THE RAPID GROWTH OF FIBERGLASS REINFORCED PLASTIC (FRP) IN FGD SYSTEMS

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Abstract

Globally, governments are becoming increasingly concerned about the air we breathe. Regulatory agencies are aggressively implementing air pollution control (APC) standards, which require sophisticated scrubbing equipment for flue gases emitted by energy generating boiler systems. The environment in these air pollution control systems is highly corrosive to stainless steel and even higher nickel alloys. As a result, fiberglass reinforced plastic (FRP) composites made from epoxy vinyl ester resins have become the preferred material of construction in many facets of air pollution control equipment from a performance perspective. The demand for corrosion resistant composites made from epoxy vinyl ester resins increased significantly in 2006 when nickel prices ballooned from $6/lb to $15/lb. Nickel prices continued to escalate into 2007, surpassing $22/lb. While pricing for nickel and its related alloys has abated significantly since this time, these materials of construction continue to command a premium over FRP. With a 60-year reputation for low maintenance and relatively stable cost, FRP provides design engineers with a reliable, cost-effective alternative that can be employed in numerous FGD applications from scrubbers and stack liners to piping and wastewater treatment. Although other materials may be cost competitive with FRP, their use typically results in higher life cycle costs due to required maintenance. This paper will compare FRP with high nickel alloy and stainless steel in "wet process" Flue Gas Desulfurization (FGD) environments. Relative cost and corrosion performance data will be presented to provide the information necessary to facilitate future design engineering decisions concerning materials of construction.

Introduction

Over the next decade, owners of coal-fired power plants around the globe are expected to spend nearly $200 Billion to add flue gas desulfurization (FGD) systems to existing and new combustion units. Most of this investment will be in China and the United States. Many emerging industrial nations, however, such as India and South Africa are also investing heavily in air pollution control (APC) technologies. The world is indeed waking up to the need to protect the air we breathe as a scarce resource for generations to come.

In the past, air pollution control equipment was routinely constructed from stainless steel and other corrosion resistant nickel alloys due to the inherent corrosivity of the scrubbing process. Prior to 2006, high nickel alloy was the material of choice for many “wet process” FGD environments found in coal fired electric power plants. More recently, however, it has been found that these environments often contain very high chloride and fluoride levels which are highly corrosive to stainless steel. The cost of stainless steel and higher nickel alloys has also increased significantly, making corrosion resistant process equipment based upon these metals very expensive relative to other materials of construction. This has spawned a tremendous need for less expensive corrosion resistant materials.

FRP has a long history of success in air pollution control processes for a range of industries. Typical applications include stack liners, storage tanks, limestone slurry piping and low pH/ high chloride scrubber systems. APC equipment made from FRP is relatively inexpensive compared to alloys with case histories supporting its use dating back to 1973 in flue gas desulfurization applications.

Alternative materials for air pollution control environments such as rubber-lined carbon steel and acid brick-lined carbon steel can also be used. These materials, however, do not all have the same service life expectancy, nor do they have the same cost. In this paper, FRP will be used as a reference material compared to other materials for service life and cost in APC processes.

FRP Cost versus Other Materials of Construction

With the rising price of nickel, Fiber Reinforced Plastic has become a very competitive material of construction. The total installed cost for FRP ranges from about $50 to $70 per square foot in North America (prices may vary in other countries). It is considerably less expensive than stainless steel (Table 1) and far less expensive than C-276 alloy clad carbon steel. FRP also has a considerably longer service life in the high chloride and fluoride environments found in FGD applications.

Table 1. Material of Construction Cost Comparison

Construction Material	Cost*	Cost Ratio
Shop Fabricated FRP	$50 / Sq Ft	1.00
Field Fabricated FRP	$70 / Sq Ft	1.40
2205 stainless steel 3/8 inch plate	$225 / Sq Ft	4.50
C-276 clad carbon steel	$330 / Sq Ft	6.60

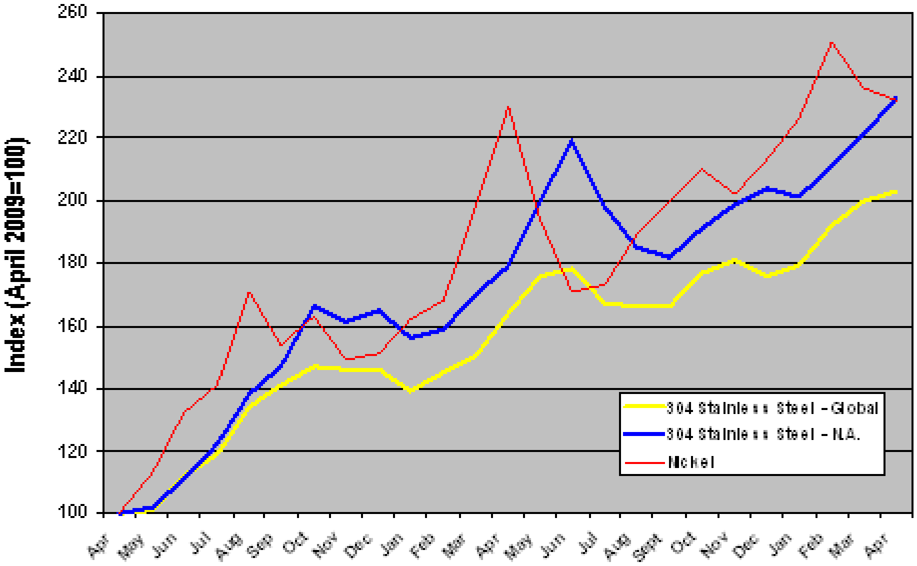
*Cost obtained from 2011 Ashland North America survey.

Differences in material costs can make a huge difference when applied to large corrosion-resistant FGD structures. One recent example is an FRP outlet hood designed for an Advatech scrubber in a southern US coal-fired power plant (Figure 1). The hood was approximately 128 feet long, 34 feet wide and 32 feet high. Designing the scrubber outlet hood with FRP rather than C-276 steel saved the utility $4.2 million. The hood was assembled on the ground and lifted as a single piece, which saved additional construction, labor and lifting costs.

Figure 1. FRP Scrubber Hood Saves Utility $4.2 MM Compared to C-276

Stainless steel prices continue to trend rapidly upward in concert with the price and availability of nickel. As the global economy strengthens and developing nations increase their infrastructure build, base metal pricing – most notably copper, nickel and stainless steel are expected to continue their upward march (Figure 2). Moreover, the availability of stainless steels and higher nickel alloys is falling off and delivery times are lengthening considerably.

Figure 2. Stainless Steel and Nickel Price Volatility – April 2009 - Present



Source: International Monetary Fund; MEPS Ltd

FRP Chemical Resistance versus Metals

Chemical resistance is a key predictor of service life in wet FGD processes. Compared to metals (Table 2), FRP made from epoxy vinyl ester resin has as good or better chemical resistance than Alloy C-276 and is superior to 2205 stainless steel. FRP has an unusual resistance to dissolved chlorides and moderate concentrations of sulfuric acid. It is superior to alloys in aqueous acidic high chloride environments. Based on more than 30 years of experience and testing in wet FGD processes, FRP made from epoxy vinyl ester resin has the chemical resistance necessary for long-term service life.

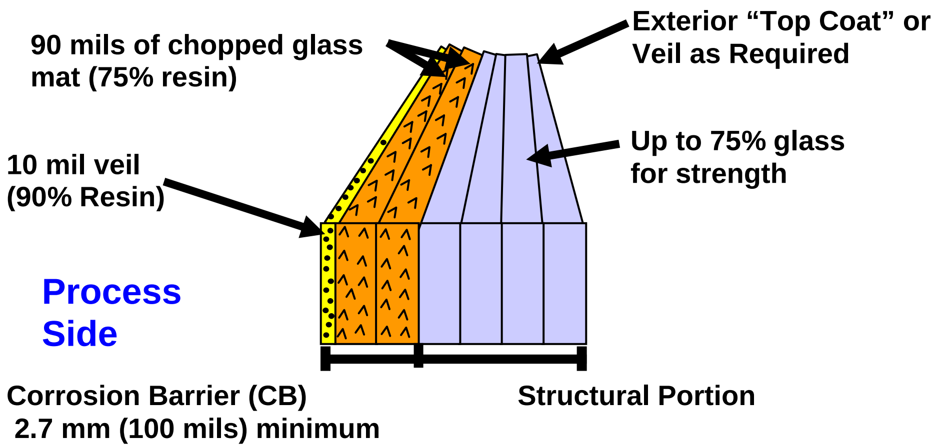
Table 2. Epoxy Vinyl Ester Resin Chemical Resistance Compared to Nickel Alloys.

Materials	**Sulfuric Acid**	**Hydrochloric Acid**	**Acid Chloride Salts**
FRP made with epoxy vinyl ester resin	100°C to 30%	80°C to 15%	100°C All conc.
2205 Stainless Steel	30°C to 30%	60°C to 1%	65°C to 2000 ppm @ low pH
Alloy C-276	100°C to 30%	80°C to 15%	65°C to 50M ppm @ low pH

Fiberglass-Reinforced Plastic (FRP)

FRP is a laminate of E-glass fiber and thermoset resin as shown in Figure 3. Corrosion resistant FRP is made from a premium epoxy vinyl ester thermoset resin. The corrosion barrier (CB), on the process side of the laminate, has high resin content for maximized corrosion resistance. The structural layers have high glass content for optimum strength and modulus.

Figure 3: Typical Corrosion Resistant FRP Laminate Construction

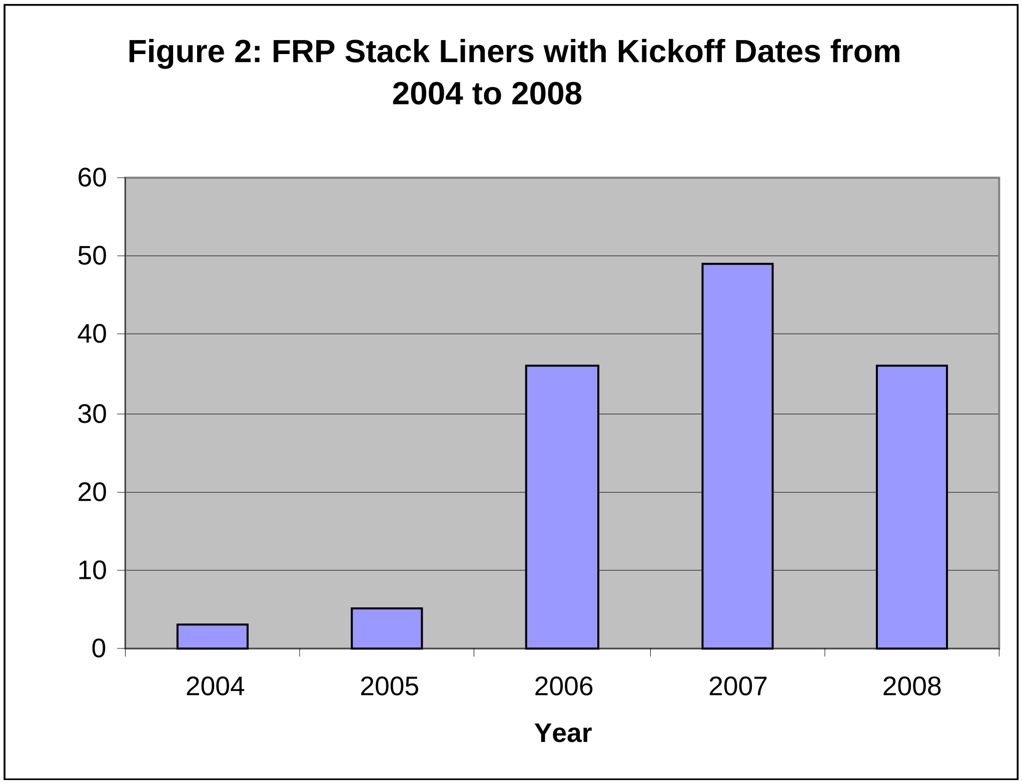


For most wet applications, the maximum operating temperature is 100°C (212°F) with excursions up to 120°C (248°F). Dry environments can operate at 177°C (350°F) with excursions up to 204°C (400°F). Because not all resins are suitable for processes that have thermal cycling or high temperature excursions, it is important to consult the resin manufacturer when designing for these applications.

FRP Growth in Wet FGD Applications

In 2005 the Environmental Protection Agency (EPA) implemented the Clean Air Interstate Rule (CAIR). CAIR intent was to reduce sulfur dioxide (SO_2) emissions by 70% and nitrogen oxide (NOx) emissions by 60% across 28 eastern US states by 2015. That same year EPA also implemented the Clean Air Mercury Rule (CAMR) to significantly reduce mercury emissions from coal fired power plants in those same states. These landmark statutes created an enormous opportunity for air pollution control projects in the coal-fired utility industry. In 2004 and 2005, only eight chimney stack liner projects were initiated. Between 2006 and 2008, however, another 118 stack liner projects were kicked off. (Thirty five were kicked off in 2006, forty nine in 2007 and thirty four in 2008.)

Figure 4. FRP Stack Liners with Kickoff Dates from 2004 – 2008



The utility, location, and kickoff dates of each stack liner are shown in Table 3. They are mostly in the Eastern United States with some in the Midwest and Southern United States. In addition to the many stack liner projects shown below, FRP was employed in the construction of 24 Jet Bubbling Reactor type scrubbers, 75 limestone slurry piping systems, dozens of FGD ducting systems and the internals of more than 50 standard absorber towers.

Table 3. FRP Stack Liners with Kickoff Dates from 2004 to 2008

Utility	Station/Location	Kickoff Year
Progress Energy	Asheville #1,2/Arden, NC	2004
AEP	Mitchell #1,2, Moundsville, WV	2004
WE Energies	Pleasant Prairie, WI	2004
Dominion	Chesterfield #6, Chester, VA	2005
Progress Energy	Roxboro #3, Semora, NC	2005
DP&L	Stuart #3, Aberdeen, OH	2005
PPL	Montour #1,2, Washingtonville, PA	2005
AEP	Mountaineer, New Haven, WV	2005
Southern	Bowen #4,Cartersville, GA	2006
TVA	Bull Run #1, Clinton, TN	2006
Duke Power	Belews Creek #2, Walnut Cove, NC	2006
AEP	Amos #3, Winfield, WV	2006

Utility	Station/Location	Kickoff Year
AEP	Cardinal #1, Brilliant, OH	2006
AEP	Cardinal #2, Brilliant, OH	2006
DP&L	Stuart #2, Aberdeen, OH	2006
Indianapolis P&L	Harding Street #7, Indianapolis, IN	2006
Kentucky Utilities	Ghent #3, KY	2006
Progress Energy	Roxboro #4, Semora, NC	2006
Southern	Gorgas #8,9,10, Parrish, AL	2006
Duke Power	Belews Creek #1, Walnut Cove, NC	2006
Progress Energy	Roxboro #1, Semora, NC	2006
AEP	Amos #1, Winfield, WV	2006
PPL	Brunner Island #3, York Haven, PA	2006
Ohio Edison	Sammis #6, Stratton, OH	2006
Allegheny Energy	Hatsfield Ferry #1,2, Masontown, PA	2006
AEP	Amos #2, Winfield, WV	2006
Duke Power	Allen #1-5, Belmont, NC	2006
Kentucky Utilities	Ghent #2, KY	2006
WE Energies	Elm Road #5,6, WI	2006
Alcoa	Warrick #2,3, Newburgh, IN	2006
Indianapolis Power & Light	Petersburg #3, Indiana	2006
Cinergy/PSI Energy, Inc.	Gibson #1, 2, & 3, Owensville, IN	2006
Dayton Power & Light	J.M. Stuart Unit 1,2,3,& 4 Aberdeen, OH	2006
DTE Energy	Monroe Units 3 & 4, Monroe, MI	2006
Duke Energy	Belews Creek #1, & 2	2006
PPL Corporation	Montour Station Washingtonville, PA	2006
Santee Cooper	Winyah #1 & 2	2006
Southern Company Alabama Power	E.C. Gaston Unit 5 Wilsonville, AL	2006
Southern Company Alabama Power	Gorgas Units 8, 9, & 10 Parrish, AL	2006
Southern Company Georgia Power	Bowen #1 & 2, Cartersville, GA	2006
TVA	Bull Run, Tennessee	2006
We Energies	Elm Road #1 & 2, Oak Creek, WI	2006
Allegheny Energy Greensberg, PA	Hatfield's Ferry Units 1,2,3 Masontown, PA	2006
AEP	Conesville #4, OH	2007
DP&L	Stuart #1, Aberdeen, OH	2007
Kentucky Utilities	Ghent #1, KY	2007
Lower CO River Auth.	Fayette #1, LaGrange, TX	2007
Lower CO River Auth.	Fayette #2, LaGrange, TX	2007
Ohio Edison	Sammis #1-4, Stratton, OH	2007
Progress Energy	Roxboro #2, Semora, NC	2007
Southern	Wansley #1, 2, Roopville, GA	2007
Alcoa	Warrick #1,4, Newburgh, IN	2007
Detroit Edison	Monroe #3, 4, MI	2007
Ohio Edison	Sammis #7, Stratton, OH	2007
Basin Electric Coop. / Sargent Lundy	Leland Olds Units 1 & 2, Stanton, ND	2007

Utility	**Station/Location**	**Kickoff Year**
Cinergy/PSI Energy, Inc. Div.	Cayuga #1, & 2,Terre Haute, IN	2007
Cinergy/PSI Energy, Inc. Div.	Miami Fort Units 7 & 8, North Bend, OH	2007
CPS Energy	J.K. Spruce Plant Unit 2, San Antonio, TX	2007
Duke Energy	C.G. Allen #1, 2, 3, 4, 5, Gaston County, NC	2007
Dynegy Midwest / Sargent Lundy	Havana Unit 6, Havana, IL	2007
Dynegy Midwest / Sargent Lundy	Baldwin #1, 2, & 3, Baldwin, IL	2007
Gainsville Regional Utilities (GRU)	Deerhaven Generating Station, Unit # 2, Gainsville, FL	2007
GenPower, LLC Nedham, MA	Longview Power Station Maidsville, WV	2007
Indianapolis Power & Light	Harding Street Station Indianapolis, IN	2007
LG&E -KUC	E.W. Brown Unit 3	2007
LG&E -KUC	Ghent Station Unit 1, 3 & 4, Ghent, KY	2007
LG&E -KUC Cummins & Barnard	Trimble County Unit #2, Bedford, KY	2007
Minnesota Power, Duluth, MN	Boswell, Unit 3, Cohasset, Minn.	2007
PacifiCorp - Utah Power	Huntington Canyon Plant Unit #2, Huntington, Utah	2007
Plumb Point Power (LS Power)	Plumb Point Energy Station Osceola, AR	2007
PPL Corporation	Brunner Island #3,York County, PA	2007
Progress Energy	Lee, Goldsboro, NC	2007
Progress Energy / Worley Parsons	Mayo #1 & 2, Roxboro, NC	2007
Progress Energy / Worley Parsons	Crystal River Units 4 & 5 Crystal River, FL	2007
Reliant Energy	Cheswick Power Station Springdale, PA	2007
Reliant Energy	Keystone Station Units #1 & 2 Shelocta, PA	2007
Salt River Project Washington Group	Springerville Station, Unit 4 Springerville, AZ	2007
SCE&Ga SCANA Corp.	Wateree Units 1 & 2, Eastover, SC	2007
Southern Company Georgia Power	Hammond #1, 2, 3, & 4, Coosa, GA	2007
TVA	Kingston, Tennessee	2007
TVA	Colbert, Alabama	2007
TXU Corp.	Sandow Plant, Unit 5, Milam County, TX	2007
TXU Corp. - Oak Grove Mgt. Co.	Oak Grove, Units 1 & 2, Robertson County, TX	2007
Western Farmers & Brazos Elec. Co-op	Hugo Unit 2, Anadarko, OK	2007
AEP	Conesville Plant Unit #4, Conesville, OH	2007
AEP	Kyger Creek 1 – 5, Gallipolis, OH	2007
AEP	Cliffy Creek 1 – 5, Madison, IN	2007
Allegheny Energy Greensberg, PA	Fort Martin Units 1&2, Maidsville, WV	2007
Ameren	Coffeen Plant, Coffeen, IL	2007
Ameren	Duck Creek Plant, Canton, IL	2007
Constellation Energy	Brandon Shores Units 1&2, Baltimore, MD	2007
Dominion	Chesterfield Unit # 6, Chester, VA	2007
Alabama Electric Coop	Lowman Station, Leroy, AL	2008

Utility	Station/Location	Kickoff Year
Allegheny Energy	Pleasants, Pleasants WV	2008
DP&L	Stuart #4, Aberdeen, OH	2008
Duke Power	Marshall, Terrel, NC	2008
City of Sringfield, IL	Dallman, Springfield, IL	2008
Alabama Power	Gaston #1, Wilsonville, AL	2008
Kentucky Utilities	Ghent #4, KY	2008
Duke Energy	Cliffside Plant Units 6 & 7, Cliffside, NC	2008
LS Power East Brunswick, NJ	Long Leaf Project, Early County, GA	2008
Ohio Valley Electric Corp.	Kyger Creek, Cheshire, Ohio	2008
Progress Energy	Cape Fear Units 1 & 2, Siler City, NC	2008
Progress Energy	L.V. Sutton, Wilmington, NC	2008
Public Service Electric & Gas Co.	Hudson Unit #2, Jersey City, NJ	2008
Public Service Electric & Gas Co.	Mercer Plant Units 1 & 2, Trenton, NJ	2008
SCE&G.	Williams Station, Charleston, SC	2008
Southern Company Alabama Power	Plant Barry, Bucks, AL	2008
Southern Company Alabama Power	J.H. Miller Units 3, & 4, West Jefferson, AL	2008
Southern Company Georgia Power	McDonough/ Atkinson #1, 2, Smyrna, GA	2008
Sunbury Generation LLC	Sunbury Units 1 & 2, Shamokin Dam, PA	2008
Wisconsin Public Service Corp.	Weston Plant, Unit #3, Wausau, WI	2008
XcelEnergy	Comanche Unit #3, Pueblo, CO	2008
Alliant Energy - Wisconsin Power & Light	Columbia Energy Center, Portage, WI	2008
CWLP, Springfield, IL	Dallman Station, Unit # 4, Springfield, IL	2008
East Kentucky Power	John Sherman Cooper Plant, Unit 2, Burnside, KY	2008
Otter Tail Power Co.	Big Stone II, Milbank, SD	2008
Public Service of New Hampshire	Merrimack Station, Units 1 & 2, Bow, NH	2008
Salt River Project / Sargent & Lundy	SRP Coronado Plant, Saint Johns, AZ	2008
Sithe Global Power, LLC Houston, TX	Desert Rock Energy Co., Farmington, NM	2008
We Energies	South Oak Creek Retrofit, Units 7 & 8, Oak Creek, WI	2008
XcelEnergy	Sherco Plant Units 1&2, Becker, Minn.	2008
NRG Energy	Indian River Units 1,2,3 & 4, Millsboro, DE	2008
Power4Georgians Coop	Washington County Power Station, Sanderville, GA	2008
Southern Company, Georgia Power	Scherer Plant Units 1,2,3,4, Juliette, GA	2008
CMS Energy	Karn / Weadock Complex, Bay City, MI	2008

The service life of stack liners made from FRP is expected to be the life of the power plant with very little maintenance. This would be equivalent or superior to the expected performance of C-276 clad steel stack liners. Flake glass coatings over carbon steel typically require inspection and maintenance very 8 years and replacement after 15 - 18 years. Brick lined stacks have a history of significantly greater ongoing maintenance and shorter service life compared to FRP stack liners.

Stainless Steel Experience

Since 2004, roughly 130 FGD scrubbers have been installed at coal-fired power plants in the US. The vast majority of these scrubbers have been constructed from stainless steel. A number of these scrubbers have experienced severe corrosion problems after short term operation – in some cases less than one year. Both austenitic and duplex stainless steels have shown susceptibility to crevice corrosion with the duplex stainless steel (2205) being the most vulnerable.

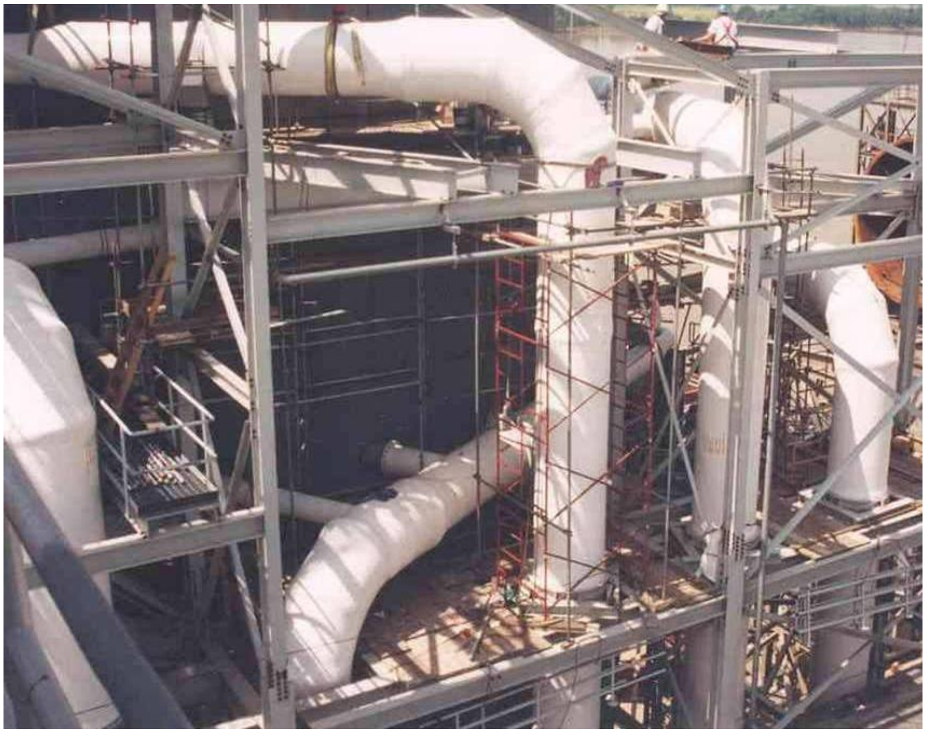
The FGD scrubber environment is exceptionally challenging for metals. The immersion zone in the scrubber operates at about 125 F (52 C), and a pH of 5. Chloride concentrations typically range around 5000 ppm but have been reported as high as 20,000 ppm in some systems depending upon the coal source in use. Dissolved fluorides further compound the challenge to metal durability. Recent work done by DNV(1) established that Alloy 2205 does not have sufficient corrosion resistance in the absorber environment, particularly in the presence of scale. It is anticipated that a great many of these FGD scrubber shells will have to be lined or replaced within the next 5 years or less.

Figure 5. Heavily Pitted Duplex Stainless Steel with Epoxy Vinyl Ester Flake Glass Repair Lining – Courtesy of Blome International

FGD Case Histories

Case histories of FRP for wet FGD processes in absorber towers or vessels, slurry piping, ductwork, and stack liners date back to the early 1970's. The most prominent applications are limestone slurry piping (Fig. 5) followed by stack liners. With an abrasion-resistant liner, FRP pipe based on epoxy vinyl ester resin has been successful in more than 150 plants sites dating back to 1977. The driving force for this growth is the high cost and challenging procurement of specialty steels, the relatively stable cost of FRP and the proven durability of FRP in these aggressive corrosive applications.

Figure 5. Limestone Slurry Piping for an FGD Process in a Power Plant
in the Eastern United States



The use of FRP in wet FGD stack liners dates back to 1979. Most of them are still in service today (Table 4). As with all construction materials in corrosive environments, FRP has specific design and fabrication requirements which will ensure its success. These requirements consist of the following:

- Proper resin selection and corrosion barrier design to maximize corrosion resistance to the FGD environment.
- Proper design by experienced and qualified FRP engineers.
- Proper fabrication and installation by knowledgeable and experienced personnel.
- Proper inspection and maintenance by qualified inspectors.

Table 4. FRP Stack Liners in FGD Service Installed between 1979 and 1986.

Station/Unit	Year Installed	Current Status
Coronado 1	1979	min. maintenance
Winyah 3	1980	min. maintenance
Coronado 2	1980	min. maintenance
Winyah 4	1981	min. maintenance
Laramie R. 3	1982	little maintenance
Holcomb 1	1983	min. maintenance
Cross 2	1983	excellent condition
North Valme 2	1985	no maintenance
Intermountain 1	1986	min. maintenance
Intermountain 2	1986	min. maintenance

Some of the stack liners, dating from 1994, are shown in Figures 6 and 7. They are located in New York and Germany respectively.

Figure 6. Milliken Power Station Stack Liners Operating in Western New York since 1994

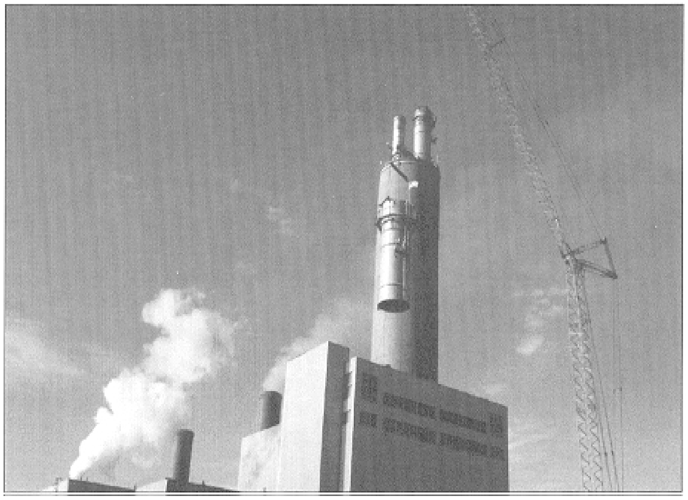


Figure 7. Two FRP Liners Operating in Ingolstadt, Germany since 1994

The use of FRP in North American power plants increased dramatically in 2006. That year 63 FRP stack liners were awarded for construction at 49 power plant sites. With more than three million square feet of laminate, this was the largest award of FRP stack liners in the history of the power industry. Figure 8 shows the installation of two stack liners in the eastern United States.

Figure 8. Stack Liner Installation in a Power Plant on the East Coast.

In addition to the rapid growth of FRP in wet FGD stack liners, FRP ductwork for transporting scrubbed flue gas to the FRP stack liners has also grown dramatically. Historically, FRP ductwork in power plants has been very successful dating back to the 1970s. Figure 9 shows the FRP ductwork, made with brominated epoxy vinyl ester resin in a 600 MW power plant. Brominated resins are used when stack and duct specifications call for fire retardancy.

Figure 9.   Scrubber and Ductwork in a 600MW Power Plant.

The construction of FRP absorber vessels and internal components grew rapidly starting in 2006. The most common FRP absorber vessels are known as Jet Bubbling Reactors (JBR). A JBR is part of a limestone slurry FGD process that has all the chemical reactions taking place in one vessel to produce high quality gypsum. One of the largest FRP scrubbers in North America was commissioned recently at a 950 MW power plant in the southern US. Figure 10 shows the massive JBR that is 120 feet in diameter and 60 feet tall. This JBR is currently removing 99% of the SO_2 from high sulfur coal flue gas.

Figure 10.   Scrubber and ductwork in a 950MW power plant.

Another rapidly growing use of FRP in power plants is for cooling towers. While wood has long been the predominant material used for these towers, FRP is now become the material of choice for cooling towers construction. The primary reason is that FRP structures are anticipated to last more than twice as long as wood structures (50 years plus versus 25 years for wood). FRP requires little or no maintenance over its lifespan while wood towers often require a considerable amount of maintenance. FRP is not subject to internal deterioration or biological attack, and it can withstand corrosive chemical exposure by choosing a suitable resin and fabrication technique. Because FRP structural members can be manufactured in lengths up to 18 meters long and beyond, labor costs are reduced compared to lumber that requires splicing in 6 meter lengths. Figure 11 shows two six cell FRP towers in a 700 MW power station in the Midwest.

Figure 11. FRP Cooling Towers at 700 MW Midwest Power Plant.

Summary

Properly designed, fabricated and maintained, FRP made with epoxy vinyl ester resins is an ideal material of construction for limestone slurry piping, stack liners, absorber vessels and ductwork. FRP delivers the following advantages in FGD systems:

- More than 30 years of proven performance
- Much lower cost than stainless steels or higher nickel alloys
- Considerably less maintenance than alternative materials of construction

Key Words

Derakane, Hetron, corrosion, desulfurization, epoxy vinyl ester resin, fiberglass-reinforced, flue gas, high nickel alloy, plastic, reinforced thermoset plastic, sulfuric, vinyl ester resin

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