

Dual Laminate Fume Scrubbers

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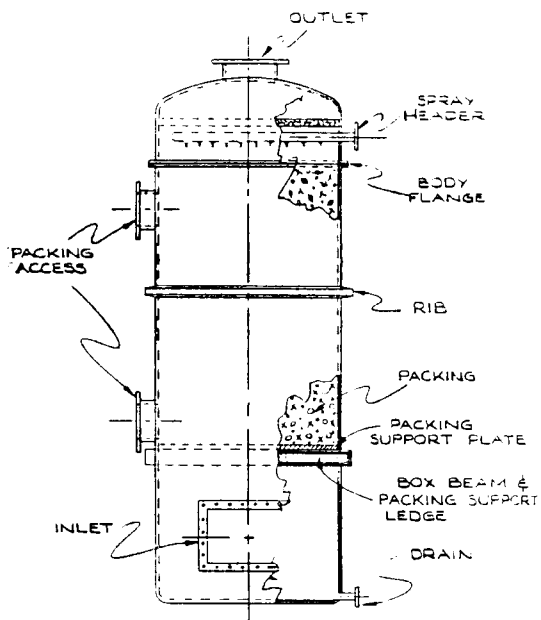
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Dual Laminate Fume Scrubbers

Introduction

In these days of increased environmental awareness it can be agreed that scrubbers are here to stay. Federal and state law have made fume scrubbing a mandatory part of almost all processes which emit to the atmosphere. The scrubbing process and equipment must be designed to accomplish the environmental objective in a cost effective manner.

The focus of this paper will be the use of "Dual Laminate" (thermoplastic lined fiberglass) scrubbers for chlorine scrubbing. New regulations will be summarized, the chemical process will be described, unique design and fabrication challenges will be highlighted, and costs and benefits will be reviewed.

Current Regulatory Requirements

The discharge of hazardous materials from various chemical processes has been a fact of human life since before the industrial revolution. In the past, abatement systems to protect worker safety were often crude and inefficient. Often, abatement was simply a matter of increasing stack height, with no effort made to reduce the mass of discharge.

In November of 1986, President Reagan signed into law the Resource Conservation and Recovery Act (RCRA). This, and the Superfund And Reinforcement Act (SARA Title III), allocated the necessary funding for the Environmental Protection Agency (EPA) to continue its enforcement activities. Additionally, the concepts of worker and community right-to know became part of Federal Regulations (29 CFR). Now for the first time unregulated discharges were made illegal and stringent disclosure policies were enforced. An example of this policy is the present reporting level of 1 lb./year for an acutely hazardous material such as chlorine. Another example: for businesses west of the Mississippi, the Uniform Fire Code, Article 80 prohibits the unregulated discharge of any amount of hazardous materials.

The enforcement of discharge regulations is now a federal, state, county and city responsibility. All industries must now curtail unauthorized discharges.

Chemical Environment In a Chlorine Scrubber

One of the most commonly discharged acutely hazardous materials is chlorine in its many forms. As a bleaching or whitening agent, chlorinated oxidizers are used in various industries, from pulp and paper to municipal waste water

treatment. The most common agents are Chlorine (Cl_2), and more recently, Chlorine Dioxide (ClO_2) Both of these materials are considered to be acutely hazardous. All industries now utilizing them must have a permit and abate their discharges.

Treatment technologies for these materials are classic. The chlorine is transformed from an uncontrollable gas to a potentially usable product, Sodium Hypochlorite ($NaOCl$), and ultimately to Salt ($NaCl$), which is non-hazardous. Chlorine has a low solubility in water and, for pH values over 7, will react to form Sodium Hypochlorite which is less hazardous.

Although the chemical process is simple, the choice of construction materials for the scrubber is difficult. The scrubber components can be subjected to the following:

1. $NaOH$, which has a pH of 7 to 14 with exotherms of up to 220°F.
2. $NaOCl$, an aggressive bleach agent in aqueous form.
3. Nascent Chlorine (Cl), which can be generated at any time due to elevated temperatures.
4. Any combination or succession of the above.

Structural considerations are critical since scrubbers must often be large and conventional structural materials such as steel are readily attacked by both Cl_2 and $NaOCl$. While fiberglass is a good possibility in this application, it is limited by the wide range of chemistry and temperatures to which the components are subjected. Even highly corrosion resistant resins may not be adequate, and degrade readily in the aggressive and unpredictable scrubber environment.

The most common polyester resins with industrial application belong to the isophthalic, bisphenol, chlorendic and vinyl ester families. For applications involving chlorine and related compounds, several resins exhibit good corrosion resistance to chlorine by forming a semi-soft surface layer after exposure. This layer, often referred to as chlorine butter, when in equilibrium with the chlorine environment, will hinder further corrosive attack. However, in a caustic chlorine scrubber there are no equilibrium conditions. The scrubber can go from an environment with a high pH condition at elevated temperature, void of any chlorine, to a one with a 12.5% sodium hypochlorite solution. Caustic and chlorine butter may combine to form a soap which would remove the butter and re-accelerate corrosive attack.

Scrubber Components and How They Work

Before discussing materials any further, the basic structure and chemical flow of a scrubber tower should be understood. The components of a typical scrubber are shown in Figure 2.

The chlorine contaminated air stream enters near the bottom and exits at the top. The air flow is slowed to less than 450 feet per minute in the scrubber body while it flows through a packing medium. At the top of the scrubber a caustic and water spray is introduced. This causes the chemical reactions and balances the pH of the water flowing into the sump.

Scrubbers typically operate at a vacuum of 10 - 20 inches of water and must be built to withstand the external pressure.

Heavy moisture laden packing must be supported and kept from being sucked out of the scrubber. A typical 10' high section of a 10' diameter scrubber would have packing weighing over 5,000 lbs.

The spray header must handle the caustic environment as well as the internal temperature of the scrubber which may be 120°F - 150°F. Headers are usually constructed from unreinforced PVC or CPVC which lose much of their mechanical strength in this temperature range.

Material Selection - Thermoplastic Linings

As in any process vessel, material selection involves finding a good balance between cost and equipment life. In order to answer this objective, dual laminate scrubbers are being more widely considered than ever before with PVC lined FRP being the most typical.

Other than fiberglass, the lining materials most considered for chlorine scrubbers include the following:

PVC (polyvinyl chloride)- this amorphous thermoplastic is the most common. It is low in cost and easily used in fabrication. PVC is excellent in handling many strong acid and alkali solutions and has a temperature capability of about 140°F

CPVC (post chlorinated PVC) - similar to PVC but higher in temperature capability (about 210° F.) Welding and fabrication are more difficult than PVC. Fiberglass is chemically bonded to the plastic material as is the case with PVC.

ECTFE (ethylene chlorotrifluoroethylene) - ECTFE can handle caustic and chlorine environments. It is similar in temperature capability to PVDF (about 300° F), but it is harder to weld and thermoform due to its higher melt point.

PVC and CPVC are by far the most common; there are significant case histories of long and successful use. PVC handles both the high pH and acidic environments extremely well. It is ideally suited to the scrubber environment if designed properly to allow for its relatively weak mechanical

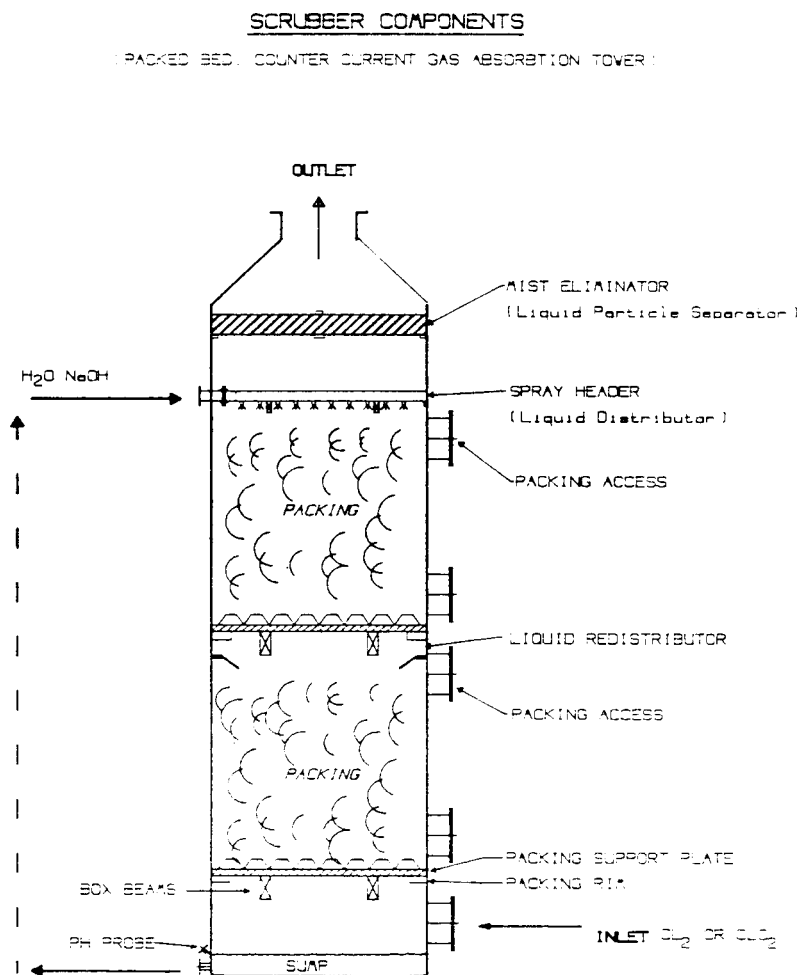


Figure 2 -Dual Laminate Scrubber

Dual Laminate Scrubbers

properties, particularly at higher temperatures.

FEP and PFA Teflon are suitable but expensive while PVDF is not generally used in scrubbers because it is not recommended for high pH levels.

Material Cost

Costs of Sheet lining materials vary significantly as shown in Chart 15. The unit costs for several of the materials discussed above are given for typical thickness values.

Chart 15 - Material Cost Comparison

Material	Per sq. Ft	Thickness
PVC	\$2.00	.19"
CPVC	\$7.00	.19"
ECTFE	\$18.00	.09"
FEP	\$80.00	.09"

Some Unique Design Considerations

Dual laminates have been used sparingly in this country while in Europe they are quite common. The majority of North American vessels are made by only a few fabricators who have the necessary qualifications and experience. While most designers of corrosion equipment are quite comfortable with FRP, relatively few have experience with dual laminates. This section will address some of the differences between FRP and dual laminate construction and outline basic questions that should be considered by the specifying engineer.

Problems to consider in designing a scrubber include:

1. Vacuum loading on shell, ribs, and bottom.
2. Large wetted packing weight and the design of packing rings, packing trays, and support beams.
3. Spray headers.
4. Mist eliminators.
5. Flow redistributors

Packed tower scrubbers can get quite large, with multiple packing sections which must be supported by the vessel not only during normal operation, but also under seismic loads. For example, Norcore Plastics recently built a 12' diameter x 60' PVC lined FRP scrubber with three 10' packing sections. The design of this class of vessel is a challenge for even a seasoned dual laminate fabricator.

The following paragraphs present just a few of the unique

design considerations in dual laminate construction.

Differential Thermal Expansion

Probably the most obvious problem in a dual laminate vessel is the difference in rate of expansion between the FRP and its thermoplastic lining. The problem is magnified as the thickness of the liner increases. PVC presents the least problem in this regard, expanding at about twice the rate of FRP. Chart 16 shows thermal expansion values of various thermoplastics.

Chart 16- Linear Thermal Expansion Coefficients of various materials

Material	Coefficient 10 ⁻⁶ in./in./°F
FRP	15 - 20
PVC	25 - 30
CPVC	35 - 40
ECTFE	60
PVDF	70
Polypropylene	80 - 85

The difference in thermal expansion coefficients, the liner thickness, and the tensile modulus of the thermoplastic lining dictate the amount of bond line shear. Finite element analysis of a 3 mm PVC lined FRP test coupon subjected to a 50°F temperature rise indicates that the stress distribution is not uniform. For this case, shear stress away from the free edges is in the order of 25 - 50 psi, increasing to 225 psi near the free edges. This tendency for shear stress concentration has definite implications in the design of PVC/FRP box beams and other similar shapes.

Care must be taken to assure good bonding and a high weld factor in corner areas; thermoformed corners are preferable. Welds should be placed in areas of lower stress and, butt fusion welds, having twice the strength of hand welds, should be used whenever possible. Low weld factors or poor construction without thermoforming can lead to premature failure.

Shell Design For Loads

Normal design must allow for heavy loads to be transferred into the FRP shell without cracking welds or causing the thermoplastic liner to disbond. PVC lined FRP support beams and gusseted thermoplastic ledges are typically used to transfer packing and mist eliminator loads to the FRP shell. Also, there is usually a large inlet in the vessel wall near the bottom which must be reinforced to allow mechanical loads to be taken with stiffness adequate to pre-

vent cracking the adjacent thermoplastic welds. Since it is desirable to minimize internal welds, normal FRP inside reinforcing joints around nozzles, ledges and beams cannot be used. The design engineer must have the skill and experience to compensate for all these unique considerations in his total design.

Creep Modulus and Elevated Temperatures

Scrubbers are in many cases just downstream of a quenching operation with significant upsets possible if quenching is lost. Since both the strength and modulus of thermoplastics are very sensitive to temperature, thermoplastic members and welds in main loading paths must be carefully sized for short term upset conditions. To give some idea of this sensitivity, the strength and stiffness of PVC drops from 100% to 22% between 70°F and 140°F. Thermoplastic parts carrying sustained load are usually designed on the basis of creep instead of strength. Attention to creep modulus characteristics is particularly important when planning for spray headers or other parts not reinforced with FRP.

Fabrication Considerations

The choice of an experienced dual laminate fabricator is important. He must be a good fiberglass fabricator as well as have the skills and equipment to fabricate with thermoplastics. These skills are very different from those necessary in thermoset fabrication.

Welding

In addition to hot air hand welding a fabricator should be able to perform butt fusion and extrusion welding. Such equipment is expensive but long term weld factors can be increased by as much as 100% in critical stress areas. Fabricators also must have workers who are fully trained and certified and who regularly engage in welding to maintain their skills.

Thermoforming

A fabricator must be able to form plastic sheet to allow smooth radius transition areas to spread loads between the bottom and side wall and in the dome. Thermoforming must also be done for box beam and packing ring fabrication. Thermoforming requires special ovens, molds and other equipment.

Bonding

Chemical and mechanical bonding to fiberglass is both a science and an art. The fabricator must use proper preparation techniques and resins. They must also regularly test the bonds to determine if plastic sheet extrusion lubricants or other factors are causing problems.

Cost Benefit - Why Spend More on Dual Laminate

The potential advantages in chemical resistance for thermoplastic liners are clear, but the costs of this type of construction may be significantly greater than a standard FRP scrubber. Chart 17 summarizes the approximate cost differences between two different sizes of scrubber towers. The costs given include the tower as well as the packing and mist eliminator, and indicate percentage increase based on FRP.

Chart 17 Scrubber Cost Comparison

Material	Size 10' x 30'	Size 3' x 30'
Dual Laminate:		
PVC/FRP	\$120,000 14%	\$35,000 59%
CPVC/FRP	\$140,000 33%	\$39,000 77%
ECTFE/FRP	\$180,000 71%	\$48,000 118%

If fiberglass might work, why pay this type of premium for dual laminate construction? The answer lies in effective evaluation and costing of potential future savings compared to higher initial capital cost. The following are some key factors in making a good long range decision.

1. Initial Cost
2. Service Life - will it be longer; how much?
3. Maintenance Cost - Will average repair costs be lower?
4. Downtime Product Loss - this adds to "out of pocket" repair costs.
5. Impact of Premature Failure
6. Estimated Future cost of Money, labor, materials - Present Value

Lower purchase cost is not always the best decision. At the 1989 NACE conference Richard Lewandowski of Fiberglass Structural Engineering indicated that the initial purchase price is only 43% of the vessel's ultimate cost. Some of the other major cost factors include lost production due to downtime (22%) and maintenance costs (22%). This clearly shows that reduced downtime and maintenance cost as well as extended life can justify higher initial cost.

The problem in evaluating these is that most plants really don't have the cost data. In the future better service records should be kept on all corrosion equipment. Over time an improved cost data base will allow for more intelligent long term decisions.

Summary and Conclusions

The 1990's will bring increased concern to limiting toxic environmental emissions. Chlorine and Chlorine Dioxide scrubbing systems will need to be added and updated.

The chemical environment in a chlorine scrubber is complex and can be unstable. Sodium hypochlorite and Nascent Chlorine at varying temperatures and pH levels can cause premature failures to FRP scrubber towers.

PVC and CPVC are ideal materials for the chemical environment but proper design is essential. Thermoplastic materials have high expansion rates and exhibit creep properties which reduce their design strength for higher temperatures and extended loading. Design engineers must understand these factors.

Fabricators should only be selected when they can demonstrate proper training, tooling and experience. There are enough North American dual laminate fabricators to assure competitive pricing. New fabricators entering the field must be patient and recognize that a long learning curve and specialized tooling are necessary.

Dual laminate is simply an alternative which should be considered for sound design and economic reasons. It may have a higher capital cost but still be less expensive in the long run. For example, the semiconductor industry has rapidly converted its DI water tankage from FRP to PVDF/FRP even though the tanks cost two to three times as much. The economic reasons are clear however. The PVDF is pure and does not leach impurities to the DI water. It will also handle ozone treatment which is used to kill bacteria. Increased chip yield more than compensates for the increased capital cost.

Dual laminates are being used in many other chemical environments. Some of these are: highly concentrated acids, acid and sulfur scrubbing, sodium chlorate, sodium hydroxide, and pure brine solutions. Dual laminate tanks, piping, and fume handling equipment are becoming increasingly common.

When a difficult application is encountered, consider dual laminate as one possibility. Assess the "long range" benefits and select only qualified designers and fabricators. The European companies have been using thermoplastic and dual laminate fabrications for over 40 years. You just may solve a difficult plant chemical problem once and for all.

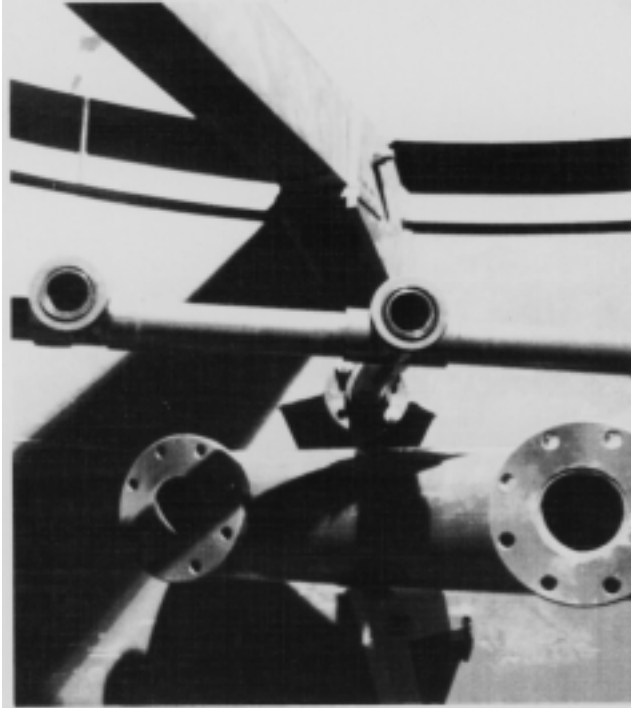


Fig. 2 - Scrubber Caustic Spray Headers

These headers are usually unreinforced PVC or CPVC; care must be taken in design to assure that low mechanical properties at high temperatures do not result in collapse of the piping.

(8' X 25" PVC/FRP - Escanabe. MI).

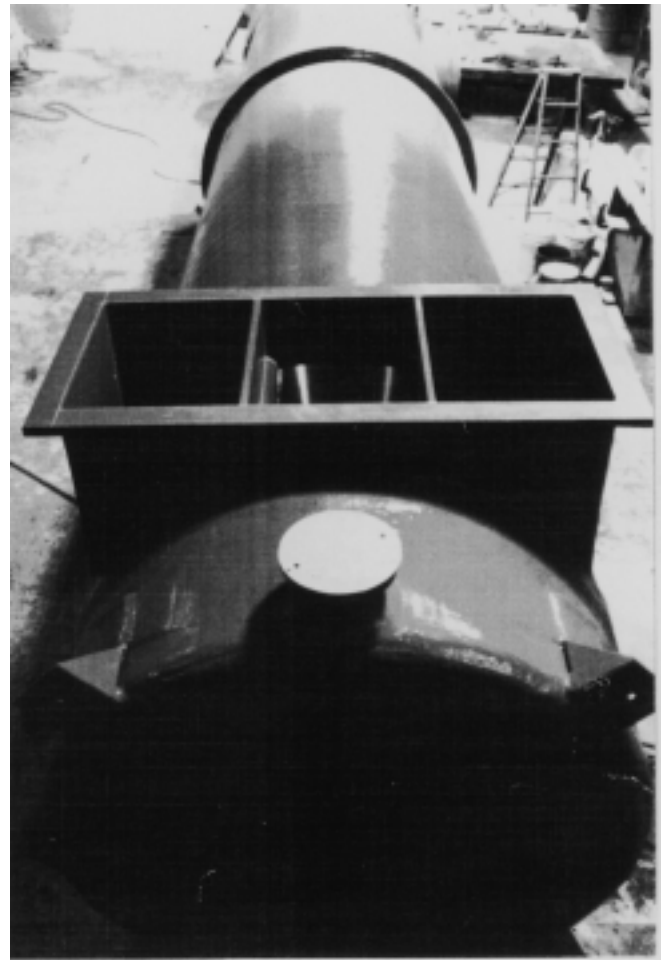


Fig. 3 - Scrubber Inlet -

Large rectangular inlets result in the need for extra reinforcement of the scrubber body. (5' x 25" CPVC/FRP - Nekoosa, WI).

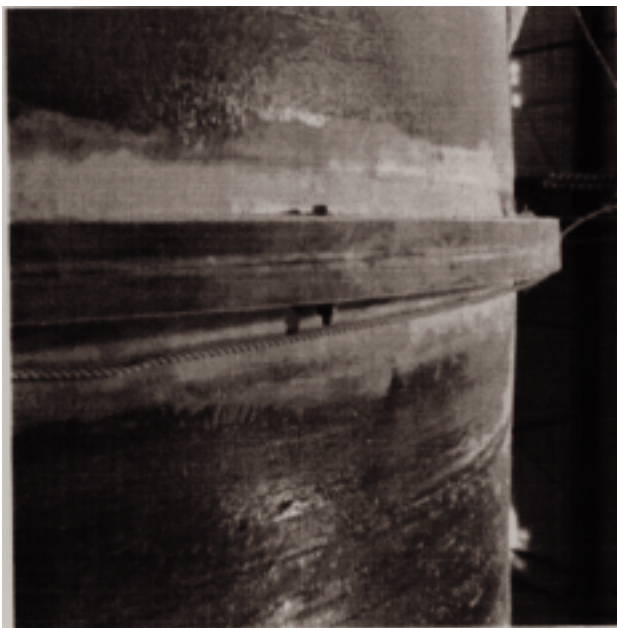


Fig. 4 - Scrubber Body Flange

A body flange may be required for maintenance, ease of shipping large towers, or to add a new section to improve scrubbing efficiency in the future.

(10' x 29' CPVC/FRP - Georgetown, SC).

Fig. 5 - Scrubber Mist Eliminator Support

Internal supports are required but they do not handle the heavy loads of the packing. The mist eliminator must also be held down so it does not get pulled into the scrubber outlet by the air flow. (5' x 25' CPVC/FRP - Nekoosa, WI).

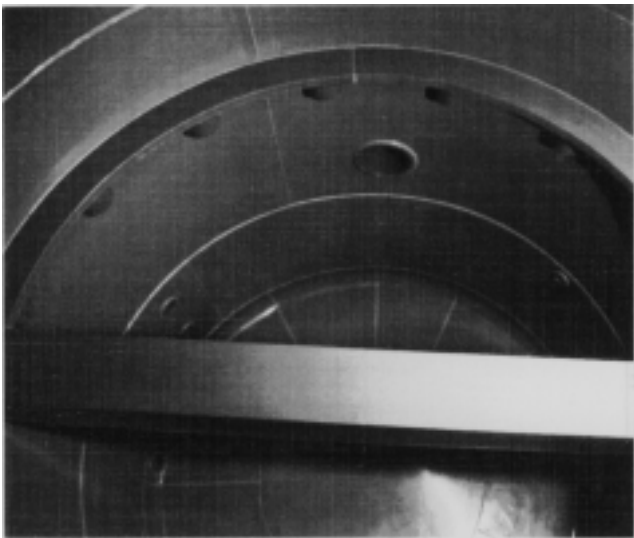
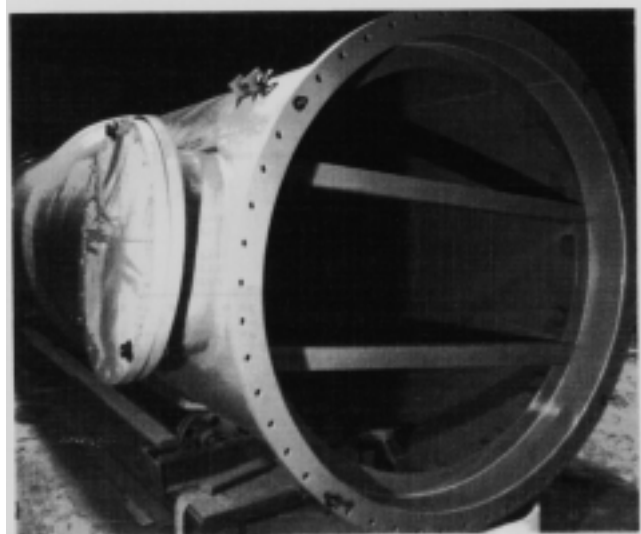
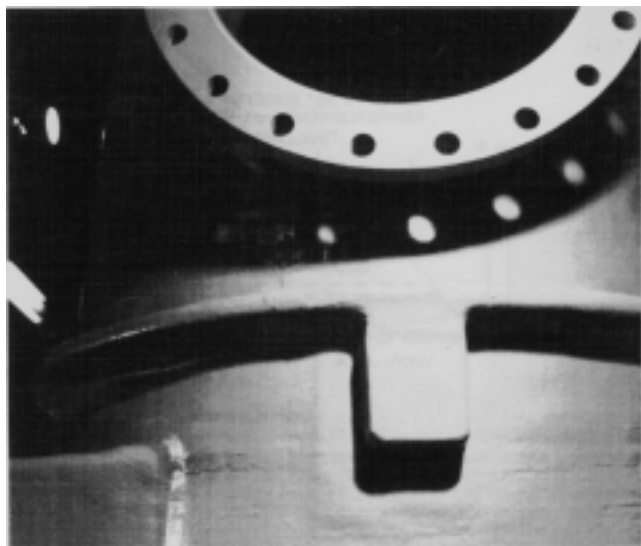


Fig. 6 - Scrubber Box Beams and Packing Rings

These must be able to handle tons of hot wetted packing. Box beams are generally FRP with PVC encapsulation. Proper thermoforming, bonding, and welding are essential. Packing rings can be constructed by thermoforming the tank or shell or by welding and gusseting a ring on a continuous liner. Each is suitable if properly designed and fabricated. (12' x 63' PVC/FRP - Wickliffe, KY).

Fig. 7 - Scrubber External Box Beam Attachment

PVC/FRP box beams generally penetrate the wall of the scrubber body. The design of the FRP joint laminating it to the tank shell is critical. Improper design can cause weld cracking in the PVC liner. Deflection of the total beam structure must be minimized. (5' x 25' CPVC/FRP - Nekoosa, WI)



FILE : SECTIONS.HSD
 TITLE : WESTVACO PACKING SUPPORT BEAM (4x10x3/8)
 COMMENTS:

NUMBER OF RECTANGULAR SECTIONS N = 4
 PROPERTIES OF INDIVIDUAL SECTIONS

	B(J)	D(J)	Y(J)	X(J)	F(J)
1	4.0	.375	.187	0	1.0
2	.375	10.75	5.375	2.09	1.0
3	.375	10.75	5.375	-2.09	1.0
4	4.0	.375	10.563	0	1.0

$$J = 1 \dots N$$

$$AREA = \sum_{J=1}^N B_J F_J D_J$$

$$Y_{bar} = \frac{1}{AREA} \sum_{J=1}^N B_J F_J D_J Y_J \quad X_{bar} = \frac{1}{AREA} \sum_{J=1}^N B_J F_J D_J X_J$$

$$I_{xx} = \frac{1}{12} \sum_{J=1}^N B_J F_J D_J^3 + \sum_{J=1}^N B_J F_J D_J [Y_{bar} - Y_J]^2$$

$$I_{yy} = \frac{1}{12} \sum_{J=1}^N B_J F_J D_J^3 + \sum_{J=1}^N B_J F_J D_J [X_{bar} - X_J]^2$$

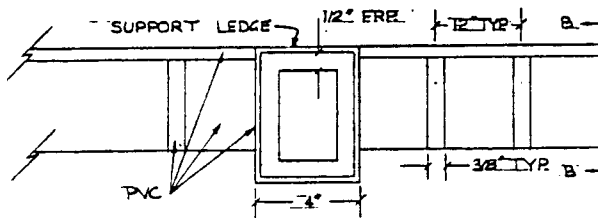
CROSSSECTIONAL AREA = 11.063 IN²

ABOUT THE X-X CENTROIDAL AXIS:

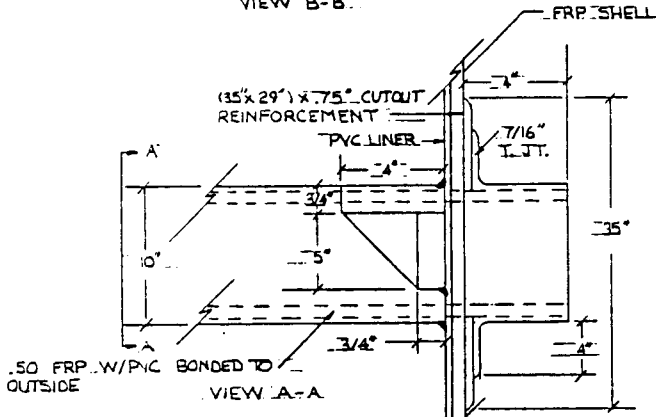
Y_{bar} = 5.375 IN I_{xx} = 158.425 IN⁴

ABOUT THE Y-Y CENTROIDAL AXIS:

X_{bar} = 0 IN I_{yy} = 39.312 IN⁴



VIEW B-B



VIEW A-A

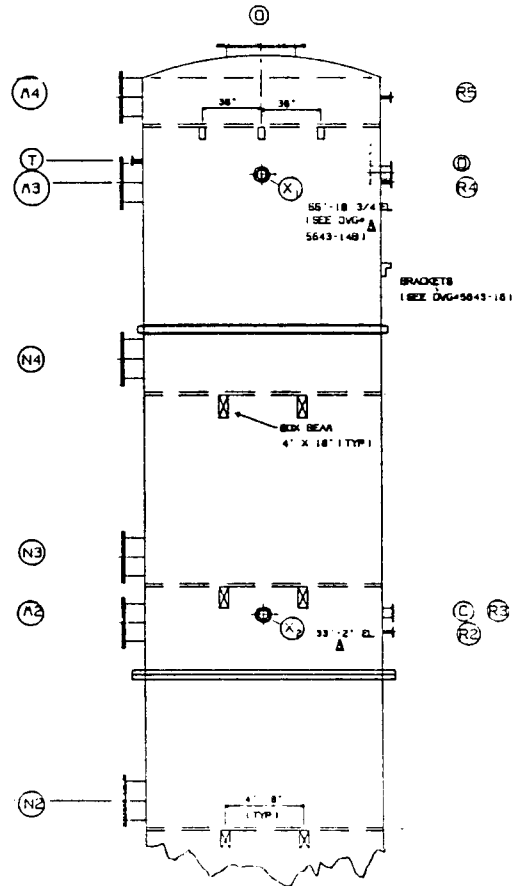


Figure 3 Dual Laminate Design and Calculations:

Proper attention to design, particularly in critical packing load areas is essential. Calculations must demonstrate structural integrity with appropriate safety factors.

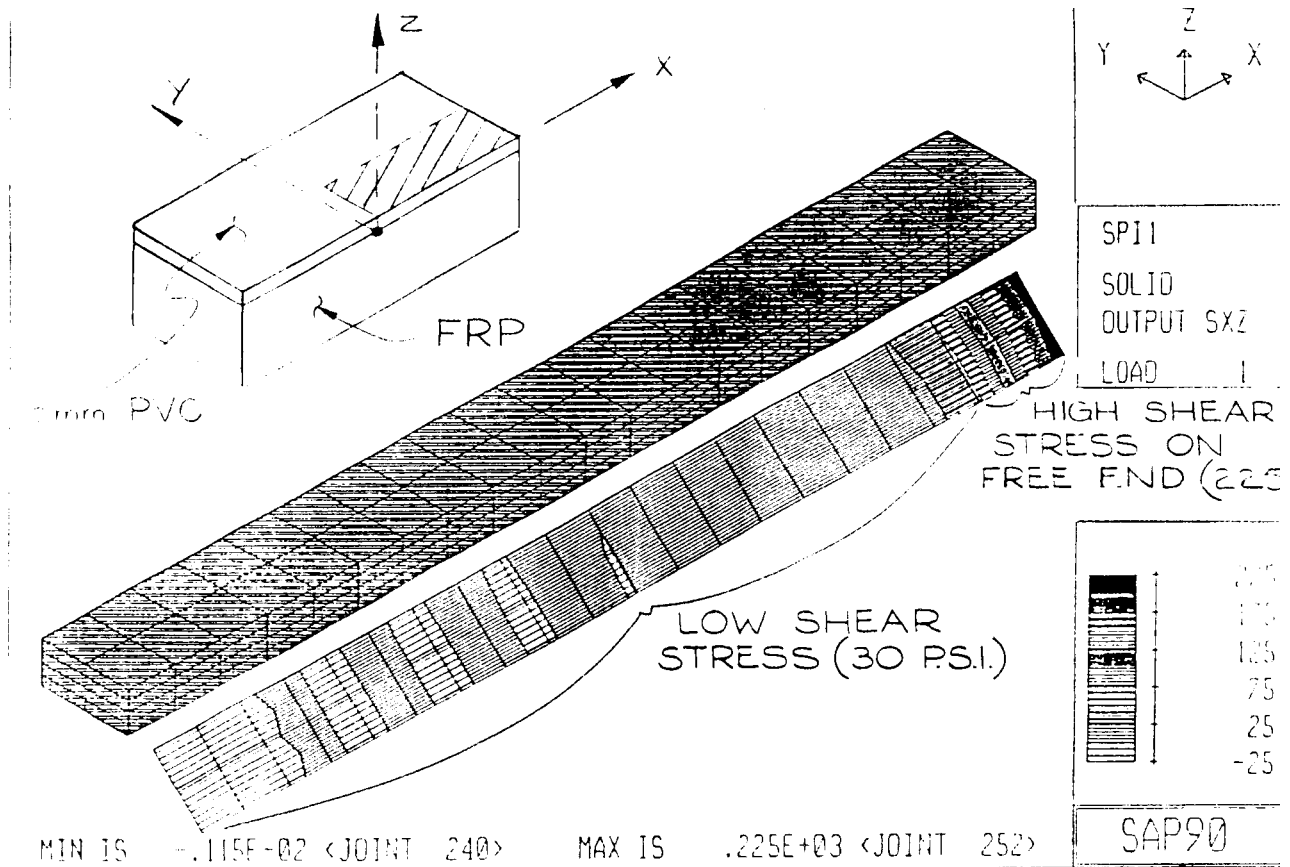


Figure 9 - Finite Element Analysis and Research -

Computer simulation of stress accumulation can help avoid problems in dual laminates design and fabrication. This plot shows stress accumulating in ends of a sample due to the higher coefficient of expansion of PVC compared to that of FRP.

Fig. 10 - Scrubber Weld Offset and Thermoforming

Axial welds should be offset in the scrubber body. All welds must also have an electrically conductive backing to allow high voltage spark testing during fabrication and at the plant site. Bottom radius sections must be thermoformed using vacuum or pressforming techniques. (4' x to 50' PVDF/FRP - Norco, LA.).

