by removing H₂S and CS₂ emissions could be sent to a treatment facility, where it would be neutralized and the solids sent to a landfill for disposal. Likewise, the sulfuric acid could be reacted with limestone to produce gypsum that would be disposed of in a special-waste landfill. The disposal costs for sulfuric acid and gypsum are listed in Table 2.

¹ In Section 6 of this report, the problem of how the sulfides may be recovered and processed to other forms that may be sold or disposed of is considered, and economic estimates are developed. Therefore, in some cases in Section 6, the various possible recovered sulfur compounds are assumed to be valuable commodities, revenue from their sales is estimated, and this estimate is used as a component of the economics. In other cases, the production of a disposable substance is evaluated.

TABLE 1 Summary of Potential Sulfur and Sulfur Compounds Recovered from Teepak Sources

Source	Rate of Emission			Sulfur Recovery (%)	Potential Recovered Sulfur (tons/yr)	Potential 100% Sulfuric Acid (tons/yr)	Potential 13% Sulfuric Acid (tons/yr)	Potential 3% Sulfuric Acid (tons/yr)	Potential Gypsum (tons/yr)
	Air (10 ³ m ³ /h)	CS ₂ (mg/m ³)	H ₂ S (mg/m ³)						
Teepak 1	290	293	320	96	1,484.1	4,532.4	34,872.3	151,111.5	7,981.9
Teepak 2	354	293	0	96	812.4	2,482.5	19,089.2	82,718.8	4,369.3
Total	644				2,296.5	7,014.9	53,961.5	233,830.3	12,351.2

TABLE 2 Summary of Disposal Costs for Possible Wastes Produced at Teepak

Item	Waste Type			
	3% H ₂ SO ₄ Solution	100% H ₂ SO ₄	Gypsum	Elemental Sulfur
Amount produced (tons/yr)	233,830	7,015	12,351	2,296
Annual costs				
Lab analysis	$\$1.3 \times 10^3$	$\$1.3 \times 10^3$	$\$2.8 \times 10^3$	$\$2.8 \times 10^3$
Transport	$\$11.1 \times 10^6$	$\$187.4 \times 10^3$	$\$79.2 \times 10^3$	$\$16.7 \times 10^3$
Treatment and landfill	$\$32.9 \times 10^6$ to $\$49.4 \times 10^6$	$\$2.2 \times 10^6$ to $\$2.8 \times 10^6$	$\$95 \times 10^3$	$\$19.9 \times 10^3$
Taxes	$\$3.0 \times 10^6$	$\$50.6 \times 10^3$	included in treatment	included in treatment
Total	$\$47 \times 10^6$ to $\$63.6 \times 10^6$	$\$2.4 \times 10^6$ to $\$3.0 \times 10^6$	$\$177 \times 10^3$	$\$39.4 \times 10^3$

Obviously, at a disposal cost approaching \$63 million per year, 3% sulfuric acid is not a good choice for disposal. The disposal cost of pure sulfuric acid, at \$3.05 million, is only a fraction of the cost for dilute acid disposal, but, as discussed in Section 4, concentrated acid production is financially infeasible. However, Teepak uses concentrated sulfuric acid, currently worth around 4.0¢/lb, as a purchased commodity for the process. For example, in 1991, 15.55 million pounds of concentrated sulfuric acid were purchased, and in 1992, 16.11 million pounds were purchased. Therefore, it is possible that weak sulfuric acid produced by biofiltration recovery of CS₂ and H₂S emissions, with subsequent concentration, could be entirely consumed at Teepak by recycle to the viscose process. Sulfuric acid is neutralized by sodium hydroxide in the viscose process, and, at Teepak, the majority of the resulting sodium sulfate is recrystallized and sold as a by-product.

From the above discussion, it is clear that disposal costs, especially for acid, are very high. The idea of marketing products from sulfide removal, especially sulfuric acid or elemental sulfur, seems sensible, since the sale of by-products would alleviate the expense of disposal and could possibly provide revenue. However, these and other alternatives cannot be evaluated unless the total cost of each option is estimated on a comparable basis. Such cost estimates are considered directly in Section 6. Sections 4 and 5 discuss generalized information on sulfuric acid and elemental sulfur as commodities.

4 SULFURIC ACID

4.1 PRODUCTION OF SULFURIC ACID

Sulfuric acid is the highest volume chemical produced in the United States, and by far the most widely used industrial chemical. About 75% of commercial sulfuric acid is produced by burning elemental sulfur and passing the resulting sulfur dioxide, with oxygen, over a vanadium pentoxide catalyst to oxidize it to sulfur trioxide. The absorption of sulfur trioxide by an acid/water system produces the final product. This process is called the "contact" process [9].

Other, similar means of producing sulfuric acid are related to an increasing need to limit environmental damage by sulfur oxides emissions [10]. Recovery of sulfur oxides from copper, zinc, or lead smelter gases and subsequent processing of the oxides to sulfuric acid currently provides over 10% of sulfuric acid production. Regeneration of spent acid (by combustion) and other environmental-based production account for most of the remaining production.

4.2 USES OF SULFURIC ACID

The production of phosphate fertilizers consumes at least 70% of yearly U.S. sulfuric acid production [11]. Phosphate rock is converted to phosphoric acid and calcium sulfates. Further processing of the acid with ammonia produces diammonium phosphate (DAP), the final product. Other uses of sulfuric acid include production of inorganic pigments, textile fibers, explosives, petroleum products, alcohols, pulp, paper, detergents, and other chemicals, as well as a leaching agent for ores, a pickling agent for iron and steel, and a component for lead storage batteries.

4.3 SULFURIC ACID MARKET

Overall growth in sulfuric acid consumption is expected to average about 0.5% per year through 1995 [12]. The 1991 production was 44.2 million tons in the United States. Also, 1.8 million tons were imported, largely by-products from Canadian smelters. The fertilizer industry has recently struggled with a worldwide oversupply of DAP [13-16]. Economic difficulties in important user countries (such as India and China) have intensified the problem [17]. However, even with a DAP recovery, the use of sulfuric acid is expected to decline in the fertilizer industry. Balancing this decline is the increasing use of sulfuric acid in leaching ore to obtain copper [18].

4.4 WASTE SULFURIC ACID

Sulfuric acid is considered a hazardous waste. Commercial treatment facilities for neutralization and disposal exist [19]. For example, Clean Harbors Environmental Services, Inc., of Chicago, Ill., neutralizes the acid with sodium hydroxide. Most of the inorganic impurities in the solution are precipitated. The water is separated from the solids and discharged to the sewage system. The solids, which are a mixture of inorganics and hydroxides, are dewatered by pressure filtration and transported to a landfill. The generalized waste treatment process at Clean Harbors is illustrated in Figure 3. The results of our study (Table 2) indicate that the cost of treating weak acid by this method is too high for consideration.

Sulfuric acid can also be neutralized by limestone to produce gypsum (calcium sulfate). The gypsum product may be disposed of or, if of high purity, sold. The neutralization proceeds according to the following reaction:

This reaction is easy to maintain as long as there is a sufficient supply of limestone. However, if excess acid is applied to a bed of limestone, it will precipitate the calcium sulfate and deactivate the limestone bed. To avoid this problem, sulfuric acid must be applied to a limestone bed at a rate less than 5 gpm/ft² (gpm is gallons per minute) and be diluted to an upper limit of about 5% [20,21]. Reacting powdered limestone in a large stirred reactor may alleviate the deactivation problem, but it will not assure quality control of the gypsum produced. Gypsum disposal is a disadvantage of this method of neutralization. The costs associated with gypsum disposal and neutralization and with disposal of sulfuric acid are listed in Table 2.

4.5 SULFURIC ACID CONCENTRATION

Since biological treatment of CS₂-laden air produces a weak sulfuric acid that has no market value and carries a very large disposal liability, concentration to a strong acid must be considered. Some of the various means of acid concentration are reviewed below. The maximum concentrations that can be attained with these methods are listed in Table 3.

4.5.1 Electrodialysis

Electrodialysis technology incorporates a succession of cation exchange membranes and an anion-exchange membrane placed between a pair of electrodes. The ions pass through the membranes in preference to all other species due to the voltage difference. Electrodialysis will not

concentrate sulfuric acid solutions above 5%, because above 5% the concentration gradient between the cells is large enough that the cation-exchange membrane passes H^+ ion due to osmotic pressure. Ionics, Inc., has done research with acid-blocking membranes in acid concentrations above 5% [22]. Unfortunately, the development was not fully successful; therefore, acid-blocking membranes have never been commercialized.

TABLE 3 Maximum Concentration Percentages for Different Methods of Concentrating H_2SO_4

Method of Concentrating H_2SO_4	Practical Maximum Concentration (%)
Bipolar Membrane	10
Electrodialysis	5
Evaporation	95

4.5.2 Bipolar Membranes

Graves Water Division, formerly Aquatech Systems, a business unit of Allied Signal Inc., has commercialized the use of electrodialysis with bipolar membrane technology [23]. This technology uses a stack of water-splitting cells placed between an electric potential to separate and concentrate the ions in a solution. Each water-splitting cell consists of three compartments — acid, salt, and base — which are bounded by the bipolar, anion, and cation membranes. The bipolar membrane, which contains a cation-selective region and an anion-selective region separated by a very thin interface, is the heart of the water-splitting cell. The water-splitting cell is placed between a pair of electrodes, with the cation-selective side toward the cathode. When an electric potential is placed across the electrodes, the cations and anions move across the monopolar membranes into their respective compartments. Bipolar membranes will not concentrate sulfuric acid solutions above 10%, because the anion exchange membrane is not perfectly selective to the H^+ ions.

4.5.3 Evaporation

Evaporation is the removal of a solvent from a solution by vaporization of the solvent. It represents the most common method of concentration of dilute sulfuric acid and the only practical way to concentrate the effluent from the biofilter. It is discussed relative to process technology and economics in Section 6.

5 SULFUR

5.1 OCCURRENCE AND EXTRACTION

The primary deposits of sulfur in North America occur in the Gulf Coast region of the United States and Mexico. Most of these deposits occur in salt domes. It is believed that the free sulfur was formed by reduction of sulfate minerals by anaerobic bacteria [24].

The sulfur is usually extracted by pumping hot water into the deposits, melting the sulfur, and pumping the melted sulfur to the surface. This technique is called the Frasch process [25]. In addition to production of sulfur by extraction methods, sulfur is also recovered as a by-product from desulfurization processing of petroleum and natural gas. This source accounts for the largest portion of world sulfur production.

5.2 USES OF SULFUR

The main use of elemental sulfur is in the production of sulfuric acid, which, as discussed in Section 4, has a wide range of industrial uses. The largest use of sulfuric acid is in the manufacturing of phosphate fertilizer.

5.3 SULFUR MARKET

Over the last few years, the sulfur market has experienced price weakness related to sulfuric acid demand, in particular for fertilizer production. However, this decline is temporary, because developing countries are raising crop production by 3%/yr and most soils require fertilizer to sustain this growth rate. Rapidly increasing levels of food production in developing countries will boost global demand for sulfur-produced fertilizers from the current 14.7 million metric tons to 18.6 million metric tons by the turn of the century [25].

5.4 SULFUR DISPOSAL

Sulfur is considered a nonhazardous waste and may be disposed of in a special-waste landfill. A complete laboratory analysis must be performed in compliance with U.S. Environmental Protection Agency (EPA) requirements [26] to show that the sulfur waste does not contain other, more hazardous, components. To estimate the disposal cost of sulfur collected at Teepak, commercial- waste landfills were contacted and asked to provide estimates. On the basis of these estimates, the average disposal cost was calculated as shown in Appendix B and summarized in Table 2.

6 COST ESTIMATES FOR CS₂ REMOVAL PROCESSES

In Section 3, disposal costs for each of three different forms of sulfate and for elemental sulfur were estimated. In this section, estimates of plant investment and operating costs are discussed for several different combinations of biological CS₂ removal and by-product production or treatment processes.

Aspen Plus, a well-known process simulator, has been applied to all processes, thereby developing process flow diagrams and plant designs; then process economic methods, coupled with Aspen Plus economic routines, have been used to estimate costs. The factored cost estimates developed have an absolute accuracy of only $\pm 30\%$. However, since the same methods have been used for each process, it is believed that good relative accuracy was obtained and that the resulting cost ranking of processes is reliable. Of course, estimated costs are dependent on the assumptions and methods used. All details of the assumptions and results for each process are given below and in Appendix A.

In order to compare the cost estimates for the biological processes with a cost estimate for a standard nonbiological CS₂ removal process, a carbon adsorption process has been simulated and costed by using methods exactly comparable to those used for the biological processes.

6.1 CARBON ADSORPTION

Carbon adsorption is a well-known process that has been extensively studied as a CS₂ removal application [1]. Rather than using previously estimated costs for carbon adsorption, new costs were developed from Aspen Plus. The new costs are believed to provide a better basis for comparison — not because they are more accurate, but because the reference material, techniques, and assumptions used are similar to those used in the biological simulations.

In previous studies of CS₂ removal by carbon adsorption, the best economics resulted by using an air feed that was only partially dried (to avoid extensive refrigerant dryer costs) and by desorbing with steam rather than with nitrogen [1]. This version is therefore the one presented here. Figure 4 shows the process flow diagram. Note that the line of adsorption towers shown in the figure is only representative, since 16 operating towers and four spares are required for the actual process.

The Teepak flow of contaminated air is split into four equal flows and each is sent to a large blower for boosting pressure to 5 psig. The air enters four refrigerant dryers that cool and remove moisture to about 50% relative humidity. The air is recombined in a single manifold and sent to the

FIGURE 4 Process Flow Diagram for a Carbon Adsorption Plant

adsorption towers, which are housed in a prefabricated building. The air is split into 16 equal streams, each of which enters a single adsorption tower that has a carbon-bed depth of 5.4 ft. In the towers, CS_2 and H_2S are removed, and the clean air is discharged to the atmosphere.

The breakthrough time is 16 h; therefore, after a given adsorption tower has been operating for 16 h, the CS_2 concentration of the existing air will rise to 10 ppm, the breakpoint. The flow will then be directed to a freshly desorbed and cooled tower, and the previous tower will be desorbed. Each tower can be cooled with chilled water or heated with 150-psig steam by internal bed coils.

Desorption is accomplished by sealing the tower and flushing with N_2 , using steam coils to heat the bed to the desorption temperature (typically 300°F), and then flooding the tower with 300°F steam, which will carry off the CS_2 . This preheating action prevents the desorption steam from exiting the tower with low CS_2 concentration while the bed is being heated. Since excessive diluting of CS_2 is prevented, this preheating step allows more efficient condensation and recovery of CS_2 . When desorption is completed, the hot bed must be cooled to less than 200°F before admitting air, to avoid the possibility of fire. The CS_2 /steam mixture from the desorption flow is sent to a chilled-water condenser, where the steam is condensed. The resulting $\text{CS}_2/\text{H}_2\text{O}$ vapor is further condensed in a refrigerant condenser, and the liquid CS_2 is decanted and stored.

A summary of the results of the simulation is given in Table 4. The table indicates that the total investment estimate is \$31.6 million, with \$8.9 million yearly operating costs, which includes a credit for the value of the recovered CS_2 of almost \$1 million per year. Total equipment cost is about \$5.6 million. More details from the simulation are given in Appendix A.

6.2 BIOFILTER

Aspen Plus process and economic simulations have been developed for a biofilter plant that would purify the Teepak air emissions and produce 3% sulfuric acid by-product. The assumptions used in preparing the biofilter plant simulation are given in Table 5.

The calculations used by Aspen Plus in completing the material balance for the biofilter are given in Appendix C. Details of the biofilter setup assumed for the simulations are given in Figures 5 and 6. A schematic process-flow diagram, showing the results of the mass balance, is given in Figure 7. A summary of the results from the Aspen Plus process and economic simulation is given in Table 6. The results indicate that the total investment is \$7.8 million, with \$65.3 million yearly operating costs. Total equipment cost is \$1.4 million. In this case, the CS_2 is destroyed and worthless dilute sulfuric acid (3%) is produced; thus, no by-product credit can be taken. The cost of disposal of the 3% sulfuric acid (by methods outlined in Appendix B and Section 3) is more than \$62 million per year. The disposal cost represents 95.8% of total operating costs.

TABLE 4 Summary of Simulation Results for a Carbon Adsorption Plant**A. Annual Operating Cost Summary**

Production capacity for all products 100.0%
 Base period 1996, Quarter I
 Plant availability 328/365.25 days
 Raw material
 Steam 40,000 lb/h at \$0.0028139/lb

	<u>Annual Cost (\$)</u>	<u>Total Annual Cost (\$)</u>
Raw material		888,000
Utilities		1,574,000
Labor (operators: two per shift, three shifts)		
Operating (16,000 h)	396,000	
Maintenance	959,000	
Supervision	271,000	
Fringe benefits	650,000	
Subtotal		2,276,000
Supplies		
Operating	40,000	
Maintenance	639,000	
Subtotal		679,000
General works		
General and administration	976,000	
Property tax	533,000	
Property insurance	213,000	
Subtotal		1,722,000
Depreciation (15 years, straight line)		1,776,000
Gross operating cost		8,915,000
Less by-product credit		993,000
Net operating cost		<u>7,922,000</u>
Summary		
Fixed cost	5,090,000	
Variable cost	1,536,00	
Gross cost excluding depreciation		7,139,000
Gross operating cost		8,915,000

B. Process Unit Direct Cost Summary

Equipment cost 5,594,600
 Total investment 31,635,000

TABLE 5 Assumptions for the Process and Economic Simulation for a Biofilter Plant

1. Contaminated Air	
Flow	400,000 ft ³ /min (679,000 m ³ /h) ^a
Moisture	Saturated at 70°F
Contamination	100 ppm CS ₂ , 80 ppm H ₂ S
2. Biofilter Unit Cost	
Units	Steel ISO containers, 8 ft × 8 ft × 40 ft
Initial cost	\$5,000
Modifications	\$4,000
Total costs	\$9,000
3. Superficial Velocity in Biofilter Bed	
	12 ft/min (this value is an average of 13 existing biofilter systems from Ref. 27)
4. Overall Chemical Reaction in Biofilter	
	$5 \text{ CS}_2 + 4 \text{ H}_2\text{S} + 10 \text{ H}_2\text{O} + 28 \text{ O}_2 \rightarrow 14 \text{ H}_2\text{SO}_4 + 5 \text{ CO}_2$
5. Total Number of Biofilter Units, N	
	From assumptions 1, 2, and 3, $N = (400,00 \text{ ft}^3/\text{min}) / [(12 \text{ ft}/\text{min})(8 \text{ ft} \times 40 \text{ ft})] = 104$
6. Configuration of Biofilter Field	
Stacks of double units	52 (see Figures 5-6)
Land area	1 acre (see Figure 6)
7. Service Lines in Biofilter Field	
Air feed	Horizontal ducting: 840 ft Vertical ducting: 520 ft
Solution feed	Hastelloy pipe: 2,192 ft
Acid recovery	Hastelloy pipe: 1,880 ft
8. Removal Efficiency of Biofilter	
CS ₂	100%
H ₂ S	100%
9. Solution Delivery Rate	
Liquid-to-gas mass ratio	0.43
10. Acid Concentration in Solution	
Acid-to-water mass ratio	0.03
11. Clean Air	
Flow	400,000 ft ³ /min
Moisture	Saturated at 70°F
Contamination	None

^a The flow assumed is about 5% higher than the nominal flow at Teepak of 644,000 m³/h.

FIGURE 5 Configuration of One Double Unit of a Biofilter Field

FIGURE 6 Biofilter Field

FIGURE 7 Process Flow Diagram for a Biofilter Plant

The disposal cost is that incurred if the 3% acid were treated and disposed of by a company specializing in such disposal; this cost is based on vendor quotes. Obviously, it is too large for serious consideration. It is given here simply for perspective. More details of the results from the Aspen Plus simulation are given in Appendixes A and C.

6.3 BIOFILTER WITH ACID CONCENTRATION

As mentioned above, the product of biofiltration is dilute sulfuric acid, which has no market value but which carries a large disposal liability. Since concentrated sulfuric acid (95%) is a valuable commodity, with a current market value of about 4¢/lb, the addition of an acid concentration plant to the biofilter was assumed to be an option worthy of study. Also, the viscose process under some assumptions could use 13% sulfuric acid to neutralize and precipitate the cellulose polymer in the final stage of the process. Therefore, another option we have chosen to study is acid concentration to 13% for the production of assumed recyclable 13% acid.² Based on the reasonable assumption

² This option is only hypothetical, since the use of 13% acid directly would require additional evaporation capacity downstream of the viscose process. This additional capacity is not included in the 13% acid production cost estimates that follow. This option is given to emphasize the large effect of capacity on acid evaporation economics.

TABLE 6 Summary of Simulation Results for a Biofilter Plant with 3% Acid Waste**A. Annual Operating Cost Summary**

Production capacity for all products	100.0%	
Base period	1995, Quarter III	
Plant availability	328/365.25 days	
Raw material		
H ₂ O	55,260 lb/h at \$0.00014273/lb	
	<u>Annual Cost (\$)</u>	<u>Total Annual Cost (\$)</u>
Raw material		62,000
Utilities		
130,000		
Waste treatment		62,562,000
Labor (operators: two per shift, three shifts)		
Operating (16,000 h)	385,000	
Maintenance	274,000	
Supervision	132,000	
Fringe benefits	316,000	
Subtotal		1,107,000
Supplies		
Operating	38,000	
Maintenance	183,000	
Subtotal		221,000
General works		
General and administration	474,000	
Property tax	152,000	
Property insurance	61,000	
Subtotal		688,000
Depreciation (15 years, straight line)		508,000
Gross operating cost		65,273,000
Less by-product credit		0
Net operating cost		<u>65,278,000</u>
Summary		
Fixed cost	2,016,000	
Variable cost	62,755,000	
Gross cost excluding depreciation		64,771,000
Gross operating cost		65,278,000

B. Process Unit Direct Cost Summary

Equipment cost	1,357,900
Total investment	7,768,000

of 4¢/lb for 95% acid, 13% acid is estimated to be worth 0.55¢/lb to Teepak. This value is used in the estimates discussed below to calculate the hypothetical recycle credit to Teepak for 13% acid.

6.3.1 Production of 13% Acid

A schematic process flow diagram showing the combined biofiltration and acid concentration plant is given as Figure 8. The biofiltration effluent acid is concentrated from 3% to 13% H_2SO_4 in a single-stage concentrator. The reboiler, constructed of zirconium, is arranged in a natural circulation loop. The use of natural circulation eliminates the need for an expensive forced-circulation pump in hot-acid service. The separator is constructed of fiberglass-reinforced plastic (FRP), and the overhead vapors are condensed in a 316L stainless steel condenser. The system is maintained under vacuum by a jet-ejector/condenser system. The distillates flow from the condensers and ejectors to an FRP distillate tank and are then pumped to battery limits for disposal. The product is cooled in a carbon-block cooler and flows by gravity to battery limits for reuse. Table 7 lists the operating constants used in the simulation.

A summary of the results from the Aspen Plus process and economics simulation is given in Table 8. As shown, the total investment is \$26.8 million, which represents \$19.1 million for the evaporation plant and \$7.7 million for the biofilter plant. The annual gross operating costs are \$6.1 million for the evaporation plant and \$1.9 million for the biofilter plant. The total equipment cost is \$4.7 million, with \$3.4 million for the evaporation plant and \$1.3 million for the biofilter plant. By-product credit of \$750,000 per year for the 13% acid recycled to the viscose process produces a net operating cost of \$7.3 million.

6.3.2 Production of 95% Acid

For the case of production of 95% sulfuric acid, Figure 9 shows the combined biofiltration and acid concentration plant. The feed acid is concentrated from 3% to 95% in a three-stage concentrator. All three reboilers are arranged in natural circulation loops. The first-stage reboiler is constructed of zirconium; the second- and third-stage reboilers are constructed of tantalum. As for the 13%-acid case, forced circulation pumps are not required in any of the stages. The first-stage separator is constructed from FRP, while the second- and third-stage separators are constructed from glass-lined steel. The acid overflows by gravity between stages. The overhead vapors from stages 1 and 2 are condensed in 316L stainless steel condensers.

The 95% solution has a relatively high vapor pressure of sulfuric acid, which requires that the vapors from stage 3 be condensed in a brick-lined, steel scrubber-condenser, with 75% H_2SO_4 as the condensing liquid. A makeup stream from the stage 2 overflow is added to the scrubber-pump

FIGURE 8 Biofiltration/Acid Concentration Plant for Producing 13% Acid

TABLE 7 Operating Constants for Acid Concentration Plants

Operating Constant	Concentration to 13%	Concentration to 95%
Feed Acid		
Flow	53,200 lb/h	53,200 lb/h
Concentration	3% H ₂ SO ₄	3% H ₂ SO ₄
Temperature	75°F	75°F
Product Acid		
Flow	12,277 lb/h	1,407 lb/h
Concentration	13% H ₂ SO ₄	95% H ₂ SO ₄
Temperature	120°F	200°F
Distillate		
Flow	40,923 lb/h	51,656 lb/h
Concentration	<100 ppm	0.25% H ₂ SO ₄
Temperature	120°F	120°F
Steam		
Consumption	53,000 lb/h	51,656 lb/h
Pressure	100 psig	250 psig
Cooling Water		
Flow	5,500 usgpm ^a	7,900 usgpm
Supply temperature	86°F	86°F
Return temperature	104°F	104°F
Electrical Power (pumps only)	10 hp	20 hp

^a usgpm = U.S. gallons per minute.

tank, and a bleed stream from the scrubber circulation loop joins the feed to stage 1. The scrubber-condenser acid is cooled in a carbon-block cooler. All stages are maintained under a vacuum by jet-ejector/condenser vacuum systems. The distillates flow from the condensers and ejectors to an FRP distillate tank and are pumped to battery limits for disposal. The product is cooled in a carbon-block cooler and flows by gravity to battery limits for recovery. The operating constants used in the simulation for this case are listed in Table 7.

About 8% of the acid value in the feed is lost with the distillate. This loss occurs because the partial pressure of the acid vapor becomes significant at strengths over 70%, resulting in a loss of acid from the overhead vapors of stage 2. The vapors from stage 3 are condensed by scrubbing with acid to avoid a much more significant loss of acid.

TABLE 8 Summary of Simulation Results for a Biofilter Plant with Acid Concentration to 13%**A. Annual Operating Cost Summary**

Production capacity for all products	100.0%	
Base period	1996, Quarter II	
Plant availability	328/365.25 days	
Raw material		
H ₂ O	55,260 lb/h at \$0.00014848/lb	
	<u>Annual Cost (\$)</u>	<u>Total Annual Cost (\$)</u>
Raw material		65,000
Utilities		
1,559,000		
Labor (operators: two per shift, three shifts)		
Operating (16,000 h)	400,000	
Maintenance	949,000	
Supervision	270,000	
Fringe benefits	647,000	
Subtotal		2,266,000
Supplies		
Operating	40,000	
Maintenance	632,000	
Subtotal		672,000
General works		
General and administration	971,000	
Property tax	527,000	
Property insurance	211,000	
Subtotal		1,709,000
Depreciation (15 years, straight line)		1,757,000
Gross operating cost		<u>8,028,000</u>
Less by-product credit		749,000
Net operating cost		<u><u>7,279,000</u></u>
Summary		
Fixed cost	4,647,000	
Variable cost	1,624,000	
Gross cost excluding depreciation		6,271,000
Gross operating cost		8,028,000

B. Process Unit Direct Cost Summary

Equipment cost	4,684,600
Total investment	26,876,000

FIGURE 9 Biofiltration/Acid Concentration Plant for Producing 95% Acid

The steam consumption increases from less than 1.3 lb steam/lb distillate for the 13% case to more than 1.4 lb/lb for the 95% case. At the same time, the steam supply pressure must be greater for the 95% case than for the 13% case because of the higher boiling point of concentrated acid.

Note that the evaporation economics are much more favorable for the 13% case. There is a breakpoint in the cost of evaporation near the region of 60-65% H_2SO_4 beyond which capital and operating costs increase significantly. This breakpoint is due to the need to switch from zirconium to tantalum construction and also because of the increased boiling point and increased partial pressure of acid at higher concentrations.

A summary of the simulation results is given in Table 9. The total investment is \$48.9 million, with components of \$41.2 million and \$7.7 million for the evaporation and biofilter plants, respectively. The annual gross operating costs are \$10.8 million and \$2.0 million, respectively, and the total equipment costs are \$7.3 million and \$1.3 million. By-product credit for the 95% acid product of \$0.73 million produces a net operating cost of \$12.2 million per year.

6.4 NEUTRALIZATION WITH LIMESTONE

Because limestone can neutralize sulfuric acid and also is a relatively inexpensive material, neutralization of the biofilter effluent with purchased limestone was considered. Two possibilities exist. The solid gypsum product of the acid-limestone reaction could be produced as a marketable commodity or the gypsum product could be landfilled. If the gypsum is to be of marketable grade, care must be taken to ensure its continuing quality. Existing plants for producing marketable gypsum use 65% sulfuric acid and a "den" reactor and other devices to ensure complete reaction. To duplicate this process at Teepak, acid concentration to 65% must be incorporated.

If the 3% acid is simply to be neutralized with limestone and the result landfilled, there is no need to ensure solid product quality. The main goal is to achieve total acid neutralization; therefore, this process has no need to concentrate the acid. Since limestone is benign in landfill, some excess limestone can be used to assure total acid neutralization.

6.4.1 Production of Marketable Gypsum

Calcium sulfate, or gypsum, is a commodity with a variety of uses (e.g., as a component of cements, plaster, paint, etc.). It occurs naturally in the earth and can be mined, so it has a relatively low market value. It can also be manufactured from 65% sulfuric acid and limestone. Therefore, another option for weak sulfuric acid disposal is to construct, along with the biofilter plant, both an evaporative acid concentration plant and a gypsum plant. Thus, the 3% acid from the biofilter is sent

TABLE 9 Summary of Simulation Results for a Biofilter Plant with Acid Concentration to 95%**A. Annual Operating Cost Summary**

Production capacity for all products	100.0%
Base period	1996, Quarter III
Plant availability	328/365.25 days
Raw material	
H ₂ O	55,260 lb/h at \$0.00015272/lb

	<u>Annual Cost (\$)</u>	<u>Total Annual Cost (\$)</u>
Raw material		67,000
Utilities		1,966,000
Labor (operators: two per shift, three shifts)		
Operating (16,000 h)	412,000	
Maintenance	1,726,000	
Supervision	428,000	
Fringe benefits	1,026,000	
Subtotal		3,592,000
Supplies		
Operating	41,000	
Maintenance	1,151,000	
Subtotal		1,192,000
General works		
General and administration	1,539,000	
Property tax	959,000	
Property insurance	384,000	
Subtotal		2,882,000
Depreciation (15 years, straight line)		3,197,000
Gross operating cost		12,895,000
Less by-product credit		730,000
Net operating cost		<u>12,165,000</u>
Summary		
Fixed cost	7,666,000	
Variable cost	2,032,000	
Gross cost excluding depreciation		9,698,000
Gross operating cost		12,895,000

B. Process Unit Direct Cost Summary

Equipment cost	8,593,800
Total investment	48,910,000

to the concentration plant, and the 65% acid from the concentrator is sent to the gypsum plant, where it is reacted with limestone to produce gypsum.

In Figure 10, only the gypsum plant is shown, since the biofilter and acid concentration plants are shown in previous figures. Limestone is delivered to the plant by truck. It is conveyed by belt to a crusher/grinder, where it is ground to a powder. The powder, transportable by entrainment in air, is sent to a cyclone and then to a mixer/reactor, where it is mixed with 65% sulfuric acid to produce gypsum. To ensure complete reaction, the mixer contents discharge into a holding chamber, or den, where they remain for a variable residence time of between 10 and 40 min. The gypsum product is removed, cut, and stored. The product cures in storage for at least two days.

A summary of the economic simulation of the composite biofilter, acid concentrator, and gypsum plant is given in Table 10. The total investment is \$40.4 million. The annual net operating costs are \$11.7 million, which includes a small by-product credit (\$0.083 million) for the gypsum produced. The total equipment costs are \$7.1 million. Additional economic data from the simulation are given in Appendix A.

6.4.2 Production of Waste Gypsum

Figure 11 shows the process flow diagram envisioned for production of 3% sulfuric acid by biofilter, neutralization by powdered limestone, and landfilling of the solid product. The biofilter field, as in previously described processes, produces 3% sulfuric acid solution, which is pumped to a stirred mixer. Powdered limestone is delivered to the plant by truck and is fed into the mixer. The water/limestone slurry is separated by decantation, and the waste gypsum is sent to landfill by truck.

A summary of the economic simulation of the composite biofiltration/neutralization is given in Table 11. The total investment is \$8.7 million. The annual net operating costs are \$3.6 million. The total equipment costs are \$1.5 million. Additional economic data from the simulation are given in Appendix A.

6.5 PRODUCTION OF ELEMENTAL SULFUR

As discussed in Section 5, elemental sulfur is an inexpensive material to landfill since it is environmentally benign. It also is a valuable feedstock used in manufacturing sulfuric acid, paper, rubber, and many other well-known products. Therefore, a possible approach for a CS_2 -removal process may be to control and limit the biological oxidation of CS_2 and H_2S in a biocolumn, as discussed in Section 2, to produce a mixture of sulfides and elemental sulfur. It is assumed that, under controlled pH, the product will be mostly elemental sulfur. This assumption is a conservative

FIGURE 10 Process Flow Diagram for a Gypsum Plant

TABLE 10 Summary of Simulation Results for a Biofilter Plant with Acid Concentration to 65% for Gypsum Production

A. Annual Operating Cost Summary

Production capacity for all products	100.0%	
Base period	1996, Quarter II	
Plant availability	328/365.25 days	
Raw material		
H ₂ O (feedstock)	54,055 lb/h at \$0.00015016/lb	
Lime (for scrubber)	2,187.4265 lb/h at \$0.032208/lb	
Water (for cooling)	7,118.3502 lb/h at \$0.00015016/lb	
	<u>Annual Cost (\$)</u>	<u>Total Annual Cost (\$)</u>
Raw material		
H ₂ O	64,000	
Lime	556,000	
Water	8,000	
Subtotal		628,000
Utilities		1,899,000
Labor (operators: two per shift, three shifts)		
Operating (16,000 h)	405,000	
Maintenance	1,428,000	
Supervision	367,000	
Fringe benefits	880,000	
Subtotal		3,079,000
Supplies		
Operating	40,000	
Maintenance	952,000	
Subtotal		992,000
General works		
General and administration	1,320,000	
Property tax	793,000	
Property insurance	317,000	
Subtotal		2,430,000
Depreciation (15 years, straight line)		2,644,000
Gross operating cost		11,673,000
Less by-product credit		83,000
Net operating cost		<u>11,590,000</u>
Summary		
Fixed cost	6,501,000	
Variable cost	2,528,000	
Gross cost excluding depreciation		9,029,000
Gross operating cost		11,673,000

B. Process Unit Direct Cost Summary

Equipment cost	7,081,600
Total investment	40,454,000

FIGURE 11 Process Flow Diagram for a Biofilter Plant with Gypsum Production for Disposal

TABLE 11 Summary of Simulation Results for a Biofilter Plant with 3% H₂SO₄ Neutralized by Limestone**A. Annual Operating Cost Summary**

Production capacity for all products	100.0%	
Base period	1995, Quarter III	
Plant availability	328/365.25 days	
Raw material		
H ₂ O	55,260 lb/h at \$0.00014273/lb	
CaCO ₃ (for neutralization of acid)	1,738.0000 lb/h at \$0.023686/lb	
	<u>Annual Cost (\$)</u>	<u>Total Annual Cost (\$)</u>
Raw material		
H ₂ O		62,000
CaCO ₃	325,000	
Subtotal		387,000
Utilities		130,000
Waste treatment		205,039
Labor (operators: two per shift, three shifts)		
Operating (16,000 h)	385,000	
Maintenance	307,000	
Supervision	138,000	
Fringe benefits	332,000	
Subtotal		1,162,000
Supplies		
Operating	38,000	
Maintenance	205,000	
Subtotal		243,000
General works		
General and administration	498,000	
Property tax	170,000	
Property insurance	68,000	
Subtotal		737,000
Depreciation (15 years, straight line)		568,000
Gross operating cost		<u>3,558,000</u>
Less by-product credit		0
Net operating cost		<u>3,558,000</u>
Summary		
Fixed cost	2,141,000	
Variable cost	848,000	
Gross cost excluding depreciation		2,990,000
Gross operating cost		<u>3,558,000</u>
<hr/>		
B. Process Unit Direct Cost Summary		
Equipment cost	1,464,400	
Total investment	8,692,000	

one, since a process that produces less sulfur and more sulfate will have higher costs. If the current process with high assumed sulfur yields is not competitive, the process with lower yields will also be noncompetitive.

In the biocolumn, colloidal elemental sulfur is excreted by the bacteria cells and can be removed from the biolayer by a flowing liquid solution, provided the bacteria are immobilized. The bacteria will attach to the plastic surfaces of the packing; therefore, a vertical, cylindrical column containing plastic rings, saddles, or other common packings can be used. This idea has been studied and patented by Torres-Cardona et al. [7] and also studied by Cork [8]. Figure 12 shows the process flow diagram envisioned for this process.

Each of the 14 towers contains plastic-ring packing with biolayer attached (see Figure 2). The contaminated air is split into 14 components, each of which enters at the bottom of a tower. The air is cleaned by biolayer extraction of CS_2 and H_2S , and the clean air exits to the atmosphere at the tower tops. A solution of controlled pH enters the top of each tower and flows downward countercurrent to the air flow. The solution carries the sulfur particles out of the towers and into a clarifier, where the sulfur settles and is removed as product. The clarified solution is pumped to a mixing tank, where makeup water is added. A controlled amount of caustic is also added in order to maintain the pH of the recycle solution. Bacterial nutrients, consisting of the compounds NH_4Cl , K_2HPO_4 , MgCl_2 , and NaCl , are also made up in the mixing tank.

On the basis of pilot-plant results [7,8], a representative, superficial gas velocity in the absorption tower of 66 ft/min is optimum. Thus, the flow area required for 400,000 cubic feet per minute (CFM) is 6,063 ft^2 , which can be accommodated by 14 towers of 24-ft diameter. Other parameters assumed on the basis of the pilot-plant results are

Liquid-to-air mass ratio	3 to 7
Gas temperature	25°C
Conversion of sulfur to elemental sulfur	97%
pH of recycle solution	7 to 8.

A summary of the results from the Aspen Plus process and economic simulations is given in Table 12. The table indicates that the total investment is \$29.4 million, with \$7.5 million yearly operating costs. The total equipment cost is \$5.2 million. Note that a by-product credit of \$0.047 million per year is taken for the elemental sulfur produced. The disposal cost of the small quantity of sulfates produced was not estimated or accounted for. More details of the results from the Aspen Plus simulation are given in Appendix A.

FIGURE 12 Process Flow Diagram for a Biocolumn Plant

TABLE 12 Summary of Simulation Results for a Biocolumn Producing Elemental Sulfur**A. Annual Operating Cost Summary**

Production capacity for all products	100.0%	
Base period	1996, Quarter I	
Plant availability	328/365.25 days	
Raw material		
H ₂ O	19,651 lb/h at \$0.00014681/lb	
NaOH	1,657.1920 lb/h at \$0.088867/lb	
	<u>Annual Cost (\$)</u>	<u>Total Annual Cost (\$)</u>
Raw material		
H ₂ O	23,000	
Lime	1,162,000	
Subtotal		1,185,000
Utilities		162,000
Labor (operators: two per shift, three shifts)		
Operating (16,000 h)	396,000	
Maintenance	901,000	
Supervision	259,000	
Fringe benefits	622,000	
Subtotal		2,178,000
Supplies		
Operating	40,000	
Maintenance	601,000	
Subtotal		640,000
General works		
General and administration	934,000	
Property tax	500,000	
Property insurance	200,000	
Subtotal		1,634,000
Depreciation (15 years, straight line)		1,668,000
Gross operating cost		<u>7,467,000</u>
Less by-product credit		47,000
Net operating cost		<u><u>7,421,000</u></u>
Summary		
Fixed cost	4,453,000	
Variable cost	1,346,000	
Gross cost excluding depreciation		5,799,000
Gross operating cost		<u>7,467,000</u>

B. Process Unit Direct Cost Summary

Equipment cost	5,221,600
Total investment	29,427,000

6.6 SUMMARY

Table 13 shows a summary of the costs of each of the CS₂ removal processes discussed above. These cost estimates are based on rough designs determined from pilot-plant and bench-scale testing, coupled with necessary assumptions, some of which are arbitrary (see Sections 6.1-6.5). Because of this rough basis and also because the method used includes factored cost estimates, the simulation results cannot be considered more than $\pm 30\%$ accurate. More accurate estimates are not possible without more complete designs that will allow vendor quotes and detailed costing, which is beyond the scope of this study. Although the conclusions developed from Table 13 must be considered tentative, they do provide useful comparative trends in costs. The relative accuracy is more reliable than the absolute accuracy, since all estimates were derived by using similar methods. On the basis of Table 13, the following observations can be made:

- The biofilter plant with limestone neutralization and gypsum disposal is by far the least costly process, with investment and operating costs both low. Further study of this option, with more accurate equipment and operating estimates and projection of landfill costs into the future, is needed.
- Of the seven process options, the biofilter plant producing 3% acid is the least costly to purchase because of relatively modest equipment needs. However, it is the most expensive to operate because of the high disposal costs of 3% acid.
- Acid-disposal costs can be eliminated by including an acid-concentrating train with the biofilter plant. Both operating and capital costs of such composite plants are proportional to the extent of acid concentration.
- The biofilter plant with a 13% acid concentration is the least costly biofilter/acid-concentration option, due to the relatively low amount of evaporation required to concentrate the acid from 3% to 13%. However, additional evaporation equipment would be needed in the viscose plant if this option were chosen. These additional costs have not been estimated.
- The investment and operating cost of the carbon adsorption process is estimated to be higher than either the biocolumn or the biofilter plant with 13% acid concentration. However, the magnitudes of the differences in cost among these three processes may not remain the same if more accurate estimates were available. A more detailed cost study to distinguish among cases 1, 3, and 7 is needed for further comparison.

TABLE 13 Summary of Costs for CS₂ Removal Processes

Case	Process	Total Investment (\$ million)	Operating Costs (\$ million/yr)		Equipment Costs (\$ million)	By-Product Credit (\$ million/yr)
			Total	Utilities		
1	Carbon adsorption	31.6	8.9	1.6	5.6	0.99
2	Biofilter, vendor disposal	7.8	65.3	0.13	1.4	0.00
3	Biofilter, 13% acid	26.9	7.3	1.56	4.7	0.75
4	Biofilter, 95% acid	48.9	12.9	1.97	8.6	0.73
5	Biofilter, 65% acid, gypsum sold	40.4	11.6	1.90	7.1	0.08
6	Biofilter, gypsum disposal	8.7	3.6	0.13	1.5	0.00
7	Biocolumn	29.4	7.5	0.16	5.2	0.05

7 CONCLUSIONS

Biological removal of sulfides from air has been demonstrated and proven by others for application at much lower air flows than the flow at Teepak. Therefore, biofiltration, the use of a porous layer of biologically active material as a removal medium, possibly can remove the CS_2 and H_2S from the Teepak air and produce a 3% sulfuric acid product. However, on the basis of existing knowledge of the rates of biological removal of CS_2 and H_2S and of allowable superficial velocities, the bed cross-sectional area will have to be very large; such a bed will require more than 100 container-sized reactors, which, double-stacked, will take up about one acre of land. The plant will require an investment on the order of \$8 million.

Biofiltration at Teepak will produce over 200,000 tons of 3% acid per year. Such dilute acid is not a marketable commodity, nor is it disposable at any reasonable cost. The options under biofiltration are thus to convert the weak acid either to some recyclable or marketable commodity or to some form that is economically disposable. The possible ways of producing a marketable product by means of biofiltration at Teepak all require acid concentration, which can only be done by expensive evaporative plants. Production of commodity-grade 95% sulfuric acid by biofiltration at Teepak requires building the biofilter plant plus a large, three-stage evaporator plant, with a total investment on the order of \$49 million.

Options for producing the marketable or recyclable commodities — 13% acid, gypsum, or elemental sulfur — are roughly comparable in terms of investment, falling in the range between \$27 and \$40 million. (This range also includes the investment required for a carbon adsorption plant). The Teepak plant can use 13% sulfuric acid. Production of 13% sulfuric acid from biofiltration for recycling at Teepak requires building the biofilter plant plus a single-stage evaporator plant, with a total investment on the order of \$27 million. However, additional costs for water evaporation from the viscose plant recycle solution are implied in this case. These costs have not been estimated in this study, but they are likely to be substantial, thus eliminating this option as a candidate for implementation. Production of commodity-grade gypsum from biofiltration at Teepak requires building the biofilter plant, a three-stage evaporator plant, and a gypsum plant, with a total investment on the order of \$40 million. Production of elemental sulfur by bacterial action in a packed column may be possible. This option would require construction of a biocolumn plant at Teepak, with a total investment on the order of \$30 million.

Biofiltration with gypsum production and disposal is by far the least costly option. If a biofiltration plant is to be built at Teepak, this option should be studied further. The actual rates of biological conversion of H_2S and CS_2 need to be measured as functions of all variables, especially superficial velocity. These data can then be used to develop a detailed process flow diagram, as well as the design of all equipment components. Vendor quotes for all the equipment can then form the basis for developing an accurate economic analysis to replace the rough comparative estimate of this report. Since the economic viability of this option depends on gypsum disposal costs, the likely rate of escalation of landfill cost must also be a part of any future study.

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APPENDIX A:
ASPEN PLUS OUTPUT

APPENDIX A:

ASPEN PLUS OUTPUT

The flowsheet simulation capabilities of Aspen Plus are used to obtain a converged, numeric model of a processing plant. Thus, for each component of the plant, process flow rates, process conditions, physical properties of materials, and heat and work requirements are obtained. Equipment sizing and costing routines then estimate the cost to purchase each major piece of equipment, or "cost block," adjusted to include installation costs. Utility consumptions are also calculated for each cost block. Aspen Plus has cost models for most major equipment items. In the present case, Aspen Plus has been used to size and cost all equipment other than such specialty items as acid boilers. Specialty items are costed by using curves from Ulrich (1984) and other sources.

On the basis of the major installed equipment costs, utility usage rates, and factors compiled for the type of plant under consideration, Aspen Plus estimates the commodity costs (piping, concrete, steel, electrical, instrumentation, insulation, and paint). Costs for buildings and other unlisted equipment are obtained by using other factors. The capital costs of utility-generating equipment and storage facilities are generated by a correlation of previously compiled cost data, usually in the form of a power law. At this point in the capital-cost-estimating step, the total direct material and construction labor costs for the plant are estimated. These costs are then adjusted for inflation and project location, using internal Aspen Plus indexes. Site factors (site preparation, tax, freight rates, etc.) are estimated by applying appropriate factors to the total plant direct-material cost. Indirect costs (management, fees, insurance, etc.) are estimated by applying factors to the project costs. The total depreciable cost is obtained by adding a contingency allowance to the sum of the direct and indirect costs. The total fixed capital cost estimate is obtained by adding nondepreciable costs, for example, land and royalties.

The next step is estimation of both fixed and variable operating costs. Variable operation costs are utilities, raw material, waste treatment, and royalties. These costs are derived from user input of known costs. By-product credit is applied as a negative variable cost. Fixed operating costs are determined by factors applied to various elements of capital costs.

The Aspen Plus output for combined process simulation/economic analysis is contained on more than 50 pages for each individual plant. It is infeasible to include this many pages for the eight plants studied. Therefore, only the Aspen Plus summary pages are included in this appendix, along with the Aspen-Plus-generated process-flow diagrams (PFDs). Note that since these diagrams represent simulations, in some cases they may not appear to be equivalent to working process-flow diagrams for the plant in question.

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FIGURE A.1 Carbon Adsorption PFD

CARBON ADSORPTION PLANT FOR CS₂ REMOVAL - ECONOMIC EVALUATION**I. ANNUAL OPERATING COST SUMMARY**

PRODUCTION CAPACITY FOR ALL PRODUCTS: 100.0 %			
BASE PERIOD: 1996, QUARTER I			
PLANT AVAILABILITY: 328/365.25 DAYS			
RAW MATERIAL	QUANTITY	PRICE	ANNUAL COST
	LB/HR	\$/LB	
STEAM	4.0000-04	2.8139-03	\$ 888,000
TOTAL RAW MATERIAL			\$ 888,000
TOTAL UTILITIES			\$ 1,574,000
LABOR			
OPERATORS: 2 PER SHIFT, 3 SHIFTS			
OPERATING (16000 HR)		\$ 396,000	
MAINTENANCE		959,000	
SUPERVISION		271,000	
FRINGE BENEFITS		650,000	
SUBTOTAL, LABOR			\$ 2,276,000
SUPPLIES			
OPERATING		\$ 40,000	
MAINTENANCE		639,000	
SUBTOTAL, SUPPLIES			\$ 679,000
GENERAL WORKS			
GENERAL & ADMIN		\$ 976,000	
PROPERTY TAX		533,000	
PROPERTY INSURANCE		213,000	
SUBTOTAL, GENERAL WORKS			\$ 1,722,000
DEPRECIATION (15 YEARS, STRAIGHT LINE)			\$ 1,776,000
GROSS OPERATING COST			\$ 8,915,000
LESS: BYPRODUCT CREDIT			\$ 393,000
NET OPERATING COST			\$ 7,922,000

SUMMARY:			
FIXED COST		\$ 4,677,000	
VARIABLE COST		\$ 2,462,000	
GROSS COST EXCL. DEPRECIATION			\$ 7,139,000
GROSS OPERATING COST			\$ 8,915,000

II. PROCESS UNIT DIRECT COST SUMMARY

COMPLETION: 1996, QUARTER I				
LOCATION: DANVILLE				
COST BLOCK ID	BLOW1	BLOW2	BLOW3	BLOW4
QUANTITY	5	5	5	5
STANDBY	1	1	1	1
CARBON STEEL COST	\$ 113,300	\$ 113,300	\$ 113,300	\$ 113,300
COST BLOCK ID	WPUMP	COND1	CPUMP	CTANK
QUANTITY	1	1	1	1
STANDBY	1	0	1	0
CARBON STEEL COST	\$ 3,600	\$ 338,900	\$ 3,300	\$ 11,700
COST BLOCK ID	ADSORB			
QUANTITY	24			
STANDBY	6			
CARBON STEEL COST	\$ 4,176,200			
PURCHASED COST	\$ 4,784,100			
(INCLUDING ACTIVATED CARBON)				
TOTAL EQUIPMENT COST	\$ 5,594,600			
TOTAL INVESTMENT	\$ 31,635,000			

III. COST BLOCK SECTION

BLOCK: ADSORB MODEL: PACK-TOWER

*** INPUT DATA ***			
NUMBER OF TOWERS	24		
NUMBER OF STANDBYS	6		
TOWER TYPE	ADSORPTION		
TOWER MATERIAL	CARBON STEEL		
PACKING TYPE	ACTIVATED CARBON		
BED DEPTH	4	FT	
PARTICLE SIZE	4 X 6 MESH		
PEAK CAPACITY ALLOWANCE FACTOR	1.06		
COST ADJUSTMENT FACTOR	1.24		
PLATFORM ALLOWANCE	1.4166	FT	
CORROSION ALLOWANCE	0.0	FT	
DESIGN TEMPERATURE	75.0000	F	
DESIGN PRESSURE	15.7000	PSI	
DIAMETER	12.0000	FT	
TANGENT-TO-TANGENT LENGTH	8.0000	FT	
VAPOR FLOW	1.9000-06	CUFT/HR	
LOADING FRACTION	0.85		
FLOODING FACTOR	0.62		
*** SIZING AND COSTING RESULTS ***			
SHELL WEIGHT	6853.5326	LB	
VOLUME	1357.1711	CUFT	
*** COST RESULTS ***			
	PER PIECE	TOTAL	
CARBON STEEL COST	\$ 139,200	\$ 4,176,200	
PURCHASED COST	\$ 159,500	\$ 4,784,100	
(INCLUDING ACTIVATED CARBON)			

BLOCK: BLOW1 MODEL: BLOWER

*** INPUT DATA ***			
NUMBER OF STANDBYS	1		
MOTOR TYPE	ENCLOSED, FAN COOLED		
COUPLING TYPE	BELT DRIVE		
MATERIAL OF CONSTRUCTION	CARBON STEEL		
PEAK CAPACITY ALLOWANCE FACTOR	1.06		
BLOWER EFFICIENCY	0.75		
*** ASSOCIATED UTILITIES ***			
UTILITY ID FOR ELECTRICITY	POWER		
CALCULATED RATE OF CONSUMPTION	476.4029	KW	
*** FLOWSHEET REFERENCE DATA ***			
INLET STREAM ID	34		
TOTAL VOLUMETRIC FLOW	6.0000-06	CUFT/HR	
GAS DENSITY	7.3338-02	LB/CUFT	
GAS TEMPERATURE	75.0000	F	
INLET PRESSURE	14.7000	PSI	
OUTLET STREAM ID	38		
OUTLET PRESSURE	15.7000	PSI	
*** SIZING AND COSTING RESULTS ***			
CALCULATED NUMBER OF BLOWERS	5		
BLOWER CLASS	1V		
MATERIAL OF CONSTRUCTION FACTOR	1.00		
OUTLET AREA PER BLOWER	5.1498	SQFT	
CALCULATED TOTAL OUTLET AREA	22.3292	SQFT	
SCALED FLOW PER BLOWER	1.2720-06	CUFT/HR	
SCALED TOTAL VOLUMETRIC FLOW	6.3600-06	CUFT/HR	
OUTLET GAS VELOCITY	68.6099	FT/SEC	
CORRECTED STATIC PRESSURE	1.0214	PSI	
MOTOR EFFICIENCY	0.91		
MOTOR SPEED	1800	RPM	
POWER REQUIRED PER BLOWER	95.2805	KW	
*** COST RESULTS ***			
	PER PIECE	TOTAL	
CARBON STEEL COST	\$ 18,900	\$ 113,300	
PURCHASED COST	\$ 18,900	\$ 113,300	

CARBON ADSORPTION PLANT FOR CS₂ REMOVAL - ECONOMIC EVALUATION

BLOCK: BLOW2 MODEL: BLOWER

*** INPUT DATA ***

NUMBER OF STANDBYS	1
MOTOR TYPE	ENCLOSED, FAN COOLED
COUPLING TYPE	BELT DRIVE
MATERIAL OF CONSTRUCTION	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
BLOWER EFFICIENCY	0.75

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	POWER
CALCULATED RATE OF CONSUMPTION	476.4029 KW

*** FLOWSHEET REFERENCE DATA ***

INLET STREAM ID	35
TOTAL VOLUMETRIC FLOW	6.0000-06 CUFT/HR
GAS DENSITY	7.3338-02 LB/CUFT
GAS TEMPERATURE	75.0000 F
INLET PRESSURE	14.7000 PSI
OUTLET STREAM ID	39
OUTLET PRESSURE	15.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF BLOWERS	5
BLOWER CLASS	IV
MATERIAL OF CONSTRUCTION FACTOR	1.00
OUTLET AREA PER BLOWER	5.1498 SQFT
CALCULATED TOTAL OUTLET AREA	22.3292 SQFT
SCALED FLOW PER BLOWER	1.2720-06 CUFT/HR
SCALED TOTAL VOLUMETRIC FLOW	6.3600-06 CUFT/HR
OUTLET GAS VELOCITY	68.6099 FT/SEC
CORRECTED STATIC PRESSURE	1.0214 PSI
MOTOR EFFICIENCY	0.91
MOTOR SPEED	1800 RPM
POWER REQUIRED PER BLOWER	95.2805 KW

*** COST RESULTS **

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 18,900	\$ 113,300
PURCHASED COST	\$ 18,900	\$ 113,300

BLOCK: BLOW3 MODEL: BLOWER

*** INPUT DATA ***

NUMBER OF STANDBYS	1
MOTOR TYPE	ENCLOSED, FAN COOLED
COUPLING TYPE	BELT DRIVE
MATERIAL OF CONSTRUCTION	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
BLOWER EFFICIENCY	0.75

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	POWER
CALCULATED RATE OF CONSUMPTION	476.4029 KW

*** FLOWSHEET REFERENCE DATA ***

INLET STREAM ID	36
TOTAL VOLUMETRIC FLOW	6.0000-06 CUFT/HR
GAS DENSITY	7.3338-02 LB/CUFT
GAS TEMPERATURE	75.0000 F
INLET PRESSURE	14.7000 PSI
OUTLET STREAM ID	40
OUTLET PRESSURE	15.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF BLOWERS	5
BLOWER CLASS	IV
MATERIAL OF CONSTRUCTION FACTOR	1.00
OUTLET AREA PER BLOWER	5.1498 SQFT
CALCULATED TOTAL OUTLET AREA	22.3292 SQFT
SCALED FLOW PER BLOWER	1.2720-06 CUFT/HR
SCALED TOTAL VOLUMETRIC FLOW	6.3600-06 CUFT/HR
OUTLET GAS VELOCITY	68.6099 FT/SEC
CORRECTED STATIC PRESSURE	1.0214 PSI
MOTOR EFFICIENCY	0.91
MOTOR SPEED	1800 RPM
POWER REQUIRED PER BLOWER	95.2805 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 18,900	\$ 113,300
PURCHASED COST	\$ 18,900	\$ 113,300

BLOCK: BLOW4 MODEL: BLOWER

*** INPUT DATA ***

NUMBER OF STANDBYS	1
MOTOR TYPE	ENCLOSED, FAN COOLED
COUPLING TYPE	BELT DRIVE
MATERIAL OF CONSTRUCTION	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
BLOWER EFFICIENCY	0.75

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	POWER
CALCULATED RATE OF CONSUMPTION	476.4029 KW

*** FLOWSHEET REFERENCE DATA ***

INLET STREAM ID	37
TOTAL VOLUMETRIC FLOW	6.0000-06 CUFT/HR
GAS DENSITY	7.3338-02 LB/CUFT
GAS TEMPERATURE	75.0000 F
INLET PRESSURE	14.7000 PSI
OUTLET STREAM ID	41
OUTLET PRESSURE	15.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF BLOWERS	5
BLOWER CLASS	IV
MATERIAL OF CONSTRUCTION FACTOR	1.00
OUTLET AREA PER BLOWER	5.1498 SQFT
CALCULATED TOTAL OUTLET AREA	22.3292 SQFT
SCALED FLOW PER BLOWER	1.2720-06 CUFT/HR
SCALED TOTAL VOLUMETRIC FLOW	6.3600-06 CUFT/HR
OUTLET GAS VELOCITY	68.6099 FT/SEC
CORRECTED STATIC PRESSURE	1.0214 PSI
MOTOR EFFICIENCY	0.91
MOTOR SPEED	1800 RPM
POWER REQUIRED PER BLOWER	95.2805 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 18,900	\$ 113,300
PURCHASED COST	\$ 18,900	\$ 113,300

BLOCK: COND1 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS	1
HEAT EXCHANGER TYPE	BEM
SHELL MATERIAL	CARBON STEEL
TUBE MATERIAL	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
NUMBER OF SHELL PASSES	1
NUMBER OF TUBE PASSES	2
FLOW DIRECTION	COUNTERCURRENT
HEAT TRANSFER COEFFICIENT	17.6110
BTU/HR-SQFT-R	

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER	COOLH2O
CALCULATED RATE OF CONSUMPTION	6.5249-05 LB/HR

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID - SHELL SIDE	COND1
SHELL PRESSURE	14.7000 PSI
SHELL INLET TEMPERATURE	350.0000 F
SHELL OUTLET TEMPERATURE	80.0000 F
UTILITY ID - TUBE SIDE	COOLH2O
TUBE PRESSURE	14.6959 PSI
TUBE INLET TEMPERATURE	67.9100 F
TUBE OUTLET TEMPERATURE	139.9100 F
HEAT DUTY	4.6896-07 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR	1.00
HEAT TRANSFER AREA PER UNIT	4.0703-04 SQFT
TOTAL SCALED HEAT DUTY	4.9710-07 BTU/HR
LOG MEAN TEMPERATURE DIFFERENCE	69.3481 F
EXCHANGER GEOMETRY CORRECTION FACTOR	1.00

*** COST RESULTS ***

CARBON STEEL COST	\$ 338,900
PURCHASED COST	\$ 338,900

CARBON ADSORPTION PLANT FOR CS₂ REMOVAL - ECONOMIC EVALUATION

BLOCK: CPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
 PUMP TYPE 1-STAGE VERTICAL SPLIT
 PUMP SPEED 3550 RPM
 MATERIAL OF CONSTRUCTION DUCTILE IRON
 PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
 CALCULATED RATE OF CONSUMPTION 1.3087 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID CPUMP
 LIQUID VOLUMETRIC FLOW 6.0284 CUFT/HR
 LIQUID DENSITY 78.3456 LB/CUFT
 INLET PRESSURE 14.7000 PSI
 OUTLET PRESSURE 34.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 1
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 VOLUMETRIC FLOW PER PUMP 401.1039 CUFT/HR
 PUMP HEAD 50.0022 FT-LBF/LB
 PRESSURE RISE 20.0000 PSI
 POWER REQUIRED PER PUMP 1.3087 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 1,700	\$ 3,300
PURCHASED COST	\$ 1,700	\$ 3,300

BLOCK: CTANK MODEL: TANK

*** INPUT DATA ***

NUMBER OF TANKS 1
 MATERIAL OF CONSTRUCTION CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 RETENTION TIME REQUIRED 8.0000 HR

*** FLOWSHEET REFERENCE DATA ***

STREAM ID CS2
 LIQUID VOLUMETRIC FLOW 6.0284 CUFT/HR

*** SIZING AND COSTING RESULTS ***

TANK TYPE CUSTOM
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 VOLUME PER TANK 61.3451 CUFT
 SCALED LIQUID FLOW 6.3901 CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST	\$ 11,700
PURCHASED COST	\$ 11,700

IV. UTILITY SECTION

UTILITY USAGE: COOLH2O (WATER)

INPUT DATA:

INLET TEMPERATURE 67.9100 F
 RETURN TEMPERATURE 139.9100 F
 PRESSURE 14.6959 PSI
 PRICE 1.2000-04 \$/LB
 COST INDEX VALUE 599.8000
 MONTH OF PRICE JANUARY
 YEAR OF PRICE 1990
 INDEX TYPE FUEL

RESULT:

COOLING VALUE 71.8725 BTU/LB
 INDEXED PRICE (1996 I Q) 1.0363-04 \$/LB

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (LB/HR)	ANNUAL COST
COND1	HEATX	6.5249-05	533,445
TOTAL:		6.5249-05	\$ 533,445

BLOCK: WPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
 PUMP TYPE 1-STAGE VERTICAL SPLIT
 PUMP SPEED 3550 RPM
 MATERIAL OF CONSTRUCTION DUCTILE IRON
 PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
 CALCULATED RATE OF CONSUMPTION 1.7450 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID WPUMP
 LIQUID VOLUMETRIC FLOW 648.1511 CUFT/HR
 LIQUID DENSITY 61.9749 LB/CUFT
 INLET PRESSURE 14.7000 PSI
 OUTLET PRESSURE 34.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 1
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 VOLUMETRIC FLOW PER PUMP 587.9491 CUFT/HR
 PUMP HEAD 50.0022 FT-LBF/LB
 PRESSURE RISE 20.0000 PSI
 POWER REQUIRED PER PUMP 1.7450 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 1,500	\$ 3,500
PURCHASED COST	\$ 1,500	\$ 3,500

UTILITY USAGE: POWER (ELECTRICITY)

INPUT DATA:

PRICE 8.0000-02 \$/KWHR
 COST INDEX VALUE 599.8000
 MONTH OF PRICE JANUARY
 YEAR OF PRICE 1990
 INDEX TYPE FUEL

RESULT:

INDEXED PRICE (1996 I Q) 6.9084-02 \$/KWHR

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (KW)	ANNUAL COST
BLOW1	BLOWER	476.4029	259,656
BLOW2	BLOWER	476.4029	259,656
BLOW3	BLOWER	476.4029	259,656
BLOW4	BLOWER	476.4029	259,656
CPUMP	PUMP	1.3087	713
WPUMP	PUMP	1.7450	951
TOTAL:		1908.6656	\$ 1,040,287

FIGURE A.2 Biofilter Plant PFD

BIOFILTER PROCESS WITH 3% H₂SO₄ WASTE - ECONOMIC EVALUATION

I. ANNUAL OPERATING COST SUMMARY

PRODUCTION CAPACITY FOR ALL PRODUCTS: 100.0 %
 BASE PERIOD: 1995, QUARTER III
 PLANT AVAILABILITY: 328/365.25 DAYS

RAW MATERIAL	QUANTITY LB/HR	PRICE \$/LB	ANNUAL COST
CACO3	1738.0000	2.3686-02	\$ 325,000
H2O	5.5260-04	1.4273-04	\$ 62,000
TOTAL RAW MATERIAL			\$ 387,000
TOTAL UTILITIES			\$ 130,000
WASTE TREATMENT			\$ 331,000
LABOR			
OPERATORS: 2 PER SHIFT, 3 SHIFTS			
OPERATING (14000 HR)			\$ 385,000
MAINTENANCE			307,000
SUPERVISION			138,000
FRINGE BENEFITS			332,000
SUBTOTAL, LABOR			\$ 1,162,000
SUPPLIES			
OPERATING			\$ 38,000
MAINTENANCE			205,000
SUBTOTAL, SUPPLIES			\$ 243,000
GENERAL WORKS			
GENERAL & ADMIN			\$ 498,000
PROPERTY TAX			170,000
PROPERTY INSURANCE			68,000
SUBTOTAL, GENERAL WORKS			\$ 737,000
DEPRECIATION (15 YEARS, STRAIGHT LINE)			\$ 568,000
GROSS OPERATING COST			\$ 3,558,000
LESS: BYPRODUCT CREDIT			\$ 0
NET OPERATING COST			\$ 3,558,000
SUMMARY:			
FIXED COST			\$ 2,141,000
VARIABLE COST			\$ 848,000
GROSS COST EXCL. DEPRECIATION			\$ 2,990,000
GROSS OPERATING COST			\$ 3,558,000

II. PROCESS UNIT DIRECT COST SUMMARY

COMPLETION: 1995, QUARTER III
 LOCATION: DANVILLE

COST BLOCK ID	APUMP	BIOSOX	BOOSTER	FLTR
QUANTITY	1	104	56	1
STANDBY	1	0	5	0
CARBON STEEL COST	\$ 3,800	\$ 1,071,600	\$ 177,100	\$ 34,600
PURCHASED COST	\$ 14,200	\$ 1,071,600	\$ 177,100	\$ 34,600
COST BLOCK ID	MIXER	RPUMP	WPUMP	
QUANTITY	1	2	1	
STANDBY	0	1	1	
CARBON STEEL COST	\$ 30,600	\$ 15,300	\$ 3,800	
PURCHASED COST	\$ 106,500	\$ 56,500	\$ 3,800	
TOTAL EQUIPMENT COST		\$ 1,464,400		
TOTAL INVESTMENT		\$ 8,692,000		

III. COST BLOCK SECTION

BLOCK: APUMP MODEL: PUMP

*** INPUT DATA ***			
NUMBER OF STANDBYS	1		
PUMP TYPE	1-STAGE VERTICAL SPLIT		
PUMP SPEED	3550	RPM	
MATERIAL OF CONSTRUCTION	3.70		
PEAK CAPACITY ALLOWANCE FACTOR	1.06		
*** ASSOCIATED UTILITIES ***			
UTILITY ID FOR ELECTRICITY	POWER		
CALCULATED RATE OF CONSUMPTION	2.6175	KW	
*** FLOWSHEET REFERENCE DATA ***			
BLOCK ID	APUMP		
LIQUID VOLUMETRIC FLOW	998.5321	CUFT/HR	
LIQUID DENSITY	62.4527	LB/CUFT	
INLET PRESSURE	14.7000	PSI	
OUTLET PRESSURE	24.7000	PSI	
*** SIZING AND COSTING RESULTS ***			
CALCULATED NUMBER OF PUMPS	1		
VOLUMETRIC FLOW PER PUMP	998.5321	CUFT/HR	
PUMP HEAD	50.0022	FT-LBF/LB	
PRESSURE RISE	10.0000	PSI	
POWER REQUIRED PER PUMP	2.6175	KW	
*** COST RESULTS ***			
CARBON STEEL COST	PER PIECE	TOTAL	
	\$ 1,900	\$ 3,800	
PURCHASED COST	\$ 7,100	\$ 14,200	

BLOCK: BOOSTER MODEL: BLOWER

*** INPUT DATA ***			
NUMBER OF STANDBYS	5		
MOTOR TYPE	ENCLOSED, FAN COOLED		
COUPLING TYPE	BELT DRIVE		
MATERIAL OF CONSTRUCTION	CARBON STEEL		
PEAK CAPACITY ALLOWANCE FACTOR	1.06		
BLOWER EFFICIENCY	0.75		
*** ASSOCIATED UTILITIES ***			
UTILITY ID FOR ELECTRICITY	POWER		
CALCULATED RATE OF CONSUMPTION	206.0794	KW	
*** FLOWSHEET REFERENCE DATA ***			
INLET STREAM ID	DRTYAIR		
TOTAL VOLUMETRIC FLOW	2.3989-07	CUFT/HR	
GAS DENSITY	7.4624-02	LB/CUFT	
GAS TEMPERATURE	70.0000	F	
INLET PRESSURE	14.7000	PSI	
OUTLET STREAM ID	1		
OUTLET PRESSURE	14.8000	PSI	
*** SIZING AND COSTING RESULTS ***			
CALCULATED NUMBER OF BLOWERS	56		
BLOWER CLASS	1		
MATERIAL OF CONSTRUCTION	1.00		
OUTLET AREA PER BLOWER	5.1498	SQFT	
CALCULATED TOTAL OUTLET AREA	284.7837	SQFT	
SCALED FLOW PER BLOWER	4.5408-05	CUFT/HR	
SCALED TOTAL VOLUMETRIC FLOW	2.5429-07	CUFT/HR	
OUTLET GAS VELOCITY	24.4926	FT/SEC	
CORRECTED STATIC PRESSURE	0.1003	PSI	
MOTOR EFFICIENCY	0.84		
MOTOR SPEED	1800	RPM	
POWER REQUIRED PER BLOWER	3.6799	KW	
*** COST RESULTS ***			
CARBON STEEL COST	PER PIECE	TOTAL	
	\$ 2,900	\$ 177,100	
PURCHASED COST	\$ 2,900	\$ 177,100	

BIOFILTER PROCESS WITH 3% H₂SO₄ WASTE - ECONOMIC EVALUATION

BLOCK: FLTR MODEL: USER

*** INPUT DATA ***

PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** USER SUPPLIED COST ***

ADJUSTED COST \$ 30,000
 MONTH OF COST JANUARY
 YEAR OF COST 1990
 INDEX TYPE EQUIPMENT

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF EQUIPMENT 1

*** COST RESULTS ***

CARBON STEEL COST \$ 34,500
 PURCHASED COST \$ 34,500

BLOCK: BIOBOX MODEL: USER

*** INPUT DATA ***

NUMBER OF PIECES OF EQUIPMENT 104
 PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** USER SUPPLIED COST ***

ADJUSTED COST \$ 9,000
 INDEX TYPE EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 10,300	\$ 1,071,600
PURCHASED COST	\$ 10,300	\$ 1,071,600

BLOCK: RPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
 PUMP TYPE 1-STAGE VERTICAL SPLIT
 PUMP SPEED 3550 RPM
 MATERIAL OF CONSTRUCTION 3.70
 PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
 CALCULATED RATE OF CONSUMPTION 34.1132 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID RPUMP
 LIQUID VOLUMETRIC FLOW 1.2308-04 CUFT/HR
 LIQUID DENSITY 62.4250 LB/CUFT
 INLET PRESSURE 14.7000 PSI
 OUTLET PRESSURE 19.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 2
 TOTAL SCALED VOLUMETRIC FLOW 1.3046-04 CUFT/HR
 VOLUMETRIC FLOW PER PUMP 6522.9302 CUFT/HR
 PUMP HEAD 50.0022 FT-LBF/LB
 PRESSURE RISE 5.0000 PSI
 POWER REQUIRED PER PUMP 17.0566 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 5,100	\$ 10,200
PURCHASED COST	\$ 18,800	\$ 37,000

BLOCK: MIXER MODEL: H-VESSEL

*** INPUT DATA ***

NUMBER OF VESSELS 1
 MATERIAL OF CONSTRUCTION TITANIUM
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 RETENTION TIME 0.5000 HR
 CORROSION ALLOWANCE 0.0 FT

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID MIXER
 VAPOR FLOW 6895.0481 CUFT/HR
 LIQUID FLOW 979.7232 CUFT/HR
 VAPOR DENSITY 6.3787-03 LB/CUFT
 LIQUID DENSITY 59.6437 LB/CUFT
 TEMPERATURE 75.0000 F
 PRESSURE 14.7000 PSI

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 3.48
 TOTAL SHELL WEIGHT 3366.9516 LB
 CALCULATED DIAMETER 6.9136 FT
 CALCULATED TANGENT-TO-TANGENT LENGTH 20.7480 FT
 VOLUME PER VESSEL 865.4221 CUFT
 TOP SHELL THICKNESS 2.0833-02 FT
 BOTTOM SHELL THICKNESS 2.0833-02 FT
 SCALED VAPOR FLOW 7308.7510 CUFT/HR
 SCALED LIQUID FLOW 1038.5066 CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST	\$ 30,600
PURCHASED COST	\$ 106,500

BLOCK: WPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
 PUMP TYPE 1-STAGE VERTICAL SPLIT
 PUMP SPEED 3550 RPM
 MATERIAL OF CONSTRUCTION DUCTILE IRON
 PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
 CALCULATED RATE OF CONSUMPTION 2.6175 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID WPUMP
 LIQUID VOLUMETRIC FLOW 890.4625 CUFT/HR
 LIQUID DENSITY 62.0576 LB/CUFT
 INLET PRESSURE 14.7000 PSI
 OUTLET PRESSURE 19.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 1
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 VOLUMETRIC FLOW PER PUMP 943.8902 CUFT/HR
 PUMP HEAD 50.0022 FT-LBF/LB
 PRESSURE RISE 5.0000 PSI
 POWER REQUIRED PER PUMP 2.6175 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 1,900	\$ 1,900
PURCHASED COST	\$ 1,900	\$ 3,800

IV. UTILITY SECTION

UTILITY USAGE: POWER (ELECTRICITY)

INPUT DATA:

PRICE 8.0000-02 \$/KWHR
 COST INDEX VALUE 599.8000
 MONTH OF PRICE JANUARY
 YEAR OF PRICE 1990
 INDEX TYPE FUEL

RESULT:

INDEXED PRICE (1995 III Q) 6.7154-02 \$/KWHR

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (KW)	ANNUAL COST
BOOSTER	BLOWER	206.0794	109,198
APUMP	PUMP	2.6175	1,737
RPUMP	PUMP	34.1132	12,076
WPUMP	PUMP	2.6175	1,387
TOTAL:		245.4278	\$ 130,048

FIGURE A.3 Biofilter/Acid Concentrator (13%) PFD

BIOFILTER PROCESS CONCENTRATING TO 13% H₂SO₄ - ECONOMIC EVALUATION

I. ANNUAL OPERATING COST SUMMARY

PRODUCTION CAPACITY FOR ALL PRODUCTS: 100.0 %			
BASE PERIOD: 1996, QUARTER II			
PLANT AVAILABILITY: 328/365.25 DAYS			
RAW MATERIAL	QUANTITY	PRICE	ANNUAL COST
	LB/HR	\$/LB	
H2O	5.5260-04	1.4848-04	\$ 65,000
TOTAL RAW MATERIAL			\$ 65,000
TOTAL UTILITIES			\$ 1,559,000
LABOR			
OPERATORS: 2 PER SHIFT, 3 SHIFTS			
OPERATING (16000 HR)		\$ 400,000	
MAINTENANCE		949,000	
SUPERVISION		270,000	
FRINGE BENEFITS		647,000	
SUBTOTAL, LABOR			\$ 2,266,000
SUPPLIES			
OPERATING		\$ 40,000	
MAINTENANCE		632,000	
SUBTOTAL, SUPPLIES			\$ 672,000
GENERAL WORKS			
GENERAL & ADMIN		\$ 971,000	
PROPERTY TAX		527,000	
PROPERTY INSURANCE		211,000	
SUBTOTAL, GENERAL WORKS			\$ 1,709,000
DEPRECIATION (15 YEARS, STRAIGHT LINE)			\$ 1,757,000
GROSS OPERATING COST			\$ 8,028,000
LESS: BYPRODUCT CREDIT			\$ 749,000
NET OPERATING COST			\$ 7,279,000
SUMMARY:			
FIXED COST		\$ 4,647,000	
VARIABLE COST		\$ 1,624,000	
GROSS COST EXCL. DEPRECIATION			\$ 6,271,000
GROSS OPERATING COST			\$ 8,028,000

II. PROCESS UNIT DIRECT COST SUMMARY

COMPLETION: 1996, QUARTER I
LOCATION: DANVILLE

COST BLOCK ID	APUMP	BICBOX	BOOSTER	FLTR
QUANTITY	1	104	56	1
STANDBY	1	0	5	0
CARBON STEEL COST	\$ 3,900	\$ 1,001,500	\$ 179,100	\$ 35,000
PURCHASED COST	\$ 14,400	\$ 1,001,500	\$ 179,100	\$ 35,000
COST BLOCK ID	RPUMP	WPUMP		
QUANTITY	2	1		
STANDBY	1	1		
CARBON STEEL COST	\$ 15,400	\$ 3,900		
PURCHASED COST	\$ 57,100	\$ 3,900		
COST BLOCK ID	COND1	COND2	COND3	CPUMP
QUANTITY	1	1	1	1
STANDBY	0	0	0	1
CARBON STEEL COST	\$ 71,800	\$ 9,200	\$ 5,200	\$ 3,300
PURCHASED COST	\$ 71,800	\$ 9,200	\$ 5,200	\$ 3,300
COST BLOCK ID	CTNK	EVAPI	INJECT1	INJECT2
QUANTITY	1	1	1	1
STANDBY	0	0	0	0
CARBON STEEL COST	\$ 140,400	\$ 464,600	\$ 5,300	\$ 5,300
PURCHASED COST	\$ 140,400	\$ 2,787,700	\$ 5,300	\$ 5,300
COST BLOCK ID	PPUMP	PTNK		
QUANTITY	1	1		
STANDBY	1	0		
CARBON STEEL COST	\$ 3,300	\$ 47,000		
PURCHASED COST	\$ 12,400	\$ 352,700		
TOTAL EQUIPMENT COST		\$ 4,684,600		
TOTAL INVESTMENT		\$ 26,876,000		

III. COST BLOCK SECTION

BLOCK: APUMP MODEL: PUMP

*** INPUT DATA ***			
NUMBER OF STANDBYS	1		
PUMP TYPE	1-STAGE VERTICAL SPLIT		
PUMP SPEED	3550	RPM	
MATERIAL OF CONSTRUCTION FACTOR	3.70		
PEAK CAPACITY ALLOWANCE FACTOR	1.06		
*** ASSOCIATED UTILITIES ***			
UTILITY ID FOR ELECTRICITY	POWER		
CALCULATED RATE OF CONSUMPTION	2.6175	KW	
*** FLOWSHEET REFERENCE DATA ***			
BLOCK ID	APUMP		
LIQUID VOLUMETRIC FLOW	914.4545	CUFT/HR	
LIQUID DENSITY	52.0482	LB/CUFT	
INLET PRESSURE	14.7000	PSI	
OUTLET PRESSURE	24.7000	PSI	
*** SIZING AND COSTING RESULTS ***			
CALCULATED NUMBER OF PUMPS	1		
VOLUMETRIC FLOW PER PUMP	914.4545	CUFT/HR	
PUMP HEAD	50.0022	FT-LBF/LB	
PRESSURE RISE	10.0000	PSI	
POWER REQUIRED PER PUMP	2.6175	KW	
*** COST RESULTS ***			
	PER PIECE	TOTAL	
CARBON STEEL COST	\$ 1,900	\$ 3,900	
PURCHASED COST	\$ 7,200	\$ 14,400	

BLOCK: BICBOX MODEL: USER

*** INPUT DATA ***			
NUMBER OF PIECES OF EQUIPMENT		104	
PEAK CAPACITY ALLOWANCE FACTOR		1.06	
*** USER SUPPLIED COST ***			
ADJUSTED COST		\$ 9,000	
MONTH OF COST		MAY	
YEAR OF COST		1994	
INDEX TYPE		EQUIPMENT	
*** SIZING AND COSTING RESULTS ***			
*** COST RESULTS ***			
	PER PIECE	TOTAL	
CARBON STEEL COST	\$ 9,600	\$ 1,001,500	
PURCHASED COST	\$ 9,600	\$ 1,001,500	

BIOFILTER PROCESS CONCENTRATING TO 13% H₂SO₄ - ECONOMIC EVALUATION

BLOCK: BOOSTER MODEL: BLOWER

*** INPUT DATA ***

NUMBER OF STANDSYS 5
 MOTOR TYPE ENCLOSED, FAN COOLED
 COUPLING TYPE BELT DRIVE
 MATERIAL OF CONSTRUCTION CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 BLOWER EFFICIENCY 0.75

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
 CALCULATED RATE OF CONSUMPTION 206.0794 KW

*** FLOWSHEET REFERENCE DATA ***

INLET STREAM ID DRTVAIR
 TOTAL VOLUMETRIC FLOW 2.3989-07 CUFT/HR
 GAS DENSITY 7.4624-02 LB/CUFT
 GAS TEMPERATURE 70.0000 F
 INLET PRESSURE 14.7000 PSI
 OUTLET STREAM ID 1
 OUTLET PRESSURE 14.8000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF BLOWERS 56
 BLOWER CLASS I
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 OUTLET AREA PER BLOWER 5.1498 SQFT
 CALCULATED TOTAL OUTLET AREA 284.7837 SQFT
 SCALED FLOW PER BLOWER 4.5408-05 CUFT/HR
 SCALED TOTAL VOLUMETRIC FLOW 2.5429-07 CUFT/HR
 OUTLET GAS VELOCITY 24.4926 FT/SEC
 CORRECTED STATIC PRESSURE 0.1903 PSI
 MOTOR EFFICIENCY 0.84
 MOTOR SPEED 1800 RPM
 POWER REQUIRED PER BLOWER 3.6799 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 2,900	\$ 179,100
PURCHASED COST	\$ 2,900	\$ 179,100

BLOCK: COND1 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 61.6385 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER COOLH2O
 CALCULATED RATE OF CONSUMPTION 5.3304-05 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE COOLH2O
 SHELL PRESSURE 14.6959 PSI
 SHELL INLET TEMPERATURE 67.9100 F
 SHELL OUTLET TEMPERATURE 139.9100 F
 BLOCK ID - TUBE SIDE COND1
 TUBE PRESSURE 14.7000 PSI
 TUBE INLET TEMPERATURE 213.2608 F
 TUBE OUTLET TEMPERATURE 212.1040 F
 HEAT DUTY 3.8311-07 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00
 HEAT TRANSFER AREA PER UNIT 6285.8468 SQFT
 TOTAL SCALED HEAT DUTY 4.0610-07 BTU/HR
 LOG MEAN TEMPERATURE DIFFERENCE 104.8122 F
 EXCHANGER GEOMETRY CORRECTION FACTOR 1.00

*** COST RESULTS ***

CARBON STEEL COST	\$ 71,800
PURCHASED COST	\$ 71,800

BLOCK: CCND2 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 61.6385 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER COOLH2O
 CALCULATED RATE OF CONSUMPTION 2.6913-04 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE COOLH2O
 SHELL PRESSURE 14.6959 PSI
 SHELL INLET TEMPERATURE 67.9100 F
 SHELL OUTLET TEMPERATURE 139.9100 F
 BLOCK ID - TUBE SIDE CCND2
 TUBE PRESSURE 14.0000 PSI
 TUBE INLET TEMPERATURE 212.3688 F
 TUBE OUTLET TEMPERATURE 209.4482 F
 HEAT DUTY 1.9343-06 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00
 HEAT TRANSFER AREA PER UNIT 322.3695 SQFT
 TOTAL SCALED HEAT DUTY 2.0504-06 BTU/HR
 LOG MEAN TEMPERATURE DIFFERENCE 103.5699 F
 EXCHANGER GEOMETRY CORRECTION FACTOR 1.00

*** COST RESULTS ***

CARBON STEEL COST	\$ 9,200
PURCHASED COST	\$ 9,200

BLOCK: COND3 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 61.6385 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER COOLH2O
 CALCULATED RATE OF CONSUMPTION 1552.9504 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE COOLH2O
 SHELL PRESSURE 14.6959 PSI
 SHELL INLET TEMPERATURE 67.9100 F
 SHELL OUTLET TEMPERATURE 139.9100 F
 BLOCK ID - TUBE SIDE COND3
 TUBE PRESSURE 13.0000 PSI
 TUBE INLET TEMPERATURE 223.3262 F
 TUBE OUTLET TEMPERATURE 205.9571 F
 HEAT DUTY 1.1161-05 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00
 HEAT TRANSFER AREA PER UNIT 18.0275 SQFT
 TOTAL SCALED HEAT DUTY 1.1831-05 BTU/HR
 LOG MEAN TEMPERATURE DIFFERENCE 108.4479 F
 EXCHANGER GEOMETRY CORRECTION FACTOR 0.98

*** COST RESULTS ***

CARBON STEEL COST	\$ 5,200
PURCHASED COST	\$ 5,200

BIOFILTER PROCESS CONCENTRATING TO 13% H₂SO₄ - ECONOMIC EVALUATION

BLOCK: CPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
 PUMP TYPE 1-STAGE VERTICAL SPLIT
 PUMP SPEED 3550 RPM
 MATERIAL OF CONSTRUCTION DUCTILE IRON
 PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
 CALCULATED RATE OF CONSUMPTION 1.3087 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID CPUMP
 LIQUID VOLUMETRIC FLOW 1.8432 CUFT/HR
 LIQUID DENSITY 57.4933 LB/CUFT
 INLET PRESSURE 13.0000 PSI
 OUTLET PRESSURE 33.0000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 1
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 VOLUMETRIC FLOW PER PUMP 401.1039 CUFT/HR
 PUMP HEAD 50.0927 FT-LBF/LB
 PRESSURE RISE 20.0000 PS
 POWER REQUIRED PER PUMP 1.3087 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 1,700	\$ 3,300
PURCHASED COST	\$ 1,700	\$ 3,300

BLOCK: CTNK MODEL: TANK

*** INPUT DATA ***

NUMBER OF TANKS 1
 MATERIAL OF CONSTRUCTION CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 RETENTION TIME REQUIRED 36.0000 HR

*** FLOWSHEET REFERENCE DATA ***

STREAM ID WATER
 LIQUID VOLUMETRIC FLOW 890.4490 CUFT/HR

*** SIZING AND COSTING RESULTS ***

TANK TYPE CUSTOM
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 VOLUME PER TANK 4.0775-04 CUFT
 SCALED LIQUID FLOW 943.8759 CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST	\$ 140,400
PURCHASED COST	\$ 140,400

BLOCK: EVAP1 MODEL: HEATX

3484 SQFT ZIRCONIUM EVAPORATOR

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 MATERIAL OF CONSTRUCTION FACTOR 5.00
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 70.4440 BTU/HR-SQFT-R

*** USER SUPPLIED COST ***

BASE COST \$ 350,000
 COST INDEX VALUE 315.00
 INDEX TYPE EQUIPMENT

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR STEAM STEAM1
 CALCULATED RATE OF CONSUMPTION 5.5614-04 LB/HR

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID - SHELL SIDE EVAP
 SHELL PRESSURE 14.7000 PSI
 SHELL INLET TEMPERATURE 75.0574 F
 SHELL OUTLET TEMPERATURE 213.2608 F
 UTILITY ID - TUBE SIDE STEAM1
 TUBE PRESSURE 150.0000 PSI
 TUBE INLET TEMPERATURE 358.4353 F
 TUBE OUTLET TEMPERATURE 358.4353 F
 HEAT DUTY 4.8010-07 BTU/HR

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST	\$ 464,600
PURCHASED COST	\$ 2,787,700

BLOCK: FLTR MODEL: USER

*** INPUT DATA ***

PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** USER SUPPLIED COST ***

ADJUSTED COST \$ 30,000
 MONTH OF COST JANUARY
 YEAR OF COST 1990
 INDEX TYPE EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST	\$ 35,000
PURCHASED COST	\$ 35,000

BLOCK: INJECT1 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 79.2495 BTU/HR-SQFT-R

*** USER SUPPLIED COST ***

ADJUSTED COST \$ 5,000
 YEAR OF COST 1984
 INDEX TYPE EQUIPMENT

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00

*** COST RESULTS ***

CARBON STEEL COST	\$ 5,300
PURCHASED COST	\$ 5,300

BIOFILTER PROCESS CONCENTRATING TO 13% H₂SO₄ - ECONOMIC EVALUATION

BLOCK: INJECT2 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS	1
HEAT EXCHANGER TYPE	BEM
SHELL MATERIAL	CARBON STEEL
TUBE MATERIAL	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
NUMBER OF SHELL PASSES	1
NUMBER OF TUBE PASSES	2
FLOW DIRECTION	COUNTERCURRENT
HEAT TRANSFER COEFFICIENT	79.2495 BTU/HR-SQFT-R

*** USER SUPPLIED COST ***

ADJUSTED COST	\$ 5,000
YEAR OF COST	1984
INDEX TYPE	EQUIPMENT

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR	1.00
---------------------------------	------

*** COST RESULTS ***

CARBON STEEL COST	\$ 5,300
PURCHASED COST	\$ 5,300

BLOCK: PPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS	1
PUMP TYPE	1-STAGE VERTICAL SPLIT
PUMP SPEED	3550 RPM
MATERIAL OF CONSTRUCTION FACTOR	3.70
PEAK CAPACITY ALLOWANCE FACTOR	1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	POWER
CALCULATED RATE OF CONSUMPTION	1.3087 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID	PPUMP
LIQUID VOLUMETRIC FLOW	265.6182 CUFT/HR
LIQUID DENSITY	57.3259 LB/CUFT
INLET PRESSURE	14.7000 PSI
OUTLET PRESSURE	24.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS	1
VOLUMETRIC FLOW PER PUMP	401.1039 CUFT/HR
PUMP HEAD	50.0022 FT-LBF/LB
PRESSURE RISE	10.0000 PSI
POWER REQUIRED PER PUMP	1.3087 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 1,700	\$ 3,300
PURCHASED COST	\$ 5,200	\$ 12,400

BLOCK: PTNK MODEL: TANK

*** INPUT DATA ***

NUMBER OF TANKS	1
MATERIAL OF CONSTRUCTION	HASTELLOY
PEAK CAPACITY ALLOWANCE FACTOR	1.06
RETENTION TIME REQUIRED	8.0000 HR

*** FLOWSHEET REFERENCE DATA ***

STREAM ID	ACID13
LIQUID VOLUMETRIC FLOW	265.6182 CUFT/HR

*** SIZING AND COSTING RESULTS ***

TANK TYPE	CUSTOM
MATERIAL OF CONSTRUCTION FACTOR	7.50
VOLUME PER TANK	2702.9315 CUFT
SCALED LIQUID FLOW	281.5553 CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST	\$ 47,000
PURCHASED COST	\$ 352,700

BLOCK: RPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS	1
PUMP TYPE	1-STAGE VERTICAL SPLIT
PUMP SPEED	3550 RPM
MATERIAL OF CONSTRUCTION FACTOR	3.70
PEAK CAPACITY ALLOWANCE FACTOR	1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	POWER
CALCULATED RATE OF CONSUMPTION	34.1080 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID	RPUMP
LIQUID VOLUMETRIC FLOW	1.2382-04 CUFT/H
LIQUID DENSITY	62.0503 LB/CUFT
INLET PRESSURE	14.7000 PSI
OUTLET PRESSURE	19.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS	2
TOTAL SCALED VOLUMETRIC FLOW	1.3125-04 CUFT/HR
VOLUMETRIC FLOW PER PUMP	6562.3723 CUFT/HR
PUMP HEAD	50.0022 FT-LBF/LB
PRESSURE RISE	5.0000 PS
POWER REQUIRED PER PUMP	17.0540 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 5,100	\$ 15,400
PURCHASED COST	\$ 19,000	\$ 57,100

BIOFILTER PROCESS CONCENTRATING TO 13% H₂SO₄ - ECONOMIC EVALUATION

BLOCK: WPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
PUMP TYPE 1-STAGE VERTICAL SPLIT
PUMP SPEED 1550 RPM
MATERIAL OF CONSTRUCTION CAST IRON
PEAK CAPACITY ALLOWANCE FACTOR 1.05

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
CALCULATED RATE OF CONSUMPTION 2.6175 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID WPUMP
LIQUID VOLUMETRIC FLOW 890.4625 CUFT/HR
LIQUID DENSITY 62.0576 LB/CUFT
INLET PRESSURE 14.7000 PSI
OUTLET PRESSURE 19.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 1
MATERIAL OF CONSTRUCTION FACTOR 1.00
VOLUMETRIC FLOW PER PUMP 943.8902 CUFT/HR
PUMP HEAD 50.0022 FT-LBF/LB
PRESSURE RISE 5.0000 PSI
POWER REQUIRED PER PUMP 2.6175 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 1,900	\$ 3,900
PURCHASED COST	\$ 1,900	\$ 3,900

IV. UTILITY SECTION

UTILITY USAGE: COOLH2O (WATER)

INPUT DATA:

INLET TEMPERATURE 67.9100 F
RETURN TEMPERATURE 139.9100 F
PRESSURE 14.6959 PSI
PRICE 1.2000-04 \$/LB
COST INDEX VALUE 599.8000
MONTH OF PRICE JANUARY
YEAR OF PRICE 1990
INDEX TYPE FUEL

RESULT:

COOLING VALUE 71.8725 BTU/LB
INDEXED PRICE (1996 II Q) 1.0480-04 \$/LB

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (LB/HR)	ANNUAL COST
COND1	HEATX	5.3304-05	440,729
COND2	HEATX	2.6913-04	22,252
COND3	HEATX	1552.9504	1,284
TOTAL:		5.6151-05	\$ 464,265

UTILITY USAGE: PCWER (ELECTRICITY)

INPUT DATA:

PRICE 8.0000-02 \$/KWHR
COST INDEX VALUE 599.8000
MONTH OF PRICE JANUARY
YEAR OF PRICE 1990
INDEX TYPE FUEL

RESULT:

INDEXED PRICE (1996 II Q) 6.9868-02 \$/KWHR

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (KW)	ANNUAL COST
BCOSTER	BLOWER	205.0794	113,594
APUMP	PUMP	2.6175	1,443
CPUMP	PUMP	1.3087	721
PPUMP	PUMP	1.3087	721
RPUMP	PUMP	14.1030	18,801
WPUMP	PUMP	2.6175	1,443
TOTAL:		248.0401	\$ 136,723

UTILITY USAGE: STEAM1 (STEAM)

INPUT DATA:

PRESSURE 150.0000 PSI
PRICE 2.5000-03 \$/LB
COST INDEX VALUE 599.8000
MONTH OF PRICE JANUARY
YEAR OF PRICE 1990
INDEX TYPE FUEL

RESULT:

HEATING VALUE 863.2760 BTU/LB
INDEXED PRICE (1996 II Q) 2.1834-03 \$/LB
INLET TEMPERATURE 358.4353 F
RETURN TEMPERATURE 358.4353 F

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (LB/HR)	ANNUAL COST
EVAP1	HEATX	5.5614-04	957,981
TOTAL:		5.5614-04	\$ 957,981

FIGURE A.4 Biofilter/Acid Concentrator (95%) PFD

BIOFILTER PROCESS CONCENTRATING TO 95% H₂SO₄ - ECONOMIC EVALUATION

I. ANNUAL OPERATING COST SUMMARY

PRODUCTION CAPACITY FOR ALL PRODUCTS.	199.0 %		
BASE PERIOD:	1996, QUARTER III		
PLANT AVAILABILITY:	328/365.25 DAYS		
RAW MATERIAL	QUANTITY	PRICE	ANNUAL COST
	LB/HR	\$/LB	
H2O	5.5260+04	1.5272-04	\$ 67,000
TOTAL RAW MATERIAL			\$ 67,000
TOTAL UTILITIES			\$ 1,966,000
LABOR			
OPERATORS: 2 PER SHIFT, 3 SHIFTS			
OPERATING (16000 HR)		\$ 412,000	
MAINTENANCE		1,726,000	
SUPERVISION		429,000	
FRINGE BENEFITS		1,026,000	
SUBTOTAL, LABOR			\$ 3,592,000
SUPPLIES			
OPERATING		\$ 41,000	
MAINTENANCE		1,151,000	
SUBTOTAL, SUPPLIES			\$ 1,192,000
GENERAL WORKS			
GENERAL & ADMIN		\$ 1,539,000	
PROPERTY TAX		959,000	
PROPERTY INSURANCE		384,000	
SUBTOTAL, GENERAL WORKS			\$ 2,882,000
DEPRECIATION (15 YEARS, STRAIGHT LINE)			\$ 3,197,000
GROSS OPERATING COST			\$12,895,000
LESS: BYPRODUCT CREDIT			\$ 730,000
NET OPERATING COST			\$12,165,000
SUMMARY:			
FIXED COST		\$ 7,666,000	
VARIABLE COST		\$ 2,032,000	
GROSS COST EXCL. DEPRECIATION			\$ 9,698,000
GROSS OPERATING COST			\$12,895,000

II. PROCESS UNIT DIRECT COST SUMMARY

COMPLETION: 1996, QUARTER II
LOCATION: DANVILLE

COST BLOCK ID	APUMP	BIOBOX	BOOSTER	COND1
QUANTITY	1	104	56	1
STANDBY	1	0	5	0
CARBON STEEL COST	\$ 3,900	\$ 1,012,900	\$ 181,200	\$ 59,900
PURCHASED COST	\$ 14,600	\$ 1,012,900	\$ 181,200	\$ 59,900
COST BLOCK ID	CCND2	COND3	DPUMP	DTNK
QUANTITY	1	1	1	1
STANDBY	0	0	1	0
CARBON STEEL COST	\$ 5,200	\$ 5,200	\$ 7,500	\$ 59,800
PURCHASED COST	\$ 5,200	\$ 5,200	\$ 7,500	\$ 59,800
COST BLOCK ID	EVAP1	EVAP2	EVAP3	FLTR
QUANTITY	1	1	1	1
STANDBY	0	0	0	0
CARBON STEEL COST	\$ 402,800	\$ 469,900	\$ 255,100	\$ 35,300
PURCHASED COST	\$ 2,416,500	\$ 2,819,300	\$ 1,530,500	\$ 35,300
COST BLOCK ID	HEAT1	HEAT2	HEAT3	INJECT1
QUANTITY	1	1	1	1
STANDBY	0	0	0	0
CARBON STEEL COST	\$ 61,100	\$ 68,600	\$ 7,500	\$ 5,400
PURCHASED COST	\$ 61,100	\$ 68,600	\$ 7,500	\$ 5,400
COST BLOCK ID	INJECT2	PTNK	RPUMP	WPUMP
QUANTITY	1	1	2	1
STANDBY	0	0	1	1
CARBON STEEL COST	\$ 5,400	\$ 35,600	\$ 15,600	\$ 3,900
PURCHASED COST	\$ 5,400	\$ 236,200	\$ 57,800	\$ 3,900
TOTAL EQUIPMENT COST		\$ 8,593,800		
TOTAL INVESTMENT		\$ 48,910,000		

III. COST BLOCK SECTION

BLOCK: APUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS	1
PUMP TYPE	1-STAGE VERTICAL SPLIT
PUMP SPEED	3550 RPM
MATERIAL OF CONSTRUCTION FACTOR	3.70
PEAK CAPACITY ALLOWANCE FACTOR	1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	POWER
CALCULATED RATE OF CONSUMPTION	2.6175 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID	APUMP
LIQUID VOLUMETRIC FLOW	908.5183 CUFT/HR
LIQUID DENSITY	62.4537 LB/CUFT
INLET PRESSURE	14.7000 PSI
OUTLET PRESSURE	19.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS	1
VOLUMETRIC FLOW PER PUMP	908.5183 CUFT/HR
PUMP HEAD	50.0022 FT-LBF/LB
PRESSURE RISE	5.0000 PSI
POWER REQUIRED PER PUMP	2.6175 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 2,000	\$ 3,900
PURCHASED COST	\$ 7,300	\$ 14,600

BLOCK: BIOBOX MODEL: USER

*** INPUT DATA ***

NUMBER OF PIECES OF EQUIPMENT	104
PEAK CAPACITY ALLOWANCE FACTOR	1.06

*** USER SUPPLIED COST ***

ADJUSTED COST	\$ 9,000
MONTH OF COST	MAY
YEAR OF COST	1994
INDEX TYPE	EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 9,700	\$ 1,012,900
PURCHASED COST	\$ 9,700	\$ 1,012,900

BLOCK: PTNK MODEL: TANK

*** INPUT DATA ***

NUMBER OF TANKS	1
MATERIAL OF CONSTRUCTION	HASTELLOY
PEAK CAPACITY ALLOWANCE FACTOR	1.06
RETENTION TIME REQUIRED	36.0000 HR

*** FLOWSHEET REFERENCE DATA ***

STREAM ID	13
LIQUID VOLUMETRIC FLOW	20.5360 CUFT/HR

*** SIZING AND COSTING RESULTS ***

TANK TYPE	CUSTOM
MATERIAL OF CONSTRUCTION FACTOR	6.64
VOLUME PER TANK	940.3882 CUFT
SCALED LIQUID FLOW	21.7682 CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST	\$ 35,600
PURCHASED COST	\$ 236,200

BIOFILTER PROCESS CONCENTRATING TO 95% H₂SO₄ - ECONOMIC EVALUATION

BLOCK: BCCSTER MODEL: BLOWER

*** INPUT DATA ***

NUMBER OF STANDBYS 5
 MOTOR TYPE ENCLOSURE, FAN COOLED
 COUPLING TYPE BELT DRIVE
 MATERIAL OF CONSTRUCTION CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 BLOWER EFFICIENCY 0.75

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
 CALCULATED RATE OF CONSUMPTION 206.0794 KW

*** FLOWSHEET REFERENCE DATA ***

INLET STREAM ID DRTYAIR
 TOTAL VOLUMETRIC FLOW 2.3989-07 CUFT/HR
 GAS DENSITY 7.4624-02 LB/CUFT
 GAS TEMPERATURE 70.0000 F
 INLET PRESSURE 14.7000 PSI
 OUTLET STREAM ID 1
 OUTLET PRESSURE 14.000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF BLOWERS 56
 BLOWER CLASS I
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 OUTLET AREA PER BLOWER 5.1498 SQFT
 CALCULATED TOTAL OUTLET AREA 284.7837 SQFT
 SCALED FLOW PER BLOWER 4.5408-05 CUFT/HR
 SCALED TOTAL VOLUMETRIC FLOW 2.5429-07 CUFT/HR
 OUTLET GAS VELOCITY 24.4926 FT/SEC
 CORRECTED STATIC PRESSURE 0.1003 PSI
 MOTOR EFFICIENCY 0.84
 MOTOR SPEED 1800 RPM
 POWER REQUIRED PER BLOWER 3.6799 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 3,000	\$ 181,200
PURCHASED COST	\$ 3,000	\$ 181,200

BLOCK: CONDI MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 61.6385 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER COOLH2O
 CALCULATED RATE OF CONSUMPTION 4.2283-05 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE COOLH2O
 SHELL PRESSURE 14.6959 PSI
 SHELL INLET TEMPERATURE 67.9100 F
 SHELL OUTLET TEMPERATURE 139.9100 F
 BLOCK ID - TUBE SIDE CONDI
 TUBE PRESSURE 14.7000 PSI
 TUBE INLET TEMPERATURE 216.3100 F
 TUBE OUTLET TEMPERATURE 212.1114 F
 HEAT DUTY 3.0390-07 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00
 HEAT TRANSFER AREA PER UNIT 4916.7668 SQFT
 TOTAL SCALED HEAT DUTY 3.2213-07 BTU/HR
 LOG MEAN TEMPERATURE DIFFERENCE 106.7852 F
 EXCHANGER GEOMETRY CORRECTION FACTOR 1.00

*** COST RESULTS ***

CARBON STEEL COST	\$ 59,900
PURCHASED COST	\$ 59,900

BLOCK: COND2 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 61.6385 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER COOLH2O
 CALCULATED RATE OF CONSUMPTION 192.9456 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE COOLH2O
 SHELL PRESSURE 14.6959 PSI
 SHELL INLET TEMPERATURE 67.9100 F
 SHELL OUTLET TEMPERATURE 139.9100 F
 BLOCK ID - TUBE SIDE COND2
 TUBE PRESSURE 14.0000 PSI
 TUBE INLET TEMPERATURE 318.0000 F
 TUBE OUTLET TEMPERATURE 209.6482 F
 HEAT DUTY 1.3867-04 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00
 HEAT TRANSFER AREA PER UNIT 1.5828 SQFT
 TOTAL SCALED HEAT DUTY 1.4700-04 BTU/HR
 LOG MEAN TEMPERATURE DIFFERENCE 159.2231 F
 EXCHANGER GEOMETRY CORRECTION FACTOR 0.95

*** COST RESULTS ***

CARBON STEEL COST	\$ 5,200
PURCHASED COST	\$ 5,200

BLOCK: COND3 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 61.6385 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER COOLH2O
 CALCULATED RATE OF CONSUMPTION 203.8857 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE COOLH2O
 SHELL PRESSURE 14.6959 PSI
 SHELL INLET TEMPERATURE 67.9100 F
 SHELL OUTLET TEMPERATURE 139.9100 F
 BLOCK ID - TUBE SIDE COND3
 TUBE PRESSURE 13.0000 PSI
 TUBE INLET TEMPERATURE 318.0000 F
 TUBE OUTLET TEMPERATURE 205.9571 F
 HEAT DUTY 1.4654-04 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00
 HEAT TRANSFER AREA PER UNIT 1.7000 SQFT
 TOTAL SCALED HEAT DUTY 1.5533-04 BTU/HR
 LOG MEAN TEMPERATURE DIFFERENCE 157.2196 F
 EXCHANGER GEOMETRY CORRECTION FACTOR 0.94

*** COST RESULTS ***

CARBON STEEL COST	\$ 5,200
PURCHASED COST	\$ 5,200

BIOFILTER PROCESS CONCENTRATING TO 95% H₂SO₄ - ECONOMIC EVALUATION

BLOCK: EVAP2 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 MATERIAL OF CONSTRUCTION FACTOR 5.00
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 400.0000 BTU/HR-SQFT-R

*** USER SUPPLIED COST ***

BASE COST \$ 350,000
 COST INDEX VALUE 315.00
 INDEX TYPE EQUIPMENT

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR STEAM STEAM1
 CALCULATED RATE OF CONSUMPTION 2.8582-04 LB/HR

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID - SHELL SIDE EVAP2
 SHELL PRESSURE 14.7000 PSI
 SHELL INLET TEMPERATURE 212.5904 F
 SHELL OUTLET TEMPERATURE 214.5921 F
 UTILITY ID - TUBE SIDE STEAM1
 TUBE PRESSURE 100.0000 PSI
 TUBE INLET TEMPERATURE 327.8091 F
 TUBE OUTLET TEMPERATURE 327.8091 F
 HEAT DUTY 2.5395-07 BTU/HR

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***
 CARBON STEEL COST \$ 469,900
 PURCHASED COST \$ 2,819,300

BLOCK: DTNK MODEL: TANK

*** INPUT DATA ***

NUMBER OF TANKS 1
 MATERIAL OF CONSTRUCTION CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 RETENTION TIME REQUIRED 4.3000 HR

*** FLOWSHEET REFERENCE DATA ***

STREAM ID WATER
 LIQUID VOLUMETRIC FLOW 952.5895 CUFT/HR

*** SIZING AND COSTING RESULTS ***

TANK TYPE CUSTOM
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 VOLUME PER TANK 4846.7753 CUFT
 SCALED LIQUID FLOW 1009.7448 CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST \$ 59,800
 PURCHASED COST \$ 59,800

BLOCK: DPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
 PUMP TYPE 1-STAGE VERTICAL SPLIT
 PUMP SPEED 3550 RPM
 MATERIAL OF CONSTRUCTION DUCTILE IRON
 PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
 CALCULATED RATE OF CONSUMPTION 17.0366 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID DPUMP
 LIQUID VOLUMETRIC FLOW 952.5895 CUFT/HR
 LIQUID DENSITY 57.6788 LB/CUFT
 INLET PRESSURE 13.0000 PSI
 OUTLET PRESSURE 173.9857 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 1
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 VOLUMETRIC FLOW PER PUMP 1009.7448 CUFT/HR
 PUMP HEAD 224.9999 FT-LBF/LB
 PRESSURE RISE 160.9857 PSI
 POWER REQUIRED PER PUMP 17.0366 KW

*** COST RESULTS ***

CARBON STEEL COST \$ 3,800 \$ 7,500
 PURCHASED COST \$ 3,800 \$ 7,500

BLOCK: EVAP1 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 MATERIAL OF CONSTRUCTION FACTOR 5.00
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 70.4440 BTU/HR-SQFT-R

*** USER SUPPLIED COST ***

BASE COST \$ 300,000
 COST INDEX VALUE 315.00
 INDEX TYPE EQUIPMENT

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR STEAM STEAM1
 CALCULATED RATE OF CONSUMPTION 3.3454-04 LB/HR

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID - SHELL SIDE EVAP1
 SHELL PRESSURE 14.7000 PSI
 SHELL INLET TEMPERATURE 75.0285 F
 SHELL OUTLET TEMPERATURE 212.5904 F
 UTILITY ID - TUBE SIDE STEAM1
 TUBE PRESSURE 100.0000 PSI
 TUBE INLET TEMPERATURE 327.8091 F
 TUBE OUTLET TEMPERATURE 327.8091 F
 HEAT DUTY 2.9724-07 BTU/HR

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***
 CARBON STEEL COST \$ 402,800
 PURCHASED COST \$ 2,416,500

BLOCK: INJECT2 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 79.2495 BTU/HR-SQFT-R

*** USER SUPPLIED COST ***

ADJUSTED COST \$ 5,000
 YEAR OF COST 1984
 INDEX TYPE EQUIPMENT

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00

*** COST RESULTS ***

CARBON STEEL COST \$ 5,400
 PURCHASED COST \$ 5,400

BIOFILTER PROCESS CONCENTRATING TO 95% H₂SO₄ - ECONOMIC EVALUATION

BLOCK: EVAP3 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
HEAT EXCHANGER TYPE BEM
SHELL MATERIAL CARBON STEEL
TUBE MATERIAL CARBON STEEL
MATERIAL OF CONSTRUCTION FACTOR 6.00
PEAK CAPACITY ALLOWANCE FACTOR 1.06
NUMBER OF SHELL PASSES 1
NUMBER OF TUBE PASSES 2
FLOW DIRECTION COUNTERCURRENT
HEAT TRANSFER COEFFICIENT 79.2495 BTU/HR-SQFT-R

*** USER SUPPLIED COST ***

BASE COST \$ 190,000
COST INDEX VALUE 315.00
INDEX TYPE EQUIPMENT

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR STEAM STEAM1
CALCULATED RATE OF CONSUMPTION 6853.8339 LB/HR

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID - SHELL SIDE EVAP3
SHELL PRESSURE 14.7000 PSI
SHELL INLET TEMPERATURE 214.5921 F
SHELL OUTLET TEMPERATURE 274.6935 F
UTILITY ID - TUBE SIDE STEAM1
TUBE PRESSURE 100.0000 PSI
TUBE INLET TEMPERATURE 327.8091 F
TUBE OUTLET TEMPERATURE 327.8091 F
HEAT DUTY 6.0895+06 BTU/HR

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST \$ 255,100
PURCHASED COST \$ 1,530,500

BLOCK: FLTR MODEL: USER

*** INPUT DATA ***

PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** USER SUPPLIED COST ***

ADJUSTED COST \$ 30,000
MONTH OF COST JANUARY
YEAR OF COST 1990
INDEX TYPE EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST \$ 35,300
PURCHASED COST \$ 35,300

BLOCK: HEAT2 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
HEAT EXCHANGER TYPE BEM
SHELL MATERIAL CARBON STEEL
TUBE MATERIAL CARBON STEEL
MATERIAL OF CONSTRUCTION FACTOR 1.06
PEAK CAPACITY ALLOWANCE FACTOR 1.06
NUMBER OF SHELL PASSES 1
NUMBER OF TUBE PASSES 2
FLOW DIRECTION COUNTERCURRENT
HEAT TRANSFER COEFFICIENT 17.6110 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER COOLH20
CALCULATED RATE OF CONSUMPTION 1.4212+05 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE COOLH20
SHELL PRESSURE 14.6959 PSI
SHELL INLET TEMPERATURE 67.9100 F
SHELL OUTLET TEMPERATURE 139.9100 F
BLOCK ID - TUBE SIDE HEAT2
TUBE PRESSURE 14.7000 PSI
TUBE INLET TEMPERATURE 214.5921 F
TUBE OUTLET TEMPERATURE 212.7823 F
HEAT DUTY 1.0215+07 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00
HEAT TRANSFER AREA PER UNIT 5815.5550 SQFT
TOTAL SCALED HEAT DUTY 1.0828+07 BTU/HR
LOG MEAN TEMPERATURE DIFFERENCE 105.9295 F
EXCHANGER GEOMETRY CORRECTION FACTOR 1.00

*** COST RESULTS ***

CARBON STEEL COST \$ 68,600
PURCHASED COST \$ 68,600

BLOCK: HEAT1 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
HEAT EXCHANGER TYPE BEM
SHELL MATERIAL CARBON STEEL
TUBE MATERIAL CARBON STEEL
MATERIAL OF CONSTRUCTION FACTOR 1.06
PEAK CAPACITY ALLOWANCE FACTOR 1.06
NUMBER OF SHELL PASSES 1
NUMBER OF TUBE PASSES 2
FLOW DIRECTION COUNTERCURRENT
HEAT TRANSFER COEFFICIENT 17.6110 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER COOLH20
CALCULATED RATE OF CONSUMPTION 1.2317+05 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE COOLH20
SHELL PRESSURE 14.6959 PSI
SHELL INLET TEMPERATURE 67.9100 F
SHELL OUTLET TEMPERATURE 139.9100 F
BLOCK ID - TUBE SIDE HEAT1
TUBE PRESSURE 14.7000 PSI
TUBE INLET TEMPERATURE 212.5904 F
TUBE OUTLET TEMPERATURE 212.7827 F
HEAT DUTY 8.9524+06 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00
HEAT TRANSFER AREA PER UNIT 5090.9958 SQFT
TOTAL SCALED HEAT DUTY 9.3835+06 BTU/HR
LOG MEAN TEMPERATURE DIFFERENCE 104.4593 F
EXCHANGER GEOMETRY CORRECTION FACTOR 1.00

*** COST RESULTS ***

CARBON STEEL COST \$ 61,100
PURCHASED COST \$ 61,100

BLOCK: INJECT1 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
HEAT EXCHANGER TYPE BEM
SHELL MATERIAL CARBON STEEL
TUBE MATERIAL CARBON STEEL
MATERIAL OF CONSTRUCTION FACTOR 1.06
PEAK CAPACITY ALLOWANCE FACTOR 1.06
NUMBER OF SHELL PASSES 1
NUMBER OF TUBE PASSES 2
FLOW DIRECTION COUNTERCURRENT
HEAT TRANSFER COEFFICIENT 79.2495 BTU/HR-SQFT-R

*** USER SUPPLIED COST ***

ADJUSTED COST \$ 5,000
YEAR OF COST 1984
INDEX TYPE EQUIPMENT

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00

*** COST RESULTS ***

CARBON STEEL COST \$ 5,400
PURCHASED COST \$ 5,400

BIOFILTER PROCESS CONCENTRATING TO 95% H₂SO₄ - ECONOMIC EVALUATION

BLOCK: RPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
 PUMP TYPE 1-STAGE VERTICAL SPLIT
 PUMP SPEED 3550 RPM
 MATERIAL OF CONSTRUCTION FACTOR 3.70
 PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID RPUMP
 LIQUID VOLUMETRIC FLOW 1.2303-04 CUFT/HR
 LIQUID DENSITY 62.4250 LB/CUFT
 INLET PRESSURE 14.7000 PSI
 OUTLET PRESSURE 19.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 2
 TOTAL SCALED VOLUMETRIC FLOW 1.3046-04 CUFT/HR
 VOLUMETRIC FLOW PER PUMP 6522.9902 CUFT/HR
 PUMP HEAD 50.0022 FT-LBF/LB
 PRESSURE RISE 5.0000 PSI
 POWER REQUIRED PER PUMP 17.0566 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 5,200	\$ 15,600
PURCHASED COST	\$ 19,300	\$ 57,900

BLOCK: HEAT3 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 2
 NUMBER OF TUBE PASSES 1
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 100.0000 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER COOLH2O
 CALCULATED RATE OF CONSUMPTION 3.5358-04 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE COOLH2O
 SHELL PRESSURE 14.6959 PSI
 SHELL INLET TEMPERATURE 67.9100 F
 SHELL OUTLET TEMPERATURE 139.9100 F
 BLOCK ID - TUBE SIDE HEAT3
 TUBE PRESSURE 14.7000 PSI
 TUBE INLET TEMPERATURE 274.4935 F
 TUBE OUTLET TEMPERATURE 212.7197 F
 HEAT DUTY 2.5413-06 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00
 HEAT TRANSFER AREA PER UNIT 200.6668 SQFT
 TOTAL SCALED HEAT DUTY 2.6938-06 BTU/HR
 LOG MEAN TEMPERATURE DIFFERENCE 139.7367 F
 EXCHANGER GEOMETRY CORRECTION FACTOR 0.96

*** COST RESULTS ***

CARBON STEEL COST	\$ 7,500
PURCHASED COST	\$ 7,500

BLOCK: WPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
 PUMP TYPE 1-STAGE VERTICAL SPLIT
 PUMP SPEED 3550 RPM
 MATERIAL OF CONSTRUCTION DUCTILE IRON
 PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
 CALCULATED RATE OF CONSUMPTION 2.6175 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID WPUMP
 LIQUID VOLUMETRIC FLOW 890.4625 CUFT/HR
 LIQUID DENSITY 62.0576 LB/CUFT
 INLET PRESSURE 14.7000 PSI
 OUTLET PRESSURE 19.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 1
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 VOLUMETRIC FLOW PER PUMP 943.8902 CUFT/HR
 PUMP HEAD 50.0022 FT-LBF/LB
 PRESSURE RISE 5.0000 PSI
 POWER REQUIRED PER PUMP 2.6175 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 2,000	\$ 3,900
PURCHASED COST	\$ 2,000	\$ 3,900

UTILITY USAGE: STEAM1 (STEAM)

INPUT DATA:

PRESSURE 100.0000 PSI
 PRICE 2.5000-03 \$/LB
 COST INDEX VALUE 599.8000
 MONTH OF PRICE JANUARY
 YEAR OF PRICE 1990
 INDEX TYPE FUEL

RESULT:

HEATING VALUE 888.4853 BTU/LB
 INDEXED PRICE (1996 III Q) 2.2458-03 \$/LB
 INLET TEMPERATURE 327.8091 F
 RETURN TEMPERATURE 327.8091 F

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (LB/HR)	ANNUAL COST
EVAP1	HEATX	3.3454-04	592,744
EVAP2	HEATX	2.8582-04	506,419
EVAP3	HEATX	6853.8339	121,436
TOTAL:		6.8890-04	\$ 1,220,599

IV. UTILITY SECTION

UTILITY USAGE: COOLH2O (WATER)

INPUT DATA:

INLET TEMPERATURE 67.9100 F
 RETURN TEMPERATURE 139.9100 F
 PRESSURE 14.6959 PSI
 PRICE 1.2000-04 \$/LB
 COST INDEX VALUE 599.8000
 MONTH OF PRICE JANUARY
 YEAR OF PRICE 1990
 INDEX TYPE FUEL

RESULT:

COOLING VALUE 71.8725 BTU/LB
 INDEXED PRICE (1996 III Q) 1.0780-04 \$/LB

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (LB/HR)	ANNUAL COST
CCND1	HEATX	4.2283-05	359,603
CCND2	HEATX	192.9456	164
CCND3	HEATX	203.8857	173
HEAT1	HEATX	1.2317-05	104,749
HEAT2	HEATX	1.4212-05	120,870
HEAT3	HEATX	3.5358-04	39,071
TOTAL:		7.2388-05	\$ 615,630

UTILITY USAGE: POWER (ELECTRICITY)

INPUT DATA:

PRICE 8.0000-02 \$/KWHR
 COST INDEX VALUE 599.8000
 MONTH OF PRICE JANUARY
 YEAR OF PRICE 1990
 INDEX TYPE FUEL

RESULT:

INDEXED PRICE (1996 III Q) 7.1865-02 \$/KWHR

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (KW)	ANNUAL COST
BOOSTER	BLOWER	206.0794	115,842
APUMP	PUMP	2.6175	1,484
DPUMP	PUMP	17.0366	9,659
WPUMP	PUMP	2.6175	1,484
TOTAL:		228.3511	\$ 129,469

FIGURE A.5 Biofilter/Acid Concentrator (65%)/Gypsum Production PFD

BIOFILTER PROCESS PRODUCING GYPSUM - ECONOMIC EVALUATION

I. ANNUAL OPERATING COST SUMMARY

PRODUCTION CAPACITY FOR ALL PRODUCTS: 100.9 & BASE PERIOD: 1996, QUARTER II PLANT AVAILABILITY: 328/365.25 DAYS			
RAW MATERIAL	QUANTITY LB/HR	PRICE \$/LB	ANNUAL COST
H2O	5 4055-94	1.5016-04	\$ 64,000
LIME	2187.4265	3.2208-02	\$ 556,000
WATER	7118.3502	1.5016-04	\$ 8,000
TOTAL RAW MATERIAL			\$ 628,000
TOTAL UTILITIES			\$ 1,899,000
LABOR			
OPERATORS: 2 PER SHIFT, 3 SHIFTS			
OPERATING (16000 HR)		\$ 405,000	
MAINTENANCE		1,428,000	
SUPERVISOR		367,000	
FRINGE BENEFITS		880,000	
SUBTOTAL, LABOR			\$ 3,079,000
SUPPLIES			
OPERATING		\$ 40,000	
MAINTENANCE		952,000	
SUBTOTAL, SUPPLIES			\$ 992,000
GENERAL WORKS			
GENERAL & ADMIN		\$ 1,320,000	
PROPERTY TAX		793,000	
PROPERTY INSURANCE		317,000	
SUBTOTAL, GENERAL WORKS			\$ 2,430,000
DEPRECIATION (15 YEARS, STRAIGHT LINE)			\$ 2,644,000
GROSS OPERATING COST			\$ 11,673,000
LESS: BYPRODUCT CREDIT			\$ 93,000
NET OPERATING COST			\$ 11,580,000
SUMMARY:			
FIXED COST		\$ 6,501,000	
VARIABLE COST		\$ 2,528,000	
GROSS COST EXCL. DEPRECIATION			\$ 9,029,000
GROSS OPERATING COST			\$ 11,673,000

III. COST BLOCK SECTION

BLOCK: ACIDTANK MODEL TANK

*** INPUT DATA ***

NUMBER OF TANKS 1
MATERIAL OF CONSTRUCTION CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR 1.06
TOTAL VOLUME 361.2690 CUFT

*** SIZING AND COSTING RESULTS ***

TANK TYPE CUSTOM
MATERIAL OF CONSTRUCTION FACTOR 1.00
VOLUME PER TANK 361.2690 CUFT

*** COST RESULTS ***

CARBON STEEL COST \$ 20,200
PURCHASED COST \$ 20,200

II. PROCESS UNIT DIRECT COST SUMMARY

COMPLETION 1996, QUARTER II
LOCATION: DANVILLE

COST BLOCK ID	APUMP	BIOBOX	BOOSTER	COND1
QUANTITY	1	104	56	1
STANDBY	1	0	5	0
CARBON STEEL COST	\$ 3,900	\$ 1,007,200	\$ 180,200	\$ 59,400
PURCHASED COST	\$ 14,500	\$ 1,007,200	\$ 180,200	\$ 59,400
COST BLOCK ID	COND2	COND3	DPUMP	DTNK
QUANTITY	1	1	1	1
STANDBY	0	0	1	0
CARBON STEEL COST	\$ 5,100	\$ 5,100	\$ 3,900	\$ 59,500
PURCHASED COST	\$ 5,100	\$ 5,100	\$ 3,900	\$ 59,500
COST BLOCK ID	EVAP1	EVAP2	FLTR	HEAT1
QUANTITY	1	1	1	1
STANDBY	0	0	0	0
CARBON STEEL COST	\$ 507,300	\$ 373,800	\$ 35,100	\$ 91,100
PURCHASED COST	\$ 3,043,700	\$ 2,242,700	\$ 35,100	\$ 91,100
COST BLOCK ID	HEAT2	INJECT	INJECT2	PTNK
QUANTITY	1	1	1	1
STANDBY	0	0	0	0
CARBON STEEL COST	\$ 44,200	\$ 6,700	\$ 5,400	\$ 42,500
PURCHASED COST	\$ 44,200	\$ 6,700	\$ 5,400	\$ 42,500
COST BLOCK ID	RPUMP	WPUMP	SCRUBBER	
QUANTITY	2	1	1	
STANDBY	0	1	0	
CARBON STEEL COST	\$ 10,400	\$ 3,900	\$ 7,200	
PURCHASED COST	\$ 18,300	\$ 3,900	\$ 7,200	
COST BLOCK ID	ACIDTANK	BELT1	BELT2	BIN
QUANTITY	1	1	1	1
STANDBY	0	0	0	0
CARBON STEEL COST	\$ 20,200	\$ 8,700	\$ 8,700	\$ 11,800
PURCHASED COST	\$ 20,200	\$ 8,700	\$ 8,700	\$ 11,800
COST BLOCK ID	BLOWER1	BLOWER2	CRUSHER	CYCLONE
QUANTITY	1	1	1	1
STANDBY	1	1	0	0
CARBON STEEL COST	\$ 3,700	\$ 3,700	\$ 28,900	\$ 1,000
PURCHASED COST	\$ 3,700	\$ 3,700	\$ 28,900	\$ 1,000
COST BLOCK ID	DEN	FILTER	FSPLIT	HOPPER
QUANTITY	1	2	1	1
STANDBY	0	0	0	0
CARBON STEEL COST	\$ 9,900	\$ 57,800	\$ 2,200	\$ 9,900
PURCHASED COST	\$ 9,900	\$ 57,800	\$ 2,200	\$ 9,900
COST BLOCK ID	M-1	M-2	PUMPI	REACTOR
QUANTITY	1	1	1	1
STANDBY	0	0	0	0
CARBON STEEL COST	\$ 4,000	\$ 4,800	\$ 1,700	\$ 5,000
PURCHASED COST	\$ 8,000	\$ 4,800	\$ 1,700	\$ 5,000
TOTAL EQUIPMENT COST	\$ 7,081,600			
TOTAL INVESTMENT	\$ 40,454,000			

BLOCK: BELT1 MODEL: USER

0.15 X 10 CONVEYOR BELT FOR LIMESTONE

*** INPUT DATA ***

PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** USER SUPPLIED COST ***

ADJUSTED COST \$ 6,000
COST INDEX VALUE 315.00
INDEX TYPE EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST \$ 8,700
PURCHASED COST \$ 8,700

BLOCK: BELT2 MODEL: USER

0.15 X 10 CONVEYOR BELT FOR GYPSUM

*** INPUT DATA ***

PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** USER SUPPLIED COST ***

ADJUSTED COST \$ 6,000
COST INDEX VALUE 315.00
INDEX TYPE EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST \$ 8,700
PURCHASED COST \$ 8,700

BIOFILTER PROCESS PRODUCING GYPSUM - ECONOMIC EVALUATION

BLOCK: APUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS	1
PUMP TYPE	1-STAGE VERTICAL SPLIT
PUMP SPEED	3550 RPM
MATERIAL OF CONSTRUCTION	3.79
PEAK CAPACITY ALLOWANCE FACTOR	1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	POWER
CALCULATED RATE OF CONSUMPTION	2.6175 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID	APUMP
LIQUID VOLUMETRIC FLOW	908.5321 CUFT/HR
LIQUID DENSITY	62.4527 LB/CUFT
INLET PRESSURE	14.7900 PSI
OUTLET PRESSURE	24.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS	1
VOLUMETRIC FLOW PER PUMP	908.5321 CUFT/HR
PUMP HEAD	50.0022 FT-LBF/LB
PRESSURE RISE	10.0000 PSI
POWER REQUIRED PER PUMP	2.6175 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 2,900	\$ 3,900
PURCHASED COST	\$ 7,200	\$ 14,500

BLOCK: BIN MODEL: TANK

*** INPUT DATA ***

NUMBER OF TANKS	1
MATERIAL OF CONSTRUCTION	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
TOTAL VOLUME	68.8636 CUFT

*** SIZING AND COSTING RESULTS ***

TANK TYPE	CUSTOM
MATERIAL OF CONSTRUCTION	1.00
VOLUME PER TANK	68.8636 CUFT

*** COST RESULTS ***

CARBON STEEL COST	\$ 11,800
PURCHASED COST	\$ 11,800

BLOCK: BLOWER1 MODEL: BLOWER

*** INPUT DATA ***

NUMBER OF BLOWERS	1
NUMBER OF STANDBYS	1
MOTOR TYPE	ENCLOSED, FAN COOLED
COUPLING TYPE	BELT DRIVE
MATERIAL OF CONSTRUCTION	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
BLOWER EFFICIENCY	0.75

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	POWER
CALCULATED RATE OF CONSUMPTION	2.2557 KW

*** FLOWSHEET REFERENCE DATA ***

INLET STREAM ID	AIR1
TOTAL VOLUMETRIC FLOW	7.0316+04 CUFT/HR
GAS DENSITY	7.3874-02 LB/CUFT
GAS TEMPERATURE	77.0000 F
INLET PRESSURE	14.6959 PSI
OUTLET STREAM ID	80
OUTLET PRESSURE	15.0633 PSI

*** SIZING AND COSTING RESULTS ***

BLOWER CLASS	II
MATERIAL OF CONSTRUCTION	1.00
OUTLET AREA PER BLOWER	1.8999 SQFT
SCALED FLOW PER BLOWER	7.4535+04 CUFT/HR
OUTLET GAS VELOCITY	0.8973 FT/SEC
CORRECTED STATIC PRESSURE	0.3725 PSI
MOTOR EFFICIENCY	0.83
MOTOR SPEED	1800 RPM
POWER REQUIRED PER BLOWER	2.2557 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 1,800	\$ 3,700
PURCHASED COST	\$ 1,800	\$ 3,700

BLOCK: BIOSOX MODEL: USER

*** INPUT DATA ***

NUMBER OF PIECES OF EQUIPMENT	104
PEAK CAPACITY ALLOWANCE FACTOR	1.06

*** USER SUPPLIED COST ***

ADJUSTED COST	\$ 9,000
MONTH OF COST	MAY
YEAR OF COST	1994
INDEX TYPE	EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 9,700	\$ 1,007,200
PURCHASED COST	\$ 9,700	\$ 1,007,200

BLOCK: CRUSHER MODEL: USER

*** INPUT DATA ***

PEAK CAPACITY ALLOWANCE FACTOR	1.06
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*** USER SUPPLIED COST ***

ADJUSTED COST	\$ 20,000
COST INDEX VALUE	315.00
INDEX TYPE	EQUIPMENT

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	POWER
SPECIFIED RATE OF CONSUMPTION	1.3000 KW

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST	\$ 28,900
PURCHASED COST	\$ 28,900

BLOCK: CYCLONE MODEL: USER

*** INPUT DATA ***

PEAK CAPACITY ALLOWANCE FACTOR	1.06
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*** USER SUPPLIED COST ***

ADJUSTED COST	\$ 720
COST INDEX VALUE	315.00
INDEX TYPE	EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST	\$ 1,000
PURCHASED COST	\$ 1,000

BIOFILTER PROCESS PRODUCING GYPSUM - ECONOMIC EVALUATION

BLOCK: BLCWR2 MODEL: BLOWER

*** INPUT DATA ***

NUMBER OF BLOWERS 1
 NUMBER OF STANDBYS 1
 MOTOR TYPE ENCLOSED, FAN COOLED
 COUPLING TYPE BELT DRIVE
 MATERIAL OF CONSTRUCTION CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 BLOWER EFFICIENCY 0.75

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY
 CALCULATED RATE OF CONSUMPTION POWER 2.3252 KW

*** FLOWSHEET REFERENCE DATA ***

INLET STREAM ID AIR2
 TOTAL VOLUMETRIC FLOW 7.2562-04 CUFT/HR
 GAS DENSITY 7.3874-02 LB/CUFT
 GAS TEMPERATURE 77.0000 F
 INLET PRESSURE 14.6959 PSI
 OUTLET STREAM ID 78
 OUTLET PRESSURE 15.0633 PSI

*** SIZING AND COSTING RESULTS ***

BLOWER CLASS II
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 OUTLET AREA PER BLOWER 1.8999 SQFT
 SCALED FLOW PER BLOWER 7.6916-04 CUFT/HR
 OUTLET GAS VELOCITY 11.2453 FT/SEC
 CORRECTED STATIC PRESSURE 0.3725 PSI
 MOTOR EFFICIENCY 0.83
 MOTOR SPEED 1800 RPM
 POWER REQUIRED PER BLOWER 2.3252 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 1,800	\$ 3,700
PURCHASED COST	\$ 1,800	\$ 3,700

BLOCK: BOOSTER MODEL: BLOWER

*** INPUT DATA ***

NUMBER OF STANDBYS 5
 MOTOR TYPE ENCLOSED, FAN COOLED
 COUPLING TYPE BELT DRIVE
 MATERIAL OF CONSTRUCTION CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 BLOWER EFFICIENCY 0.75

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY
 CALCULATED RATE OF CONSUMPTION POWER 206.0794 KW

*** FLOWSHEET REFERENCE DATA ***

INLET STREAM ID DRTYAIR
 TOTAL VOLUMETRIC FLOW 2.3939-07 CUFT/HR
 GAS DENSITY 7.4624-02 LB/CUFT
 GAS TEMPERATURE 70.0000 F
 INLET PRESSURE 14.7000 PSI
 OUTLET STREAM ID 1
 OUTLET PRESSURE 14.8000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF BLOWERS 56
 BLOWER CLASS I
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 OUTLET AREA PER BLOWER 5.1498 SQFT
 CALCULATED TOTAL OUTLET AREA 284.7837 SQFT
 SCALED FLOW PER BLOWER 4.5408-05 CUFT/HR
 SCALED TOTAL VOLUMETRIC FLOW 2.5429-07 CUFT/HR
 OUTLET GAS VELOCITY 0.1003 FT/SEC
 CORRECTED STATIC PRESSURE 0.84
 MOTOR EFFICIENCY 0.84
 MOTOR SPEED 1800 RPM
 POWER REQUIRED PER BLOWER 3.6799 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 3,000	\$ 180,200
PURCHASED COST	\$ 3,000	\$ 180,200

BLOCK: COND1 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 61.6385 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER COOLH2O
 CALCULATED RATE OF CONSUMPTION 4.1610-05 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE COOLH2O
 SHELL PRESSURE 14.6959 PSI
 SHELL INLET TEMPERATURE 67.9100 F
 SHELL OUTLET TEMPERATURE 139.9100 F
 BLOCK ID - TUBE SIDE COND1
 TUBE PRESSURE 14.7000 PSI
 TUBE INLET TEMPERATURE 213.8857 F
 TUBE OUTLET TEMPERATURE 212.1050 F
 HEAT DUTY 2.9906-07 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00
 HEAT TRANSFER AREA PER UNIT 4998.3876 SQFT
 TOTAL SCALED HEAT DUTY 3.1701-07 BTU/HR
 LOG MEAN TEMPERATURE DIFFERENCE 105.2085 F
 EXCHANGER GEOMETRY CORRECTION FACTOR 1.00

*** COST RESULTS ***

CARBON STEEL COST	\$ 59,400
PURCHASED COST	\$ 59,400

BLOCK: COND2 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS 1
 HEAT EXCHANGER TYPE BEM
 SHELL MATERIAL CARBON STEEL
 TUBE MATERIAL CARBON STEEL
 PEAK CAPACITY ALLOWANCE FACTOR 1.06
 NUMBER OF SHELL PASSES 1
 NUMBER OF TUBE PASSES 2
 FLOW DIRECTION COUNTERCURRENT
 HEAT TRANSFER COEFFICIENT 61.6385 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER COOLH2O
 CALCULATED RATE OF CONSUMPTION 192.9456 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE COOLH2O
 SHELL PRESSURE 14.6959 PSI
 SHELL INLET TEMPERATURE 67.9100 F
 SHELL OUTLET TEMPERATURE 139.9100 F
 BLOCK ID - TUBE SIDE COND2
 TUBE PRESSURE 14.0000 PSI
 TUBE INLET TEMPERATURE 318.0000 F
 TUBE OUTLET TEMPERATURE 209.6480 F
 HEAT DUTY 1.3867-04 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 1.00
 HEAT TRANSFER AREA PER UNIT 1.5828 SQFT
 TOTAL SCALED HEAT DUTY 1.4700-04 BTU/HR
 LOG MEAN TEMPERATURE DIFFERENCE 159.2223 F
 EXCHANGER GEOMETRY CORRECTION FACTOR 0.95

*** COST RESULTS ***

CARBON STEEL COST	\$ 5,100
PURCHASED COST	\$ 5,100

BIOFILTER PROCESS PRODUCING GYPSUM - ECONOMIC EVALUATION

BLOCK: COND3 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS	1
HEAT EXCHANGER TYPE	BEM
SHELL MATERIAL	CARBON STEEL
TUBE MATERIAL	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
NUMBER OF SHELL PASSES	1
NUMBER OF TUBE PASSES	2
FLOW DIRECTION	COUNTERCURRENT
HEAT TRANSFER COEFFICIENT	61.5385 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER	COOLH2O
CALCULATED RATE OF CONSUMPTION	203.8857 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE	COOLH2O
SHELL PRESSURE	14.6959 PSI
SHELL INLET TEMPERATURE	47.9100 F
SHELL OUTLET TEMPERATURE	139.9100 F
BLOCK ID - TUBE SIDE	COND3
TUBE PRESSURE	13.0000 PSI
TUBE INLET TEMPERATURE	318.0000 F
TUBE OUTLET TEMPERATURE	205.9568 F
HEAT DUTY	1.4654-04 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR	1.00
HEAT TRANSFER AREA PER UNIT	1.7000 SQFT
TOTAL SCALED HEAT DUTY	1.5533-04 BTU/HR
LOG MEAN TEMPERATURE DIFFERENCE	157.2194 F
EXCHANGER GEOMETRY CORRECTION FACTOR	0.94

*** COST RESULTS ***

CARBON STEEL COST	\$ 5,100
PURCHASED COST	\$ 5,100

BLOCK: DEN MODEL: TANK

*** INPUT DATA ***

NUMBER OF TANKS	1
MATERIAL OF CONSTRUCTION	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
RETENTION TIME REQUIRED	0.5000 HR

*** FLOWSHEET REFERENCE DATA ***

STREAM ID	GSOLID
LIQUID VOLUMETRIC FLOW	24.9028 CUFT/HR

*** SIZING AND COSTING RESULTS ***

TANK TYPE	CUSTOM
MATERIAL OF CONSTRUCTION FACTOR	1.00
VOLUME PER TANK	15.8382 CUFT
SCALED LIQUID FLOW	26.3970 CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST	\$ 9,900
PURCHASED COST	\$ 9,900

BLOCK: DTNK MODEL: TANK

*** INPUT DATA ***

NUMBER OF TANKS	1
MATERIAL OF CONSTRUCTION	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
RETENTION TIME REQUIRED	4.0000 HR

*** FLOWSHEET REFERENCE DATA ***

STREAM ID	WATER
LIQUID VOLUMETRIC FLOW	936.7608 CUFT/HR

*** SIZING AND COSTING RESULTS ***

TANK TYPE	CUSTOM
MATERIAL OF CONSTRUCTION FACTOR	1.00
VOLUME PER TANK	4766.2391 CUFT
SCALED LIQUID FLOW	992.9665 CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST	\$ 59,500
PURCHASED COST	\$ 59,500

BLOCK: DPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF PUMPS	1
NUMBER OF STANDBYS	1
PUMP TYPE	1-STAGE VERTICAL SPLIT
PUMP SPEED	3550 RPM
MATERIAL OF CONSTRUCTION	DUCTILE IRON
PEAK CAPACITY ALLOWANCE FACTOR	1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	POWER
CALCULATED RATE OF CONSUMPTION	2.6175 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID	DPUMP
LIQUID VOLUMETRIC FLOW	936.7608 CUFT/HR
LIQUID DENSITY	57.7046 LB/CUFT
INLET PRESSURE	13.0000 PSI
OUTLET PRESSURE	18.0000 PSI

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR	1.00
VOLUMETRIC FLOW PER PUMP	992.9665 CUFT/HR
PUMP HEAD	50.0922 FT-LBF/LB
PRESSURE RISE	5.0000 PSI
POWER REQUIRED PER PUMP	2.6175 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 2,000	\$ 3,900
PURCHASED COST	\$ 2,000	\$ 3,900

BLOCK: FILTER MODEL: USER

*** INPUT DATA ***

NUMBER OF PIECES OF EQUIPMENT	2
PEAK CAPACITY ALLOWANCE FACTOR	1.06

*** USER SUPPLIED COST ***

ADJUSTED COST	\$ 20,000
COST INDEX VALUE	315.00
INDEX TYPE	EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 28,900	\$ 57,800
PURCHASED COST	\$ 28,900	\$ 57,800

BIOFILTER PROCESS PRODUCING GYPSUM - ECONOMIC EVALUATION

BLOCK: EVAP2 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS	1
HEAT EXCHANGER TYPE	BEM
SHELL MATERIAL	CARBON STEEL
TUBE MATERIAL	CARBON STEEL
MATERIAL OF CONSTRUCTION FACTOR	5.00
PEAK CAPACITY ALLOWANCE FACTOR	1.06
NUMBER OF SHELL PASSES	1
NUMBER OF TUBE PASSES	2
FLOW DIRECTION	COUNTERCURRENT
HEAT TRANSFER COEFFICIENT	70.4440 BTU/HR-SQFT-R

*** USER SUPPLIED COST ***

BASE COST	\$ 290,000
COST INDEX VALUE	315.00
INDEX TYPE	EQUIPMENT

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR STEAM	STEAM1
CALCULATED RATE OF CONSUMPTION	1.6806-04 LB/HR

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID - SHELL SIDE	EVAP2
SHELL PRESSURE	14.7000 PSI
SHELL INLET TEMPERATURE	213.0659 F
SHELL OUTLET TEMPERATURE	225.9485 F
UTILITY ID - TUBE SIDE	STEAM1
TUBE PRESSURE	100.0000 PSI
TUBE INLET TEMPERATURE	327.8091 F
TUBE OUTLET TEMPERATURE	327.8091 F
HEAT DUTY	1.4931-07 BTU/HR

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST	\$ 373,800
PURCHASED COST	\$ 2,242,700

BLOCK: EVAP1 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS	1
HEAT EXCHANGER TYPE	BEM
SHELL MATERIAL	CARBON STEEL
TUBE MATERIAL	CARBON STEEL
MATERIAL OF CONSTRUCTION FACTOR	6.00
PEAK CAPACITY ALLOWANCE FACTOR	1.06
NUMBER OF SHELL PASSES	1
NUMBER OF TUBE PASSES	2
FLOW DIRECTION	COUNTERCURRENT
HEAT TRANSFER COEFFICIENT	70.4440 BTU/HR-SQFT-R

*** USER SUPPLIED COST ***

BASE COST	\$ 380,000
COST INDEX VALUE	315.00
INDEX TYPE	EQUIPMENT

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR STEAM	STEAM1
CALCULATED RATE OF CONSUMPTION	5.1097-04 LB/HR

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID - SHELL SIDE	EVAP1
SHELL PRESSURE	14.7000 PSI
SHELL INLET TEMPERATURE	75.0571 F
SHELL OUTLET TEMPERATURE	213.0659 F
UTILITY ID - TUBE SIDE	STEAM1
TUBE PRESSURE	100.0000 PSI
TUBE INLET TEMPERATURE	327.8091 F
TUBE OUTLET TEMPERATURE	327.8091 F
HEAT DUTY	4.5319-07 BTU/HR

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST	\$ 507,300
PURCHASED COST	\$ 3,043,700

BLOCK: FLTR MODEL: USER

*** INPUT DATA ***

PEAK CAPACITY ALLOWANCE FACTOR	1.06
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*** USER SUPPLIED COST ***

ADJUSTED COST	\$ 30,000
MONTH OF COST	JANUARY
YEAR OF COST	1990
INDEX TYPE	EQUIPMENT

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF EQUIPMENT	1
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*** COST RESULTS ***

CARBON STEEL COST	\$ 35,100
PURCHASED COST	\$ 35,100

BLOCK: FSPLIT MODEL: USER

*** INPUT DATA ***

PEAK CAPACITY ALLOWANCE FACTOR	1.06
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*** USER SUPPLIED COST ***

ADJUSTED COST	\$ 1,500
COST INDEX VALUE	315.00
INDEX TYPE	EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST	\$ 2,200
PURCHASED COST	\$ 2,200

BLOCK: HOPPER MODEL: TANK

*** INPUT DATA ***

NUMBER OF TANKS	1
MATERIAL OF CONSTRUCTION	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
TOTAL VOLUME	13.1370 CUFT

*** SIZING AND COSTING RESULTS ***

TANK TYPE	CUSTCM
MATERIAL OF CONSTRUCTION FACTOR	1.00
VOLUME PER TANK	13.1370 CUFT

*** COST RESULTS ***

CARBON STEEL COST	\$ 9,900
PURCHASED COST	\$ 9,900

BLOCK: INJECT1 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS	1
HEAT EXCHANGER TYPE	BEM
SHELL MATERIAL	CARBON STEEL
TUBE MATERIAL	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
NUMBER OF SHELL PASSES	1
NUMBER OF TUBE PASSES	2
FLOW DIRECTION	COUNTERCURRENT
HEAT TRANSFER COEFFICIENT	79.2495 BTU/HR-SQFT-R

*** USER SUPPLIED COST ***

ADJUSTED COST	\$ 5,000
COST INDEX VALUE	315.00
INDEX TYPE	EQUIPMENT

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR	1.00
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*** COST RESULTS ***

CARBON STEEL COST	\$ 6,700
PURCHASED COST	\$ 6,700

BIOFILTER PROCESS PRODUCING GYPSUM - ECONOMIC EVALUATION

BLOCK: HEAT1 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS	1
HEAT EXCHANGER TYPE	HEM
SHELL MATERIAL	CARBON STEEL
TUBE MATERIAL	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
NUMBER OF SHELL PASSES	1
NUMBER OF TUBE PASSES	2
FLOW DIRECTION	COUNTERCURRENT
HEAT TRANSFER COEFFICIENT	17.6110 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER	COOLH2O
CALCULATED RATE OF CONSUMPTION	2.1040-05 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE	COOLH2O
SHELL PRESSURE	14.6959 PSI
SHELL INLET TEMPERATURE	67.9100 F
SHELL OUTLET TEMPERATURE	139.9100 F
BLOCK ID - TUBE SIDE	HEAT1
TUBE PRESSURE	14.7000 PSI
TUBE INLET TEMPERATURE	213.0659 F
TUBE OUTLET TEMPERATURE	212.7826 F
HEAT DUTY	1.5122-07 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR	1.00
HEAT TRANSFER AREA PER UNIT	9671.6470 SQFT
TOTAL SCALED HEAT DUTY	1.6029-07 BTU/HR
LOG MEAN TEMPERATURE DIFFERENCE	104.9622 F
EXCHANGER GEOMETRY CORRECTION FACTOR	1.00

*** COST RESULTS ***

CARBON STEEL COST	\$ 91,100
PURCHASED COST	\$ 91,100

BLOCK: HEAT2 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS	1
HEAT EXCHANGER TYPE	HEM
SHELL MATERIAL	CARBON STEEL
TUBE MATERIAL	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
NUMBER OF SHELL PASSES	1
NUMBER OF TUBE PASSES	2
FLOW DIRECTION	COUNTERCURRENT
HEAT TRANSFER COEFFICIENT	17.6110 BTU/HR-SQFT-R

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER	COOLH2O
CALCULATED RATE OF CONSUMPTION	8.4200-04 LB/HR

*** FLOWSHEET REFERENCE DATA ***

UTILITY ID - SHELL SIDE	COOLH2O
SHELL PRESSURE	14.6959 PSI
SHELL INLET TEMPERATURE	67.9100 F
SHELL OUTLET TEMPERATURE	139.9100 F
BLOCK ID - TUBE SIDE	HEAT2
TUBE PRESSURE	14.7000 PSI
TUBE INLET TEMPERATURE	225.9485 F
TUBE OUTLET TEMPERATURE	212.7793 F
HEAT DUTY	6.0516-06 BTU/HR

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR	1.00
HEAT TRANSFER AREA PER UNIT	3267.4313 SQFT
TOTAL SCALED HEAT DUTY	6.4147-06 BTU/HR
LOG MEAN TEMPERATURE DIFFERENCE	112.9110 F
EXCHANGER GEOMETRY CORRECTION FACTOR	0.99

*** COST RESULTS ***

CARBON STEEL COST	\$ 44,200
PURCHASED COST	\$ 44,200

BLOCK: INJECT2 MODEL: HEATX

*** INPUT DATA ***

NUMBER OF HEAT EXCHANGERS	1
HEAT EXCHANGER TYPE	HEM
SHELL MATERIAL	CARBON STEEL
TUBE MATERIAL	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
NUMBER OF SHELL PASSES	1
NUMBER OF TUBE PASSES	2
FLOW DIRECTION	COUNTERCURRENT
HEAT TRANSFER COEFFICIENT	79.2495 BTU/HR-SQFT-R

*** USER SUPPLIED COST ***

ADJUSTED COST	\$ 5,000
YEAR OF COST	1994
INDEX TYPE	EQUIPMENT

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR	1.00
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*** COST RESULTS ***

CARBON STEEL COST	\$ 5,400
PURCHASED COST	\$ 5,400

BLOCK: M-1 MODEL: H-VESSEL

*** INPUT DATA ***

NUMBER OF VESSELS	1
MATERIAL OF CONSTRUCTION	HASTELLOY
PEAK CAPACITY ALLOWANCE FACTOR	1.06
RETENTION TIME	8.3333-02 HR
CORROSION ALLOWANCE	0.0 FT

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID	G79
VAPOR FLOW	0.0 CUFT/HR
LIQUID FLOW	19.3153 CUFT/HR
VAPOR DENSITY	MISSING LB/CUFT
LIQUID DENSITY	95.2041 LB/CUFT
TEMPERATURE	77.0000 F
PRESSURE	14.6959 PSI

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR	1.98
TOTAL SHELL WEIGHT	152.4670 LB
CALCULATED DIAMETER	1.0280 FT
CALCULATED TANGENT-TO-TANGENT LENGTH	3.0831 FT
VOLUME PER VESSEL	2.3436 CUFT
TOP SHELL THICKNESS	2.0833-02 FT
BOTTOM SHELL THICKNESS	2.0833-02 FT
SCALED VAPOR FLOW	0.0 CUFT/HR
SCALED LIQUID FLOW	20.4742 CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST	\$ 4,000
PURCHASED COST	\$ 8,000

BLOCK: SCRUBBER MODEL: USER

*** INPUT DATA ***

PEAK CAPACITY ALLOWANCE FACTOR	1.06
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*** USER SUPPLIED COST ***

ADJUSTED COST	\$ 5,000
COST INDEX VALUE	315.00
INDEX TYPE	EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST	\$ 7,200
PURCHASED COST	\$ 7,200

BIOFILTER PROCESS PRODUCING GYPSUM - ECONOMIC EVALUATION

BLOCK: M-2 MODEL: H-VESSEL

*** INPUT DATA ***

NUMBER OF VESSELS	1	
MATERIAL OF CONSTRUCTION	CARBON STEEL	
PEAK CAPACITY ALLOWANCE FACTOR	1.06	
RETENTION TIME	8.3333-02	HR
CORROSION ALLOWANCE	0.0	FT

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID	G78	
VAPOR FLOW	0.0	CUFT/HR
LIQ' D FLOW	117.2086	CUFT/HR
VAPOR DENSITY	MISSING	LB/CUFT
LIQUID DENSITY	61.9900	LB/CUFT
TEMPERATURE	77.0513	F
PRESSURE	14.6959	PSI

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR	1.00	
TOTAL SHELL WEIGHT	431.3224	LB
CALCULATED DIAMETER	1.8750	FT
CALCULATED TANGENT-TO-TANGENT LENGTH	5.6244	FT
VOLUME PER VESSEL	17.2557	CUFT
TOP SHELL THICKNESS	2.0833-02	FT
BOTTOM SHELL THICKNESS	2.0833-02	FT
SCALED VAPOR FLOW	0.0	CUFT/HR
SCALED LIQUID FLOW	124.2411	CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST	\$ 4,800
PURCHASED COST	\$ 4,800

BLOCK: PTNK MODEL: TANK

*** INPUT DATA ***

NUMBER OF TANKS	1	
MATERIAL OF CONSTRUCTION	CARBON STEEL	
PEAK CAPACITY ALLOWANCE FACTOR	1.06	
RETENTION TIME REQUIRED	36.0000	HR

*** FLOWSHEET REFERENCE DATA ***

STREAM ID	ACID95	
LIQUID VOLUMETRIC FLOW	38.6852	CUFT/HR

*** SIZING AND COSTING RESULTS ***

TANK TYPE	CUSTOM	
MATERIAL OF CONSTRUCTION FACTOR	1.00	
VOLUME PER TANK	1771.4734	CUFT
SCALED LIQUID FLOW	41.0063	CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST	\$ 42,500
PURCHASED COST	\$ 42,500

BLOCK: REACTOR MODEL: H-VESSEL

*** INPUT DATA ***

NUMBER OF VESSELS	1	
MATERIAL OF CONSTRUCTION	CARBON STEEL	
PEAK CAPACITY ALLOWANCE FACTOR	1.06	
LIQUID DENSITY	62.4279	LB/CUFT
RETENTION TIME	0.1666	HR
CORROSION ALLOWANCE	0.0	FT

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID	GREACTOR	
VAPOR FLOW	2.5985-04	CUFT/HR
LIQUID FLOW	0.0	CUFT/HR
VAPOR DENSITY	4.8301-02	LB/CUFT
TEMPERATURE	212.0000	F
PRESSURE	14.6959	PSI

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR	1.00	
TOTAL SHELL WEIGHT	467.3004	LB
CALCULATED DIAMETER	1.9516	FT
CALCULATED TANGENT-TO-TANGENT LENGTH	5.8543	FT
VOLUME PER VESSEL	19.4590	CUFT
TOP SHELL THICKNESS	2.0833-02	FT
BOTTOM SHELL THICKNESS	2.0833-02	FT
SCALED VAPOR FLOW	2.7544-04	CUFT/HR
SCALED LIQUID FLOW	0.0	CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST	\$ 5,000
PURCHASED COST	\$ 5,000

BLOCK: PUMP1 MODEL: PUMP

*** INPUT DATA ***

NUMBER OF PUMPS	1	
PUMP TYPE	1-STAGE VERTICAL SPLIT	
PUMP SPEED	3550	RPM
MATERIAL OF CONSTRUCTION	DUCTILE IRON	
PEAK CAPACITY ALLOWANCE FACTOR	1.06	

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	POWER	
CALCULATED RATE OF CONSUMPTION	1.3087	KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID	PUMP1	
LIQUID VOLUMETRIC FLOW	114.8305	CUFT/HR
LIQUID DENSITY	61.9900	LB/CUFT
INLET PRESSURE	14.6959	PSI
OUTLET PRESSURE	19.6959	PSI

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR	1.00	
VOLUMETRIC FLOW PER PUMP	401.1039	CUFT/HR
PUMP HEAD	50.0022	FT-LBF/LB
PRESSURE RISE	5.0000	PSI
POWER REQUIRED PER PUMP	1.3087	KW

*** COST RESULTS ***

CARBON STEEL COST	\$ 1,700
PURCHASED COST	\$ 1,700

BLOCK: RPUMP MODEL: PUMP

*** INPUT DATA ***

PUMP TYPE	1-STAGE VERTICAL SPLIT	
PUMP SPEED	3550	RPM
MATERIAL OF CONSTRUCTION FACTOR	3.70	
PEAK CAPACITY ALLOWANCE FACTOR	1.06	

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID	RPUMP	
LIQUID VOLUMETRIC FLOW	1.2308-04	CUFT/HR
LIQUID DENSITY	62.4250	LB/CUFT
INLET PRESSURE	14.7000	PSI
OUTLET PRESSURE	19.7000	PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS	2	
TOTAL SCALED VOLUMETRIC FLOW	1.3046-04	CUFT/HR
VOLUMETRIC FLOW PER PUMP	6522.9902	CUFT/HR
PUMP HEAD	50.0022	FT-LBF/LB
PRESSURE RISE	5.0000	PSI
POWER REQUIRED PER PUMP	17.0566	KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 5,200	\$ 10,400
PURCHASED COST	\$ 19,200	\$ 38,300

BIOFILTER PROCESS PRODUCING GYPSUM - ECONOMIC EVALUATION

BLOCK: WPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
 PUMP TYPE 1-STAGE VERTICAL SPLIT
 PUMP SPEED 3550 RPM
 MATERIAL OF CONSTRUCTION DUCTILE IRON
 PEAK CAPACITY ALLOWANCE FACTOR 1.05

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
 CALCULATED RATE OF CONSUMPTION 2.5175 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID WPUMP
 LIQUID VOLUMETRIC FLOW 890.4625 CUFT/HR
 LIQUID DENSITY 62.0575 LB/CUFT
 INLET PRESSURE 14.7000 PSI
 OUTLET PRESSURE 19.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 1
 MATERIAL OF CONSTRUCTION FACTOR 1.00
 VOLUMETRIC FLOW PER PUMP 943.8902 CUFT/HR
 PUMP HEAD 50.0022 FT-LBF/LB
 PRESSURE RISE 5.0000 PSI
 POWER REQUIRED PER PUMP 2.6175 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 2,000	\$ 3,900
PURCHASED COST	\$ 2,000	\$ 3,900

IV. UTILITY SECTION

UTILITY USAGE: COOLH2O (WATER)

INPUT DATA:

INLET TEMPERATURE 67.9100 F
 RETURN TEMPERATURE 139.9100 F
 PRESSURE 14.6959 PSI
 PRICE 1.2000-04 \$/LB
 COST INDEX VALUE 599.8000
 MONTH OF PRICE JANUARY
 YEAR OF PRICE 1990
 INDEX TYPE FUEL

RESULT:

COOLING VALUE 71.8725 BTU/LB
 INDEXED PRICE (1996 II Q) 1.0599-04 \$/LB

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (LB/HR)	ANNUAL COST
COND1	HEATX	4.1610-05	347.944
COND2	HEATX	192.9456	161
COND3	HEATX	203.8857	170
HEAT1	HEATX	2.1040-05	175.938
HEAT2	HEATX	8.4200-04	70.408
TOTAL:		7.1110-05	\$ 594.622

UTILITY USAGE: POWER (ELECTRICITY)

INPUT DATA:

PRICE 8.0000-02 \$/KWHR
 COST INDEX VALUE 599.8000
 MONTH OF PRICE JANUARY
 YEAR OF PRICE 1990
 INDEX TYPE FUEL

RESULT:

INDEXED PRICE (1996 II Q) 7.0660-02 \$/KWHR

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (KW)	ANNUAL COST
BLOWER1	BLOWER	2.2557	1,257
BLOWER2	BLOWER	2.3252	1,296
SCOSTER	BLOWER	206.0794	114,882
APUMP	PUMP	2.6175	1,459
DPUMP	PUMP	2.6175	1,459
PUMP1	PUMP	1.3087	730
WPUMP	PUMP	2.6175	1,459
CRUSHER	USER	1.3900	725
TOTAL:		221.1218	\$ 123,268

UTILITY USAGE: STEAM1 (STEAM)

INPUT DATA:

PRESSURE 100.0000 PSI
 PRICE 2.5000-03 \$/LB
 COST INDEX VALUE 599.8000
 MONTH OF PRICE JANUARY
 YEAR OF PRICE 1990
 INDEX TYPE FUEL

RESULT:

HEATING VALUE 888.4853 BTU/LB
 INDEXED PRICE (1996 II Q) 2.2081-03 \$/LB
 INLET TEMPERATURE 327.8091 F
 RETURN TEMPERATURE 327.8091 F

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (LB/HR)	ANNUAL COST
EVAP1	HEATX	5.1007-04	888,575
EVAP2	HEATX	1.6806-04	232,766
TOTAL:		6.7812-04	\$ 1,181,341

FIGURE A.6 Biofilter/Line Neutralizer PFD

BIOFILTER PROCESS WITH 3% H₂SO₄ NEUTRALIZED - ECONOMIC EVALUATION

I. ANNUAL OPERATING COST SUMMARY

PRODUCTION CAPACITY FOR ALL PRODUCTS: 100.0 %			
BASE PERIOD: 1995, QUARTER III			
PLANT AVAILABILITY: 328/365.25 DAYS			
RAW MATERIAL	QUANTITY	PRICE	ANNUAL COST
	LB/HR	\$/LB	
CACO ₃	1738.0000	2.3696-02	\$ 325,000
H ₂ O	5.5260-04	1.4273-04	\$ 62,000
TOTAL RAW MATERIAL			\$ 387,000
TOTAL UTILITIES			\$ 130,000
WASTE TREATMENT			\$ 331,000
LABOR			
OPERATORS: 2 PER SHIFT, 3 SHIFTS			
OPERATING (15000 HR)		\$ 385,000	
MAINTENANCE		307,000	
SUPERVISION		138,000	
FRINGE BENEFITS		332,000	
SUBTOTAL, LABOR			\$ 1,162,000
SUPPLIES			
OPERATING		\$ 38,000	
MAINTENANCE		205,000	
SUBTOTAL, SUPPLIES			\$ 243,000
GENERAL WORKS			
GENERAL & ADMIN		\$ 498,000	
PROPERTY TAX		170,000	
PROPERTY INSURANCE		68,000	
SUBTOTAL, GENERAL WORKS			\$ 737,000
DEPRECIATION (15 YEARS, STRAIGHT LINE)			\$ 568,000
GROSS OPERATING COST			\$ 3,558,000
LESS: BYPRODUCT CREDIT			\$ 0
NET OPERATING COST			\$ 3,558,000
SUMMARY:			
FIXED COST	\$ 2,141,000		
VARIABLE COST	\$ 848,000		
GROSS COST EXCL. DEPRECIATION			\$ 2,990,000
GROSS OPERATING COST			\$ 3,558,000

II. PROCESS UNIT DIRECT COST SUMMARY

COMPLETION: 1995, QUARTER III
LOCATION: DANVILLE

COST BLOCK ID	APUMP	BICBOX	BOOSTER	FLTR
QUANTITY	1	104	56	1
STANDBY	1	0	5	0
CARBON STEEL COST	\$ 3,800	\$ 1,071,600	\$ 177,100	\$ 34,600
PURCHASED COST	\$ 14,200	\$ 1,071,600	\$ 177,100	\$ 34,600
COST BLOCK ID	MIXER	RPUMP	WPUMP	
QUANTITY	1	2	1	
STANDBY	0	1	1	
CARBON STEEL COST	\$ 30,600	\$ 15,300	\$ 3,800	
PURCHASED COST	\$ 106,500	\$ 56,500	\$ 3,800	
TOTAL EQUIPMENT COST	\$ 1,464,400			
TOTAL INVESTMENT	\$ 8,692,000			

III. COST BLOCK SECTION

BLOCK: APUMP MODEL: PUMP

*** INPUT DATA ***			
NUMBER OF STANDBYS	1		
PUMP TYPE	1-STAGE VERTICAL SPLIT		
PUMP SPEED	3550	RPM	
MATERIAL OF CONSTRUCTION FACTOR	3.70		
PEAK CAPACITY ALLOWANCE FACTOR	1.06		
*** ASSOCIATED UTILITIES ***			
UTILITY ID FOR ELECTRICITY	POWER		
CALCULATED RATE OF CONSUMPTION	2.6175	KW	
*** FLOWSHEET REFERENCE DATA ***			
BLOCK ID	APUMP		
LIQUID VOLUMETRIC FLOW	908.5321	CUFT/HR	
LIQUID DENSITY	62.4527	LB/CUFT	
INLET PRESSURE	14.7000	PSI	
OUTLET PRESSURE	24.7000	PSI	
*** SIZING AND COSTING RESULTS ***			
CALCULATED NUMBER OF PUMPS	1		
VOLUMETRIC FLOW PER PUMP	908.5321	CUFT/HR	
PUMP HEAD	50.0022	FT-LBF/LB	
PRESSURE RISE	10.0000	PSI	
POWER REQUIRED PER PUMP	2.6175	KW	
*** COST RESULTS ***			
CARBON STEEL COST	PER PIECE	TOTAL	
	\$ 1,900	\$ 3,800	
PURCHASED COST	\$ 7,100	\$ 14,200	

BLOCK: BOOSTER MODEL: BLOWER

*** INPUT DATA ***			
NUMBER OF STANDBYS	5		
MOTOR TYPE	ENCLOSED, FAN COOLED		
COUPLING TYPE	BELT DRIVE		
MATERIAL OF CONSTRUCTION	CARBON STEEL		
PEAK CAPACITY ALLOWANCE FACTOR	1.06		
BLOWER EFFICIENCY	0.75		
*** ASSOCIATED UTILITIES ***			
UTILITY ID FOR ELECTRICITY	POWER		
CALCULATED RATE OF CONSUMPTION	206.0794	KW	
*** FLOWSHEET REFERENCE DATA ***			
INLET STREAM ID	DRTVAIR		
TOTAL VOLUMETRIC FLOW	2.3989-07	CUFT/HR	
GAS DENSITY	7.4624-02	LB/CUFT	
GAS TEMPERATURE	70.0000	F	
INLET PRESSURE	14.7000	PSI	
OUTLET STREAM ID	1		
OUTLET PRESSURE	14.8000	PSI	
*** SIZING AND COSTING RESULTS ***			
CALCULATED NUMBER OF BLOWERS	56		
BLOWER CLASS	1		
MATERIAL OF CONSTRUCTION FACTOR	1.00		
OUTLET AREA PER BLOWER	5.1498	SQFT	
CALCULATED TOTAL OUTLET AREA	284.7837	SQFT	
SCALED FLOW PER BLOWER	4.5408-05	CUFT/HR	
SCALED TOTAL VOLUMETRIC FLOW	2.5429-07	CUFT/HR	
OUTLET GAS VELOCITY	24.4926	FT/SEC	
CORRECTED STATIC PRESSURE	0.1003	PSI	
MOTOR EFFICIENCY	0.84		
MOTOR SPEED	1800	RPM	
POWER REQUIRED PER BLOWER	3.6799	KW	
*** COST RESULTS ***			
CARBON STEEL COST	PER PIECE	TOTAL	
	\$ 2,900	\$ 177,100	
PURCHASED COST	\$ 2,900	\$ 177,100	

BIOFILTER PROCESS WITH 3% H₂SO₄ NEUTRALIZED - ECONOMIC EVALUATION

BLOCK: FLTR MODEL: USER

*** INPUT DATA ***

PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** USER SUPPLIED COST ***

ADJUSTED COST \$ 30,000
MONTH OF COST JANUARY
YEAR OF COST 1990
INDEX TYPE EQUIPMENT

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF EQUIPMENT 1

*** COST RESULTS ***

CARBON STEEL COST \$ 34,600
PURCHASED COST \$ 34,600

BLOCK: BIOBOX MODEL: USER

*** INPUT DATA ***

NUMBER OF PIECES OF EQUIPMENT 104
PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** USER SUPPLIED COST ***

ADJUSTED COST \$ 9,000
INDEX TYPE EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 10,300	\$ 1,071,600
PURCHASED COST	\$ 10,300	\$ 1,071,600

BLOCK: RPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
PUMP TYPE 1-STAGE VERTICAL SPLIT
PUMP SPEED 3550 RPM
MATERIAL OF CONSTRUCTION FACTOR 3.70
PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
CALCULATED RATE OF CONSUMPTION 34.1132 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID RPUMP
LIQUID VOLUMETRIC FLOW 1.2308-04 CUFT/HR
LIQUID DENSITY 62.4250 LB/CUFT
INLET PRESSURE 14.7000 PSI
OUTLET PRESSURE 19.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 2
TOTAL SCALED VOLUMETRIC FLOW 1.3046-04 CUFT/HR
VOLUMETRIC FLOW PER PUMP 6522.9902 CUFT/HR
PUMP HEAD 50.0022 FT-LBF/LB
PRESSURE RISE 5.0000 PSI
POWER REQUIRED PER PUMP 17.0566 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 5,100	\$ 15,300
PURCHASED COST	\$ 18,800	\$ 56,500

BLOCK: MIXER MODEL: H-VESSEL

*** INPUT DATA ***

NUMBER OF VESSELS 1
MATERIAL OF CONSTRUCTION TITANIUM
PEAK CAPACITY ALLOWANCE FACTOR 1.06
RETENTION TIME 0.5000 HR
CORROSION ALLOWANCE 0.0 FT

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID MIXER
VAPOR FLOW 6895.0481 CUFT/HR
LIQUID FLOW 979.7232 CUFT/HR
VAPOR DENSITY 6.3787-03 LB/CUFT
LIQUID DENSITY 59.6437 LB/CUFT
TEMPERATURE 75.0000 F
PRESSURE 14.7000 PSI

*** SIZING AND COSTING RESULTS ***

MATERIAL OF CONSTRUCTION FACTOR 3.49
TOTAL SHELL WEIGHT 3366.9516 LB
CALCULATED DIAMETER 6.9136 FT
CALCULATED TANGENT-TO-TANGENT LENGTH 20.7480 FT
VOLUME PER VESSEL 865.4221 CUFT
TOP SHELL THICKNESS 2.0833-02 FT
BOTTOM SHELL THICKNESS 2.0833-02 FT
SCALED VAPOR FLOW 7308.7510 CUFT/HR
SCALED LIQUID FLOW 1038.5066 CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST	\$ 30,600
PURCHASED COST	\$ 106,500

BLOCK: WPUMP MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
PUMP TYPE 1-STAGE VERTICAL SPLIT
PUMP SPEED 3550 RPM
MATERIAL OF CONSTRUCTION DUCTILE IRON
PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
CALCULATED RATE OF CONSUMPTION 2.6175 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID WPUMP
LIQUID VOLUMETRIC FLOW 890.4625 CUFT/HR
LIQUID DENSITY 62.0576 LB/CUFT
INLET PRESSURE 14.7000 PSI
OUTLET PRESSURE 19.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 1
MATERIAL OF CONSTRUCTION FACTOR 1.00
VOLUMETRIC FLOW PER PUMP 943.8902 CUFT/HR
PUMP HEAD 50.0022 FT-LBF/LB
PRESSURE RISE 5.0000 PSI
POWER REQUIRED PER PUMP 2.6175 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 1,900	\$ 3,800
PURCHASED COST	\$ 1,900	\$ 3,800

IV. UTILITY SECTION

UTILITY USAGE: POWER (ELECTRICITY)

INPUT DATA:

PRICE 8.0000-02 \$/KWHR
COST INDEX VALUE 599.8000
MONTH OF PRICE JANUARY
YEAR OF PRICE 1990
INDEX TYPE FUEL

RESULT:

INDEXED PRICE (1995 III Q) 6.7164-02 \$/KWHR

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (KW)	ANNUAL COST
BOOSTER	BLOWER	206.0794	109,198
APUMP	PUMP	2.6175	1,387
RPUMP	PUMP	34.1132	18,076
WPUMP	PUMP	2.6175	1,387
TOTAL:		245.4278	\$ 130,048

FIGURE A.7 Biocolumn PFD

PACKED COLUMN FOR CS₂ REMOVAL WITH SULFUR PRODUCTION - ECONOMIC EVALUATION

I. ANNUAL OPERATING COST SUMMARY

PRODUCTION CAPACITY FOR ALL PRODUCTS: 100.0 %			
BASE PERIOD: 1996, QUARTER I			
PLANT AVAILABILITY: 328/365.25 DAYS			
RAW MATERIAL	QUANTITY	PRICE	ANNUAL COST
	LB/HR	\$/LB	
H2O	1.9651-04	1.4681-04	\$ 23,000
NACH	1657.1920	8.3857-02	\$ 1,152,000
TOTAL RAW MATERIAL			\$ 1,185,000
TOTAL UTILITIES			\$ 162,000
LABOR			
OPERATORS: 2 PER SHIFT, 3 SHIFTS			
OPERATING (16000 HR)		\$ 395,000	
MAINTENANCE		901,000	
SUPERVISOR		259,000	
FRINGE BENEFITS		622,000	
SUBTOTAL, LABOR			\$ 2,178,000
SUPPLIES			
OPERATING		\$ 40,000	
MAINTENANCE		601,000	
SUBTOTAL, SUPPLIES			\$ 640,000
GENERAL WORKS			
GENERAL & ADMIN		\$ 934,000	
PROPERTY TAX		500,000	
PROPERTY INSURANCE		200,000	
SUBTOTAL, GENERAL WORKS			\$ 1,634,000
DEPRECIATION (15 YEARS, STRAIGHT LINE)			\$ 1,668,000

GROSS OPERATING COST			\$ 7,467,000
LESS: BYPRODUCT CREDIT			\$ 47,000
NET OPERATING COST			\$ 7,421,000

SUMMARY:			
FIXED COST		\$ 4,453,000	
VARIABLE COST		\$ 1,346,000	
GROSS COST EXCL. DEPRECIATION			\$ 5,799,000
GROSS OPERATING COST			\$ 7,467,000

II. EQUIPMENT DIRECT COST SUMMARY

COMPLETION: 1996, QUARTER I

COST BLOCK ID	BICCOLM	BOOSTER	CLARIFI	LIQ1
QUANTITY	14	61	1	2
STANDBY	0	5	0	1
CARBON STEEL COST	\$ 4,643,600	\$ 193,800	\$ 143,800	\$ 16,400
COST BLOCK ID	LIQ2	RAWMTL		
QUANTITY	2	1		
STANDBY	1	0		
CARBON STEEL COST	\$ 15,400	\$ 208,500		
TOTAL EQUIPMENT COST	\$ 5,221,600			
TOTAL INVESTMENT	\$ 29,427,000			

III. COST BLOCK SECTION

BLOCK: BICCOLM MODEL: PACK-TOWER

*** INPUT DATA ***

NUMBER OF TOWERS	14
TOWER TYPE	ABSORPTION
TOWER MATERIAL	CARBON STEEL
PACKING TYPE	SUPER INTALOX
PACKING MATERIAL	PVC
PACKING SIZE	50-MM
PEAK CAPACITY ALLOWANCE FACTOR	1.06
PLATFORM ALLOWANCE	1.4166 FT
CORROSION ALLOWANCE	0.0 FT
DIAMETER	24.0000 FT
TANGENT-TO-TANGENT LENGTH	14.0000 FT
LOADING FRACTION	0.85
FLOODING FACTOR	0.52

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID	BICCOLM
DESIGN PRESSURE	14.7000 PSI
DESIGN TEMPERATURE	55.8583 F
VAPOR FLOW	2.5426-07 CUFT/HR
LIQUID FLOW	1.3807-04 CUFT/HR
VAPOR DENSITY	7.6681-02 LB/CUFT
LIQUID DENSITY	47.5123 LB/CUFT
SURFACE TENSION	75.2324 DYNE/CM
NUMBER OF STAGES	3
VAPOR VISCOSITY	1.7852-02 CP
LIQUID VISCOSITY	0.6500 CP

*** SIZING AND COSTING RESULTS ***

SHELL WEIGHT	2 5869-04 LB
VOLUME	9952.5886 CUFT

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 331,700	\$ 4,643,600
PURCHASED COST	\$ 331,700	\$ 4,643,600

BLOCK: BOOSTER MODEL: BLOWER

*** INPUT DATA ***

NUMBER OF STANDBYS	5
MOTOR TYPE	ENCLOSED, FAN COOLED
COUPLING TYPE	BELT DRIVE
MATERIAL OF CONSTRUCTION	CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR	1.06
BLOWER EFFICIENCY	0.75

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	POWER
CALCULATED RATE OF CONSUMPTION	229.5733 KW

*** FLOWSHEET REFERENCE DATA ***

INLET STREAM ID	DRYVAIR
TOTAL VOLUMETRIC FLOW	2 6649-07 CUFT/HR
GAS DENSITY	7 2685-02 LB/CUFT
GAS TEMPERATURE	85.0000 F
INLET PRESSURE	14.7000 PSI
OUTLET STREAM ID	
OUTLET PRESSURE	14.8000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF BLOWERS	61
BLOWER CLASS	1
MATERIAL OF CONSTRUCTION FACTOR	1.00
OUTLET AREA PER BLOWER	5.1498 SQFT
CALCULATED TOTAL OUTLET AREA	312.2237 SQFT
SCALED FLOW PER BLOWER	4.6309-05 CUFT/HR
SCALED TOTAL VOLUMETRIC FLOW	2.8248-07 CUFT/HR
OUTLET GAS VELOCITY	24.9782 FT/SEC
CORRECTED STATIC PRESSURE	0.1030 PSI
MOTOR EFFICIENCY	0.84
MOTOR SPEED	1800 RPM
POWER REQUIRED PER BLOWER	3.7471 KW

*** COST RESULTS ***

	PER PIECE	TOTAL
CARBON STEEL COST	\$ 2,900	\$ 193,800
PURCHASED COST	\$ 2,900	\$ 193,800

PACKED COLUMN FOR CS₂ REMOVAL WITH SULFUR PRODUCTION - ECONOMIC EVALUATION

BLOCK: CLARIFI MODEL: USER

PAGE 311 ULRICH FOR A 15M DIAMETER CLARIFIER

*** INPUT DATA ***

PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** USER SUPPLIED COST ***

BASE COST \$ 100,000
COST INDEX VALUE 315.00
INDEX TYPE EQUIPMENT

*** SIZING AND COSTING RESULTS ***

*** COST RESULTS ***

CARBON STEEL COST \$ 143,800
PURCHASED COST \$ 143,800

BLOCK: LIQ1 MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
PUMP TYPE 1-STAGE VERTICAL SPLIT
PUMP SPEED 3550 RPM
MATERIAL OF CONSTRUCTION DUCTILE IRON
PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
CALCULATED RATE OF CONSUMPTION 34.0038 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID LIQ1
LIQUID VOLUMETRIC FLOW 1.3955-04 CUFT/HR
LIQUID DENSITY 47.5017 LB/CUFT
INLET PRESSURE 14.7000 PSI
OUTLET PRESSURE 19.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 2
MATERIAL OF CONSTRUCTION FACTOR 1.00
TOTAL SCALED VOLUMETRIC FLOW 1.4792-04 CUFT/HR
VOLUMETRIC FLOW PER PUMP 7396.0401 CUFT/HR
PUMP HEAD 50.0022 FT-LBF/LB
PRESSURE RISE 5.0000 PSI
POWER REQUIRED PER PUMP 17.0019 KW

*** COST RESULTS ***

PER PIECE TOTAL
CARBON STEEL COST \$ 5,500 \$ 16,400
PURCHASED COST \$ 5,500 \$ 16,400

BLOCK: LIQ2 MODEL: PUMP

*** INPUT DATA ***

NUMBER OF STANDBYS 1
PUMP TYPE 1-STAGE VERTICAL SPLIT
PUMP SPEED 3550 RPM
MATERIAL OF CONSTRUCTION DUCTILE IRON
PEAK CAPACITY ALLOWANCE FACTOR 1.06

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY POWER
CALCULATED RATE OF CONSUMPTION 34.0304 KW

*** FLOWSHEET REFERENCE DATA ***

BLOCK ID LIQ2
LIQUID VOLUMETRIC FLOW 1.3536-04 CUFT/HR
LIQUID DENSITY 47.5181 LB/CUFT
INLET PRESSURE 14.7000 PSI
OUTLET PRESSURE 19.7000 PSI

*** SIZING AND COSTING RESULTS ***

CALCULATED NUMBER OF PUMPS 2
MATERIAL OF CONSTRUCTION FACTOR 1.00
TOTAL SCALED VOLUMETRIC FLOW 1.4349-04 CUFT/HR
VOLUMETRIC FLOW PER PUMP 7174.3011 CUFT/HR
PUMP HEAD 50.0022 FT-LBF/LB
PRESSURE RISE 5.0000 PSI
POWER REQUIRED PER PUMP 17.0152 KW

*** COST RESULTS ***

PER PIECE TOTAL
CARBON STEEL COST \$ 5,100 \$ 15,400
PURCHASED COST \$ 5,100 \$ 15,400

BLOCK: RAWMTL MODEL: TANK

*** INPUT DATA ***

NUMBER OF TANKS 1
MATERIAL OF CONSTRUCTION CARBON STEEL
PEAK CAPACITY ALLOWANCE FACTOR 1.06
RETENTION TIME REQUIRED 4.0000 HR

*** FLOWSHEET REFERENCE DATA ***

STREAM ID 1
LIQUID VOLUMETRIC FLOW 1.5201-04 CUFT/HR

*** SIZING AND COSTING RESULTS ***

TANK TYPE CUSTOM
MATERIAL OF CONSTRUCTION FACTOR 1.00
VOLUME PER TANK 7.7342-04 CUFT
SCALED LIQUID FLOW 1.6113-04 CUFT/HR

*** COST RESULTS ***

CARBON STEEL COST \$ 208,500
PURCHASED COST \$ 208,500

IV. UTILITY SECTION

UTILITY USAGE: POWER (ELECTRICITY)

INPUT DATA:

PRICE 8.0000-02 \$/KWHR
COST INDEX VALUE 539.8000
MONTH OF PRICE JANUARY
YEAR OF PRICE 1990
INDEX TYPE FUEL

RESULT:

INDEXED PRICE (1996 I Q) 6.9084-02 \$/KWHR

THIS UTILITY IS PURCHASED

USAGE:

COST BLOCK ID	MODEL	USAGE RATE (KW)	ANNUAL COST
BOOSTER	BLOWER	228.5733	124,580
LIQ1	PUMP	34.0038	18,533
LIQ2	PUMP	34.0304	18,548
TOTAL:		296.6076	\$ 161,661

APPENDIX B:
CALCULATION OF DISPOSAL COSTS

APPENDIX B:

CALCULATION OF DISPOSAL COSTS

Calculations for the possible amounts of sulfuric acid, sulfur, and gypsum that may be produced by sulfide recovery from Teepak air are based on averaged flow from two different airborne sulfide-contaminant sources at Teepak:

Teepak Source Number 1

Air flow	290,000.00 m ³ /h
Contaminants	
CS ₂	293.00 mg/m ³
H ₂ S	324.00 mg/m ³

Teepak Source Number 2

Air flow	354,000.00 m ³ /h
Contaminants	
CS ₂	293.00 mg/m ³
H ₂ S	0.40 mg/m ³

B.1 SOURCE 1 PRODUCTION RATES

The CS₂ emission from the first source is

$$\begin{aligned}
 &= (293.00 \text{ mg CS}_2/\text{m}^3)(2.90 \times 10^5 \text{ m}^3/\text{h}) \\
 &= 8.50 \times 10^7 \text{ mg CS}_2/\text{h}.
 \end{aligned}$$

The amount of sulfur that may be produced from the CS₂ emission is calculated by multiplying the total CS₂ emission by the ratio of the atomic weight of sulfur to the molecular weight of CS₂:

$$\begin{aligned}
 &= [8.50 \times 10^7 \text{ mg CS}_2/\text{h}][2.00(32.06) \text{ mg S}/76.13 \text{ mg CS}_2] \\
 &= 7.16 \times 10^7 \text{ mg S/h}.
 \end{aligned}$$

Similarly, the amount of sulfuric acid that may be produced from the sulfur is

$$\begin{aligned}
 &= [8.50 \times 10^7 \text{ mg CS}_2/\text{h}][2.00(98.07) \text{ mg H}_2\text{SO}_4/76.13 \text{ mg CS}_2] \\
 &= 2.19 \times 10^8 \text{ mg H}_2\text{SO}_4/\text{h}.
 \end{aligned}$$

Likewise, the amount of gypsum that may be produced is

$$\begin{aligned}
 &= [8.50 \times 10^7 \text{ mg CS}_2/\text{h}][2.00(172.18) \text{ mg CaSO}_4 \cdot 2\text{H}_2\text{O}/76.13 \text{ mg CS}_2] \\
 &= 3.84 \times 10^8 \text{ mg CaSO}_4 \cdot 2\text{H}_2\text{O}/\text{h}.
 \end{aligned}$$

The H₂S emission from Source 1 is calculated as follows:

$$(324.00 \text{ mg H}_2\text{S}/\text{m}^3)(2.90 \times 10^5 \text{ m}^3/\text{h}) = 9.40 \times 10^7 \text{ mg H}_2\text{S}/\text{h}.$$

The amount of sulfur from H₂S is

$$\begin{aligned}
 &= (9.40 \times 10^7 \text{ mg H}_2\text{S}/\text{h})(32.06 \text{ mg S}/34.08 \text{ mg H}_2\text{S}) \\
 &= 8.84 \times 10^7 \text{ mg S}/\text{h}.
 \end{aligned}$$

The amount of sulfuric acid from H₂S is

$$\begin{aligned}
 &= (9.40 \times 10^7 \text{ mg H}_2\text{S}/\text{h})(98.07 \text{ mg H}_2\text{SO}_4/34.08 \text{ mg H}_2\text{S}) \\
 &= 2.70 \times 10^8 \text{ mg H}_2\text{SO}_4/\text{h}.
 \end{aligned}$$

The amount of gypsum from H₂S is

$$\begin{aligned}
 &= (9.40 \times 10^7 \text{ mg H}_2\text{S}/\text{h})(172.18 \text{ mg CaSO}_4 \cdot 2\text{H}_2\text{O}/34.08 \text{ mg H}_2\text{S}) \\
 &= 4.75 \times 10^8 \text{ mg CaSO}_4 \cdot 2\text{H}_2\text{O}/\text{h}.
 \end{aligned}$$

The total production of sulfur, sulfuric acid, and gypsum produced from Source 1 is calculated by adding the respective contributions from the H₂S and CS₂ in the airstream. The total potential production rates from Source 1 are

$$\begin{aligned}
 \text{Sulfur total} &= 7.16 \times 10^7 + 8.84 \times 10^7 \\
 &= 1.60 \times 10^8 \text{ mg S}/\text{h};
 \end{aligned}$$

$$\begin{aligned}
 \text{Sulfuric acid total} &= 2.19 \times 10^8 + 2.70 \times 10^8 \\
 &= 4.89 \times 10^8 \text{ mg H}_2\text{SO}_4/\text{h}; \text{ and}
 \end{aligned}$$

$$\begin{aligned}
 \text{Gypsum total} &= 3.84 \times 10^8 + 4.75 \times 10^8 \\
 &= 8.59 \times 10^8 \text{ mg CaSO}_4 \cdot 2\text{H}_2\text{O}/\text{h}.
 \end{aligned}$$

B.2 SOURCE 2 PRODUCTION RATES

The CS₂ emission from Source 2 is

$$\begin{aligned} &= (293.00 \text{ mg CS}_2/\text{m}^3)(3.54 \times 10^5 \text{ m}^3/\text{h}) \\ &= 1.04 \times 10^8 \text{ mg CS}_2/\text{h}. \end{aligned}$$

The amount of sulfur that may be produced from CS₂ is

$$\begin{aligned} &= [1.04 \times 10^8 \text{ mg CS}_2/\text{h}][2.00(32.06) \text{ mg S}/76.13 \text{ mg CS}_2] \\ &= 8.76 \times 10^7 \text{ mg S/h}. \end{aligned}$$

Similarly, the amount of pure sulfuric acid is

$$\begin{aligned} &= [1.04 \times 10^8 \text{ mg CS}_2/\text{h}][2.00(98.07) \text{ mg H}_2\text{SO}_4/76.13 \text{ mg CS}_2] \\ &= 2.68 \times 10^8 \text{ mg H}_2\text{SO}_4/\text{h}. \end{aligned}$$

Likewise, the amount of gypsum is:

$$\begin{aligned} &= [1.04 \times 10^8 \text{ mg CS}_2/\text{h}][2.00(172.18) \text{ mg CaSO}_4 \cdot 2\text{H}_2\text{O}/76.13 \text{ mg CS}_2] \\ &= 4.70 \times 10^8 \text{ mg CaSO}_4 \cdot 2\text{H}_2\text{O/h}. \end{aligned}$$

Since the amount of H₂S from Source 2 is only 0.40 mg/m³, it is assumed that this very small amount of hydrogen sulfide makes no contribution to the amount of sulfur, sulfuric acid, or gypsum that may be produced.

B.3 TOTAL PRODUCTION RATES FROM SOURCES 1 AND 2

The total sulfur, sulfuric acid, and gypsum collection possibilities are calculated by adding the contributions from each source (a 96% yield is assumed):

$$\begin{aligned} \text{Total sulfur production rate} &= (7.16 + 8.84 + 8.76)(0.96) \times 10^7 \\ &= 2.38 \times 10^8 \text{ mg S/h}; \end{aligned}$$

$$\begin{aligned} \text{Total sulfuric acid production} &= (2.19 + 2.70 + 2.68)(0.96) \times 10^8 \\ &= 7.27 \times 10^8 \text{ mg H}_2\text{SO}_4/\text{h}; \end{aligned}$$

$$\begin{aligned} \text{Total gypsum production rate} &= (3.84 + 4.75 + 4.70)(0.96) \times 10^8 \\ &= 1.28 \times 10^9 \text{ mg CaSO}_4 \cdot 2\text{H}_2\text{O/h}. \end{aligned}$$

The yearly production rates are as follows:

$$\begin{aligned}\text{Sulfur} &= (2.38 \times 10^8 \text{ mg S/h})(1.10 \times 10^{-9} \text{ ton/1.00 mg}) (1.00 \text{ h}/1.14 \times 10^{-4} \text{ yr}) \\ &= 2,296.49 \text{ tons/yr};\end{aligned}$$

$$\begin{aligned}\text{Sulfuric acid} &= (7.27 \times 10^8 \text{ mg H}_2\text{SO}_4/\text{h})(1.10 \times 10^{-9} \text{ ton/1.00 mg}) (1.00 \text{ h}/1.14 \times 10^{-4} \text{ yr}) \\ &= 7,014.91 \text{ tons/yr};\end{aligned}$$

$$\begin{aligned}\text{Gypsum} &= (1.28 \times 10^9 \text{ mg CaSO}_4 \cdot 2\text{H}_2\text{O/h})(1.10 \times 10^{-9} \text{ ton/1.00 mg}) (1.00 \text{ h}/1.14 \times 10^{-4} \text{ yr}) \\ &= 12,350.88 \text{ tons/yr}.\end{aligned}$$

B.4 3% SULFURIC ACID SOLUTION

B.4.1 Amount Produced

The amount of 3% sulfuric acid that is produced from the biofilter is

$$\begin{aligned}&= (7,014.91 \text{ tons/yr})[1 + (97/3)] \\ &= 233,830.33 \text{ tons/yr}.\end{aligned}$$

B.4.2 Volume

In order to calculate the disposal cost for Teepak's 233,830.33-tons/yr 3% sulfuric acid stream, the volume of the stream must be calculated. The density of a 3% sulfuric acid solution is about 63.96 lb/ft³ or 0.86 ton/yd³.

$$\begin{aligned}\text{Volume} &= (233,830.33 \text{ tons/yr})/(0.86 \text{ ton/yd}^3) \\ &= 271,895.73 \text{ yd}^3/\text{yr}, \text{ or} \\ &= 54,922,937.46 \text{ gal/yr}.\end{aligned}$$

B.4.3 Disposal Cost

The cost for the disposal of a 3% sulfuric acid solution is \$0.60 to \$0.90 per gallon; therefore, a cost range was calculated:

$$\begin{aligned}\text{Minimum cost} &= (54,922,937.46 \text{ gal/yr})(\$0.60/\text{gal}) \\ &= \$32,953,762.48/\text{yr}, \text{ and}\end{aligned}$$

$$\begin{aligned}\text{Maximum cost} &= (54,922,937.46 \text{ gal/yr})(\$0.90/\text{gal}) \\ &= \$49,430,643.71/\text{yr}.\end{aligned}$$

B.4.4 Taxes

For acid disposal, there is usually a city tax of about \$0.025/gal and a hazardous waste tax of about \$0.030/gal. The total tax is about \$0.055/gal. The total tax is

$$(\$0.055/\text{gal})(54,922,937.46 \text{ gal/yr}) = \$3,020,761.56/\text{yr}.$$

The disposal cost range, including taxes, is

$$\$35,974,524.04/\text{yr} \text{ to } \$52,451,405.27/\text{yr}.$$

B.4.5 Transportation Cost

If the distance over which the acid is transported is less than 500 mi, the cost is \$914.00 per load (one load = 4,500 gal). The total volume (in gallons) divided by 4,500 gives the total number of loads:

$$(54,915,875.75 \text{ gal/yr})/(4,500.00 \text{ gal/load}) = 12,203.53 \text{ loads/yr}.$$

The transportation cost for 12,204 loads is

$$(\$914.00/\text{load})(12,204 \text{ loads}) = \$11,154,456.00/\text{yr}.$$

B.4.6 Total Disposal Cost

The total annual disposal cost for 3% sulfuric acid, including taxes and transportation costs, is

$$\$47,128,980.04 \text{ to } \$63,605,861.27.$$

B.5 PURE SULFURIC ACID

B.5.1 Volume

The density of pure sulfuric acid is about 114.44 lb/ft³ or 1.54 tons/yd³. The volume of pure sulfuric acid that may be produced at Teepak is

$$\begin{aligned}\text{Volume} &= (7,014.91 \text{ tons/yr}) / (1.54 \text{ tons/yd}^3) \\ &= 4,555.14 \text{ yd}^3/\text{yr}, \text{ or} \\ &= 920,019.23 \text{ gal/yr.}\end{aligned}$$

B.5.2 Disposal Cost

The price for the disposal of pure sulfuric acid ranges from \$2.45 to \$3.06/gal. The disposal cost range is

$$\begin{aligned}\text{Minimum cost} &= (\$2.45/\text{gal})(920,019.23 \text{ gal/yr}) \\ &= \$2,254,047.11/\text{yr}, \text{ and}\end{aligned}$$

$$\begin{aligned}\text{Maximum cost} &= (\$3.06/\text{gal})(920,019.23 \text{ gal/yr}) \\ &= \$2,815,258.84/\text{yr.}\end{aligned}$$

B.5.3 Taxes

The city tax is about \$0.025/gal, with a \$0.030/gal hazardous waste tax; the total tax is about \$0.055/gal:

$$(\$0.055/\text{gal})(920,019.23 \text{ gal/yr}) = \$50,601.06/\text{yr}.$$

Therefore, the disposal cost range, including taxes, is

$$\$2,304,648.17 \text{ to } \$2,865,859.90.$$

B.5.4 Transportation Cost

For trips of less than 500 mi, the transportation cost is \$914.00 per load. Since one load equals 4,500 gal, the total number of loads is

$$(920,019.23 \text{ gal/yr}) / (4,500.00 \text{ gal/load}) = 204.45 \text{ loads/yr}.$$

The cost for transportation of 205 loads is

$$(\$914.00/\text{load})(205.00 \text{ loads/yr}) = \$187,370.00/\text{yr}.$$

B.5.5 Total Disposal Cost

The total disposal cost for pure sulfuric acid, including taxes and transportation, is

$$\$2,492,018.17/\text{yr} \text{ to } \$3,053,229.90/\text{yr}.$$

B.6 SULFUR

B.6.1 Volume

The density of solid sulfur is 127.92 lb/ft³ or 1.73 tons/yd³. The volume of sulfur produced is

$$\begin{aligned} \text{Volume} &= (2,296.49 \text{ tons/yr})/(1.73 \text{ tons/yd}^3) \\ &= 1,327.45 \text{ yd}^3/\text{yr}. \end{aligned}$$

B.6.2 Disposal Cost, Including Taxes

The cost for disposal is \$15.00/yd³. The disposal cost for 1,327.45 yd³/yr is

$$(1,327.45 \text{ yd}^3/\text{yr})(\$15.00/\text{yd}^3) = \$19,911.76/\text{yr}.$$

B.6.3 Transportation Cost

Each roll-off container holds 20 yd³. The number of roll-off containers that Teepak will use is

$$(1,327.45 \text{ yd}^3/\text{yr})/(20.00 \text{ yd}^3/\text{container}) = 66.37 \text{ containers/yr}.$$

The transportation cost for each 20-yd³ roll-off container is \$250.00. The transportation cost for 67 containers is

$$(67 \text{ containers/yr})(\$250.00/\text{container}) = \$16,750.00/\text{yr}.$$

B.6.4 Total Disposal Cost

The disposal cost for elemental sulfur, including taxes and transportation, is

\$36,661.76/yr.

B.7 SULFURIC ACID NEUTRALIZATION WITH LIMESTONE

B.7.1 Limestone

To calculate the amount of limestone needed to neutralize the sulfuric acid produced at Teepak, we note that one molecule of H_2SO_4 is neutralized by one molecule of CaCO_3 . Therefore, the weight of the sulfuric acid produced at Teepak is divided by the molecular weight of H_2SO_4 ; this value is multiplied by the molecular weight of CaCO_3 . The amount of limestone that Teepak needs each year is

$$\begin{aligned} &= (7,014.91 \text{ tons } \text{H}_2\text{SO}_4 / 98.08 \text{ ton mole}) (100.09 \text{ tons } \text{CaCO}_3 / \text{ton mole}) \\ &= 7,158.67 \text{ tons } \text{CaCO}_3. \end{aligned}$$

The cost for limestone is \$4.30/ton. The total yearly cost for limestone at Teepak is

$$\begin{aligned} &= (\$4.30/\text{ton})(7,158.67 \text{ tons/yr}) \\ &= \$30,782.28/\text{yr}. \end{aligned}$$

B.7.2 Volume

The density of gypsum is 144.77 lb/ft^3 , or 1.95 ton/yd^3 . The volume of gypsum produced each year is

$$\begin{aligned} \text{Volume} &= (12,350.88 \text{ tons/yr}) / (1.95 \text{ tons/yd}^3) \\ &= 6,333.78 \text{ yd}^3/\text{yr}. \end{aligned}$$

B.7.3 Disposal Cost, Including Taxes and Fees

The disposal cost for gypsum is \$15.00/ yd^3 . The cost for disposal of $6,333.78 \text{ yd}^3/\text{yr}$ is

$$(6,333.78 \text{ yd}^3/\text{yr})(\$15.00/\text{yd}^3) = \$95,006.77/\text{yr}.$$

B.7.4 Transportation Cost

The number of 20-yd³ containers needed is

$$(6,333.78 \text{ yd}^3/\text{yr})/(20.00 \text{ yd}^3/\text{container}) = 316.69 \text{ containers/yr.}$$

The transportation cost for each 20-yd³ container is \$250.00. The transportation cost for 317 containers is

$$(317.00 \text{ containers/yr})(\$250.00/\text{container}) = \$79,250.00/\text{yr.}$$

B.7.5 Total Disposal Cost

The total disposal and transportation cost, including taxes and the limestone cost, is

$$\$205,039.05/\text{yr.}$$

APPENDIX C:
CALCULATIONS USED IN COMPLETING THE MATERIAL BALANCE

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CALCULATIONS USED IN COMPLETING THE MATERIAL BALANCE

1. Total Gas Rate

$$\frac{PV}{RT} = \frac{(1 \text{ atm}) (400,000 \text{ ft}^3/\text{min})}{(0.73 \text{ ft}^3\text{atm}/\text{mole}^\circ\text{R}) (530^\circ\text{R})} = 1,034 \text{ mole/min}$$

$$(1,034 \text{ mole/min}) (28.8 \text{ lb/mole}) = 29,779 \text{ lb/min}$$

2. Molar Rate of CS₂ Removed

$$(1,034 \text{ mole gas/min}) \left(\frac{100 \text{ mole CS}_2}{10^6 \text{ mole gas}} \right) = 1,034 \times 10^{-4} \text{ mole CS}_2/\text{min}$$

3. Molar Rate of H₂S Removed

$$1,034 \left(\frac{80}{10^6} \right) = 827 \times 10^{-4} \text{ mole H}_2\text{S/min}$$

4. Mass Rate of Sulfur Converted to H₂SO₄

$$(0.1034 \text{ mole CS}_2/\text{min}) (64 \text{ lb S/mole CS}_2) + (0.0827) 32 = 9.264 \text{ lb S/min}$$

5. Mass Rate of H₂SO₄ Produced

$$(9.264 \text{ lb S/min}) \frac{98 \text{ lb acid}}{32 \text{ lb S}} = 28.37 \text{ lb acid/min}$$

6. Mass Rate of Solution to Biofilter Field

$$(29,779 \text{ lb gas/min}) (0.43 \text{ lb liq/lb gas}) = 12,804.97 \text{ lb liq/min}$$

7. Mass Rate of H₂O Consumed

$$18 \text{ lb H}_2\text{O/mole H}_2\text{O} \left(\frac{10 \text{ mole H}_2\text{O}}{5 \text{ mole CS}_2} \right) 1,034 \times 10^{-4} \text{ mole CS}_2/\text{min} = 3.7 \text{ lb/min}$$

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