Fiberglass Reinforced Plastics Applications in Gas Cleaning Systems of Sulfuric Acid Plants

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ABSTRACT

Fiberglass reinforced plastics (FRP) is the preferred material of construction for the humidification, scrubbing, cooling, and mist removal equipment of gas cleaning systems for both metallurgical and spent acid regeneration sulfuric acid plants using MECS DynaWave® reverse jet scrubber technology. The development and application of fiberglass reinforced plastics construction over the last 20 years have made lead and brick-lined equipment a thing of the past for sulfuric acid plant gas cleaning systems, and in today's tight economy offer welcome cost savings over the high cost alloy alternatives. The gas cleaning process as well as the design and construction of carefully engineered FRP equipment to fit the operating environment are discussed.

INTRODUCTION

A source of clean gas containing sulfur dioxide and sufficient oxygen to convert it to sulfur trioxide is essential for reliable production of sulfuric acid. Sulfuric acid (H_2SO_4) plants are commonly classified into two basic categories, depending on the raw materials used:

- ☑ Sulfur burning (hot gas design)
- ☑ Metallurgical/spent acid regeneration (cold gas design)

Plants using elemental sulfur produce clean sulfur dioxide (SO_2) and require no gas cleaning. SO_2 gas is oxidized and absorbed in the acid stream. In metallurgical-type plants, by-product SO_2 gas from smelter processing sulfides of iron, copper, zinc, lead, nickel, molybdenum, or other metal is used. The gases from the smelter are heavily contaminated with dust, acid mist, fumes, volatile metals, and other gases. Gas from the spent acid decomposition contains unburned carbon, undecomposed sulfur trioxide (SO_3), inorganic contaminants, and excess water. If not removed, the contaminants will reduce product acid quality, foul the mist eliminators and catalyst beds, and accelerate corrosion of equipment in the acid plant.

The gas purification process comprises of the following four basic steps:

1. Cooling
2. Condensing
3. Particulate Scrubbing
4. Aerosol Collection

The first step is to cool the hot feed gas by adiabatic humidification to a temperature suitable for FRP construction. For the weak sulfuric acid operating environment, the maximum temperature limit for epoxy vinyl ester resins is 210°F (100°C). In addition to gas quenching, the DynaWave® scrubber has the added benefit of dust / solids removal from the gas phase at this first step. The second step is to further cool the gas stream and condense water such that the acid plant water balance can be maintained and strong sulfuric acid produced. The third step is where the bulk of the particulate between 10 and 1 microns is removed from the gas stream. The final step collects the submicron particulate or aerosols, such as acid mist and condensed metallic fumes/vapors, from the gas stream.

The gas cleaning system typically handles dirty feed gases with inlet temperatures ranging from 600°F (316°C) to 800°F (427°C). The equipment will operate with weak sulfuric acid concentrations ranging from 1% to 25% H_2SO_4 by weight, and temperatures between 100°F (38°C) and 180°F (82°C).

The warm weak sulfuric acid environment makes for a harsh operating condition for standard materials of construction. Thirty years ago the material of choice for equipment fabricated to handle the extremely corrosive weak H_2SO_4 was lead-lined steel with acid-proof or carbon brick added for protection against high gas temperatures at the transition zones. However, the lead lined construction was labor intensive and required extended construction time. These materials were marginal at best, resulting in frequent plant shutdowns and ongoing maintenance to keep operational. Because of increasing costs, excessive maintenance requirements, and potential health hazards, lead-lined steel vessels were replaced by FRP over the last twenty years as the preferred material of construction. The move to FRP construction was kicked off with the introduction of the ASME RTP-1 standard in the 1980's and the emergence of DynaWave® froth scrubbing technology as a solution for acid plant gas cleaning systems.

The benefits of using FRP construction include reduced maintenance, field fabrication and repair possible, corrosion resistance, and low cost, as the use of expensive metal alloys are now reduced to the hot gas inlet barrel at the dry/wet interface and weak acid coolers. MECS has designed more than 70 gas cleaning systems for metallurgical and spent acid regeneration plants utilizing FRP construction and DynaWave® froth scrubbing technology over the last 23 years. The initial gas cleaning system installations date back to the late 1980's and early 1990's, and continue to operate well today with no major repairs required on the FRP equipment over the many years of service.

PROCESS

Figures 1 and 2 below illustrate the typical gas cleaning system flow schemes for metallurgical and spent acid regeneration acid plants, respectively. The dirty feed gas enters the top of the primary DynaWave® scrubber through an inlet barrel, where it is quenched and scrubbed with a counter-current spray of weak acid discharged from a large bore spray nozzle. After the gas and liquid collide in the barrel, they continue co-currently through the scrubber to the disengagement vessel where the liquid and gas are separated by gravity and liquid entrainment removed from the gas with a chevron demisting device.

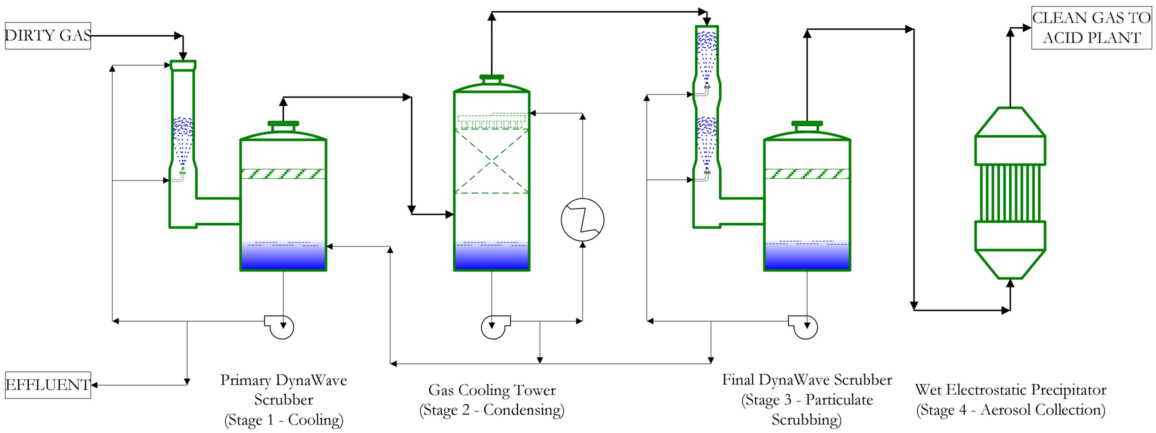

Figure 1. Typical gas cleaning system arrangement for a metallurgical acid plant.

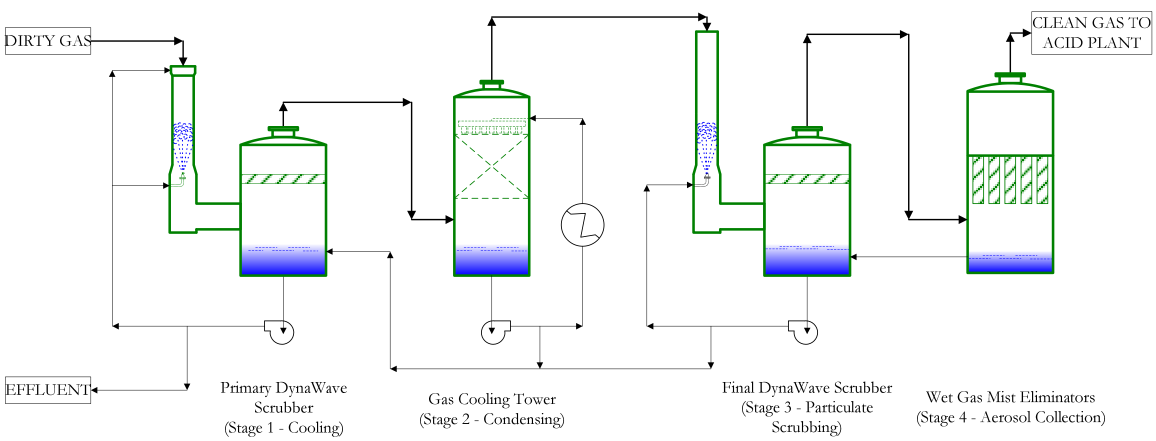

Figure 2. Typical gas cleaning system arrangement for a spent acid regeneration plant.

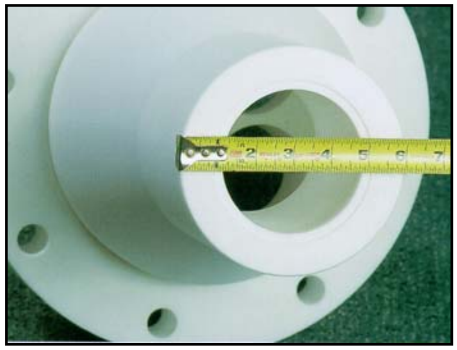

Figure 3. Typical DynaWave® reverse jet spray nozzle.

A separate flow of weak acid is sent to the weir bowl located at the top of the inlet barrel. The weak acid collects in an annular space and overflows into the interior of the barrel creating a falling film or liquid curtain on the barrel walls for protection against the high temperature gas. The primary scrubber inlet barrel and weir bowl are typically constructed of Hastelloy G-30 for additional protection. The weak acid is circulated from the base of the scrubber tank to the reverse jet spray nozzle and weir bowl by a rubber-lined or FRP centrifugal pump.

Figure 4. FRP Weir Bowl and creation of the protective liquid curtain on the interior of the primary DynaWave® inlet barrel.

Process gas from the primary DynaWave® scrubber is sent to the gas cooling tower, and flows upward through a layer of random plastic packing. The gas is contacted with cold weak acid flowing downward through the packed section to reduce the gas temperature. As the gas is cooled, water vapor is condensed from the gas, and mist and fume particle growth enhanced for improved collection efficiency downstream. The gas exits the top of the gas cooling tower and flows to the final reverse jet scrubber. The weak acid is collected in the base of the gas cooling tower, and circulated through a plate and frame heat exchanger for cooling, and back to the top of the packed section with a rubber-lined or FRP centrifugal pump.

The gas from the gas cooling tower enters the inlet barrel of the final DynaWave® scrubber where it is scrubbed with a counter-current spray of weak acid from a large bore spray nozzle. This may occur in one or two stages depending on the impurity loading of the inlet feed gas. The gas and liquid mixture flows from the scrubber barrel to the scrubber tank, where the liquid is separated from the gas and collects in the base of the tank. A chevron entrainment separator in the vessel further removes entrained liquid from the exiting gas.

Figure 5. Gas cooling tower and final DynaWave® scrubber for a spent acid regeneration plant under construction

Following the final DynaWave® scrubber, the gas is further conditioned with the collection of aerosol contaminants. For a metallurgical acid plant, a wet electrostatic precipitator is used to remove the remaining submicron acid mist and condensed metallic fumes/vapors which were not captured by the DynaWave® scrubbers. The wet electrostatic precipitators are constructed of FRP with multiple parallel collection tubes which contain discharge electrodes for ionization of the process gas. An electrical charge is imparted on the suspended particles which are then attracted to the collection tube wall via an electrostatic field and gravity flushed to the bottom of the vessel. For a spent acid regeneration plant which processes spent acid from a refinery alkylation process, wet gas mist eliminators are utilized to collect submicron acid mist which was not captured by the DynaWave® scrubbers. The acid mist is removed by impingement on glass fiber elements, through either impaction or diffusion. The wet gas mist eliminators are MECS HE "High Efficiency" elements. The elements are typically constructed of FRP wire cages for corrosion resistance to the wet gas conditions. Drainage from the wet gas mist eliminator elements goes to the bottom of the final DynaWave® scrubber vessel. The wet gas elements are either placed in the upper section of the final DynaWave® scrubber vessel or in a separate FRP vessel. The wet gas mist eliminators are not recommended in metallurgical acid plants which generally have high solids loading and metallic fumes/vapors in the feed gas which would plug the elements over a relatively short operating period.

Figure 6. Dual wet gas mist eliminator vessels for a spent acid regeneration plant under construction.

With the DynaWave® Froth Scrubbing technology, scrubbing liquid is injected countercurrent to the gas stream to balance liquid and gas momentums, forming a Froth Zone.

Figure 7. Liquid component of the Froth Zone formation as viewed from the top of the primary DynaWave® inlet barrel during commissioning.

A Froth Zone is a region of intense turbulence, with substantial back-mixing and a high rate of liquid surface renewal with intense mass and energy transfer. The momentum of the gas causes the liquid to spread out radially toward the walls and form a standing wave or Froth Zone at the point where the liquid and gas momentums are balanced. Turbulent films of liquid occlude and envelop the particulate or gaseous contaminants while also providing the gas-liquid contacting necessary for mass and heat transfer. The wave shifts up or down within the barrel depending upon relative gas and liquid momentums. Due to the large, open bore injectors that are used, fine liquid particles created by atomization are not present in the exhaust gas. The creation of large droplets makes gas-liquid separation easy, preventing carryover of liquids and contaminants in the exhaust gas.

The corrosion resistance of FRP makes it an ideal material of construction for the vessels, piping, gas ducts, and pump casings within the gas cleaning system of a sulfuric acid plant. The sketch shown in Figure 8. illustrates the primary components of a DynaWave® scrubber with the material of construction indicated.

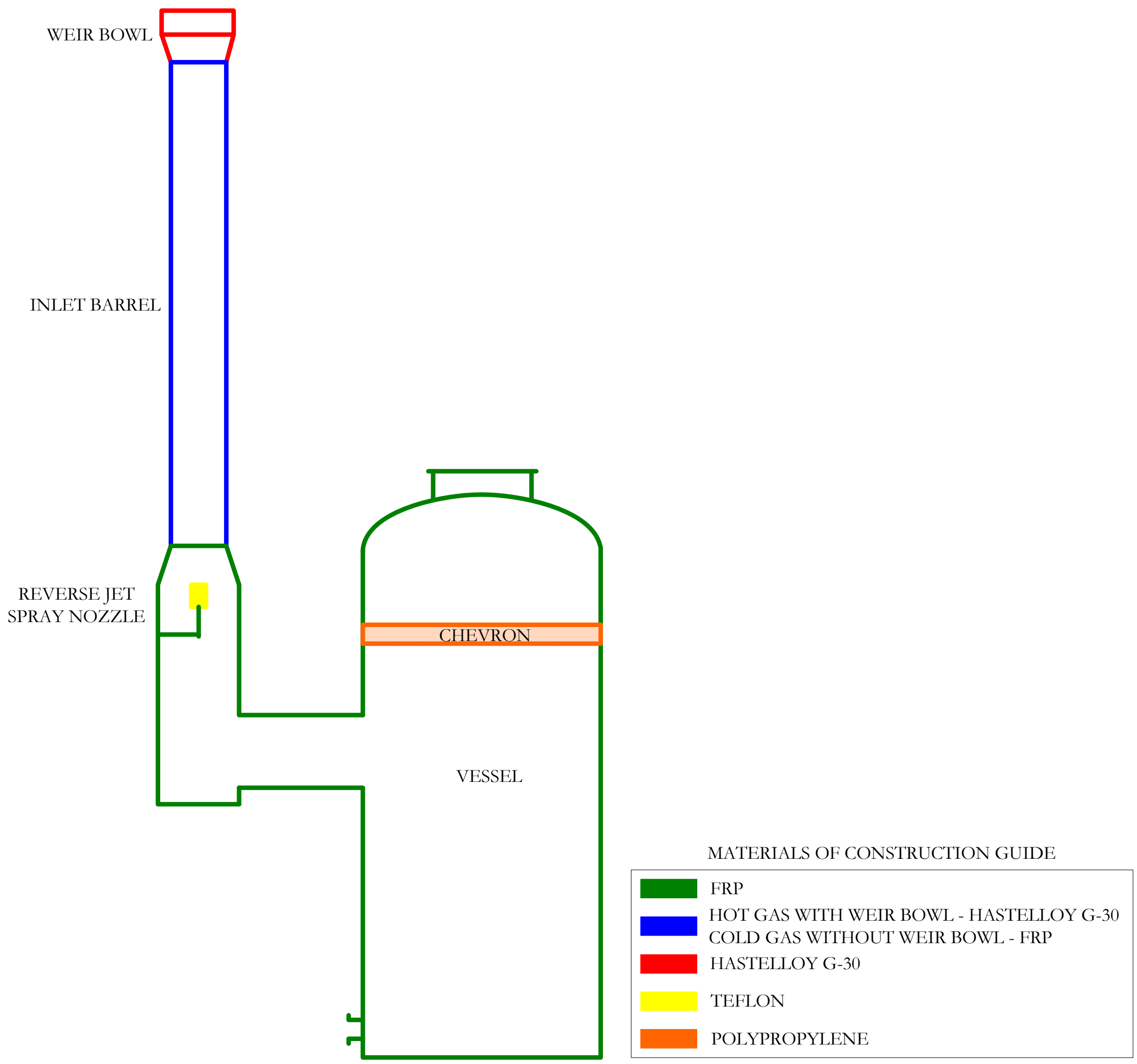

Figure 8. Typical DynaWave® scrubber components and materials of construction

FIBERGLASS-REINFORCED PLASTIC (FRP)

FRP consists of glass fibers that are bonded together with a thermoset resin to form a composite structure that can be used to make boats, bath tubs, and showers. In an environment of harsh chemicals, FRP structural layers must be combined with a corrosion barrier including careful consideration of its composition. The following information describes the composition of corrosion-resistant FRP and the processes by which it is made.

The standard composition of a corrosion resistant laminate is shown in Figure 9. From left to right, the figure shows that the corrosion barrier consists of a veil followed by at least two layers of chopped strand mat. The purpose of the corrosion barrier is to provide a resin rich layer of glass to protect the structural layers from chemical attack. The veil layer contains about 90% resin and comes into direct contact with the chemical environment. The chopped strand mat layers back up the veil and contain about 75% resin. The total thickness of the corrosion barrier is normally 100 mils, but the corrosion barrier may be thicker for very aggressive chemical environments.

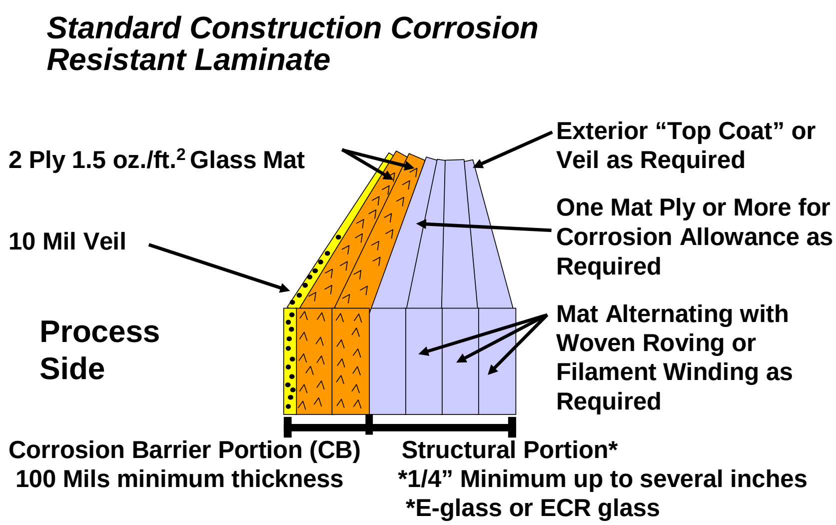

Figure 9. Corrosion Resistant Laminate Construction.

The structural layers, as shown on the right side of the diagram, give strength and stiffness to FRP. Depending on the fabrication method, the structural layers can consist of a combination of glass types that are applied in layers as needed for the desired properties. The higher the glass content, the stronger and stiffer the FRP becomes. The properties of the structural layer are accomplished by a careful selection of the glass layer types and fabrication method. The structural layers can consist of heavy layers of woven glass called woven roving alternating with layers of chopped strand mat. Or it can consist of helically wound glass roving interspersed with chopped roving to give high glass content/high strength structural layers. Others types of construction consist of hoop wound roving with layers of unidirectional glass in the axial direction.

RESIN SELECTION

Resin selection is the first critical step for the successful use of FRP in chemical service. Not all resins are suitable for chemical resistant applications, so the resin needs to be carefully selected based on the three critical pieces of information: (1) the generic identity of the chemical or chemicals, (2) the concentration of each chemical, and (3) the operating temperature of the chemical or chemicals that comprise the chemical environment.

Thermoset resins come in a variety of compositions that greatly affect the chemical resistance of FRP. Corrosion resistant FRP made from epoxy vinyl ester resin has excellent chemical resistance to acids, bases, salts, and many types of solvents. Also, FRP made from epoxy vinyl ester has unusual toughness and resistance to cracking caused by mechanical impact and thermal cycling.

In gas cleaning processes, MECS will typically use FRP equipment made from DERAKANE®411-350 epoxy vinyl ester resin or DERAKANE 470 epoxy novolac resin. The resin choice will depend on the temperature and concentration of the sulfuric acid. FRP made with DERKANE 470-300 resin generally can be used at higher concentrations and /or temperatures in acid. For example, FRP made with DERAKANE 411-350 resin is suitable for 75% sulfuric acid up to a maximum temperature of 100 deg F, whereas DERAKANE 470-300 resin is suitable up to 180°F.

FRP FABRICATION METHODS

The oldest and most basic process for FRP fabrication is called hand lay-up or contact molding, as shown in Figure 10. In the hand lay-up process, the mold surface is wet out with catalyzed resin using a brush or paint roller. Glass veil and chopped strand mat are then applied to the mold surface and are rolled out to remove any air bubbles. Once the corrosion barrier is completed, the process of applying resin and glass and rolling out is repeated using alternating layers of chopped strand mat and woven roving until the desired thickness is achieved. The resin is allowed to cure for up to 24 hours before the FRP is removed from the mold. Hand lay-up is used to make tank shells, bottoms, tops, manways, covers, nozzles, pipes, and many other chemical resistant parts. Hand lay-up is also used to join FRP parts by a process called "secondary bonding". An example would be joining a tank bottom to a tank shell.

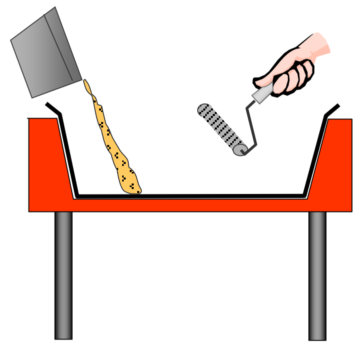

Figure 10. Typical Hand Lay-Up Molding Process

A process that is similar to hand lay-up is hand spray-up as shown in Figure 11. Instead of applying the chopped strand mat by hand, a chopper gun is used to spray the resin and glass at the same time to form the chopped strand mat. It can be used in the corrosion barrier and in the alternating layers of mat and woven roving that form the structural layers of the laminate.

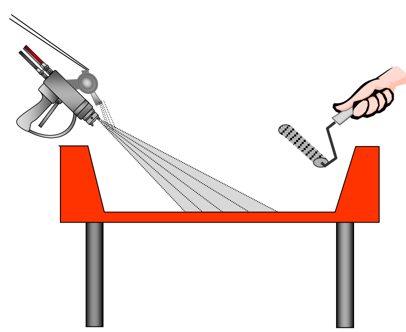

Figure 11. Typical Spray-Up Molding Process

In the filament winding process, shown in Figure 12, the structural layers are applied by winding glass roving over a cured corrosion barrier that has been previously applied by hand lay-up or spray up. The advantage of filament winding is that the structural layers have a high glass content are stronger than hand lay-up structural layers. The stronger layers do not have to be as thick as hand lay-up layers and can be used to reduce cost.

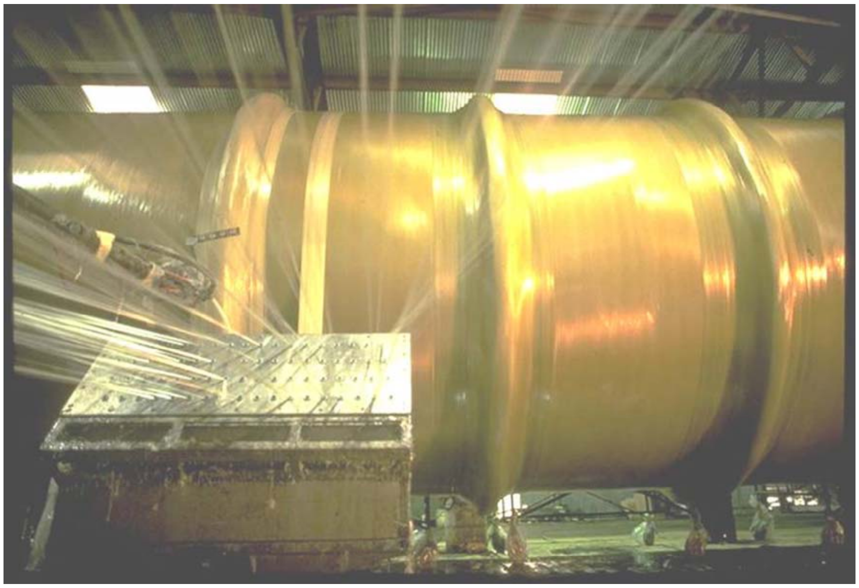

Figure 12. Horizontal Filament Winding in a Shop Setting

Vertical filament winding, shown in Figure 13, consists of hoop winding glass roving combined with layers of unidirectional glass in the axial direction. This method has been used to fabricate FRP vessels up to 120 feet in diameter. Normally shop fabricated vessels are limited to 16 feet in diameter.

Figure 13. Vertical Filament Winding in a Field Setting

FRP APPLICATIONS

FRP is used to fabricate tanks, pipes, scrubbers, pumps, and fans. Examples are shown below starting with field wound tanks in Figure 14.

Figure 14. Large Field Wound Hot Water Storage Tanks

Figure 15. A Pressure Blower and an Axial Fan

Figure 16. Large Flue Gas Scrubber for a Power Plant

Figure 17. Field Wound Ducts and Chimney Liners for Flue Gas

Figure 18. All FRP Cooling Towers

Figure 19. Abrasion Resistant Pipe for Phosphate Fertilizer Process Slurry

OPERATING TEMPERATURE AND PESSURE LIMITATIONS

Operating temperature limitations are determined by the chemical type and concentration. See the DERAKANE Chemical resistance guide at derakane.com. for these limitations. Most liquids are limited to 210°F no matter what the chemical concentration. Gases can be handled as high as 350°F. The pressure limitation for tanks is 15 psig and 150 psig for pipe. Higher pressures require special fabrication standards and procedures.

SUMMARY

The operating conditions associated with a sulfuric acid plant gas cleaning system requires that the selected material of construction withstand 1 to 25% H_2SO_4 by weight at temperatures up to 180°F. This service is not compatible with most common metallic materials of construction. Only high cost metal alloys offer the corrosion resistance required. The use of fiberglass reinforced plastics for the construction of gas cleaning systems with MECS DynaWave® scrubbing technology offer a perfect solution for effective cleaning of the process gas while handling the highly corrosive operating environment. FRP has a distinct advantage over metal alloys or lead-lined construction as used in the past with lower installation costs, reduced maintenance, and long service life which has been proven with over 20 yrs of operating experience.