DEMONSTRATION OF INNOVATIVE APPLICATIONS OF TECHNOLOGY FOR THE CT-121 FGD PROCESS

at

Georgia Power's

Plant Yates

Final Report

Volume 3a
Materials and Maintenance

DOE DE-FC22-90PC89650
SCS C-90-00284

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January 1997

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VOLUME SUMMARY

The Yates material demonstration program was an innovative approach to analyzing the performance of construction materials in a full-scale, forced-oxidized limestone scrubber retrofitted to a boiler burning high-sulfur coal. During the design process, a variety of materials were selected for use, including some that were expected to fail in a relatively short time and others that were proven to be survivable in this type of environment. Information on field performance of construction materials was collected primarily by subjective examinations conducted during scheduled, mechanical, routine, and planned shutdowns.

A variety of materials were tested at Yates for use in piping, pumps, and valves, among others. These materials including stainless steels, aluminum, high density polyethylene, fiberglass reinforced plastics, rubber-lined carbon steel, basalt, and plastic lined pipe. One of the most important lessons learned during the demonstration was the criticality of proper material selection during the design phase. The scrubber equipment fabricated of materials with superior characteristics for the environments in which they were placed required very little maintenance, while some of the marginal material (purposely selected for evaluation) resulted in chronic maintenance requirements. Thus, it can be concluded that the reliability and availability of the scrubber are as dependent on material specification as they are on the fundamental design elements.

One of the biggest project successes was in the widespread use of FRP for major process vessels and piping. This material withstood a harsh environment of high solids content, high chloride concentration, and low pH slurries throughout the two year demonstration period and beyond. The only area of concern was in the inlet duct and plenum of the JBR, where FRP surfaces were subject to high velocity slurry sprays and suffered severe erosion damage. To mitigate erosion, several coating materials were evaluated in this duct. The most promising of these materials was a silicon carbide and resin material that displayed excellent resistance to the erosive forces. FRP pipe was also used with much success; however, it is important to have a QA program in place to assure that the FRP has been fabricated, prepared, and installed correctly.

Rubber lined pumps seemed to provide adequate protection in the low pH, high chloride environment; however, the A-49 seemed to be a more suitable material for the seal plate adapters than the A-04 material, which quickly corroded. Some pumps were outfitted with A-49 (27% chromium) impellers, which also performed well in this harsh environment

Valve selection was another focus because of the large amount of knife gate slurry valves require in the process. All valves used were lined to avoid the use of expensive alloy body materials. The materials used included 316 stainless steel for the gates in water service and 317LM for those in slurry service. One of the most important lessons learned was to avoid penetrating the valve liner when bolting up the valve body. This can lead to invasive penetration of the slurry material, which can quickly corrode the valve body.

Generally, high-alloy stainless steels, such as Hastelloy C-22 and C-276 and 317LM, as well as rubber lined carbon steel, FRP, and HDPE, are all well suited to the harsh environments present within a closed-loop flue gas desulfurization process. Each has superior corrosion resistance and excellent erosion resistance, with very few exceptions. Care should be exercised to ensure the most appropriate material is selected for each application to minimize corrective maintenance and maximize process availability.

1.0 INTRODUCTION

Coal fired power plants have emerged as an important source of energy in the United States. Sulfur dioxide emissions are a major disadvantage of the increased usage of coal; therefore, various technologies for minimizing these emissions have been developed. These technologies include coal switching, removal of sulfur prior to combustion, and scrubbing the flue gas generated after combustion. Regardless of the post-combustion limestone scrubbing technology chosen, failures of construction materials are a major cause of poor reliability. Acidity and chloride concentration have been considered major factors in corrosion failures of scrubbing components. However, temperature, dew point, slurry velocity, and scale formation have been found to have a significant effect on the corrosion behavior.

The Yates material demonstration program was an innovative approach to analyzing the performance of construction materials in a full-scale, forced-oxidized limestone scrubber retrofitted to a boiler burning high-sulfur coal. During the design process, a variety of materials were selected for use, including some that were expected to fail in a relatively short time and others that were proven to be survivable in this type of environment. More importantly, materials that have been reported as marginal, questionable, or unusable for the expected service were also selected to allow evaluation of a complete array of materials. Information on field performance of construction materials was collected primarily by subjective examinations conducted during scheduled, mechanical, routine, and planned shutdowns. The JBR had 100% reliability during the test program.

2.0 TECHNICAL APPROACH

A variety of materials have been used in existing full-scale limestone scrubbers with varying degrees of success. These materials can be classified into the following groups:

- Metals;
- Organic linings and plastics; and
- Ceramics and inorganic materials.

Several different metal alloys were evaluated in the CT-121 scrubber and associated processes. Although maintenance costs are relatively low on nickel stainless steel and alloy metals, the very high initial costs are sometimes prohibitive. As an alternative to high cost metals, carbon steel coated with organic or inorganic materials has been utilized extensively in Europe, Asia, and at several installations in the US. Although these construction materials have a low initial cost, experience has shown that frequent maintenance and repair have made these materials less desirable in some parts of the system. It is typically left up to the original equipment manufacturer (OEM) management to select the most cost-effective material or combination of materials to produce the most cost effective bid and meet warranty requirements with little regard for long-term maintenance cost.

2.1 Material Performance

Ironically, a variety of materials have been selected by different OEM's to meet the same specification requirements with success ranging from catastrophic failure, to maintenance required every outage, to little or no maintenance, all of which were originally bid to the meet some warranty and reliability requirements. Results of material supplier testing indicate that nickel has a significant influence on erosion and corrosion resistance. In general, the material supplier bench scale tests indicate that high nickel based alloys perform much better than the stainless steel, and that, in general, it is not possible to successfully utilize stainless steel in high chloride, low pH environments.

This section includes discussions of the historical performance and characteristics, from an end-user point of view, of many of the materials evaluated for use in the CT-121 scrubber, some in the form of test coupons with the majority being in-situ test results. The materials discussion is divided into two primary material groups; metal alloys, and non-alloy linings and plastics.

2.1.1 Metal Alloy Performance

Metals have been used in the majority of FGD systems. A variety of stainless steels, such as 316L and 317L, which are susceptible to a number of failure modes in acid chloride environments, have been used in absorbers, reaction tanks, spray headers, dampers, and ductwork when open loop systems were frequently constructed during the 1980's. Moderate use of Inconel 625, Ferrallium 255, Titanium, Hastelloy G, Alloy C-22 and Alloy C-276 in critical locations, such as inlet and outlet ducts, and dampers, have been tested with all but the Alloys having mixed results. The Alloy materials demonstrated excellent results.

Environmental variables such as low pH, high chloride concentrations, and high temperatures have a significant effect on pitting, crevice corrosion, and intergranular corrosion of stainless steels. The effects of chlorides are of particular importance since the closed-loop nature of many of the scrubber systems designed today does not provide for a blowdown stream to control chloride, thus making high chloride concentrations combined with low pH a typical operating scenario.

Ferrallium, one of the more recent, popular materials, and duplex stainless steel are much more resistant than stainless steel to pitting/crevice corrosion and intergranular corrosion. However, both are more sensitive to improper heat treatment and welding, and therefore may not provide the overall expected metal performance. Titanium alloys are highly resistant to chloride attack but have been known to fail in high-fluoride environments and are difficult to attach to different materials, with better than average welding skills required. High nickel alloys are also susceptible to corrosion failures, but they are generally much more resistant to corrosion than other stainless steels. Of course, this protection comes at a considerably higher material cost.

2.1.2 Non-Alloy Linings and Plastics Performance

This section includes discussions of most of the non-alloy materials utilized in the industry and evaluated for use in the CT-121 scrubber. These materials include organic and inorganic linings, as well as plastics and ceramics.

Carbon steel with organic lining has been used in scrubbers as an alternative to nickel-based alloys. Lining materials such as rubber, vinyl ester, epoxies, polyesters, fluoroelastomers, brick, and monolithic ceramic linings have been used in many applications. Rubber, vinyl ester, epoxies and polyesters have been used in mild environments such as scrubbers and reaction tanks. Mechanical damage, thermal shock, improper application, and poor bonding are among the reasons that these materials have failed in the past. Typically, any high chloride, low pH scrubber liquor penetrating the lining will wick and corrode the carbon steel resulting in failure. Failures of this nature normally require substantial repair to the substrate and lining, requiring the system to be brought off-line, defective lining removed, substrate repaired and sand blasted and cleaned for re-application, coating re-applied and cured. In addition, it is often challenging to find the source of the lining failure, which sometimes require significant portions of the linings to be replaced.

2.2 Material Selection

This section includes discussions of materials chosen for use in the CT-121 demonstration scrubber. The discussion includes the basis for material selection and the locations at which each material was applied. Figure 2-1 is the process flow diagram that includes all of the equipment discussed in this report.

(Insert Figure 2-1, a fold-out 11x17 CAD drawing, after this page)

2.2.1 Metal Alloy, Linings and Plastics Selection

The major cause of poor reliability in flue gas desulfurization systems is poor process design and a significant uncertainty regarding materials of construction for various parts of the FGD system. Much of the alloy material supplier information comes from bench scale tests, material coupons inserted into existing streams, or field tests of several square feet of various stainless steels, alloys, and non-metallic linings. These materials are usually installed under pristine conditions in actual flue gas environments. From these tests, one would conclude the only appropriate material selection for most operating systems would be a high-nickel alloy, although these results should be viewed with some skepticism.

Few materials, linings, stainless steel, or alloys survive typical full scale applications without any failure. Accordingly, the operating company must make a decision from a wide range of lining and alloy suppliers and OEM recommendations to meet both capital requirements and maintenance requirements over the life of the plant. The objective is to select a material which will give satisfactory service at the lowest cost, based on that material's performance at a site with similar chemical characteristics.

2.3 Pumps

Pumps are used for a variety of services in the JBR system including flue gas pre-cooling, gypsum slurry removal, gypsum slurry transfer, washing water, return water, limestone classifier feed, and limestone slurry. Until recently, rubber-lined pumps with packed seals and flush water have been used with good success for moving slurries, but polypropylene and ni-hard metal have also been tried. The maintenance experience with pumps have varied widely at different plants with similar parameters. Some maintenance foremen report few problems while some have reported that pumps are the most pressing problem keeping their units on-line. The reasons for these differences are not obvious in all cases but some pump manufacturers have had noticeably greater success than others. Some reported failures and high maintenance areas have been:

- Broken shafts;
- Rubber disbonding;
- Repeated water seal packing replacement;
- Excessive wear;
- Mechanical damage from foreign non-process objects;
- High solids concentrations with large particles; and
- Loosening of throat liners.

The original specification included packed seal water glands with an estimated seal water flow of 5 to 15 gpm per pump with new packing. Based on concerns over water balance and high maintenance, all pumps except the classifier feed pump were purchased with Alloy C-22 / Carpenter 20 mechanical seals, with replaceable silicon carbide rotating faces. The seal manufacturer elected not to try the mechanical seals in the classifier feed pumps operating at 50 to 55 percent solids until operating experience with the gas cooling pumps was gained at 20 to 25 percent solids.

2.4 Blowers

Several operating scrubbers now have compressors or blowers to supply the air required to oxidize the sulfite to sulfate. The typical scrubber requires multiple compressors, which are very high maintenance items because the air injection points are located near the bottom of the reaction tank to assure proper oxidation. With the JBR, the fundamentally different process chemistry allows air injection points to be located approximately mid-way in the tank such that inexpensive, low maintenance blowers can be used. Standard materials of construction were utilized for the blowers as indicated in Section 3. Except for oil changes, no maintenance, including routine maintenance, was carried out on the blowers.

2.5 Limestone Preparation Equipment

Most FGD systems have a wet ball mill to obtain the desired limestone particle size required for their process. Recycle water at a very high chloride concentrations and limestone are fed to the mill as 1/4 in. rock and ground to the specification requirement of the process vendor. The ground stone overflows to a natural rubber-lined tank where additional recycle water is added, if required. The slurry is then pumped to a gum rubber-lined hydrocyclone for classification. The hydrocyclone overflow goes to an natural rubber-lined overflow launder where a rubber-lined distributor directs it to the FRP storage tank or back to the grind tank during when the mill sum slurry tank levels are low. The hydrocyclone underflow goes to an rubber-lined underflow launder where it returns to the ball mill feed for regrinding. The ball mill shell is manufactured from carbon steel with a internal coating to protect the mill from the high chloride recycle water. The ball mill internals have a rubber liner for cushioning the ball impact and rubber lifting bars for lifting the balls to crush the limestone. Some consideration was given to upgrading the balls to resist the high chloride content but based on the manufacturer's recommendation, balls manufactured from hardened steel, the ball mill manufacturer's standard material was selected.

2.6 Piping

The piping used in most FGD systems is required to handle gas cooling slurry, additive slurry, gypsum slurry and return water. The type of material selected depends on the type of slurry or liquor to be handled. The piping used in most FGD systems is predominantly rubber-lined carbon steel which is selected for its low cost, erosion and corrosion resistance, and its ability to handle most conditions encountered in scrubber service. Some venders specialize in fiberglass reinforced plastic (FRP), and stainless steel has been utilized as well. Rubber-lined carbon steel is the most commonly used material in slurry piping and has given generally good service. There has been lining wear in elbows due to high velocities and disbonding of the rubber when a pinhole leak develops in the rubber. The leak allows liquor to get behind the rubber and develop a balloon inside the pipe, causing locally high velocities and eventually failure. Failed rubber lining material usually ends up in pre quench nozzles, spray nozzles, wash nozzles, hydrocyclones, and ball mill discharge screens. FRP piping has been used with good success but suffers from poor manufacturing techniques, improper joint installation, and lack of acceptance because of perceived difficult handling and maintenance requirements.

The piping material used at the test facility was selected to a large extent on the type of service encountered. Given the fact that the majority of process vessels were FRP, the decision was made to evaluate FRP pipe in parallel with the process vessels so that the pipe would be subjected to the same service conditions. In addition, rubber-lined carbon steel, high density polypropylene, polypropylene lined carbon steel, high-density polyethylene (HDPE), EPDM rubber hose, natural rubber hose with neoprene cover, cast basalt, and stainless steel were also tested in similar service. This testing was conducted in the same piping system to allow a side by side comparison of various non standard piping systems and to provide an understanding of the performance and maintenance aspects of each pipe.

2.7 Spray Nozzles

Spray nozzles are used to deliver the scrubbing slurry or liquor to the pre-quench and gas cooling section, and wash water for the upper and lower decks and mist eliminator. The function of the spray nozzles is to disperse the slurry or liquid in the gas stream in fine droplets and to provide a coarse, dense spray pattern for washing off solids build-up. The gas cooling nozzles handle a slurry and therefore are susceptible to internal abrasion. The remaining nozzles handle reclaim water which make them much less susceptible to internal abrasion than the cooling nozzles. Many types of materials ranging from plastic to extremely hard silicon carbide have been used for spray nozzles. Wear, pluggage and installation problems are the only difficulties typically reported by scrubber operators.

A wide variety of materials were tested including silicon carbide for its abrasion resistance, Alloy C-276 for corrosion and heat resistance, polypropylene, and fiberglass. Fiberglass was utilized in many different areas due to its low cost and ease of installation.

2.8 Agitators

Agitators for slurry tanks usually have rubber-coated carbon steel blades and shafts. The rubber provides excellent abrasion resistance as well as protection against corrosion. Stainless steel and bare carbon steel agitators have been used in some locations. For the test program, rubber-lined carbon steel blades and shafts were used with a 1/4 inch additional build-up on the leading edge for added for abrasion resistance.

2.9 Fans

Fans are located in the flue gas stream to overcome the additional pressure drop imposed by the additional absorber system components and chimney. The fan can be located upstream or downstream from the absorber system. Exotic materials of construction are required for fans located downstream of the absorber; therefore, most fans are located upstream, operate on hot flue gas, and consequently can be constructed of carbon steel. In some cases, even with properly operating precipitators, fans have shown erosion and constant refurbishment and/or blade replacement may be required.

Part of the test plan included de-tuning and eventually taking off-line the electrostatic precipitator (ESP). Removing the ESP from service resulted in an extremely high ash load on the fan while still proceeding with the test matrix. Working in close consultation with the fan manufacturer, it was decided to install chromium carbide wear blades which were attached over the existing carbon steel blades to aid in minimizing wear potential during high fly-ash testing.

2.10 Process Vessels

Several process vessels are required for a typical absorber system. Carbon steel with some form of lining is the most common; however, stainless steel was also used. Tank linings have been used in the reaction tank, limestone preparation system tank, limestone slurry storage tank, gypsum slurry transfer tank, and washing water tank. Disbonding typically occurs in the life of the tank because not enough specifics regarding lining materials, surface preparation, lining application, and operating conditions are available during the design stage. Even stainless steel tanks have experienced microbiological corrosion. Few scrubber systems have FRP process vessels in such a wide variety of services as found at Plant Yates. The only tank that is not FRP was the ball mill sump tank supplied by the mill vendor.

2.11 Mist Eliminators

Regardless of the type of scrubber, all must have some form of mist removal equipment. The mist eliminator is a device employed to collect, remove, and return slurry droplets to the reaction tank. The mist eliminator is usually located inside the absorber vessel near the gas exit and is subject to the same environmental conditions as the absorber internals. The mist eliminators must be able to withstand high pressure water sprays that are used to wash away deposits that commonly build up on internals. Most mist eliminators are chevron-type with a variety of vane shapes to reduce plugging or improve washing effectiveness to reduce scaling.

Practically all of the mist eliminator vanes are constructed of some sort of plastic or fiberglass, but some stainless steel and alloy vanes have been used. The mist eliminator vanes advertised as fiberglass are most likely polyester. The fiberglass reinforced plastic (FRP) mist eliminator vane design chosen for the project is based on Chiyoda's proven mist eliminator which is manufactured of pultruded vinyl ester resin with fiberglass reinforcement for strength.

2.12 Coatings And Linings

Material failures in FGD systems have resulted from a variety of causes, such as corrosion, erosion, and lining failure due to poor application or to high temperature excursions. The utilization of FRP was an attempt to provide the industry with a material that met all performance requirements at an economical cost. Although the FRP manufacturing process is fully developed, one major problem that plagued the FRP test program was erosion in the gas cooling duct and the JBR gas cooling duct drain, gas risers and upper deck drains. Materials selected for this area could not withstand the abrasion caused by 20 to 25 wt.% slurry impingement directly on the FRP. Rubber, Duromar, Duromix, porcelain tiles, and a sacrificial nexus veil were tried with varying degrees of success. Finally silicon carbide mixed with resin and applied with the FRP system seems to be the most appropriate solution.

2.13 Expansion Joints

Expansion joints are installed in FGD systems to provide capacity for deflection to relieve strains caused by thermal expansion and to provide a convenient point for material change. They are usually installed in the inlet and outlet ductwork to provide axial flexibility. Thus, the expansion joints are exposed to the same corrosive and erosive conditions as the ducts in which they are installed. Expansion joints are generally U-shaped and constructed of an elastomer with fabric or wire reinforcement. Based on vendor recommendations, Teflon expansion joints were purchased due to their superior corrosion resistance and the ability to be repaired in the field without curing or special bonding agents.

2.14 Valves

Valves are used in FGD systems for isolation and control functions. Valve problems are not generally materials related, but plugging and mechanical problems have frequently occurred. For the demonstration project, "V" ported ball valves were used for flow control with ceramic lined balls utilized in slurry service. Process drain valves were knife gate style, while small instrument connection valves were PVC ball valves. Stainless steel knifegate valves have been used for isolation functions, especially at high pressures where metal is required. However, in Europe, Asia, and in some installations in the US, butterfly valves have been utilized for low pressure service. It has been reported that 100 percent isolation can not be achieved with butterfly valves, hence they are not typically used in the US. In an attempt to get a side by side comparison of different knife gate vale manufactures, four different vendors were chosen each with different design philosophy.

3.0 RESULTS AND DISCUSSION

This section includes a discussion of the design and materials of construction for each type of equipment used at in the CT-121 demonstration project, as well as lessons learned and recommendations for future applications of the CT-121 technology. The equipment types discussed include:

- Pumps;
- Oxidation Air Blowers;
- Limestone Preparation Equipment;
- Piping;
- Nozzles;
- Agitators;
- Fans;
- Process Vessels;
- Mist Eliminators;
- Coatings and Linings;
- Expansion Joints; and
- Valves.

3.1 Pumps

The pumps discussed in this section include:

- Limestone Slurry Pumps;
- Gypsum Draw-off Pumps;
- Washing Water Pumps;
- Gypsum Slurry Transfer Pumps;

- Pond Water Return Pumps;
- Limestone Pile Run-off Sump Pumps;
- Limestone Prep Area Sump Pumps;
- Chemical Containment Sump Pumps;
- Limestone Classifier Pumps; and
- Emergency Blowdown Pumps.

3.1.1 Limestone Slurry Pumps

These pumps are horizontal, centrifugal, end-suction, v-belt driven type pumps. There are two (2) 100 percent pumps required for this service. They are each rated for a design flow of 175 gpm of slurry at 35% solids and a net total pumping head of 110 ft. with an efficiency of 56% and a speed at design of 1970 rpm. These pumps are Warman model 3/2 CAH manufactured for slurry service with Borg Warner International Pump (BWIP) mechanical seals. The horsepower required at design is 9.9. The motor nameplate is 15 hp with a 1.15 service factor. The motor is mounted reverse overhead.

The limestone slurry pumps take suction from the limestone slurry tank and discharge into the JBR or return it to the storage tank when the JBR is at pH setpoint.. Up to seventy-five (75) gpm goes to the JBR while the remaining one hundred (100) gpm continuously recirculates back to the limestone slurry tank.

3.1.1.1 Materials

- Casing — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Cover Plate Liner — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Frame Plate Liner — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Shaft — Steel
- Shaft Sleeves — Alloy 20

- Impeller A49 High Chrome
- Base Plate Ductile Iron

Mechanical Seals - BWIP type rubber in shear (RIS) mechanical seal with no water required for flush or cooling. The materials of construction are Hastelloy C for the stationary assembly and Alloy 20 for the rotating assembly with silicon carbide rotating seals.

3.1.1.2 Maintenance

For ease of maintenance the motor was required to be mounted reverse overhead to allow for ease of maintenance on the pump as well as the motor. Only routine maintenance such as lubrication checks and belt replacement was performed during the test program.

3.1.1.3 Lessons Learned

The original material quoted and furnished for the impellers was metal because of the high tip speed. Warman's A-49, which is a corrosion resistant white iron with approximately 27% chrome, was selected. After about a year or so of operation this material had some signs of corrosion but was holding up to the low pH and high chlorides values that were observed. The impeller is still in operation today without any signs of progressing corrosion or wear.

The original material quoted for the seal plate adapter was A-04 which was supposed to withstand the high chlorides, but after about a year of operation, the adapters were changed to the A-49 material due to the extensive corrosion and pitting resulting from the low pH and high chloride chemistry. Figure 3-1 shows the seal plate adapter in situ, and Figure 3-1a shows a close up of the excessive corrosion problem. It should be noted that at no time during the operation of the pumps did the seal plate adapter fail, which would allow slurry to leak out of the back of the pump.

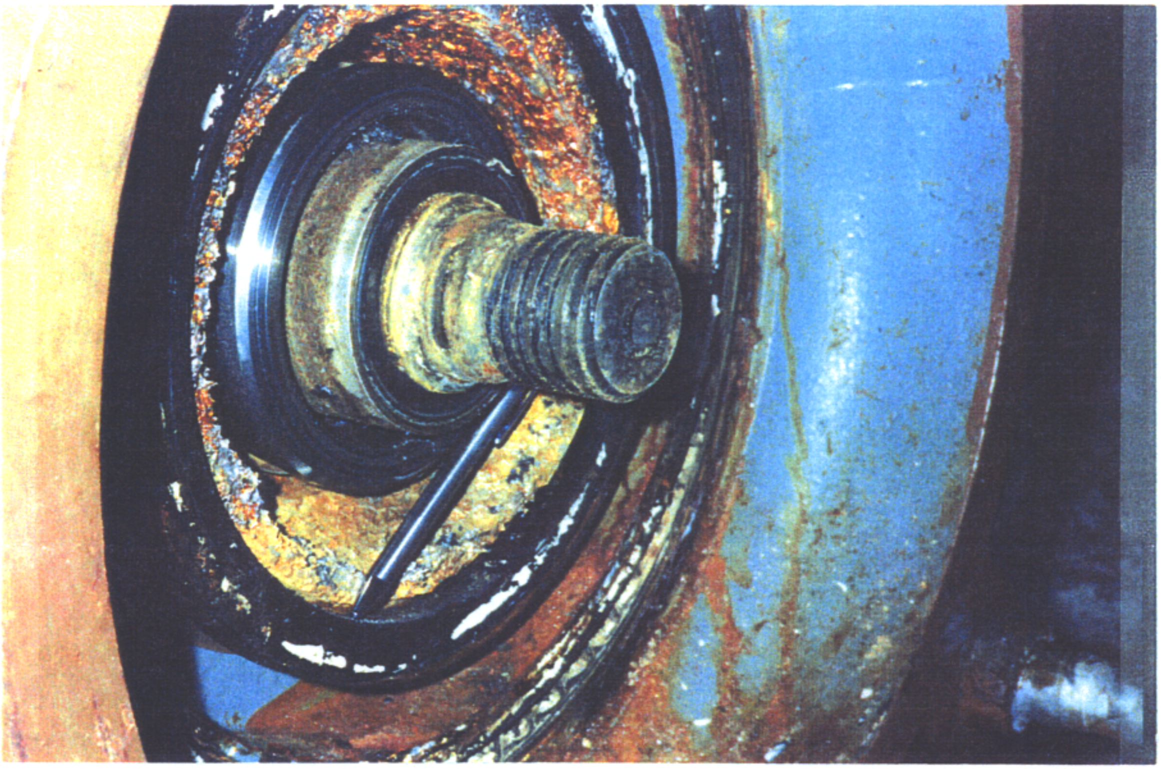

Figure 3-1. Limestone Slurry Pump Seal Plate Adapter Corrosion

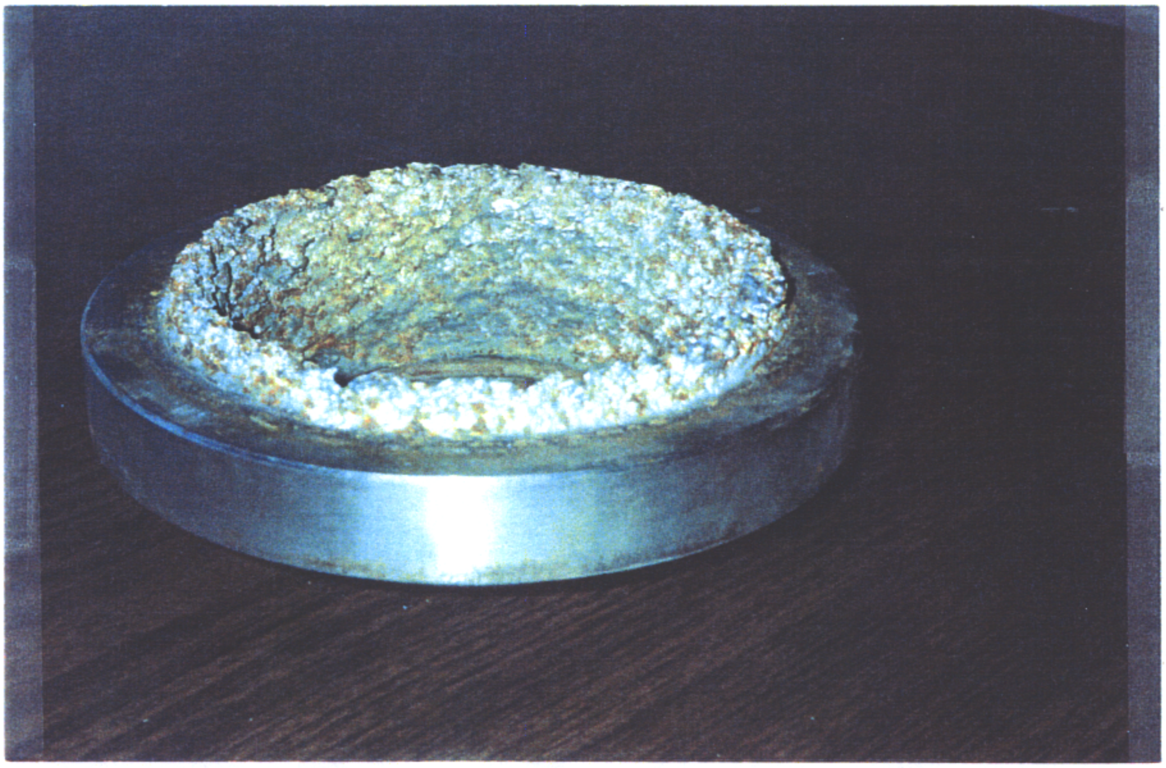

Figure 3-1a. Seal Plate Adapter Corrosion (Close-up)

Another valuable lesson learned on the slurry pumps was the fact that the original design for these type pumps contained expeller vanes on the outside of the impeller shrouds. This was incorporated to help minimize any recirculation to the low pressure sides of the impeller for the packed seal design. However after a short period of running time, two of the zero leakage RIS mechanical seals failed. After investigation, it was found that the expeller vanes shown in Figure 3-2 were actually pumping away the slurry needed to lubricate and cool the seals. Therefore these vanes on all rubber-lined impellers were removed. The hard metal pump impellers were supplied without expeller vanes when spare parts were purchased but were never replaced during the test program.

3.1.2 Gypsum Draw-off Pumps

These pumps are horizontal, centrifugal, end-suction, v-belt driven type pumps. There are two (2) 100 percent pumps required for this service. They are each rated for a design flow of 320 gpm at 15 to 25 percent solids and a net total pumping head of 25 ft. with an efficiency of 61% and a speed at design of 945 rpm. These pumps are Warman model 4/3 CAH manufactured for slurry service with Borg Warner BWIP mechanical seals. The horsepower required at design is 3.7. The motor nameplate is 5 hp with a 1.15 service factor. The motor is mounted reverse overhead.

The gypsum draw-off pumps take suction from the JBR and discharge into the gypsum slurry transfer tank as required to maintain solids concentration or level in the JBR.. During times with high ash loading, 196 gpm is passed to the gypsum transfer tank while 125 gpm continuously recirculates back to the JBR. Low ash requires only 122 gpm to the gypsum transfer tank.

3.1.2.1 Materials

- Casing — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Cover Plate Liner — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Frame Plate Liner — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined

- Shaft Steel
- Shaft Sleeves Alloy 20
- Impeller Ductile Iron ASTM A536 Skeleton/Natural Rubber Elastomer Lined
- Base Plate Ductile Iron

Mechanical Seals - BWIP type RIS mechanical seal with no water required for flush or cooling. The materials of construction are Hastelloy C for the stationary assembly and Alloy 20 for the rotating assembly, with silicon carbide rotating seals.

3.1.2.2 Maintenance

The motor was required to be mounted reverse overhead to allow for ease of maintenance on the pump as well as the motor.

3.1.2.3 Lessons Learned

The original material quoted and furnished for the impellers was R08 natural rubber utilized mainly for chemical duties. After a year or so of operation this material was holding up very well to the low pH high chlorides values we were seeing. Therefore the pump design team recommended that the R-08 impellers continue to operate until failure; these impellers are still in these pumps. This material has been quite satisfactory for the low pH and high chloride levels in the process slurry. The seal plate adapters behind the impellers did not show the same type of excessive corrosion as the limestone pumps as indicated in Figure 3-3 . The original material was A-04, and this material was change during mechanical seal replacement as routine maintenance to the A-49 material due the expected corrosion and pitting which had been observed in the pumps.

The valuable lesson learned on this slurry pump was that the original design for these type pumps contained expeller vanes on the backside of the impellers. This was incorporated to help

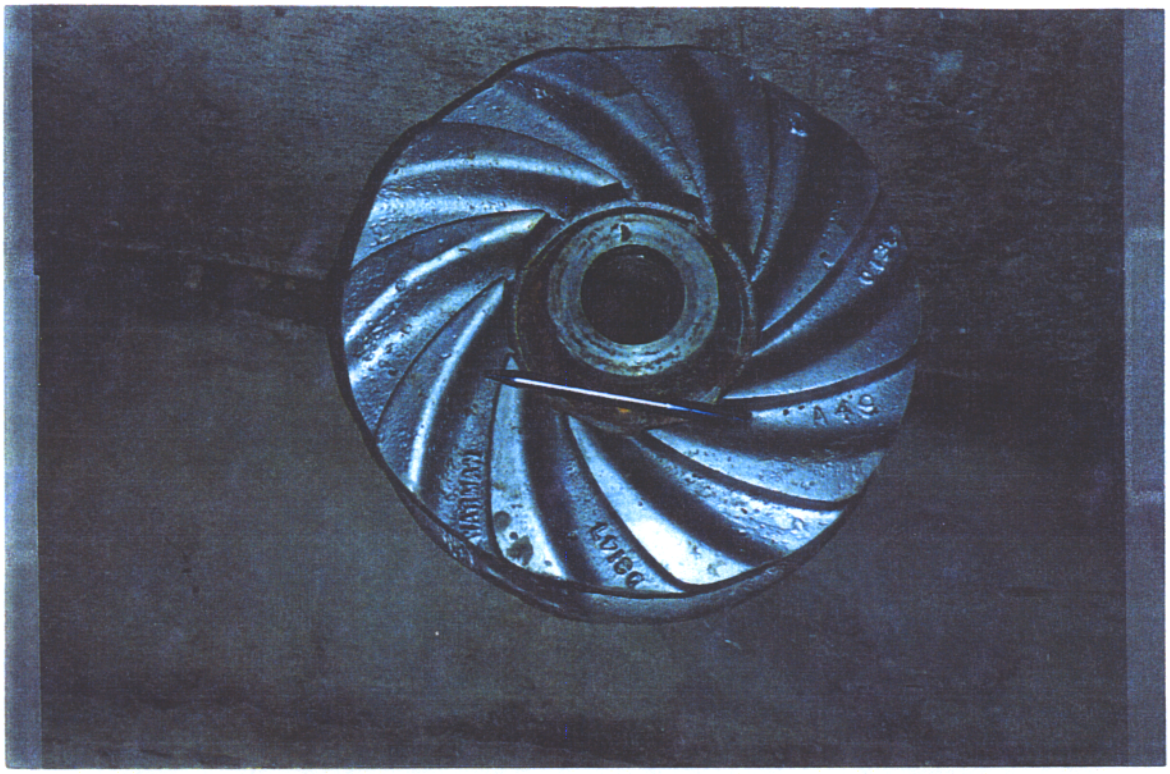

Figure 3-2. Gypsum Draw-off Pump Expeller

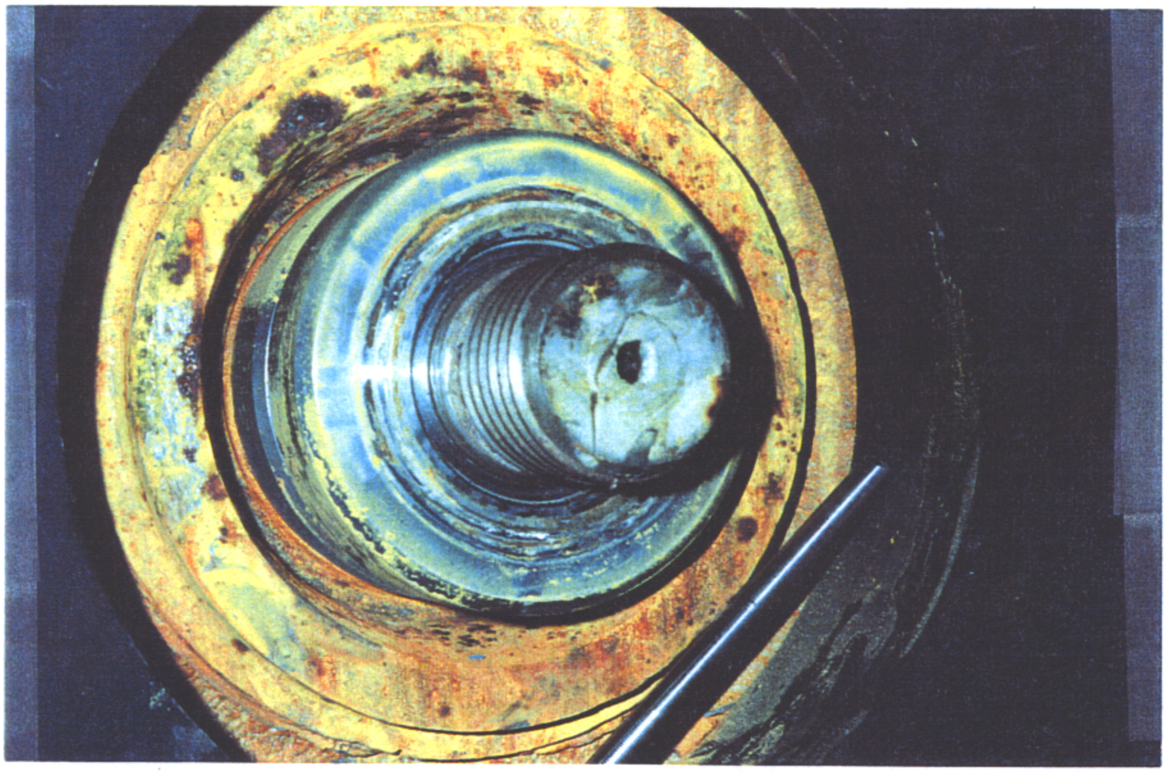

Figure 3-3. Gypsum Draw-off Pump Seal Plate Adapter

minimize any recirculation of slurry to the packing gland behind the low pressure side of the impeller. However after a short period of running time, the zero leakage RIS mechanical seals began to fail. After investigation of this problem, it was discovered that the expeller vanes were actually pumping away the product needed to lubricate and cool the seals. Therefore these vanes on the rubber-lined impellers were removed and reinstalled. The spare part impellers were supplied without expeller vanes.

3.1.3 Washing Water Pumps

These pumps are horizontal, centrifugal, end-suction, v-belt driven type pumps. There are two (2) 100 percent pumps required for this service. They are each rated for a design flow of 260 gpm at 1% solids and a net total pumping head of 132 ft. with an efficiency of 60% and a speed at design of 2215 rpm. These pumps are Warman model 3/2 CAH manufactured for slurry service with Borg Warner BWIP mechanical seals. The horsepower required at design is 14.4. The motor nameplate is 20 hp with a 1.15 service factor. The motor is mounted reverse overhead.

The washing water pumps take suction from the washing water tank and provide spray water to the mist eliminator and JBR decks. A continuous recirculation line allows 130 gpm to recirculate back to the washing water tank while 130 gpm passes to the mist eliminator or JBR decks. The 130 gpm flow to the mist eliminator and JBR deck wash is intermittent.

3.1.3.1 Materials

The following materials were used:

- Casing — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Cover Plate Liner — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Frame Plate Liner — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Shaft — Steel

- Shaft Sleeves   Alloy 20
- Impeller   A49 High Chrome
- Base Plate   Ductile Iron

Mechanical Seals - BWIP type RIS mechanical seal with no water required for flush or cooling. The materials of construction are Hastelloy C for the stationary assembly and Alloy 20 for the rotating assembly with silicon carbide rotating seals..

3.1.3.2 Maintenance

The motor was required to be mounted reverse overhead to allow for ease of maintenance on the pump as well as the motor.

3.1.3.3 Lessons Learned

The original material quoted and furnished for the impellers was Warman A-49 high chrome because of high tip speeds. After a year or so of operation this material was holding up very well to the low process pH values. Therefore, the pump design team recommended the A-49 material that is presently in these pumps remain until failure. This material has been quite satisfactory for the system chemistry. The seal adapters behind the impellers had the original material A-04, and were changed to the A-49 material due the extensive corrosion and pitting observed in the other pumps. The A-49 has operated satisfactorily in the scrubber, as shown in Figure 3-4.

3.1.4 Gas Cooling Pumps

These pumps are horizontal, centrifugal, end-suction, v-belt driven type pumps, operating in parallel. There are three (3) 50 percent pumps required for this service. They are each rated for a design flow of 2250 gpm at a solids concentration of 20 to 25 percent and a net total pumping head of 113 ft. with an efficiency of 70% and a speed at design of 870 rpm. These pumps are Warman model 8/6 CAH manufactured for slurry service with Borg Warner BWIP mechanical seals. The horsepower required at design is 91.7. The motor nameplate is 125 hp with a 1.15 service factor. The motor is mounted reverse overhead.

The gas cooling pumps take suction from the JBR and discharge to the inlet spray nozzles of the inlet gas duct to saturate the gas before entering the JBR

3.1.4.1 Materials

- Casing — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Throat Bushing — A49 High Chrome
- Shaft — Steel
- Shaft Sleeves — Alloy 20
- Impeller — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Base Plate — Ductile Iron

Mechanical Seals - BWIP type RIS mechanical seal with no water required for flush or cooling. The materials of construction are Hastelloy C for the stationary assembly and alloy 20 for the rotating assembly with silicon carbide seals.

3.1.4.2 Maintenance

The motor was required to be mounted reverse overhead to allow for ease of maintenance on the pump as well as the motor.

3.1.4.3 Lessons Learned

The pumps were originally supplied with R-26 rubber liner impellers. However within a few months to a year of operation these impellers were replaced with A49 high chrome impellers. The reason for the change was due to the pumping of entrained materials such as test coupons that came loose from the JBR wall. The low pH in the JBR caused the bolts that held the coupons to erode away and drop the test coupons. The loose coupons gouged and cut the rubber on the impellers and liners as shown in Figures 3-5 and 3-6. A suction screen was installed inside the JBR to minimize the pumping of non-gypsum materials and has worked quite well.

The same scenario applies to the seal adapters behind the impellers. The original material was A-04, but again they were changed to the A-49 material due the extensive corrosion and pitting, as shown in Figures 3-7 and 3-8, resulting from the chemistry problems.

3.1.5 Gypsum Slurry Transfer Pumps

These pumps are horizontal, centrifugal, end-suction, v-belt driven type pumps. There are two (2) 100 percent pumps required for this service. They are each rated for a design flow of 850 gpm with a slurry concentration of 5 to 25 percent and a net total pumping head of 182 ft. with an efficiency of 67% and a speed at design of 2480 rpm. These pumps are Warman model 4/3 CAH manufactured for slurry service with Borg Warner BWIP mechanical seals. The horsepower required at design is 59.5. The motor nameplate is 75 hp with a 1.15 service factor. The motor is mounted reverse overhead.

The gypsum transfer pumps take suction from the gypsum slurry transfer tank and discharge to the gypsum stack.

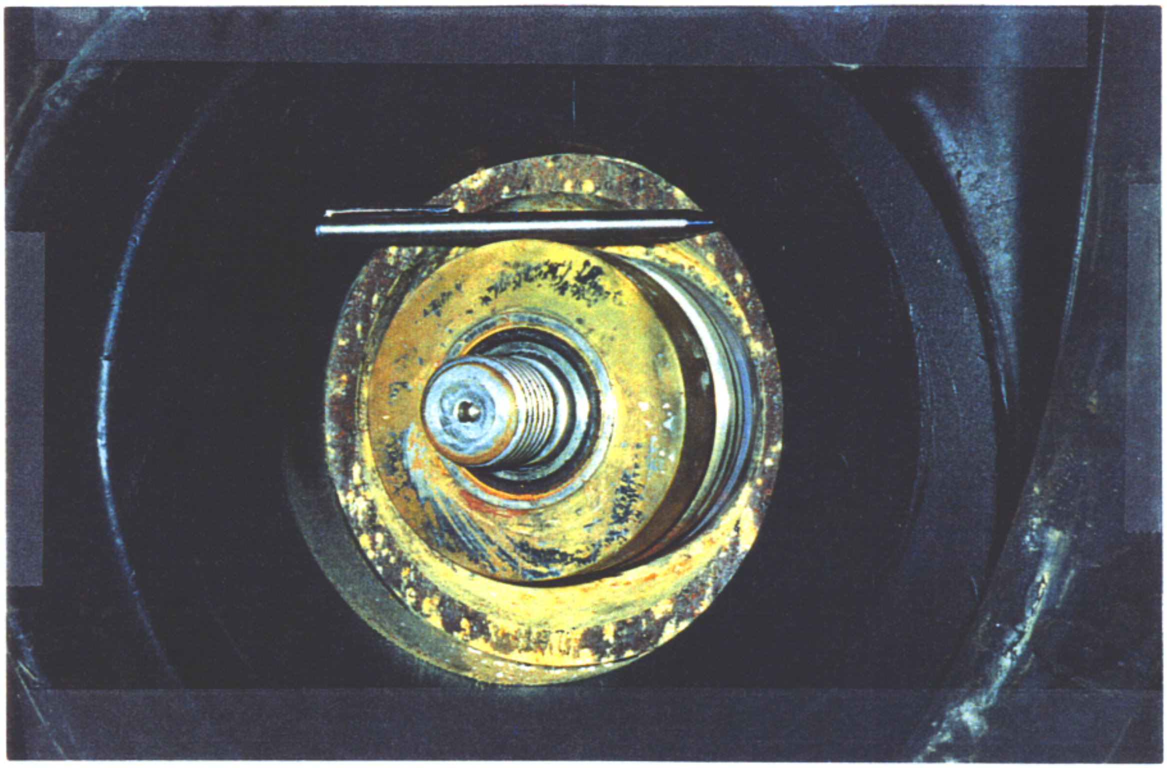

Figure 3-4. Wash Water Pump Seal Plate Adapter

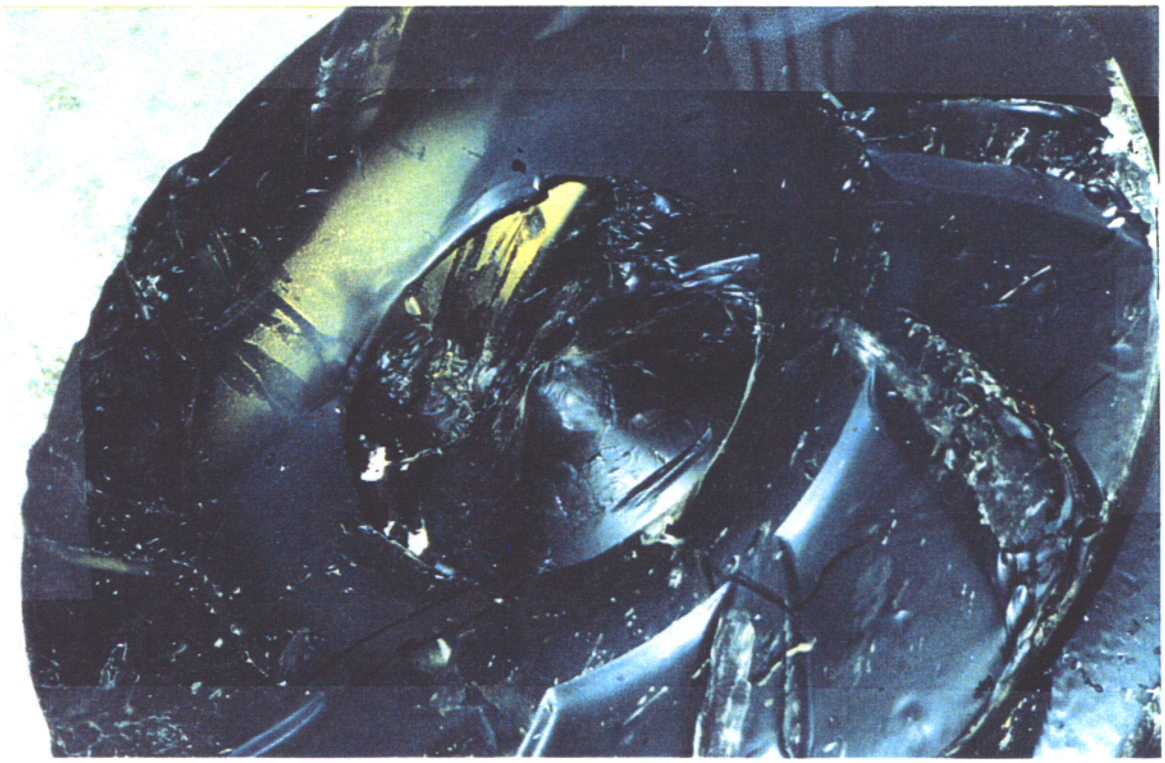

Figure 3-5. Gas Cooling Pump Impeller Damage

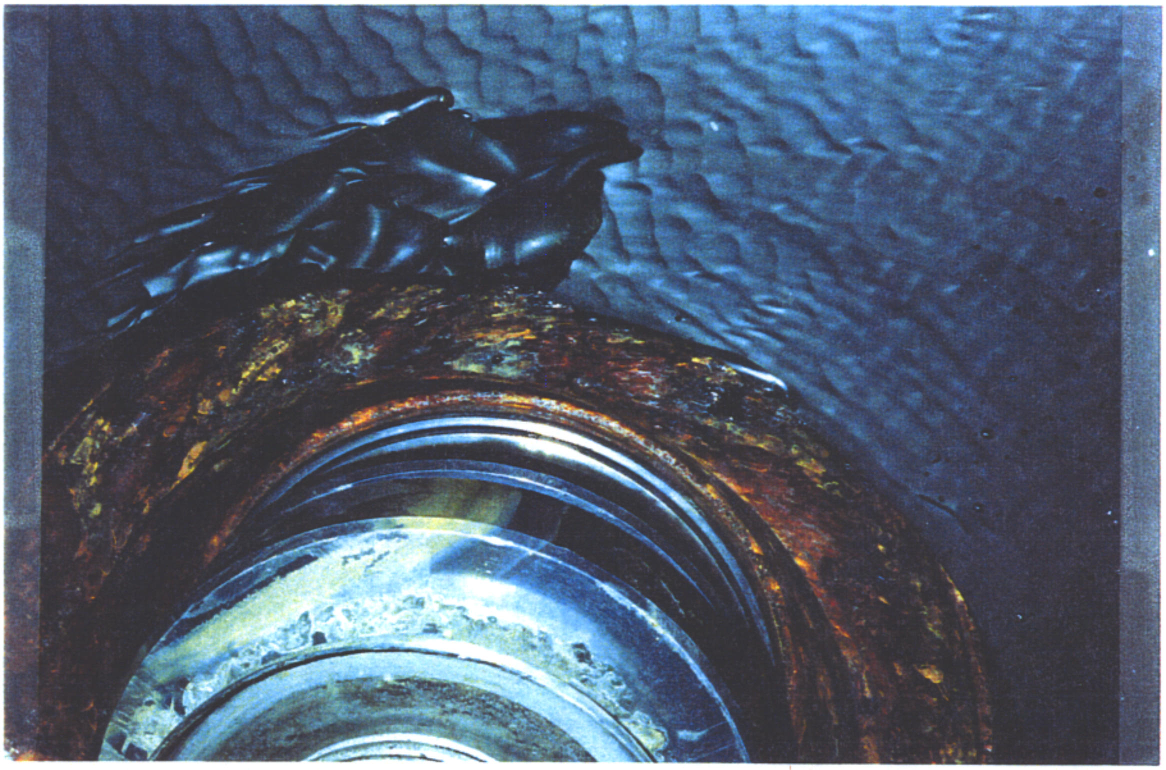

Figure 3-6. Gas Cooling Pump Liner Damage

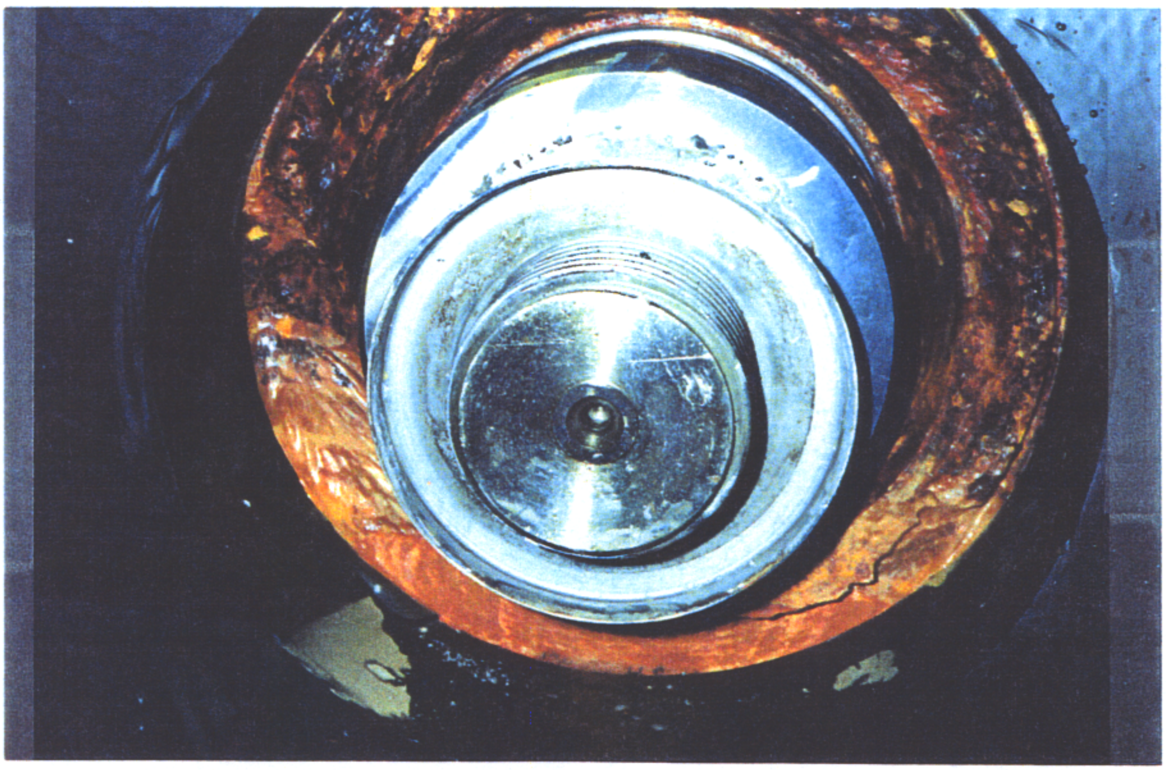

Figure 3-7. Gas Cooling Pump Seal Adapter Corrosion

3.1.5.1 Materials

- Casing — Ductile Iron ASTM A536/ ASTM A536 Hi-Chrome (A49) Liner
- Volute Liner — ASTM A536 Hi-Chrome (A49)
- Shaft — Steel
- Shaft Sleeves — Alloy 20
- Impeller — ASTM A536 Hi-Chrome (A-49)
- Base Plate — Ductile Iron

Mechanical Seals - BWIP type RIS mechanical seal with no water required for flush or cooling. The materials of construction are Hastelloy C for the stationary assembly and Alloy 20 for the rotating assembly with silicon carbide rotating seals.

3.1.5.2 Maintenance

The motor was required to be mounted reverse overhead to allow for ease of maintenance on the pump as well as the motor.

3.1.5.3 Lessons Learned

The original material quoted and furnished for the volute liner, casing and impellers required high chrome because of tip speeds and was specified as Warman's A-49, which had approximately 27% chrome. After a year or so of operation this material was holding up to the low pH values we were seeing as shown in Figure 3-9, casing, and Figures 3-10 and 3-11, impeller. Therefore Warman recommended the A-49 material that is presently in these pumps continue to operate. This material has been quite satisfactory for the low pH and high chloride levels seen. The same scenario applies to the seal adapters behind the impellers. The original material was A-04, but again they were changed to the A-49 material due to extensive corrosion and pitting as shown in Figure 3-12 resulting from the low pH, high chloride problems.

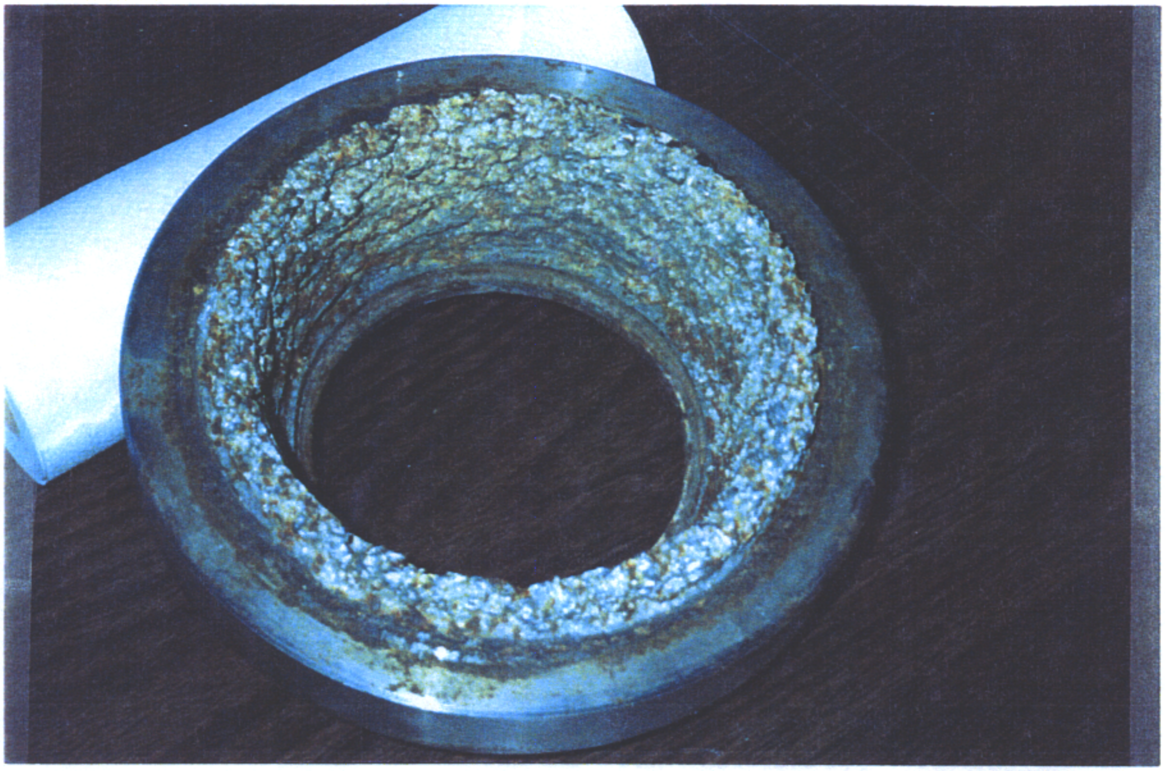

Figure 3-8. Seal Adapter Corrosion (Close-up)

Figure 3-9. Gypsum Slurry Transfer Pump Casing

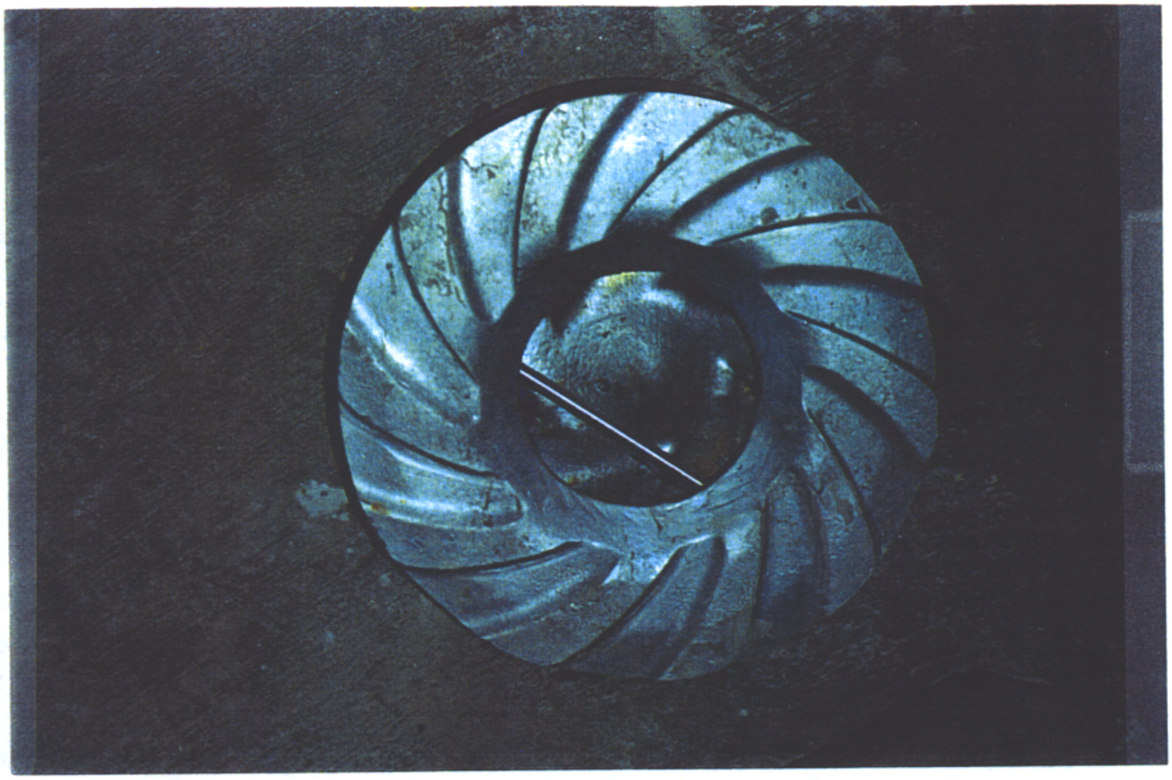

Figure 3-10. Gypsum Slurry Transfer Pump Impeller (View 1)

Figure 3-11. Gypsum Slurry Transfer Pump Impeller (View 2)

3.1.6 Pond Water Return Pumps

These pumps are horizontal, centrifugal, end-suction, v-belt driven type pumps. There are two (2) 100 percent pumps required for this service. They are each rated for a design flow of 1300 gpm and a net total pumping head of 188 ft. and a speed at design of 1616 rpm. These pumps are Warman model 6/4 EAH manufactured for slurry service with Borg Warner BWIP mechanical seals. The horsepower required at design is 101.32. The motor nameplate is 125 hp with a 1.15 service factor. The motor is mounted reverse overhead.

3.1.6.1 Materials

- Casing — Ductile Iron ASTM A536/ ASTM A536 Hi-Chrome (A49) Liner
- Volute Liner — ASTM A536 Hi-Chrome (A49)
- Shaft — Steel
- Shaft Sleeves — Alloy 20
- Impeller — ASTM A536 Hi-Chrome (A-49)
- Base Plate — Ductile Iron

Mechanical Seals - BWIP type RIS mechanical seal with no water required for flush or cooling. The materials of construction are Hastelloy C for the stationary assembly and Alloy 20 for the rotating assembly with silicon carbide rotating seals.

3.1.6.2 Maintenance

The motor was required to be mounted reverse overhead to allow for ease of maintenance on the pump as well as the motor.

3.1.6.3 Lessons Learned

The original material quoted and furnished for the impellers requiring high chrome because of tip speeds was Warman's A-49 which had approximately 27% chrome. The original material for the seal adapters was A-04 which have not experienced the erosion and pitting resulting from the low pH problems as shown in Figure 3-13.

3.1.7 Limestone Pile Run-off Sump Pumps

These pumps are vertical cantilever, submerged suction, duplex mounted, centrifugal, type pumps rated for a capacity 100 gpm and a head of 65 ft. at the discharge flange above the base plate. These pumps were supplier by Nagle Pump Company.

These pumps are located in a sump adjoining the limestone pile and conveyor limestone to ball mill loading conveyor. These pumps pump area runoff to the gypsum slurry transfer tank.

3.1.7.1 Material

- Casing — Cast Iron
- Suction Liner — Cast Iron
- Impeller — Bronze

3.1.7.2 Maintenance

There has been no maintenance on these pumps since they are not handling any slurries or low pH water.

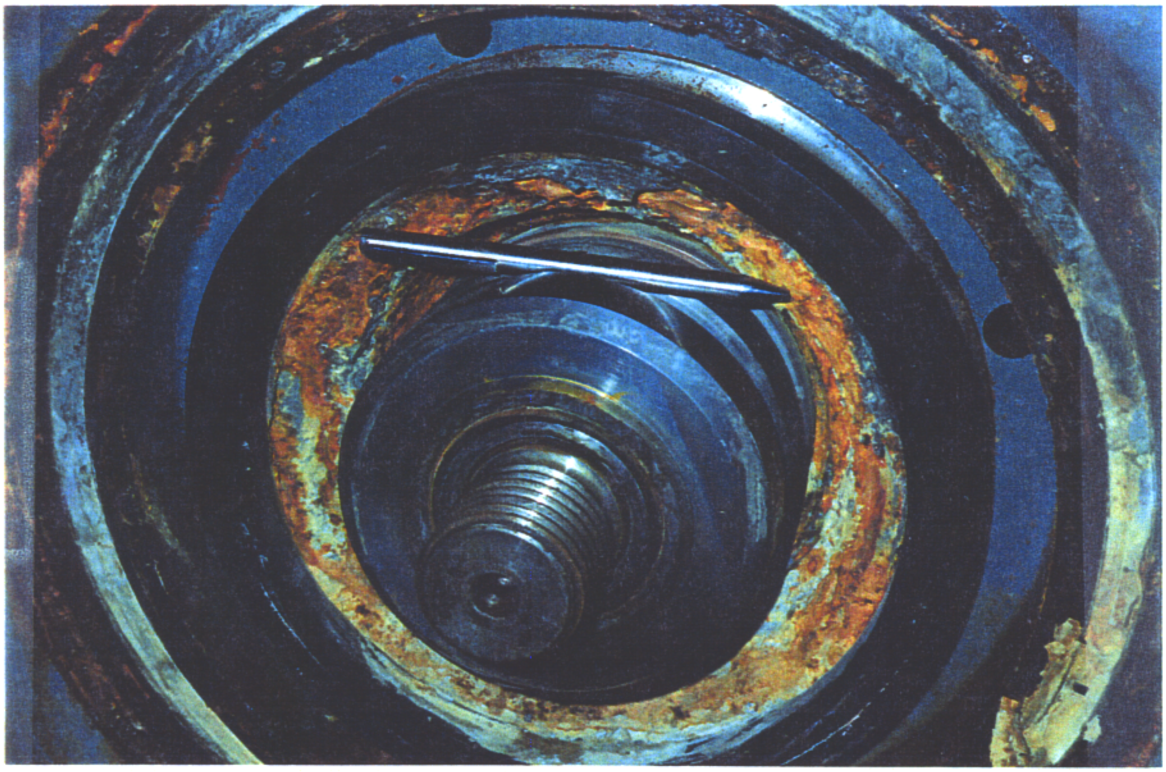

Figure 3-12. Gypsum Slurry Transfer Pump Seal Adapter Pitting

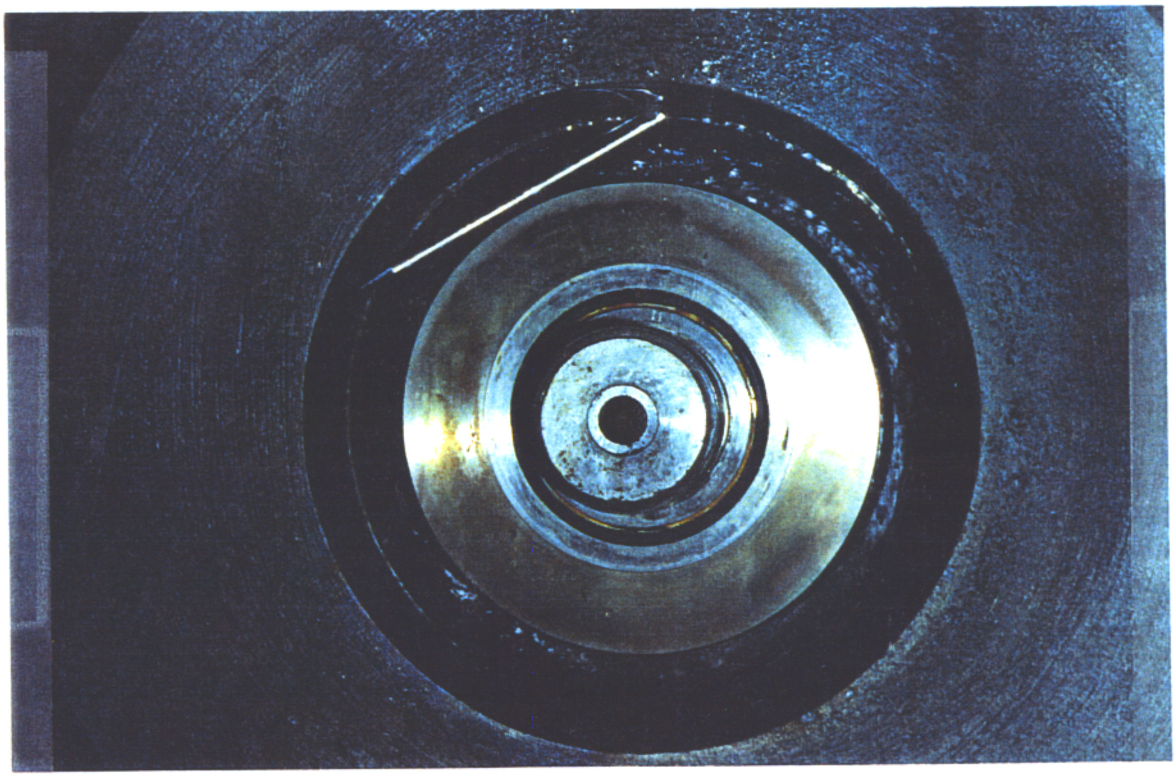

Figure 3-13. Pond Water Return Pump Seal Adapter

3.1.7.3 Lessons Learned

The above type pump is satisfactory for this service.

3.1.8 Limestone Prep Area Sump Pumps

These pumps are vertical cantilever, submerged suction, duplex mounted, centrifugal, type pumps rated for a capacity 100 gpm and a head of 50 ft. at the discharge flange above the base plate. These pumps were supplied by Nagle Pump Company.

These pumps collect area runoff, cooling water, and any spillage/leakage of limestone slurry and discharge back to the gypsum slurry transfer tank.

3.1.8.1 Materials

- Casing — Cast Iron with Elastomer Lining
- Suction Liner — Cast Iron with Elastomer Lining
- Impeller — Cast Iron Skeleton with Elastomer Liner

3.1.8.2 Maintenance

Maintenance was minimal on these pumps.

3.1.8.3 Lessons Learned

These pumps have performed satisfactorily for the above service. Although these slurry pumps have operated satisfactorily, one might consider for the future that it would be beneficial to have all the slurry type pumps furnished be the same pump manufacturer. This would minimize the number of vendors one would have to deal with for service work and parts ordering.

Furthermore it may prove that more pumps supplied by the same vendor could result in a quantity savings.

3.1.9 Chemical Containment Sump Pumps

These pumps are vertical cantilever, submerged suction, duplex mounted, centrifugal, type pumps rated for a capacity 100 gpm and a head of 32 ft. at the discharge flange above the base plate. These pumps were supplier by Nagle Pump Company.

These pumps pump spillage/leakage, agitator seal water, oxidation air humidification water, washdown water, and any rain water from a collection sump in the area of the FGD reactor to the gypsum slurry transfer tank for disposal to the gypsum storage pond.

3.1.9.1 Materials

- Casing — Cast Iron with Elastomer Lining
- Suction Liner — Cast Iron with Elastomer Lining
- Impeller — Cast Iron Skeleton with Elastomer Liner

3.1.9.2 Maintenance

Maintenance was minimal on these pumps.

3.1.9.3 Lessons Learned

These pumps have performed satisfactorily for the above service with the exception of plugging of the pump intakes. This required pump removal and disassembly and cleaning; then the pumps had no problems until sitting for a long time. Although these slurry pumps have operated for a considerable amount of time, one might consider for the future that it would be beneficial to have all the slurry type pumps furnished be the same pump manufacturer. This would minimize the number of vendors one would have to deal with for service work and parts ordering. Furthermore it might work out that more pumps supplied by this vendor could result in a quantity savings.

3.1.10 Limestone Classifier Pumps (Limestone Prep./Ball Mill Pumps)

These pumps are horizontal, centrifugal, end-suction, v-belt driven type pumps. There are two (2) 100 percent pumps required for this service. They are each rated for a design flow of 170 gpm at 50 to 60 percent limestone slurry and a net total pumping head of 60 ft. with an efficiency of 60% and a speed at design of 1490 rpm. These pumps are Warman model 3/2 CAH manufactured for slurry service and were originally provided with packed seals with water flushing. The horsepower required at design is 6.7. The motor nameplate is 10 hp with a 1.15 service factor. The motor is mounted overhead.

3.1.10.1 Materials

- Casing — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Cover Plate Liner — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Frame Plate Liner — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Shaft — Steel
- Shaft Sleeves — Alloy 20
- Impeller — Ductile Iron ASTM A536 Skeleton/Natural Rubber Elastomer Lined
- Base Plate — Ductile Iron

Mechanical Seals - BWIP type RIS mechanical seal with no water required for flush or cooling. The materials of construction are Hastelloy C for the stationary assembly and Alloy 20 for the rotating assembly. See comment regarding seals in lessons learned, below.

3.1.10.2 Maintenance

As indicated in Figures 3-14 and 3-15, the pumps were located very close together and the motors were located over the pumps. This made maintenance extremely difficult for the high maintenance required for these pumps.

3.1.10.3 Lessons Learned

The original material quoted and furnished for the impellers was R-08 rubber impeller and R-26 rubber liners. After about four months of operation this material was not holding up to the high solids and tramp material being pumped as shown in Figures 3-16 and 3-17. Therefore Warman recommended the A-49 material as a replacement to try in the pumps. This material has been quite satisfactory to date.

The pumps supplied by the manufacturer were sized incorrectly for head. After the pumps were installed and the system was commissioned, it was found the pumps could not pump the limestone slurry adequately to the classifier. The supplier of the ball mill had to resheave the pump and supply larger motors in order to produce more head.

These pumps were supplied with packed stuffing boxes with seal water in lieu of mechanical seals. The ball mill vendor was concerned about using a mechanical seal in a slurry concentration of approximately 50%. After nearly two (2) years of operating the BWIP zero leakage mechanical seals in limestone and gypsum services, it was decided to convert the packed seals on the classifier pumps to the BWIP zero leakage mechanical seals. They have performed beautifully to date.

While installing these seals, a valuable lesson was learned regarding accessibility to the seals. The ball mill manufacturer mounted the motors over the pump bearing housings. This made it difficult to install the mechanical seals as well as perform maintenance on the pumps. The present piping configuration and process equipment arrangement does not allow reverse overhead mounting

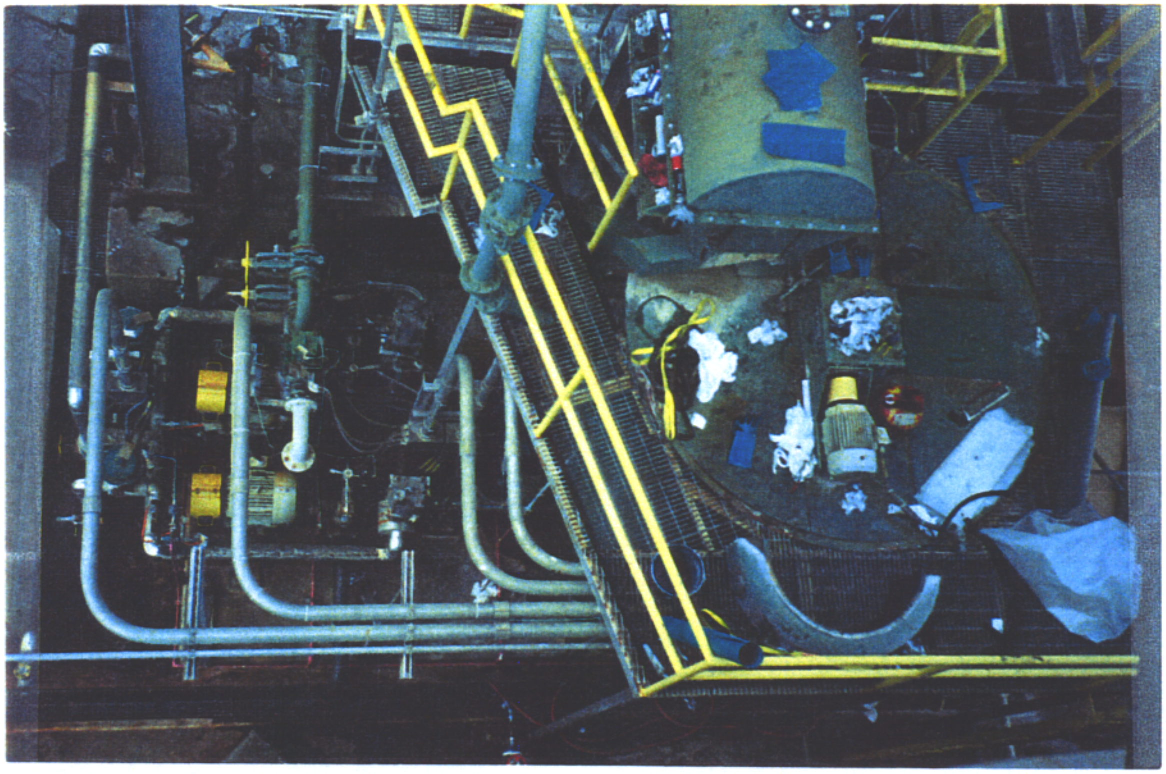

Figure 3-14. Limestone Classifier Pump Arrangement (Plan View)

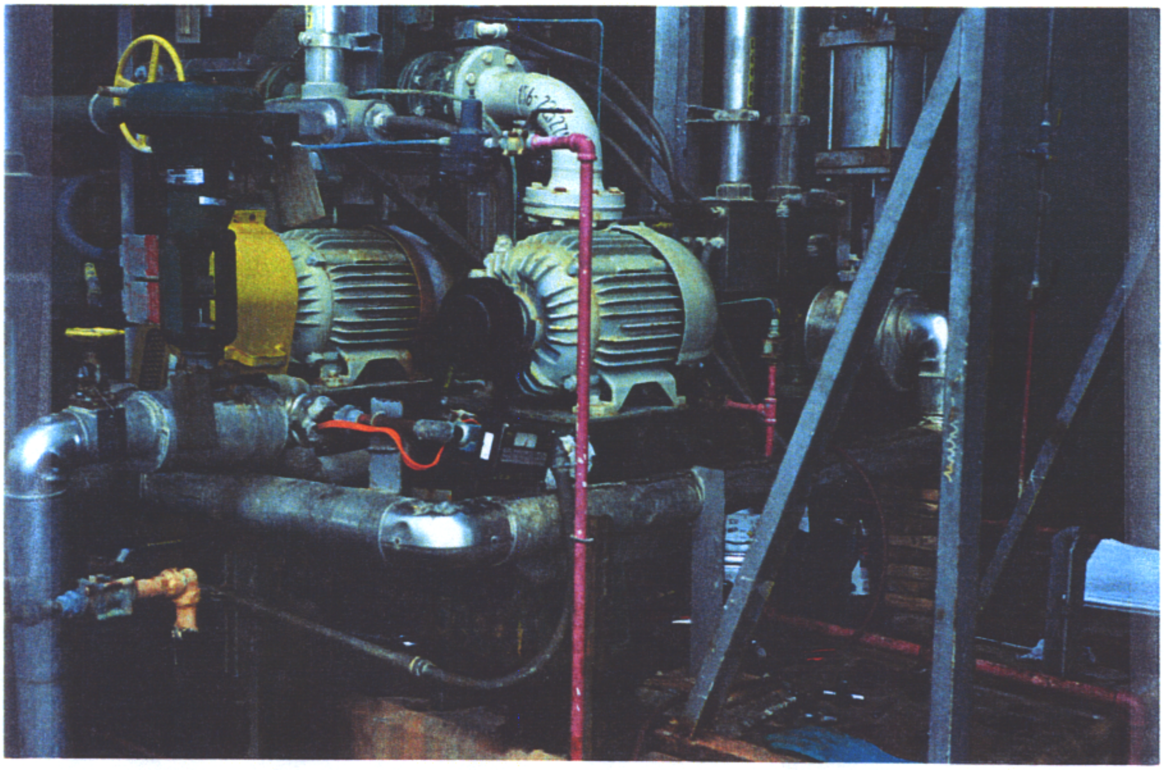

Figure 3-15. Limestone Classifier Pump Arrangement (Elevation View)

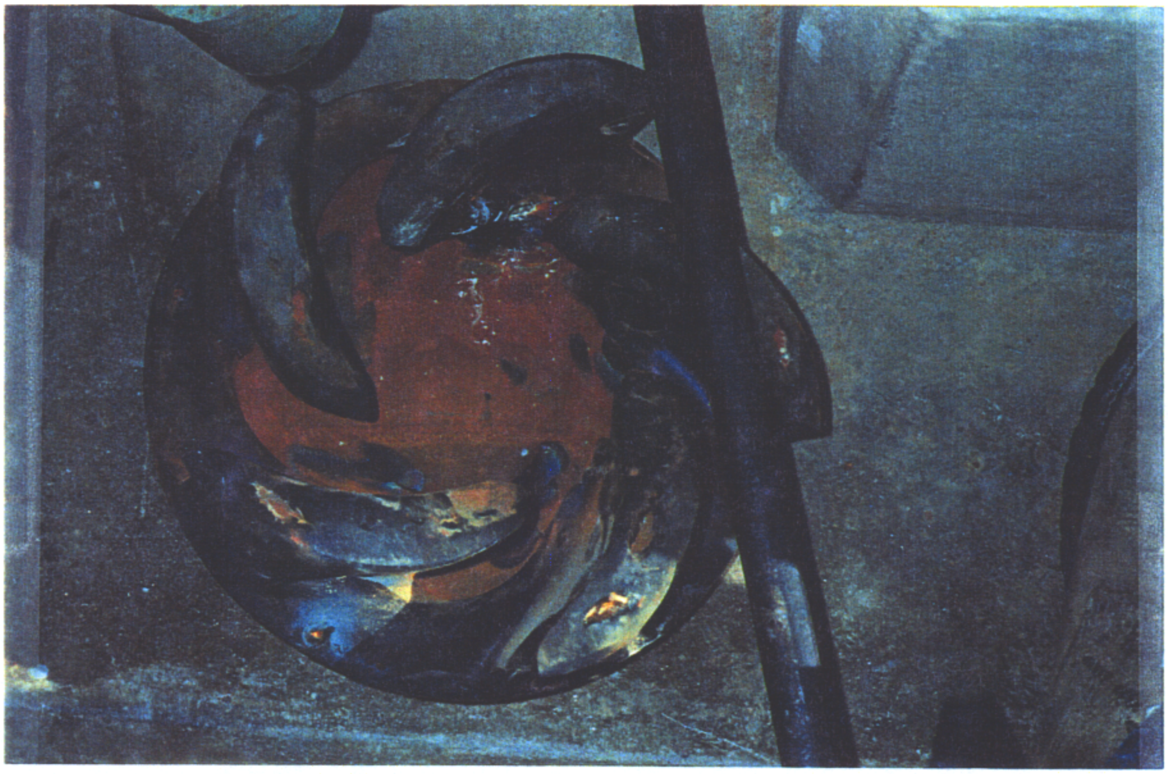

Figure 3-16. Limestone Classifier Pump Impeller

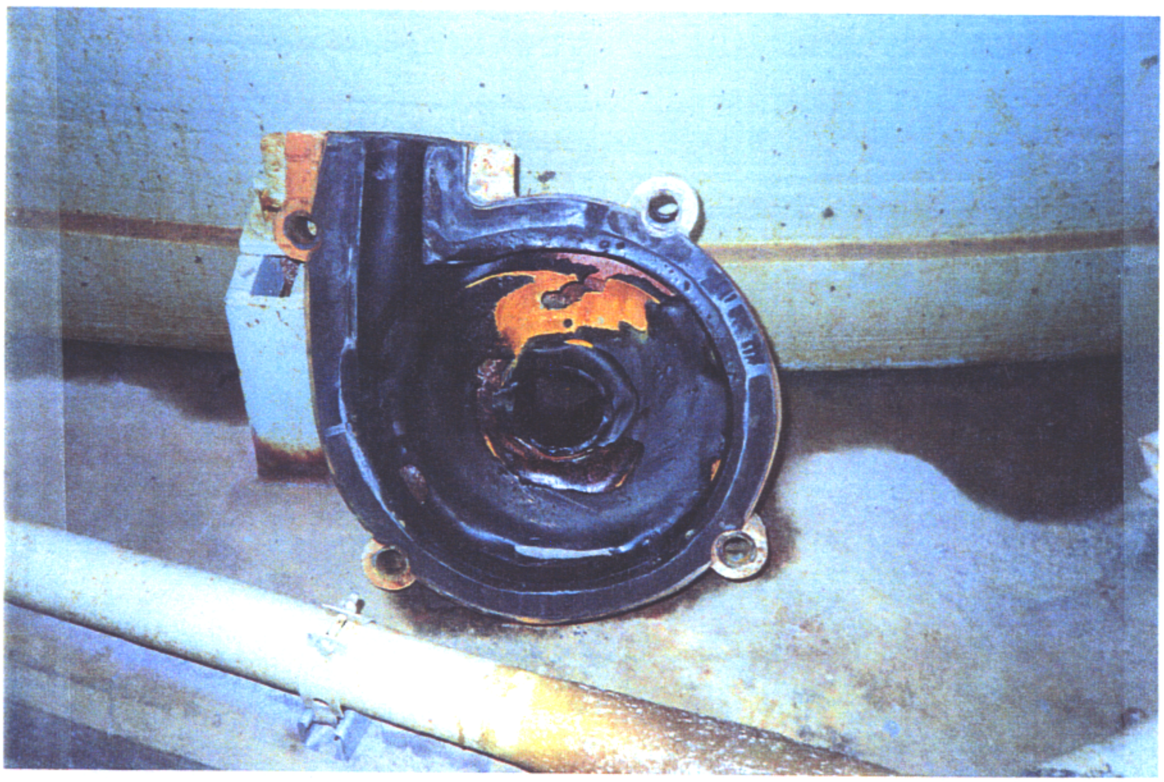

Figure 3-17. Limestone Classifier Pump Casing

of the motors as the other horizontal pumps are configured. However, in the near future, plans are being made to reroute pipe and install the motors as desired. In retrospect, experience dictates that it should be communicated to suppliers of auxiliary equipment the need for accessibility to equipment and in-house knowledge of materials and equipment considered to be superior.

3.1.11 Emergency Blowdown Pumps

These pumps are horizontal, centrifugal, end-suction, v-belt driven type pumps. There are two (2) 100 percent pumps required for this service. They are each rated for a design flow of 1250 gpm and a net total pumping head of 85 ft. and a speed at design of 1153 rpm. These pumps are Warman model 6/4 DAH manufactured for slurry service with Borg Warner BWIP mechanical seals. The horsepower required at design is 44. The motor nameplate is 50 hp with a 1.15 service factor. The motor is mounted reverse overhead.

3.1.11.1 Materials

- Casing — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Cover Plate Liner — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Frame Plate Liner — Ductile Iron ASTM A536/Natural Rubber Elastomer Lined
- Shaft — Steel
- Shaft Sleeves — Alloy 20
- Impeller — A49 High Chrome
- Base Plate — Ductile Iron

Mechanical Seals - BWIP type RIS mechanical seal with no water required for flush or cooling. The materials of construction are Hastelloy C for the stationary assembly and Alloy 20 for the rotating assembly. See comment regarding seals in lessons learned, below.

3.1.11.2 Maintenance

The motor was required to be mounted reverse overhead to allow for ease of maintenance on the pump as well as the motor.

3.1.11.3 Lessons Learned

The original material quoted and furnished for the impellers requiring high chrome because of high tip speeds was Warman's A-49, which has approximately 27% chrome. This material has been quite satisfactory for the low pH values observed. The original seal plate adapter material was A-04, and has worked quite well.

3.2 Oxidation Air Blowers

These blowers are horizontal, centrifugal, multi-stage, direct driven type blowers, and were designed to be operated in parallel. There are two (2) 50 percent blowers required for this service. They are each rated for a design flow of 3400 acfm of air at the inlet with a discharge pressure of 200" WC. (7.22 psig) with an operating efficiency of approximately 67%. The operating speed of these blowers is 3600 rpm. These blowers are Hoffman model 65106A. The horsepower required at design is 140. The motor nameplate is 150 hp with a 1.15 service factor.

The blowers are required to oxidize the sulfite to sulfate in the JBR to produce the desired byproduct of gypsum.

3.2.1 Materials

- Housing — Cast Iron ASTM A-48
- Rotors — Cast Iron ASTM A-48

- Timing Gears — ASTM A-148
- Base Frame — Steel ASTM A-36

3.2.2 Maintenance

Maintenance has been minimal on these blowers.

3.2.3 Lessons Learned

The original quotation from the blower manufacturer strongly recommended suction side dampers to aid in balancing the blowers. The decision was made to install the dampers on the downstream side which made it more difficult to balance the flows because of the blowers operating in parallel. Other than this, blowers associated with the FGD system have operated excellently. We could not have selected any other manufacturer of different type of equipment that would have performed as successfully as these blowers. During a high-sulfur test with the Unit -1 precipitator off-line, additional oxidation air was required for the process. Duplicate type blowers were purchased and connected to selected inlet air lines of the JBR. The test was successful and the blowers worked flawlessly.

3.3 Plant Air Compressors

These air compressors are oil-flooded rotary screw type compressors with associated equipment for a complete air package. The compressors are Sullair model 20/16-150L rated for approximately 700 SCFM (800 ACFM) at 110 psig discharge pressure. The design brake horsepower is 170. The motor supplied was rated at 200 horsepower with a 1.15 service factor. Coalescing filters furnished with these compressors filter any carryover of oil to the system. In-line aftercoolers cool the air after it leaves the compressor to reduce the amount of moisture carryover to the dryers. Air dryers manufactured by C. M. Kemp are heat regenerated, desiccant-type, rated for a minus 40 degree dew point for good dry instrument quality air.

3.3.1 Materials

Standard materials of construction were used. No alloy materials required for this service.

3.3.2 Maintenance

Maintenance has been minimal on the compressors. Dryers have been serviced due to excess carryover of moisture. This excess carryover has been attributed to an aftercooler leak that was repaired and the aftercooler was put back into service.

3.3.3 Lessons Learned

The oil-flooded rotary screw compressors with coalescing oil filtration filters that can supply instrument quality air and service air are satisfactory for the Chiyoda process.

3.4 Limestone Preparation System - Ball Mill

The ball mill for the limestone preparation system is a single-compartment overflow type unit. It is a 7 1/2' x 11' FGD ball mill, manufactured by Allis Minerals Systems Grinding Division.

The purpose of the grinding mill is to wet grind limestone rock into a fine powder which is mixed with water to form a limestone slurry mixture of about 30-35 wt.% solids.

3.4.1 Materials

- Balls — High Carbon Forged Steel
- Shell — ASTM A36 Steel Plate
- Trunnions
- Feed End — ASTM A278 Gr. 50 Cast Iron

- Disch. End ASTM A278 Gr. 50 Cast Iron
- Head Liners Rubber (2" thick. plates)

3.4.2 Maintenance

There have been several service representatives sent to the plant to resolve items such as overflow problems experienced at the feed inlet to the mill and problems associated with the reducer from oil contamination from product spillage directly on to the top of the trunnion lube oil system. This is due to the slurry overflow and underflow launder and hydrocyclone distribution system being located directly over the ball mill as shown in Figure 3-18 and the spillage that occurs during every movement or the recycle pipes, as shown in Figure 3-19. Maintenance on the gear reducer has been a concern because of excessive gear noise. Several attempts to reduce the noise have been made such as using certain additives in the oil or changing to a higher viscosity of oil.

3.4.3 Lessons Learned

To resolve the contamination problem in the oil, a deflector was built to cover the reducer. The lesson learned is to set the trunnion lube oil system somewhere other than directly underneath the inlet feed area to the mill.

As far as a lesson to be learned regarding the gear reducer oil problems, it would benefit the user to have more input into the requirements for the gear reducer and other auxiliary components on the ball mill.

One of the major lessons we learned from this mill design was to have future rock analysis taken for determining the proper Bond Work Index for the rock to be crushed. The second stone chosen (from Dravo quarries in Rome, Georgia) was harder than the original stone. This resulted in operations having to lower the mill throughput to provide the grind size and slurry

Figure 3-18. Limestone Preparation Area Arrangement

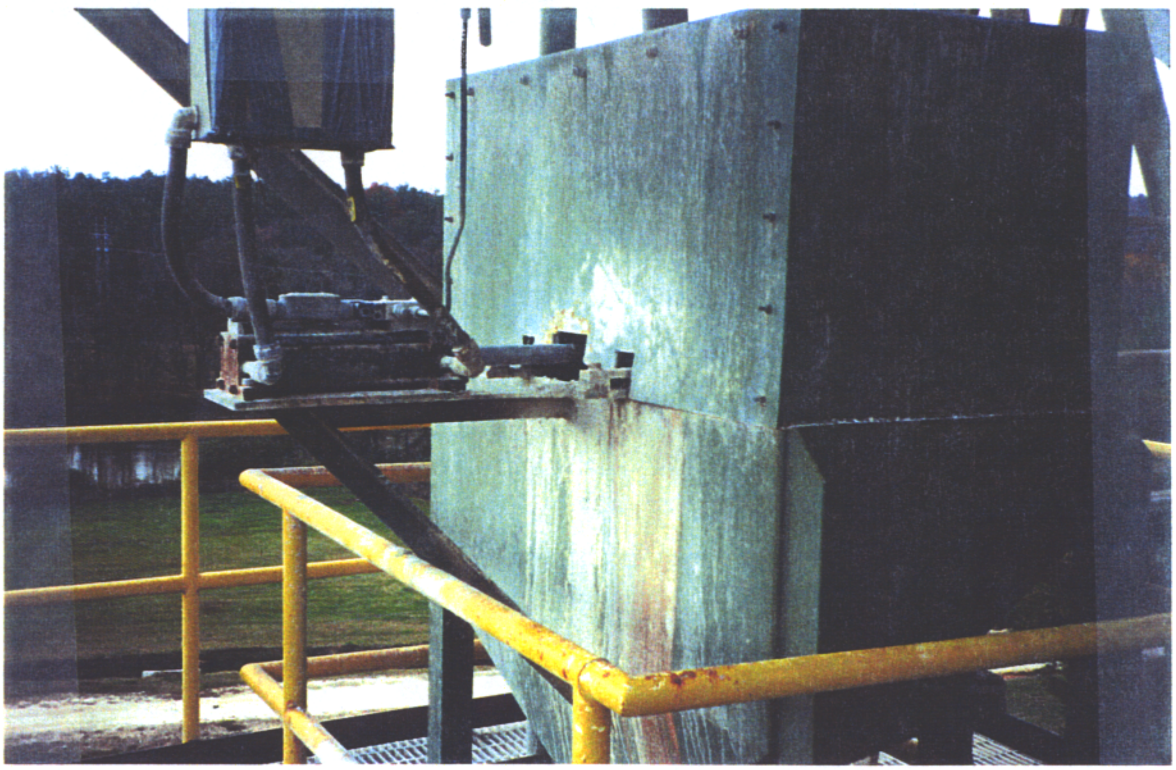

Figure 3-19. Limestone Slurry Distribution Launder

concentration needed. This caused the slurry to occasionally overflow the inlet, resulting in problems with spillage, particularly in the area of the trunion lube oil system.

3.5 Piping

A variety of piping materials were utilized during this project to determine the best application for the unique operating characteristics of the CT-121 process. Material determinations were based on criteria such as current market trends in new installations, abrasion/corrosion resistance, maintainability, and costs. Unlike a fully commercial installation where piping sizes and materials would be more standardized, the demonstration status of the Yates CT-121 installation allowed many different materials to be tested simultaneously.

3.5.1 Materials

The following sections discuss the different piping materials used during the test project and provide some indication of required maintenance and lessons learned for each material.

3.5.1.1 Fiberglass Reinforced Plastic (FRP)

Given the fact that the majority of the process vessels were manufactured from FRP, a great effort was made to evaluate the use of FRP pipe in parallel with the major vessels. FRP was predominantly used in two applications:

1. Inside the JBR for upper and lower deck wash piping where corrosion resistance in a saturated environment was required, and
2. In low-pressure slurry piping applications such as the suction on the gas cooling pumps and the limestone slurry return piping.

Application of FRP pipe in these applications yields information on both the corrosion and erosion resistance of the pipe.

The experience with the deck wash piping inside the JBR has been excellent from a corrosion-resistance standpoint. There have been no material failures or corrosive attack of the deck wash piping due to acidic attack. A slight amount of erosion damage was noted on the end of several of the deck wash pipes which point upstream toward the gas cooling duct. This erosion damage was attributed to impingement of gypsum and fly ash particles being conveyed by the flue gas stream into the vessels. Given the erosion pattern (i.e., the pipe caps in the center of the JBR were affected and the pipe caps on the periphery of the vessel were not), it was obvious that the impingement was due to the relatively high velocity of the flue gas entering the center portion of the vessel. The deck wash piping on the periphery was located in a relatively low velocity region of the vessel. The pipe caps were replaced and coated to prevent future erosion of the deck wash pipe.

The FRP pipe used in slurry service performed better than expected. For the most part, all of the FRP slurry piping was used in low-pressure service. It became cost prohibitive to wind FRP pipe to approach the hoop strength of rubber-lined, carbon steel pipe, so none was used in high-pressure applications. However, for low-pressure service, the cost of FRP piping gave a economic advantage, particularly as the diameter of the pipe increased.

There was one recorded failure of the FRP slurry pipe located on the suction of one of the gas cooling pumps. This pipe transports 20% by weight gypsum slurry at a pH value between 3.5 and 5.0. The failure occurred at a tee connection where a flush valve was connected. There were several contributing factors:

- The FRP pipe supported half the weight of the valve and actuator;
- While there was very little erosion damage noted in the FRP slurry piping, it is possible that the slurry could have provided a thinning action to the tee joint;
- The pipe is subject to a fairly high vibration when the pump is running; and
- Each time the slurry lines were flushed, the pipe endured a “shock” or “hammer” effect due to the action of the valve.

While there was no detailed failure analysis performed on pipe, it was theorized that some combination of the above factors contributed to the failure.

Repair of the joint was done in place under less than ideal conditions. Because wafer valves were used, it was not possible to remove the pipe from service without draining the JBR. Furthermore, the slurry valves did not provide a 100 percent tight closure. Therefore, the repair was made in place with a trickle of slurry coming through the pipe. It is a testament to the ease and forgiveness of FRP pipe that the tee, while repaired under non-ideal conditions, has not failed since being repaired.

3.5.1.1.1 FRP Pipe Lessons Learned

It is important to have a QA program in place before implementing FRP piping in to the design. One shipment of shop fabricated pipe contained air bubbles “trapped” in the walls of the piping. These bubbles were visible both externally and internally to the pipe. It is recommended that cross section samples be taken during the pipe fabrication process to ensure that no air bubbles are found in the pipe walls.

A clear film (resembling wax paper) is used to prevent FRP pipe from adhering to the mandrel during the manufacturing process. Typically, this film is removed from the interior of the pipe prior to shipping and installation. However, with long sections of small bore piping, this becomes more difficult. Upon installation, the film can come off the inside wall of the pipe and plug small diameter nozzles such as the ones used for deck washing. It is recommended that the interior of the pipe be thoroughly inspected to remove all foreign debris.

Plant maintenance personnel can be easily trained to perform simple FRP repairs. Working with FRP is as much art as science. Therefore, the more FRP work the maintenance crew performs, the more proficient they will become. On-site personnel repaired the majority of FRP pipe failures, cracks, and fabrications. It is also a good idea to have a stock lengths of FRP pipe and flanges where new replacement sections can be fabricated quickly on site.

Future installations should give more consideration to being able to isolate sections of FRP pipe with flanges to better facilitate repairs.

3.5.1.2 Rubber-Lined Carbon Steel

Much of the limestone and gypsum slurry piping used at the Yates CT-121 installation was rubber-lined carbon steel piping. Rubber-lined carbon steel was thought to be indicative of current market trends in the majority of FGD systems. In addition, rubber-lined carbon steel pipe proved to be one of the more economical choices in high pressure slurry service.

There were two primary causes of rubber-lined carbon steel pipe failures:

1. Delamination of the rubber lining off the inside wall of the pipe, and
2. Erosion of the rubber lining and steel pipe at elbows.

The observed trend at the Yates CT-121 installation was much of the large diameter piping tended to delaminate whereas most of the smaller bore piping tended to suffer erosion at the elbows.

The best example of delamination and erosion problems was experienced on the gas cooling pump discharge line. Two of three gas cooling pumps discharge to a common header where multiple connections to individual slurry lines are made. The rubber-lined header experienced severe erosion due to the high velocity and directional changes at that point in the system. Since the slurry contained between 10,000 and 30,000 ppm of chlorides and a pH between 4.0 and 5.0, it did not take long for the slurry to penetrate the outer carbon steel pipe once the rubber lining failed. The rubber-lined header was replace with a basalt-lined header. Additional sections of this header immediately adjacent to the gas cooling pump discharge were replaced with polypropylene lined carbon steel piping. Other than this header, rubber-lined carbon steel pipe performed quite satisfactorily.

In addition to slurry service, rubber-lined carbon steel pipe evaluated for pond return water containing high chlorides. The rubber-lined pipe worked extremely well in this corrosive, clear water service.

3.5.1.2.1 Rubber-Lined Carbon Steel Pipe Lessons Learned

Prefabricating rubber-lined pipe spools tended to cause alignment problems once the spool pieces reached the field. It was found that if pipe spools could be fabricated with a loose or rotating flange on one end (or both ends), the alignment and installation was much easier.

Another valuable lesson to be learned on the rubber-lined pipe would be to stop the rubber on the flanges slightly below the bottom of the bolt holes and install spacers (a metallic type gasket style) for tightening the flanges. The flanges with full faced rubber tended to squeeze the rubber out beyond the flanges and at the same time pulled and weakened the area of the rubber transitioning from the flange face to the pipe inside diameter.

Most of the rubber-lined pipe was prefabricated in spool pieces by a local fabricator. Due to the pre-fab nature of the product, a large amount of engineering and design was necessary to detail the installation prior to fabrication. If construction/installation errors were found in the field, the prefabricated spool pieces would not fit. As a consequence, a great deal of flexibility should be designed into a rubber-lined piping system to prevent unnecessary field changes.

3.5.1.3 High Density Polyethylene (HDPE)

High density polyethylene is an excellent abrasion/corrosion resistant pipe to use in areas where piping can be buried or trenched, such as the discharge for the gypsum slurry from the process area to the retention pond and for return of the pond water to the process. This type pipe is considerably less expensive than the carbon steel/rubber-lined type pipe. HDPE pipe will thermally expand great distances when not constrained. Therefore it would not be acceptable in the immediate process area since it could not be supported rigidly throughout. The HDPE pipe used in this installation is marketed under the brand name Drisco Pipe.

3.5.1.3.1 HDPE Pipe Lessons Learned

This product has excellent abrasion resistance and assembly techniques. Future installations should strive to incorporate as much of this type of material as possible.

3.5.1.4 Polypropylene

Polypropylene pipe and polypropylene-lined carbon steel pipe were used in several areas of the installation. The solid polypropylene pipe was used for mist eliminator vane wash water. Installation of polypropylene pipe is similar to PVC and provide excellent corrosion resistance in a saturated acid gas environment.

The polypropylene-lined carbon steel pipe used at Plant Yates is marketed under the brand name Towneprene. The fabrication of this material is similar to rubber-lined carbon steel except that the polypropylene lining is harder than the rubber lining. Experience in slurry service has been very good. The polypropylene seems to bond better to the interior pipe wall and the harder material seems to resist erosion better. However, pre-fabrication and field erection problems are similar to the rubber-lined carbon steel piping. Additionally, polypropylene-lined fittings were ordered to replace rubber-lined fittings as they wore out. The experience has been very positive.

Molded polypropylene fittings were used in combination with EPDM rubber hose for slurry service with excellent results. Both male and female quick couplings proved to have very good erosion resistance.

3.5.1.4.1 Polypropylene Pipe and Polypropylene-Lined Carbon Steel Pipe Lessons Learned

Prefabricating pipe spools tended to cause alignment problems once the spool pieces reached the field. It was found that if pipe spools could be fabricated with a loose or rotating flange on one end (or both ends), the alignment and installation were much easier.

Unlike the rubber-lined carbon steel pipe, the polypropylene-lined pipe can be used to cover the flange faces and will function as the gasket between the two flanges. A polypropylene spacer can be used either as a gasket or to facilitate field alignment of the piping.

3.5.1.5 Basalt

Basalt-lined pipe was use primarily in the gas cooling slurry distribution header. Basalt is placed inside a carbon steel pipe and shimmed such that the spacing between the basalt and the steel pipe were equal at all points. Mortar is pumped between the basalt and pipe to hold the basalt in place. The pipe is then flanged together such that only the basalt, a chemically resistant material, is exposed to the slurry.

3.5.1.5.1 Basalt Lessons Learned

The first basalt-lined pipe failed within weeks because the cement bonding the basalt cylinders and joints was attacked by the low pH levels of the slurry (as low as 3.5). A new basalt header was manufactured with low pH compatible mortar. The steel casing housing the basalt cylinders was coated inside and out. This was installed over two years ago and the header has not developed any leaks.

3.5.1.6 Aluminum

Aluminum proved to be a very poor material for all components associated with this process. Due to the low pH process conditions and the high solid content slurry, even the smallest slurry leak would lead to a catastrophic failure of the aluminum components.

Aluminum was primarily used in two major areas: (1) half flanges for connecting rubber hose to flange header connections; (2) knife gate valve bodies. Since rubber hose seemed to perform so well in these process conditions, much effort was made to maximize its utilization. Unfortunately, the only type of connection device which could be used on the selected rubber hose was half flanges. The half flanges would eventually start to leak over time causing failure of the connection. It was found that greater life expectancy could be achieved by painting the aluminum half flanges with epoxy paint and using carbon steel half flanges. However, once the paint was eroded/corroded off, failure of the flange occurred quickly. These aluminum half flanges were eventually discarded in favor of the molded polypropylene fittings.

Aluminum was also used in knife gate valves. This too proved to be a problem since if and when a polypropylene lining in the valve failed, the valve body failed almost immediately. Here again, epoxy paints prolonged the inevitable failure, but it did eventually fail, as shown in Figure 3-20.

3.5.1.6.1 Aluminum Lessons Learned

Aluminum is not well suited for use in FGD processes, particularly valve bodies, as shown in Figure 3-20.

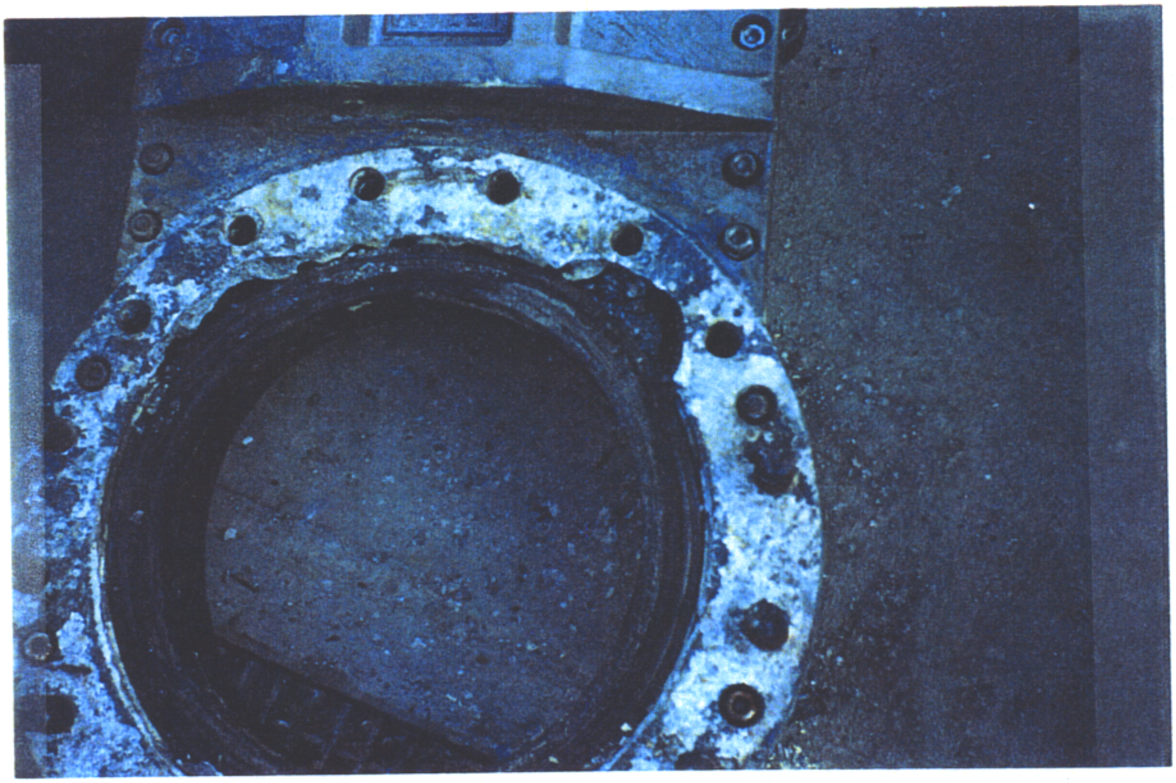

Figure 3-20. Aluminum Knife Gate Valve Body Failure

3.5.1.7 EPDM Rubber Hose

Natural rubber hose for transporting the gypsum slurry from the basalt header to the nozzles for gas recirculation was an excellent choice. Based on tests at Plant Yates in the early '70s, rubber hose was one of the best materials to use for transporting abrasive materials. The rubber hose was good not only for abrasion but also for corrosive materials.

3.5.2 Maintenance

Maintenance was minimal on piping. However, for small replacement orders, for example, tees, elbows and short runs of pipe for the FGD piping, it was found that composite FRP pipe was cheaper and quicker to obtain.

3.5.3 Lessons Learned

A few pieces handling the recirculation of slurry back to the JBR through a distribution header were manufactured of carbon steel with a basalt liner after the original carbon steel/rubber-lined pipe wore out. The basalt was needed in this header because the transition of the slurry from the gas cooling pumps to the distribution pipes cause extreme erosion in the originally supplied carbon steel/rubber-lined pipe. This erosion problem was caused by the high velocities experienced because the lines from the gas cooling header back to the JBR were too small. Otherwise carbon steel/rubber-lined pipe would have worked quite satisfactorily in this case.

Another valuable lesson to be learned on the rubber-lined pipe would be to stop the rubber on the flanges to slightly below the bottom of the bolt holes and install spacers (a metallic type gasket style) for tightening the flanges. The flanges with full faced rubber tended to squeeze the rubber way out beyond the flanges and at the same time pulled and weakened the area of the rubber transitioning from the flange face to the pipe inside diameter.

Natural rubber hoses for transporting the gypsum slurry from the basalt header to the nozzles for gas recirculation was an excellent choice. Based on tests at Plant Yates in the early ’70s, rubber hose was one of the best materials to use for transporting abrasive materials. The rubber hose was good not only for abrasion but also for corrosive materials.

HDPE is an excellent abrasion and corrosion resistant piping material to use in areas where piping can be buried or trenched (e.g., discharge of gypsum slurry from the process area to the retention pond and for return of the pond water to the process). This type of pipe is considerably less expensive than the carbon steel/rubber-lined type pipe. HDPE pipe will thermally expand great distances when not constrained. Therefore it would not be acceptable in the immediate process area since it could not be supported rigidly throughout.

The choices for the various type pipes used for the Chiyoda process were excellent.

Although the FRP fittings and short runs of pipe were easier and cheaper to obtain, it is not recommended to furnish this type pipe as a total replacement to the carbon steel/rubber-lined pipe. There are several reasons for this:

- First the FRP pipe will not be as rigid as the carbon steel/rubber-lined pipe.
- FRP pipe would deteriorate from loading by the slurry and the exposure to ultra-violet rays.

The cost for FRP vs. carbon steel/rubber-lined pipe would be more expensive when ordered in bulk quantities.

3.6 Nozzles

There were several nozzle applications within the CT-121 scrubber, including:

- Gas cooling nozzles (including humidification nozzles);
- JBR deck wash nozzles; and
- Mist eliminator wash nozzles;

3.6.1 Gas Cooling Nozzles

During normal operation, two of the three gas cooling pumps provided gas cooling slurry to the transition duct or JBR dirty gas plenum. The gas cooling pumps circulate process slurry from the JBR to the gas cooling spray nozzles, located in the transition duct. The function of this cooling water is to protect the fiberglass reinforced plastic and heat-sensitive PVC components of the transition duct and the JBR.

The gas cooling and transition duct cooling spray system consist of three banks of spray nozzles and two headers. The first bank (i.e., most upstream), used for flue gas humidification, may be fed from plant make-up water and or pond water to humidify the flue gas the transition duct prior to reaching the gas cooling spray. The next two spray nozzle banks, situated in and around the perimeter of the inlet duct, serve to saturate and cool the flue gas to its adiabatic saturation temperature.

3.6.1.1 Materials

- Silicon Carbide — Gas Cooling Slurry Nozzles
- C-276 — Gas Humidification Water Nozzles

3.6.1.2 Maintenance

Maintenance was minimal, and only minor problems were documented. These problems were mainly dealing with pluggage and attachment to spray headers. The use of calibrated torque wrenches was a good solution to the attachment problem.

3.6.1.3 Lessons Learned

In the initial design, the nozzles became plugged from loosened scale and other debris in the JBR. This problem was resolved by installing a single "hockey net" style screen in the JBR at the location of the suctions of the three gas cooling pumps. The free pass area of the screen was selected at 3/8" so that any object small enough to pass through the screen would pass through the nozzles.

One of the major problems associated with the nozzles was the method of attaching the nozzles to the spray header (bolt materials) and the transition of the slurry through the spray header to the nozzles. It seems the change in direction from the spray header to the nozzles (90 degrees) created erosion problems requiring spray header replacement from time to time. As for nozzle attachments, bolt materials were changed from stainless steel to CD4MCU high chrome.

3.6.2 JBR Decks Wash Nozzles

The JBR has two decks; an upper deck and lower deck, that must be washed periodically to prevent fouling of gas flow passages. The lower deck encounters the largest volume of residue and particulate matter and must be washed once every hour. The upper deck, by design, encounters a much lesser volume of residue and only requires washing every eight hours.

3.6.2.1 Materials

- Upper Deck Nozzles — Polypropylene Bete Nozzle MP375W
- Lower Deck Nozzle — Fiberglass Reinforced Plastic (FRP)

3.6.2.2 Maintenance

Only minimal maintenance was required.

3.6.2.3 Lessons Learned

The material selections for these nozzles were excellent for the application.

3.6.3 Mist Eliminator Nozzles

The mist eliminator contains two banks of mechanical separators. These mechanical mist separators alter the direction of air flow to remove entrained moisture from the gas as it flows toward the stack. The mist eliminator elements encounter a small degree of process slurry residue carried into the mist eliminator by the gas flow. To minimize the possibility of air passage fouling, the mist eliminators must be periodically washed.

The first bank of mist eliminators must be washed, front and back, every eight (8) hours with pond water via the washing water tank and washing water pumps. The second bank of mist eliminators is washed, on the front side only, every twenty-four (24) hours with make-up water (ash sluice water).

Each wash header associated with the mist eliminator banks are equipped with twelve (12) pneumatic valves that are operated through a sequencer during the wash cycle. All the mist eliminator wash water is drained to the JBR.

The mist eliminator sections are fed from a recycle water tank for a reliable, constant pressure source of wash water. However, the washing water pumps are only capable of supplying water at rated pressure to one header at a time. The control system is programmed to prevent simultaneous multiple header operation. A queuing function may be used to allow the operator to step up washes for execution upon completion of a current wash cycle.

3.6.3.1 Materials

The wash nozzles were constructed of polyurethane.

3.6.3.2 Maintenance

Only minimal maintenance was required.

3.6.3.3 Lessons Learned

Material selection was excellent.

3.7 Agitators

Several agitators were installed in the CT-121 system at Plant Yates. Descriptions of each agitator and operating experiences with each are summarized below.

3.7.1 JBR Agitator

The JBR agitator is designed to keep the process slurry in a suspended state and mix the flue gas, oxidation air, and limestone slurry to facilitate the continuous reaction, forming new gypsum crystals. All pumps that take suction from the JBR are interlocked with the agitator and the agitator must be running for a minimum of 600 seconds before any of the pumps taking suction from the JBR may be started.

The JBR agitator is vertical and has a 176" diameter turbine (impeller) and a mixing speed of 15 RPM. The centerline of the agitator impeller is located 5'-0" above the bottom of the JBR. The shaft extends below the impeller to within 1'-0" of the bottom to engage a slap ring for positive location of the agitator. The JBR was baffled with four (4) 42" wide baffles extended 7" off the tank wall at 90° angles from each other. The baffles extend the entire height of the tank. The agitator is driven by a 75 HP, 1800 RPM, 460 VAC, 3 phase motor.

The JBR agitator and all other agitators for this project were rubber coated and furnished by Chemineer.

3.7.2 Gypsum Slurry Transfer Tank (GSTT) Agitator

The GSTT agitator serves to prevent settling of the suspended particles in the GSTT. The GSTT agitator is vertical and a 50" diameter turbine and has a mixing speed of 56 RPM.. The gypsum slurry transfer tank was baffled with four (4) 10" wide baffles extended 1-11/16" off the tank wall at 90° angles from each other. The baffles extend the entire height of the tank. The agitator is driven by a 2 HP, 1200 RPM, 460 VAC, 3 phase motor.

3.7.3 Mill Sump Slurry Tank (MSST) Agitator

The MSST is equipped with an agitator to prevent settling of the suspended particles in the mill sump. The MSST agitator is vertical and has a 104" diameter turbine and a mixing speed of 30 RPM.. The MSST was baffled with four (4) 28" wide baffles extended 4-11/16" off the tank wall at 90° angles from each other. The baffles extend the entire height of the tank. The agitator is driven by a 10 HP, 900 RPM, 460 VAC, 3 phase motor.

3.7.4 Chemical Containment Area Sump Agitator

The chemical containment area sump is located between the scrubber dry fan and the JBR. Water that may leak from the duct cooling spray system, recirculating lines, or associated components is collected in this sump. The water collected in this sump will have a relatively high percentage of solids. Because of this it is necessary to employ an agitator to keep the solids in the sump in suspension.

The agitator is set to run continuously when the sump level is at least 20% full. All water collected by the chemical area sump is delivered to the gypsum transfer tank by the two chemical containment area sump pumps.

The chemical containment area sump agitator is vertical and has a 64" diameter turbine and a mixing speed of 37 RPM. The chemical containment area sump is square and as a result, no baffling is required. The agitator is driven by a 2 HP, 1200 RPM 460 VAC, 3 phase motor.

3.7.5 Limestone Area Sump Agitator

The limestone prep area sump is located adjacent to the ball mill. The limestone preparation area sump is designed to collect the water drainage from the limestone preparation system. Every effort is exercised to maintain zero discharge of liquid from the scrubber system into the ground water. The sump is equipped with two pumps and an agitator. The two pumps discharge through separate lines into the gypsum slurry transfer tank. The pumps are designed to operate automatically according to the level in the sump, but can be operated manually from the local control station. The purpose of the agitator is to keep limestone draining into the sump suspended in water so it can be removed by the pumps. The limestone prep area sump agitator is identical to the agitator for the chemical containment area sump.

3.7.6 Materials

All agitators were furnished with shaft and turbine assembly fabricated from carbon steel and coated with 3/16" thickness of No. 5506 (55-65 Shore "A" hardness) natural rubber. One extra thickness was applied to the turbine blade edges.

3.7.7 Maintenance

No maintenance has been required to the agitators. Inspection of the rubber coatings on the turbine blades has revealed very little wear.

3.7.8 Lessons Learned

The agitators have performed very reliably. The primary lessons learned are:

- Require a rubber liner installer to do field applications, independent of the agitator manufacturer;
- Rubber coated carbon steel wetted components perform acceptably. The use of expensive alloys is not required; and

- Slurry tanks require baffles in low velocity areas to prevent buildup of slurry in these areas.

3.8 Fans

A fan is necessary to remove the gases from the boiler and force these gases through the liquid process slurry contained in the reaction zone of the scrubber. The function of this large Howden Sirocco, Class 5, fan will be to maintain proper furnace draft and force the flue gas through the scrubber jet bubbling reactor.

3.8.1 Materials

The fan was fabricated from carbon steel blades with chrome carbide liners.

3.8.2 Lessons Learned

There were several incidents of fan wheel vibration that occurred each time the fan was washed. The resulting investigation revealed that a certain amount of fly ash buildup was required to help dynamically balance the fan. Once this buildup was achieved the vibration problems became considerably less. Therefore, prior to the final DOE test the fan wheel was left alone and not cleaned.

The fan hub bolts are shielded by ASTM A120 and A53 carbon steel pipe stubs, as shown in Figure 3-21. The shields have been penetrated on some bolts. These were intended to be sacrificial per the fan manufacturer. There are plans to cover these shields with rubber or some other material that can withstand abrasion and corrosion in the future. For now, the eroded shields will be patched.

Figure 3-21. ID Fan Hub Bolts and Shields

During the early stages of the project there were problems with high temperatures on the lubricating oil. This was traces to clogged oil coolers. Existing in-line strainers were replaced with auto wash features to minimize the oil cooler plugging problems.

3.9 Process Vessels

A majority of the process vessels used in the CT-121 system were constructed of FRP. Each is described individually below.

3.9.1 Jet Bubbling Reactor (JBR)

From the gas cooling section, the flue gas enters the JBR. The JBR is the central feature of the CT-121 process, and was made entirely of FRP. The gas enters an enclosed plenum chamber formed by an upper deck plate and a lower deck plate. Sparger tube openings in the lower deck plate force the gas into the slurry contained in the jet bubbling (froth) zone of the JBR vessel. After bubbling through the slurry, the gas flows upward through gas risers which pass through both the lower and upper deck plates. Entrained liquor in the gas disengages in a second plenum above the upper deck plate, and the cleaned gas passes to the mist eliminator.

3.9.2 Limestone Slurry Storage Tank (LSST)

The LSST is a FRP vessel constructed by Ershigs. The LSST has a storage capacity of 124,365 gallons. Limestone slurry is delivered to the LSST from the limestone preparation system. An agitator is employed to keep the slurry in suspension until required by the scrubber pH control system. One of two limestone slurry pumps transport the limestone slurry from the LSST to the JBR.

The limestone ball mill system is interlocked with the limestone slurry tank level. When the limestone slurry tank level reaches 82% full an automatic shutdown of the limestone preparation system is initiated.

3.9.3 Gypsum Slurry Transfer Tank (GSTT)

The GSTT is a FRP vessel constructed by Ershigs. The capacity of the gypsum slurry transfer tank is 8,800 gallons. The gypsum slurry draw-off pumps remove gypsum slurry from the JBR and deliver it to the gypsum slurry transfer tank. The gypsum slurry transfer tank is equipped with an eight inch overflow stand pipe designed to route tank overflow to the chemical containment sump. The GSTT is equipped with an motor driven agitator to maintain solid suspension

3.9.4 Materials

The Yates CT-121 scrubber was the first of its kind to use FRP for all major process vessels, ductwork, and a significant portion of slurry piping. Considerable effort was expended to frequently evaluate the erosion and corrosion resistance of the FRP materials used in this CT-121 design. In general, the wide use of FRP for this highly abrasive, high chloride, closed loop environment was successful.

3.9.5 Lessons Learned

- With the exception of the JBR inlet plenum, the JBR vessel and all other process equipment and vessels constructed of FRP exhibited no signs of corrosion or erosion damage during the demonstration project;
- Erosion of the FRP materials in the gas cooling transition duct and JBR inlet plenum was one of the most difficult problems to resolve due to the proximity of the gas cooling nozzles to the JBR inlet plenum, the high superficial velocity of flue gas (approximately 60 ft/sec at full load), and high solids concentration (23 wt.%) of the gas cooling slurry;
- The erosion damage required patching during almost all but the earliest inspections of the JBR internals, but did not become severe enough to require a forced outage;
- Quantification of erosion damage in the gas cooling duct was made easier by the FRP lay-up technique, in which FRP layers were of different colors to ease identification of the depth of erosion damage; and
- The high ionic strength slurry, which had measured chloride concentrations as high as 68,000 ppm, had no observed negative impact on the FRP.

With some design modifications, the observed inlet plenum erosion could also be resolved in future applications of FRP technology. These modifications include moving the gas cooling section further from the JBR in future designs, replacing the FRP in the gas cooling section with stainless steel wallpaper, or applying erosion resistant coatings to the wear-prone surfaces.

3.10 Mist Eliminator

The mist eliminator is a device employed to collect, remove, and return slurry droplets to the reaction tank. The mist eliminator is usually located inside the absorber vessel near the gas exit and is subject to the same environmental conditions as the absorber internals. The mist eliminators must be able to withstand high pressure water sprays that are used to wash away deposits that commonly build up on internals. Most mist eliminators are chevron type with a variety of vane shapes to reduce plugging or improve washing effectiveness to reduce scaling.

The mist eliminator vanes are typically constructed of some form of plastic, with or without fiberglass reinforcement. Frequently the material is described as FRP; however, it is most likely polyester.

The Yates mist elimination system employs a pre-conditioning stage and two banks of vanes mounted in a separate vessel in the horizontal flue gas flow downstream of the JBR. The pre-conditioning stage consists of the upper part of the JBR where flue gas with entrained droplets leave the reaction zone through gas risers and enters the large upper section where the velocity is greatly reduced allowing droplet fallout. This along with a direction change significantly reduces load to the horizontal mist eliminators. Turning vanes are utilized to evenly distribute the gas flow to the mist eliminator face. The gas then changes direction three times as it passes through the vanes where droplets impinge, coagulate and drain down the vertical vanes. The support system consists of troughs with external drains allowing the slurry to return to the reaction tank. The first stage is automatically washed front and back with clarified return water every eight hours, while the second stage is washed every twenty four hours with fresh make up water.

3.10.1 Materials

In keeping with the materials theme, the mist eliminator housing was specified as FRP, the same material as the preceding JBR and downstream chimney. After an exorbitant cost estimate was received from the manufacturer, further investigation revealed that when FRP is not fabricated in a round shape, it may not be the most cost-competitive choice. After reviewing several options, it was decided to pursue C-276 wallpaper on carbon steel with four by eight foot sheets, welded six on twelve with plug welds covered by patches in the center. A specification was developed and vendors qualified to bid the mist eliminators. The winning bid was one-half the cost of FRP due to the FRP hand layup construction requirements. It should be noted that in subsequent bids with different sub-component construction methods and manufacturers, the FRP flat design is more economical than the C-276 wallpaper.

The mist eliminator elements are vertically stacked in the support/drain system in removable bundles. The vane design is based on Chiyoda's proven mist eliminator, manufactured of pultruded vinyl ester resin with fiberglass reinforcement for strength. Layers of glass fabric are pulled through a resin bath and then through a hot mold where the vinyl ester resin solidifies by curing or cooling producing a one-quarter inch thick continuous vane. The mist eliminator vanes are held together with a pin and post design which also provides for proper spacing. The majority of mist eliminators scale or plug requiring frequent manual cleaning. Breakage occurs during cleaning either by striking with a hammer or during scale removal with high pressure water spray. Typically when a droplet reaches a spray tower mist eliminator, it is not fully oxidized and due to the high operating pH, an excessive amount of unreactive additive is present. The droplets collect on the vanes where additional SO_2 removal takes place and the resulting species precipitate out, forming a hard scale. The JBR operates at a very low excess additive concentration, and droplets reaching the mist eliminator are one hundred percent oxidized preventing chemical scale formation.

3.10.2 Maintenance

The wallpaper construction in the mist eliminators housing has performed extremely well due to the material selection, fundamentally different chemical operation of the JBR, element vane thickness, and pre-conditioning step. The C-276 wallpaper did not experience any failures, nor were any alloy repairs required during the entire test program. The mist eliminator wash and drain systems functioned well, with minimal element and floor build-up that is common in most mist eliminator systems.

The mist eliminator elements have also performed extremely well with no scale and minimal build-up during normal operation. Manual washing was never required; however, routine low pressure washing was carried out as a part of the preventative maintenance program. One project test phase required de-tuning of the precipitator to maximize ash loading to the JBR. In addition, another test phase decreased the mist eliminator wash sequence to operate once every twenty four hours. Once again, the mist eliminator performance was superb and scaling was minimal.

3.10.3 Lessons Learned

The mist eliminator housing had access doors upstream, downstream and between the mist eliminator elements. The doors located upstream and downstream were not hinged, requiring additional maintenance personnel for removal and storage. The mating flange for the upstream and downstream mist eliminators had carbon steel nuts welded to the carbon steel outside flange to facilitate tightening. Slurry and flue gas penetrated the gasket and followed the alloy bolts to the nuts causing galling, removal problems and localized flange corrosion. If the exterior flange and nuts had been manufactured from alloy and the proper gasket material specified, the problem would have been alleviated.

The design of the JBR opening required expansion of the ductwork leading to the mist eliminator in both horizontal and vertical planes. This required straightening and turning vanes to be installed to meet the face velocity deviation requirements. Entrained slurry collected on the horizontal turning vanes, rendering them ineffective for proper straightening, as shown in Figure 3-22. With the JBR outlet ductwork width maximized and a slight increase in overall height, the turning vanes could be minimized.

3.11 Coatings and Linings

- Many different coatings and linings were used throughout the process equipment. The primary function of such materials was usually erosion or corrosion resistance. The materials evaluated include:

Figure 3-22. JBR Outlet Horizontal Turning Vanes

Figure 3-23. Silicon Carbide Coating Application

Silicon carbide with FRP, used in the gas cooling duct and gas risers, as shown in Figure 3-25;

- Conveyor belt material, used on the gas risers;
- Duromar, used in the gas cooling duct and on the gas risers;
- Duromix, used in the gas cooling duct and on the gas risers (although good corrosion resistance was observed, there were some adherence difficulties);
- Coors porcelain tiles, used in the gas cooling duct;
- Nexus veil, used in the gas cooling duct; Hetron 992 resin with silicon carbide additive, used on the JBR floor under agitator; and
- Chrome carbide, used on the ID fan blade liners, where it exhibited excellent wear and corrosion resistance.

3.12 Expansion Joints

Expansion joints are installed in FGD systems to provide capacity for deflection to relieve strains caused by thermal expansion and to provide a convenient point for material change. They are usually installed in the inlet and outlet ductwork to provide axial flexibility. Thus, the expansion joints are exposed to the same corrosive and erosive conditions as the ducts in which they are installed. Expansion joints are generally U-shaped and constructed of an elastomer with fabric or wire reinforcement.

3.12.1 Materials

Some expansion joints are manufactured from high nickel alloy which has a potential for work hardening when vibration occurs and is expensive. The majority of joints upstream or dry have acceptable and predictable service life. Downstream or wet expansion joints problems have been with the attachment material rather than the joint material itself. The type of expansion joint selected is dependent upon temperature and gas/slurry chemical composition. The majority of the joint material selected has been chlorobutyl or fluoroelasteomer with fiberglass reinforcement.

Expansion joint specifications went to four bidders with material requirements unspecified. Several vendors quoted rubber joints, with the low bidder quoting Teflon coated fiberglass, a relatively new material. The Teflon was advertised as surpassing rubber in corrosion resistance and superior field repair without the chemical cure required for rubber.

3.12.2 Maintenance

All expansion joints, with the exception of the JBR inlet, performed well with no maintenance required. The JBR inlet expansion joint was in a difficult location with high flue gas velocities and all slurry passing over the joint returning to the reaction zone. The joint design required the belt inside corners to be inside the ductwork exposed to the full force of gas and slurry. After initial operation the joint was noted as having abrasion on all four inside corners exposed to the environment as shown in Figure 3-24. Furthermore, the center of the inlet duct joint attached to the JBR indicated signs of abrasion and eventually failed. The new joint was manufactured of a double thickness of Teflon with a corrosion resistant coating on the inside. This joint replaced the single ply inlet and within several months developed the same wear pattern indicated on the first joint. At that time a request for pricing went out for supply of a Viton joint with a internal chemical bearer with fiberglass reinforcement. The successful bidder had the joint manufactured and shipped for installation during the next available outage. The Viton joint has performed extremely well with no noticeable erosion or corrosion during the test plan.

The carbon steel backing bar and bolts experienced corrosion problems from the initial operation; however, they did not fail during the test period.

3.12.3 Lessons Learned

The Teflon coated joints performed reasonably well with normal flue gas velocity and slurry puddling. After replacing the inlet joint with coated Viton, it is evident that Viton will hold up to the chemical composition and abrasive/corrosive conditions encountered in the gas cooling duct.

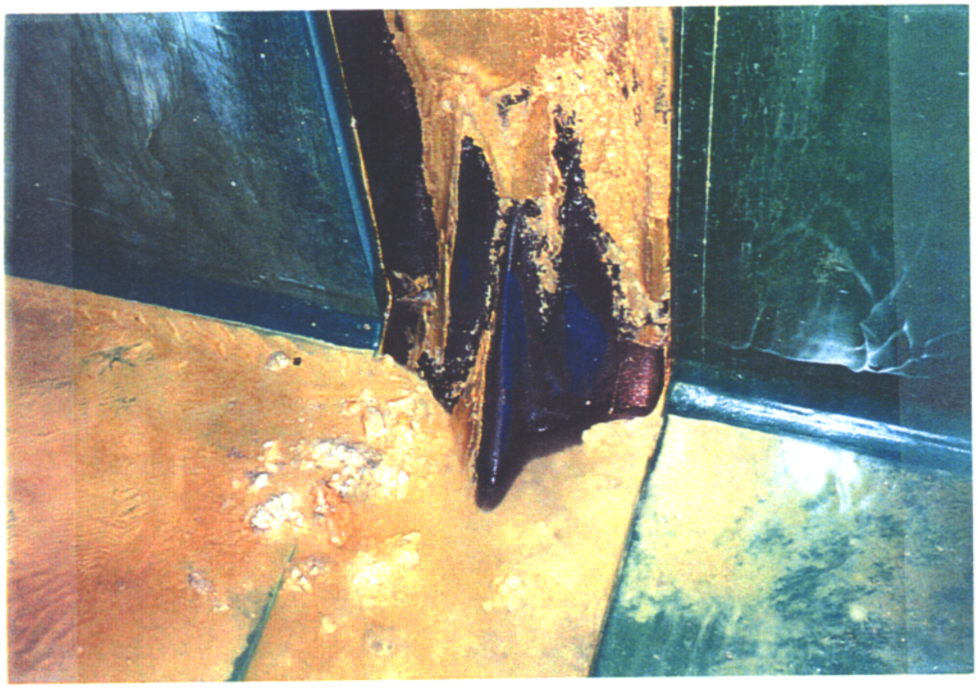

Figure 3-24. Expansion Joint Erosion Damage

3.13 Valves

Knife gate valves were used for return water and slurry service. Several different manufacturers valves were used to evaluate different designs. All of the valves used were lined to avoid the use of expensive alloy body materials. The gate materials used were 316 stainless steel for recycled water and 317LM for slurry services. Typical industry recommendations for materials for services in this pH and chloride concentration range are for alloy materials rather than the stainless materials that were used at Yates.

Actuators selected for the knife gate valves were pneumatic cylinders with spring returns (see Figure 3-25) to allow the valve to go to a desired position in the event of an air supply failure. These actuators were very large and heavy and in most cases had to be supported independently from the valve due to the weight.

3.13.1 Newcon Knife Gate Valves

The Newcon valves initially used had aluminum bodies with polyurethane liners and 317LM gates. The body used bolts to hold two body halves together. During routine replacement of the liners of these valves, these bolts were inserted incorrectly penetrating the polyurethane liner, as shown in Figure 3-26. This allowed the process fluid to come in contact with the aluminum body. Failure of the body was rapid. This occurred with several of the Newcon valves.

The aluminum bodies were replaced with epoxy coated ductile iron bodies and there were no further problems with these valves.

3.13.2 Warman Knife Gate Valves

The Warman design utilized a natural rubber-lined ductile iron body with a Teflon coated 317LM gate. These valves performed very well.

3.13.3 Townley Knife Gate Valves

The Townley design utilized an elastomer (Townleyprene) lined ductile iron body with a 317LM gate. These valves had bonnets rather than the standard design of the gate rising up out of the body with a body to gate seal. The Townley valve also had the advantage that, unlike the other valves, the valve had flanges and did not have to bolted between two flanges. This feature would make the valve very useful for connections that would need to be broken during service for maintenance. These valves also performed very well. Because of the many additional design features of this valve, the cost was significantly higher than the standard design knife gate valves.

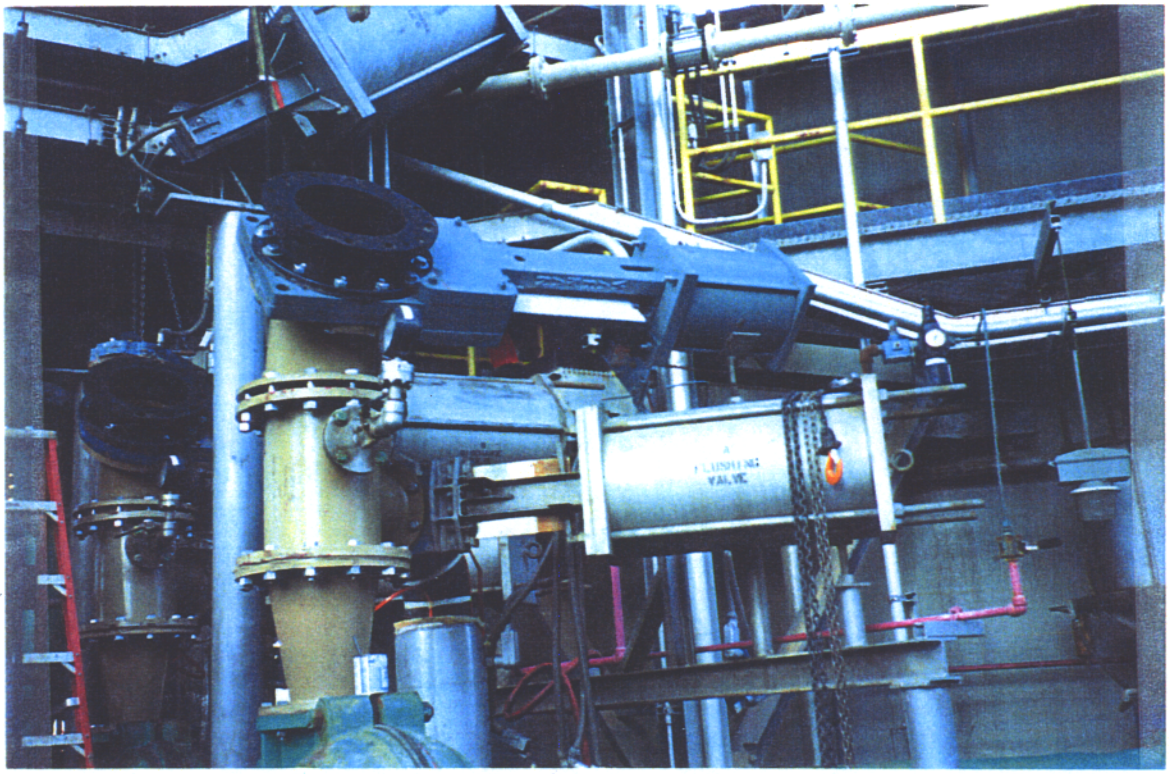

Figure 3-25. Knife Gate Valve Actuator Arrangement

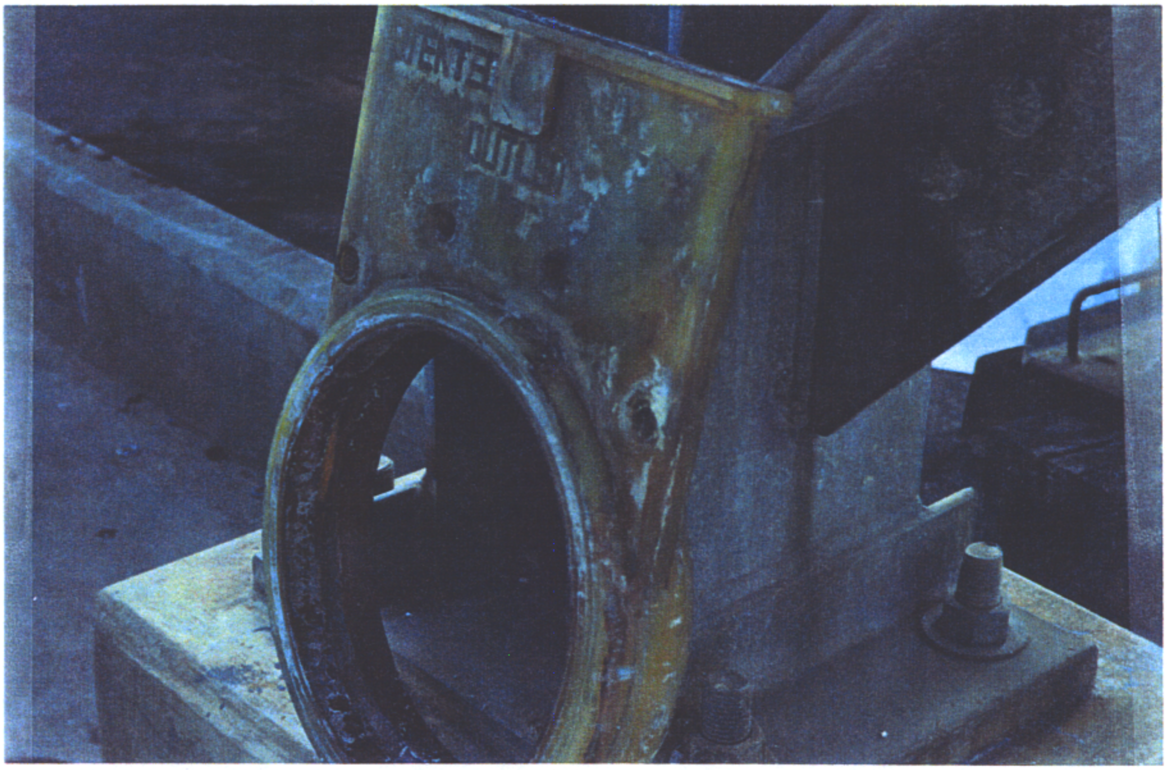

Figure 3-26. Newcon Knife Gate Valve Polyurethane Liner Holes

3.13.4 Clarkson Knife Gate Valves

The Clarkson design utilized a elastomer lined ductile iron body with a 317LM gate. These valves also performed very well; however, leakage from the body was a housekeeping problem. These valves had a flush hole in the bottom of the valve that pushed slurry out of the valve when it was closed.

3.13.5 Fisher Control Valves

Slurry control valves were Fisher Controls V500 316 stainless steel ball segment control valves with ceramic coated ball plugs. These valves were inspected after over two years service and no wear was found inside the valve.

3.13.6 Miscellaneous Drain Valves

At several locations in the system, small PVC ball valves were used for drain or for instrument connections. These valves were a major problem in freezing weather and had to be replaced.

3.13.7 Maintenance

Except for the problems with the bolting on the aluminum bodied Newcon valves and the freezing problems with the PVC ball valves, maintenance on the valves consisted of routine inspection and replacement of worn liners. In addition, there were some failures of 316 stainless steel gates in knife gate valves in recycle water service.

3.13.8 Lessons Learned

The lessons leaned regarding the valves selected for evaluation include:

- 317LM gates in knife gate valves were sufficient for this service rather than more expensive alloy materials;
- Lined knife gate valves performed satisfactorily in slurry service only requiring routine liner replacement;.
- Ceramic ball valves work extremely well in slurry throttling service;
- Inexpensive ball valves do not work well in freezing environments; and
- Spring return pneumatic actuators for slurry valves are unnecessary and are too large and heavy.