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Where There Is Fire - There Is Smoke

While the fiberglass reinforcements used in corrosion resistant laminates will not burn, most thermoset resins used as the matrix for "FRP" laminates will support combustion. Even the "fire retardant" resins will burn vigorously when fire is supported by an outside source. The rate of flame spread is somewhat lower for these fire retardant resins. Fire retardant thermoset resins typically contain halogens or bromine molecules. When combustion occurs, these additives suppress, or smother, the flame and the laminate becomes self extinguishing.

When the more common thermoset resins (polyesters, epoxies vinylesters, etc.) used for fiberglass reinforced plastic composites burn - large amounts of heavy, black, dense smoke can be generated. The carbon chains in these resins contribute to that smoke. There is no difference in the density of the smoke generated between a non-fire retardant resin, and a fire retardant resin. The only difference is that the amount of smoke may be less when fire retardant resins are used, and the fire is not supported by an external source.

In the past, smoke was not a major consideration for FRP composite pipe and duct. Much of the early corrosion resistant equipment was used in chemical process plants. As one plant engineer of a major chemical plant told us one time, "When we have a fire in a chemical plant - we are allowed to have smoke". In those cases of typically wide open spaces, or facilities with low occupancy, the smoke generated is the least of the problems when a chemical plant or refinery catches on fire.

However, the number of facilities using FRP composite pipe and duct where smoke is of major concern is increasing. For example, in an electronics plant the generation of a large amount of smoke can actually cause more damage than the fire itself. The bombing several years back of the World Trade Center was another good example where the smoke generated caused more problems, and more injuries, than did the fire itself. You may recall seeing people stumbling out of the World Trade Center building almost blackened from the smoke.

How Much Smoke?

ASTM E-84 test results for polyesters, vinylesters, and epoxies typically yield smoke generation values in excess of "750". It can be said unequivocally that if FRP composite pipe and duct is exposed to a "raging fire", there will be lots and lots of smoke generated. The ASTM test can only provide a hint of how much smoke. Full scale testing conducted by Indspec on a fire retardant polyester duct spool vividly demonstrated just how much smoke can be generated in a short period of time. (Color photographs and video of this test are available).

We regularly see specifications for piping, duct and tank projects where both non-fire retardant and fire retardant polyester, vinylester and epoxy resins are specified. But, then occasionally the specifier goes on to establish an allowable smoke generation number of 50 or less. This just is not going to happen!

Inquiries to all of the major manufacturers of resin systems used for corrosion resistant applications have solicited written responses that they have no, and know of no, polyester and vinylester thermoset resin systems that will generate, by themselves, smoke generation values under 350, let alone under 50. If you are going to be specifying flame spread and smoke generation levels - we recommend that you consult with either a knowledgeable fabricator, or one of the resin manufacturers.

How Important Is Smoke In A Fire?

Before you spend a lot of time trying to develop low smoke alternatives - perhaps you first need to answer the question - "Just how important is low smoke in my service environment?". If your tank, piping or duct application is mostly outdoors in an industrial location - perhaps smoke is of only minor importance. Again, in these cases, if you are going to have a major plant fire - the smoke generated probably is the least of anyone's worries. Likewise, in many service installations where there is low "people occupancy", such as water and waste treatment facilities, composting facilities, warehousing buildings, etc. - then, again, low smoke is perhaps only of secondary importance.

The Two "Factors" Of Smoke

For those service environments where personnel safety is of primary importance - two distinctly separate aspects of the smoke exposure need to be considered and evaluated.

Heavy dense smoke can not only make breathing difficult, but can obscure the escape paths when people are trying to escape from a building during a fire. Again, the tragedy at the World Trade Center was a good example - where people had difficulty finding and getting to stairwells; and then finding their way rapidly to safe exits.

Smoke toxicity, especially from organic materials, is also a critical safety consideration. Even if the smoke is very light, but if it is highly toxic - personal injuries can occur. This is one of the reasons that the New York City and New York State Fire Marshals have now added to their code requirements consideration for low smoke **toxicity**.

The measurement for smoke toxicity that has been accepted by most specifying agencies in the United States is the University of Pittsburgh's Smoke Toxicity Protocol. This is the test procedure that has been adopted by the New York State and New York City Fire Marshals' offices. New York State and New York City regard these test results somewhat differently. It is our understanding that New York City requires that a material to be less toxic than wood, i.e., have a higher LD_{50}, while New York State has not specified a required minimum toxicity result from this test. Instead, New York State requires that all materials be tested, and then simply records the test results in a database. However, it is our interpretation that test results under the University of Pittsburgh Protocol need to be 55 or higher. Extensive testing of the polyester resins, including the fire retardant polyester systems, produce results far less than this 55 benchmark.

What Are Some Of The Ways Of Achieving Low Smoke Generation and Low Smoke Toxicity?

The ATH Alternate: A filler, such as ATH (aluminum trihydrate), can be added to the resin in very high concentrations. To achieve any meaningful reduction, such filler loadings need to occur up to as high as 50% of the total resin volume. This would also reduce the smoke development. However, unless the filler is also put into the corrosion liner, the duct or pipe still would not meet any reasonable specifications for low smoke generation.

The ATH additive has been primarily used for applications such as subway seating, tunnel liners, and other architectural type applications. By adding the very high levels of ATH filler to polyester and vinylester resins necessary to achieve smoke reduction for corrosion resistant equipment, you greatly decrease the structural strength of the pipe and duct laminate. In fact, the fall off of properties with a 50% filler level is great enough that it is not possible to meet most physical properties of present specifications for such corrosion resistant equipment.

Also, high levels of ATH added to the resins significantly down grades the chemical resistance of those laminates. ATH modified resin systems would not be expected to meet most chemical service requirements. In addition, long term properties of laminates modified with ATH can lead to future laminate cracking and crazing. We are aware of one law suit that is now going on where ATH was improperly specified for a corrosion resistant piping project.

It is our opinion that the addition of aluminum trihydrate to the resin, for corrosion resistant equipment, is not an acceptable method of achieving low smoke generation and definitely not low smoke toxicity.

The "Paint" Solution: Another way of obtaining reduced smoke of FRP pipe and duct, during an external fire, is by means of an intumescent paint. This intumescent paint is applied as a thin film coating to the exterior of the pipe or duct. When exposed to a fire, the paint expands to a "char foam" that has 30 to 50 times it's normal paint film thickness. This intumescent coating then acts as a protective insulating barrier to the underlying FRP pipe or duct.

Intumescent coatings have demonstrated their ability to reduce smoke generation. Smoke generation values of 100 or less *may* be achieved through the use of intumescent coatings.

The intumescent coatings and paints were originally developed for application to structural steel members. The concept was that they would help keep the steel temperatures below the buckling or collapse temperature - preventing catastrophic failures. The intumescent paints that have been used extensively for this type of steel protection service have generally performed as expected.

Little actual experience has been accumulated with intumescent paints and coatings on FRP composites. We do know that the intumescent coatings do not hold up well when exposed to high moisture, rain, and weathering. Thus, the use of such intumescent coatings on FRP would be limited to in-door exposure, and in low humidity environments. The intumescent coatings offer no protection for internal duct fires, or where there is a burn through. In these cases, the interior corrosion laminate acts as a tunnel for flame spread.

Little empirical data is currently available to show how the intumescent coatings applied on FRP laminates would perform in actual fire exposures. Would they keep the underlying laminates below their self ignition point? How well will they bond, and retain the bond, to FRP laminates? Will they really reduce the smoke generation and smoke toxicity in actual field experiences - getting the same results as obtained on small laboratory tests of coupons?

The Furan Option: FRP corrosion resistant laminates made with furan resins have excellent corrosion resistance, especially for solvents. In addition, furan laminates also provide very good high temperature strength retention properties. Request the separate technical bulletin on the furan laminates for additional benefits of using this unique resin system for pipe and duct.

One of the often overlooked attributes of furan resin composites is its excellent inherent low flame spread and low smoke generation. The fire retardant furan version will typically provide an ASTM E-84 flame spread of under 10, and a smoke generation of under 50. Because of the combination of outstanding chemical properties, and the low smoke and flame - the furan resins have been used extensively for duct in the pharmaceutical industry. We have some very interesting Factory Mutual test results that we would like to share with you for duct with furan composite corrosion liners.

In these tests, despite direct flame impingement on the interior of the test duct, with temperatures reaching 1800°F - the duct never caught on fire. When the flame was removed, the fire immediately went out. In these tests, which used a phenolic structural laminate, smoke generation was minimal and consisted primarily of water and other volatiles that were in the original laminate. If you would like to know more about the furan and phenolic resins for FRP corrosion resistant composites - please give us a call. The furan composite option might be your best solution to providing a fire retardant and low smoke environment in your facilities.

The Phenolic Solution: As a class of resins used for reinforced composites, the phenolics have exceptional fire retardancy, low smoke generation, and low smoke toxicity. The ignition point for phenolics is almost twice that of standard polyesters and vinylesters. This means that in some cases when not directly exposed to fire, they do not even start to burn.

And, the phenolic resins contribute extremely low smoke generation. It is for this reason that phenolic laminates have been used extensively in subways, underground tunnels and the "Chunnel" connecting Great Britain and France. In standards such as the ASTM E-84 tunnel test, the phenolic laminates routinely have a smoke generation of 10 or under. The phenolics generate only 1% to 2% of the total smoke that is typically generated by other laminates, such as the polyesters, vinylesters, and epoxies.

We have available color photographs of recent full scale duct tests conducted showing the dramatic difference between a fire retardant polyester resin and the Indspec FIRE PRF_2 phenolic resin system. If your application is in an environment where low smoke is a must - then we would recommend looking "long and hard" at the phenolics, either for the entire laminate, or for the structural or exterior portion of the pipe or duct wall.

Besides low smoke generation, the phenolics also have, as an inherent part of their resin molecular structure, low smoke toxicity. It is the only resin system that has consistently passed the very stringent New York Fire Marshall's smoke toxicity tests, without heavy filler loading which compromises corrosion and mechanical properties. If you would like more information on those tests, how they are conducted, and the comparative results - please write us and we will provide that additional input.

The phenolic resin systems are about as close an "answer" as currently exists for low flame spread, low smoke generation, and low smoke toxicity.

Smoke and More Smoke
A Summary

Step 1: Make your first selection of the best resin system for your service environment based on what it takes to handle the corrosion service environment. FRP composite pipe and duct is typically used because it is the lowest cost (and in some cases the only) material of construction that will handle the chemicals present in the service environment.

Time and time again we see specifications come across our desks that are driven entirely by trying to meet an arbitrary Factory Mutual or UL standard - without any regard as to whether the resin systems specified will even handle the corrosive environment. In most cases, they will not.

Step 2: Select the type and thickness of corrosion barrier/liner needed to handle the chemical service environment. If it takes a synthetic veil to handle the service environment (for example, sodium hypochlorite or hydrofluoric acid) then be sure to clearly call out that type of reinforcement. If it takes a full 100 mil SPI type liner to handle the service environment, again make sure that the specifications call for that minimum liner.

If a corrosion allowance is desirable to achieve maximum service life - be sure to include that extra thickness. If a conductive liner is required to prevent static build up and discharge, causing an internal explosion and fire - make sure that you work with a knowledgeable fabricator to develop specifications for such a conductive corrosion liner and the "bleed off" of the static charges.

Again, we often see specifications come through where the only requirement is FM or UL approval, where such approval was obtained only on a very nominal 20 to 30 mil corrosion liner. (One of the tricks of passing FM approval is to submit for testing pipe or duct that has only a very minimal resin rich liner.) In those cases, Factory Mutual approval does **not** also extend to the same duct construction, but with a heavier liner. In other words, first design the pipe or duct first for the corrosive environment and application - and then take into consideration fire retardancy, smoke and toxicity.

Step 3: Decide whether fire retardancy (low flame spread), smoke generation or smoke toxicity are even important or necessary for your application. These features are going to cost you extra money. If they are not required, do not specify them. Well over 90% of all FRP composite pipe and duct installed to date is not fire retardant and does not provide low smoke generation and low smoke toxicity properties. Be realistic about what is, and is not, required for your application - do not specify just because someone says it would be "nice" to have FM or UL approval for the corrosion resistant equipment you are going to install.

When choosing and specifying the materials for your system, consider the cost of the materials, installation and, most importantly, long-term operating costs. Installation of a Factory Mutual approved system may provide lower insurance rates. However, such a system may also cost more in materials and labor, and may require replacement or repairs in half the time when compared to a properly constructed dual laminate system.

Recommendation #1: If fire retardancy is important, but smoke is not a major consideration, then use a premium grade fire retardant vinylester resin, or a furan resin - depending upon the specific chemical service environment of your application. An example of this type of application might be where duct or pipe is installed up on a rack in an outdoors process plant environment. In this case you probably would not want fire spreading to other process equipment, propagating a major fire. But, because the installation is outdoors the small amount of smoke that would be contributed by the duct or pipe itself is not of major concern.

Recommendation #2: If not only fire retardancy (flame spread) is of major concern, but also so is smoke generation and smoke toxicity - then we recommend that you select the internal corrosion barrier/liner of your duct or pipe based upon the best resin matrix for your service environment. If the application is for pressure piping - the resin matrix for the liner need not be fire retardant. However if the application is for duct, then we would recommend using a fire retardant resin for the corrosion barrier/liner. The probable choice, depending upon the chemicals present and the operating temperatures, would be either one of the premium grade vinylester resins, or furan.

The structural and outer wall for **Recommendation #2** would be the Indspec FIRE PRF_2 phenolic resin. This gives you the best of both worlds. This construction provides an inner corrosion barrier using the proper resin for the service environment, and a structural and exterior surface using a resin matrix that has **outstanding** low flame spread, low smoke generation and low smoke toxicity. Be sure to specify the proper "tie coat" between the inner corrosion barrier/liner and the phenolic structural wall. Consult Industrial Fiberglass Specialties for such recommendations.

Typical applications where you would use **Recommendation #2** type construction would be for duct and pipe inside high occupancy buildings, duct in electronic and pharmaceutical plants where dense smoke could cause severe contamination problems, and those applications where, because of adjacent residential areas, smoke generation would not be "neighborly".

In a clean room, or other facility where even a little smoke can cause major damage, or where the insurance premiums make it mandatory - the cost of a FM system may be worthwhile. However, in most facilities, your "best buy" per year of service life would be **Recommendation #2**. A dual laminate system with furan or vinylester liner for long term corrosion protection, and an structural laminate of FIRE PRF_2 phenolic resin for excellent fire resistance and very low smoke emissions from fires in contact with the exterior.

Recommendation #3: Consult Industrial Fiberglass Specialties for the selection of your optimum piping and duct system. We will be glad to work with you in not only developing engineered recommendations for your lowest cost per year of service life - but, will also be glad to work with you on developing guide specifications that are tailored to your specific needs, insuring you (or your client) receive your "best buy".