COMPOSITES & POLYCON 2009
American Composites Manufacturers Association
January 15-17, 2009
Tampa, FL USA

MATERIALS OF CONSTRUCTION IN WET SCRUBBING SYSTEMS FOR FLUE GAS DESULFURIZATION

by

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ABSTRACT

Currently, the wet-lime scrubbing process is a widely adopted approach for the elimination of sulfur oxides (SO_X) from the flue gas in coal fired power plants. The process equipment is also referred to as a scrubbing plant. A scrubbing plant is comprised of several components that are designed to implement the complex physical and chemical changes that are necessary to convert the incoming "dirty" flue gas to a "clean" flue gas prior to release to the atmosphere via the stack.

This paper reviews the various materials-of-construction (MOC) in a typical scrubbing plant following the various stages of the process: from inlet to the chemical conversion of SO_X, the absorption of particulate matter and quenching of the dry incoming flue gas all take place simultaneously. Fiber reinforced plastic (FRP) composites based on epoxy vinyl ester resins have now emerged as well accepted, cost-effective MOC for a majority of the scrubber components, including the vessel itself. The considerations for the use of FRP components in scrubber plants are discussed with relevant examples and case histories.

KEYWORDS: corrosion, epoxy vinyl ester resin, vinyl ester resin, reinforced thermoset plastic, FRP, abrasion resistant FRP, flue gas, desulfurization, scrubber, high nickel alloy, chemical resistance, corrosion mitigation, materials of construction.

INTRODUCTION

Since the late 1990s there has been a renewed interest in electrical power generation from coal fired plants. During this period, increasingly stringent air pollution control regulations have been enacted that require coal based power plants/utilities and independent generators in the mining and chemical process industries to remove acidic gases, particulates, heavy metals, etc. from the flue gas before releasing it to the atmosphere. These regulations have spurred the development of "clean coal" technologies, and advancements in the design and construction of air pollution control (APC) equipment. These advancements in the APC equipment have allowed the end user the ability to burn lower grades of coal that typically contain higher levels of sulfur, while complying with the environmental standards on emission of flue gas.

The composition of the flue gas includes the oxides, fluorides and chlorides of nitrogen, sulfur, carbon, and of some metals like aluminum, magnesium and iron. The process of eliminating these acidic gases is carried out in processing plants that are commonly known as scrubbers. Wet lime based Flue Gas Desulfurization (FGD) has emerged as the preferred method for sulfur dioxide (SO_2) removal from flue gas in coal fired power plants. This cost effective process removes up to 99% of the SO_2. The chemical environment made up of a combination of residual acidic gases, moisture and elevated temperature that occurs in the APC equipment does create a more corrosive environment than the individual components.

Due to the corrosive nature of the scrubbing process, the selection of the MOC is vital to successful operation of the power plant. A variety of materials have been successfully used in wet FGD systems including rubber lined carbon steel, flake glass filled epoxy vinyl ester resins, high nickel alloy clad carbon steel, nickel based alloys, and FRP that are based on epoxy vinyl ester resins and epoxy novolac vinyl ester resins.

This paper highlights a successful application at a coal fired power plant/utility in the Republic of South Africa, where vinyl ester resin based FRP composites were the preferred MOC for the various components involved in the scrubbing plant that utilizes the MECS DynaWave® "Froth Zone" technology, a unique scrubbing process. FRP was selected as the preferred material of construction based on the cost-effectiveness, ease of installation and performance under the severe conditions created during the scrubbing process.

The operating conditions and material selections for this application are described below. It discusses the challenges encountered in practice and the practical solutions developed for sustainable operation.

PROCESS FLOW BACKGROUND

End users require a FGD scrubber that will quench incoming gas, remove acidic gases, and eliminate particulates. In many conventional scrubbers or simple caustic scrubbers, these three different functions occur in three different zones of the scrubber: a quench zone, an acidic gas removal zone, and a particulate removal zone.

This unique scrubbing process is different from conventional scrubbers. It performs all three of these functions in a single zone which is called the “froth zone”. This straight forward approach reduces both capital and operating costs. Most importantly, this approach minimizes the working equipment inside the vessel, which makes this unique scrubbing process extremely reliable.

The schematic of the process is shown in Figure 1. The various sections of the process are described as follows:

- The hot dirty gas exits the boiler, enters at the top of the vessel and travels down the inlet barrel.
- Wet lime or caustic slurry is sprayed upward, opposite the flow of the gas, into the barrel
- The gas collides with the liquid creating a turbulent zone where the gas/liquid interface is continuously and rapidly renewed. Scrubbing is effectively accomplished by the thorough mixing of the gas and scrubbing liquid in the Inlet Barrel.
- Where the momentum of the gas and liquid balances, the liquid reverses direction and then falls to the base of the Inlet Barrel.
- The gas exiting the Inlet Barrel turns and moves vertically upward through the scrubber. The gas encounters a set of chevrons that remove the remaining liquid droplets.
- Air is introduced into the scrubber sump through a positive displacement blower, through an air sparging system to oxidize the slurry and prevent settlement of solids in the base of the vessel.
- After the chevron, the gas exits the tower and with some assistance from a fan it is transferred into the chimney stack and then to the atmosphere.

MATERIALS OF CONSTRUCTION SELECTION

The process environment and operating conditions help define the technical considerations needed in the selection of the MOC for the various parts of the APC system. The temperature of the flue gas exiting the boilers introduces thermal stresses on the FRP components. The acidic gases combined with moisture, creates a highly corrosive environment. In addition, the presence of particulate matter such as fly ash, lime slurry and other solid materials abrade and erode the surfaces of the APC equipment.

The material selection process takes into consideration the temperature, the corrosiveness and the abrasion/erosion potential of the environment. ASTM Special Technical Publication 837 [1] defines a scheme to classify the various zones of a FGD system. This is a scale based on the severity of the temperature, chemical and abrasion/erosion environments. The classification is indicated by a three-digit code that characterizes the service. While the ASTM refers to “Protective Linings”, this classification system will be utilized in this work to classify the environments in the various zones of the system and apply it to FRP components.

This classification system is presented in Table 1. The system generates a three digit rating where the first digit indicates the severity of the chemical environment, the second refers to the severity of the abrasion/erosion and the third digit refers to the severity of the temperature.

For this case history two premium bisphenol-A epoxy based vinyl ester resins with different crosslink densities were used to fabricate most of the FRP components: CoREZYN® VE8360, and CoREZYN® VE8300, heretofore referred to as VER1 and VER2 respectively. VER1 has a higher crosslink density than VER2.

A description of the various zones is as follows:

ZONE 1: Gas Ducting from Boiler to Scrubber Inlet

ASTM-STP-837 Rating: 1-2-3
Operating Condition: Flue gas at 180 °C (356 °F)
Material of Construction: Mild steel
Comments: Mild steel is cost effective in a hot, dry gas application. There should be some consideration given to the potential for abrasion when particulate matter is present. This consideration is very important especially if the flow is turbulent. Care has to be exercised to prevent any carry over of liquid because acid will form and corrosion will occur. External painting of the steel is required for protection from the atmosphere. The maintenance of this structure can be extensive. Epoxy novolac vinyl ester resin based FRP have been successfully used to replace steel in many of these corrosive environments. Figure 2 shows the mild steel gas ducting that was used in this case history.

ZONE 2: Inlet Barrel
ASTM-STP-837 Rating: 1-3-3
Operating Condition: Flue gas enters at 180 °C (356 °F), cooling to 50 °C (122 °F) during the reaction in the froth zone of the scrubber.
Material of Construction: Epoxy vinyl ester resin (VER1) based FRP is the structural portion. The composite's internal surface layer for this component is made from a mixture of the VER1 and a silica compound for improved wear resistance. The portion of the barrel inside the scrubber has corrosion barriers on both the internal and external surfaces.
Comments: A photograph of the FRP Inlet Barrel is shown in Figure 3. (Note the ease of transportation of lightweight FRP). In this configuration, the Inlet Barrel requires an enlarged section where the spray nozzles for the upper stage are mounted, to prevent flow and pressure losses. The nozzles that spray into the lower stage are mounted through the vessel wall. The barrel in the picture fits into the vessel, interfacing at the flange, the "bottom" part protruding into the vessel, forming the lower stage froth zone.

The liquor spray is generated by large bore nozzles, wherein substantial flows are generated. Photograph in Figure 4 shows installed configuration.

ZONE 3: Scrubber Vessel
ASTM-STP-837 Rating: 1-1-2
Operating Condition: Houses the entire operational system and acts as the sump and disentrainment vessel to remove droplets through the chevron mist eliminators. The material of construction for the mist eliminators is polypropylene.
Lime / Limestone / Gypsum reagents; acidic gas at about 50 °C (122 °F);
Vacuum: -5 kPa (-0.7 psi)
Material of Construction: Epoxy vinyl ester resin (VER2) based FRP. The vessel is 5.5 meters (18 feet) in diameter and 17 meters (56 feet) tall. Two of the vessels were installed at the plant.
Comments: A photograph of the scrubber vessel is shown in Figure 5. The vessel was shop fabricated and transported to site. The lightweight of FRP enabled transport of the large vessel with relatively simple material handling equipment. FRP emerged as the most cost effective material. The strength, corrosion resistance, processability and durability of the epoxy vinyl ester resin enabled an efficient vessel structure. Abrasion of the vessel walls was successfully avoided by placing all the internal components such that high liquid velocities near the walls were avoided.

ZONE 4: Slurry Circulation and Spray System
ASTM-STP-837 Rating: 1-3-2
Operating Condition: Pressure piping up to 400 kPa (60 psi). Extreme abrasion was encountered in this system in the piping and pumps.
Material of Construction: Epoxy vinyl ester resin (VER2) based FRP with a liner containing silica compounds for abrasion resistance.
Comments: This piping system is used to pump slurry from the vessel sump to the nozzles to form the froth zone. Substantial flow is generated to obtain about 100 kPa (15 psi) delivery pressure on the large orifice nozzles.

ZONE 5: Exit Ducting and Chimney Stack
ASTM-STP-837 Rating: 1-1-1
Operating Condition: Clean gas with very low concentration of acid and solids.
Material of Construction: Epoxy vinyl ester resin (VER2) based FRP.
Comments: Despite the relatively mild conditions, FRP was found to be the most cost effective solution on an installed cost basis. Finite Element Analysis was performed to design the attachment between the steel support structure and the FRP stack. The stack was 2.8 meters (9.2 feet) in diameter and 62 meters (200 feet) tall. A modular design was adopted to facilitate the construction and installation of the stack. Figure 6 shows the stack under construction and Figure 7 shows the stack in operation.

Zone 6: Bleed-off / Filter Pressing
ASTM-STP-837 Rating: 1-3-2
Operating Condition: Removal of solids and return water to the scrubber.
Material of Construction: Epoxy vinyl ester resin (VER2) based FRP with a liner containing silica compounds for abrasion resistance.

Comments: This is a challenging abrasive environment. The erosion resistance is imparted to the components following established material solutions.

CONCLUSIONS

The successful application of FRP composites, as versatile construction materials for APC equipment, has been demonstrated through this established case history. While the process environment was severe in terms of chemical corrosion, abrasion, and temperature, cost effective solutions were developed through the use of premium epoxy vinyl ester resin based FRP. The versatility of FRP was demonstrated by the wide choices in resin type and material construction options.

FRP based on epoxy vinyl ester resins have emerged as a successful material of construction for APC equipment for coal fired utilities. As compared to conventional high performance metallic alloys, significant cost-savings are realized through the use of FRP materials for FGD applications such as scrubber vessels and internals, abrasion resistant piping, and stack liners.

The three vital elements of proper material selection: good design, thorough analysis and quality manufacturing are emphasized for successful application of FRP composites in challenging environments.

Note: DynaWave® is a registered trademark of MECS, Inc.
CoREZYN® is a registered trademark of Interplastic Corp.

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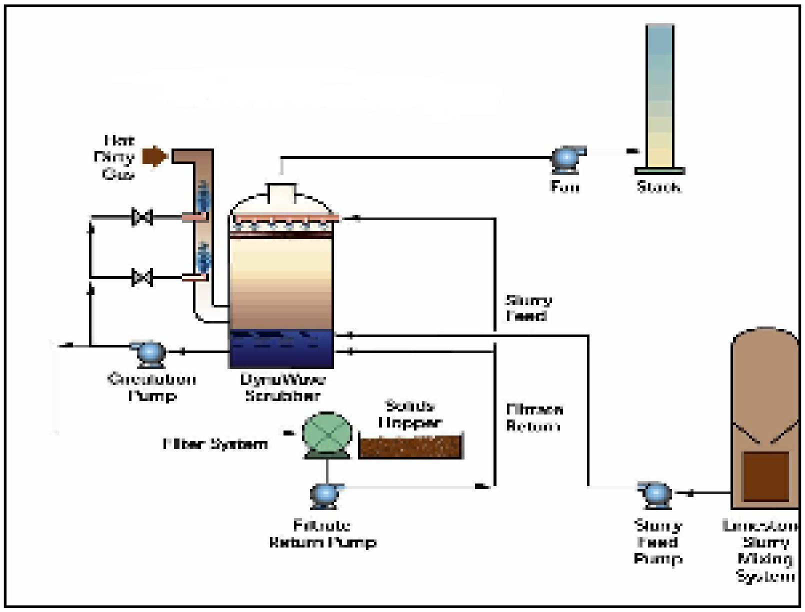

Figure 1: Schematic of Air Pollution Control system

LEVEL	Chemical Environment	Abrasion/ Erosion Environment	Temperature Environment
1	**pH** 3 to 8	Low-velocity liquid or gas flow	Ambient to 140 °F (60 °C); saturated liquid/gas temperatures
2	**pH** 0.1 to 3, acid concentration up to 15%	High-velocity gas flow, liquid flow, or liquid sprays	Reheated gas temperatures: 140 °F – 200 °F (60 ºC – 93 ºC)
3	Acid concentration greater than 15%	High-energy liquids or gases carrying particulates	Unscrubbed Flue gas temperatures: 200°F – 440°F (93 ºC – 230 ºC)

Table 1: Classification of Process Environment per ASTM STP 837 [Reference 1]

Figure 2: Photograph of Gas Inlet Ducting (Zone 1)

Figure 3: Photograph of FRP Inlet Barrel being transported to site (Zone 2)

Figure 4: Photograph of FRP Inlet Barrel as installed (Zone 2)

Figure 5: Photograph of FRP Scrubber Vessel in transit to site. (Zone 3)

Figure 6: Photograph of FRP stack module being assembled (Zone 5)

Figure 7: Photograph of FRP stack module in operation (Zone 5)