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VACUUM PROCESSING WITH Scotchcast® Brand RESIN

By

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Higher vacuum processing, in the micron range, has become more common since many modern vacuum pumps used with resin processing equipment are capable of attaining ultimate vacuum of 100 microns or less (1 micron = 10^{-3} mm Hg.)

Pressures as low as a few hundred microns may be attained during such operations as drying and pre-evacuation of components before flooding with an impregnant. Before exposing an impregnating or casting resin to such low pressures, the vapor pressure of the resin system must be considered. If the vapor pressure of the resin system exceeds the pressure of the air over it, evaporation of the more volatile components will occur with significant material loss. Vapor pressure of resin is the pressure at any given temperature of the vapor in equilibrium with the liquid form. At elevated

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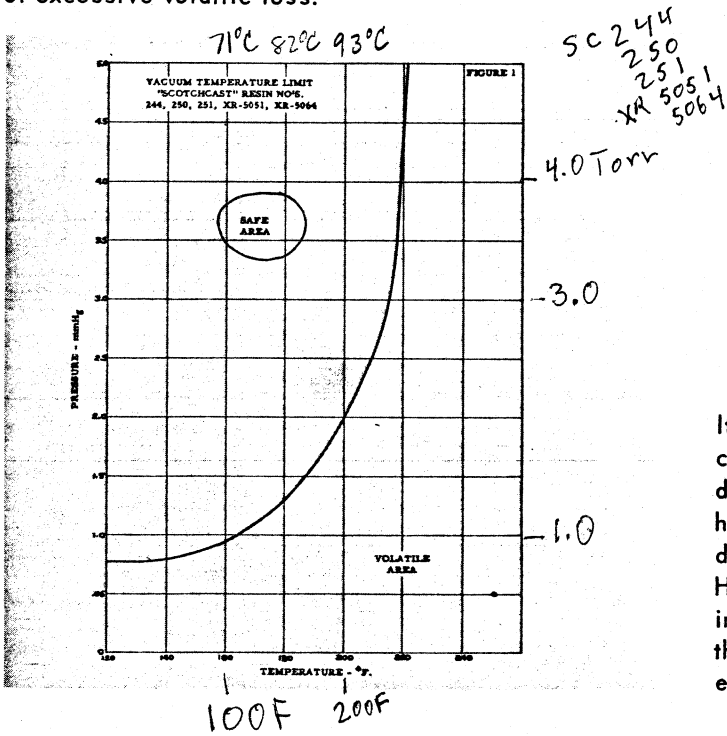
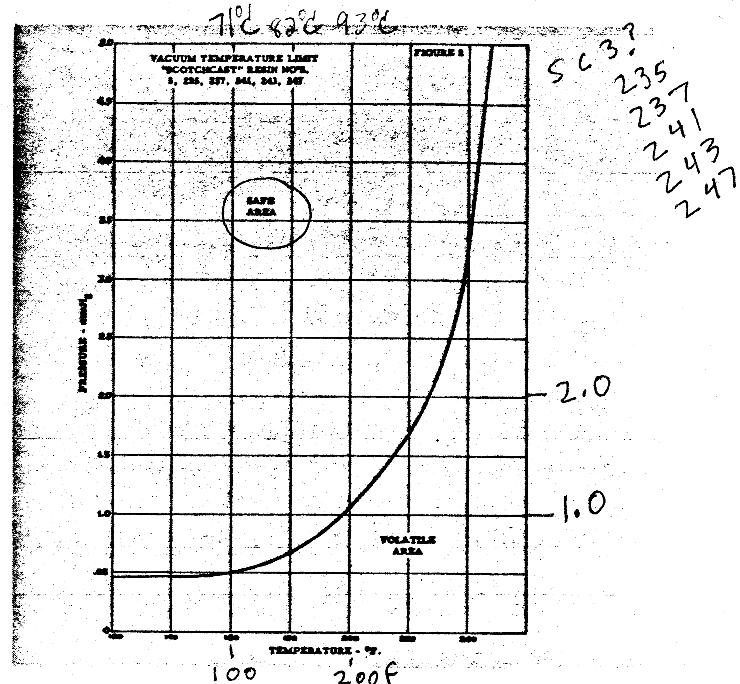
temperatures, the vapor pressure of the resin system is increased, making it even more susceptible to volatile loss at very low pressures.

To determine the safe pressure-temperature area for a number of "SCOTCHCAST" Resins, they were exposed to temperatures of 167° F., 203° F., and 248° F. at low pressures ranging from 500 microns to 5,000 microns (0.5 mm to 5.0 mm Hg). Approximately 2 cc of each resin was used with an exposed area of 1.5 cm^2. The volatile loss at each temperature and pressure was determined and plotted by means of an Ainsworth semi-micro recording vacuum balance. An exposure time of 15 minutes to the various pressures and temperatures was selected as representing an average process time; i.e., pre-evacuation and impregnation steps on a production line.

Using the weight-loss plots of the resins tested, safe pressure-temperature area curves were determined. Figures 1 and 2 outline the lowest pressures recommended at the intercepted temperatures for 15-minute exposure.

Of course, these curves can be used only as a guide since volatile loss is greatly dependent upon exposure time, area of exposure, and depth of the resin mass, as well as temperature and pressure. Figure 2, for example, shows a minimum recommended pressure of 450 microns (0.45 mm Hg) at 120° F. If the exposure time was only 2 or 3 minutes rather than 15 minutes, a higher temperature – up to 200° F. – could be used without danger of excessive volatile loss.





In most cases of resin evacuation and impregnation, very little practical advantage is gained by exposure to very low pressure; i.e., below several mm Hg. The principal reason is that the gas pressure in a mass of resin or component during evacuation is not just that of the vacuum chamber pressure but the sum of the chamber pressure plus the hydrostatic pressure produced by the resin. In other words, a bubble at the bottom of a container of resin is exposed to a much higher pressure that one at the top of the resin. The effect of a head of resin with a specific gravity of 1.4 on a bubble at various depths is shown in Table I.

TABLE I

Head of Resin over Bubble Inches	Pressure in mm Hg on Bubble
0.5	1.3
1.0	2.6
2.0	5.2
5.0	13.0
8.0	21.0
12.5	32.5

It can be seen from this table that in a 5-inch deep casting, even though the pressure over the resin is reduced to near absolute vacuum there still remains a hydrostatic pressure of 13 mm Hg at the bottom. Reducing the pressure over the casting from several mm Hg to a few microns is not nearly as effective as bringing the entrapped air in the resin to the surface, where the low pressure of the vacuum chamber is effective in expanding and removing it.

Figure 3 illustrates the effect of hydrostatic pressure on the size of a bubble rising through resin to the surface.

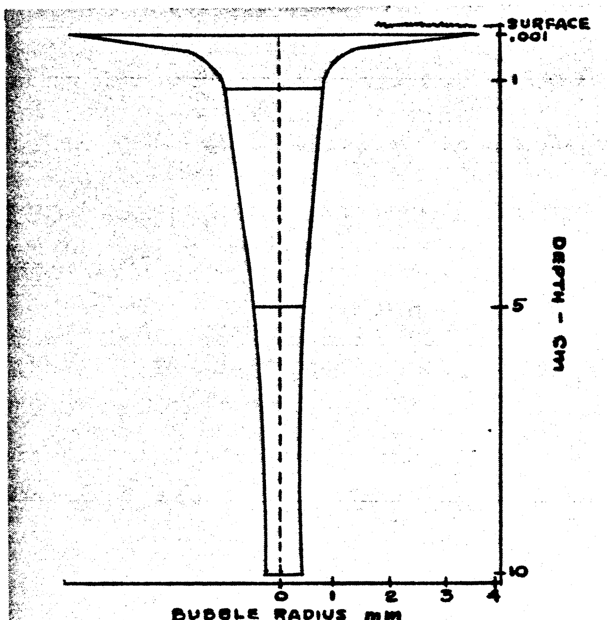


FIGURE 3

Disregarding surface tension and assuming absolute vacuum over the liquid, a bubble rising in resin will act as diagramed. Assume that a bubble has a radius of 0.5 mm at a depth of 5 cm. Then, from the equation

$$r = ro\left(\frac{ho}{h}\right)^{1/3} \quad \text{where:}$$

r = radius of bubble in mm at depth h,
ro = radius of bubble at level ho,
ho = original bubble depth in mm,
h = new bubble depth in mm.

We find that the bubble has a radius at other depths as follows:

Depth of Bubble	Radius of Bubble
.001 cm	4. mm
1.0 cm	0.855 mm
5. cm	.5 mm (assumed)
10. cm	.4 mm

Anyone who has evaluated resins has noticed that beginning at about a pressure of 20 mm Hg, violent "boiling" occurs. This is caused by the violent eruption of large air bubbles entrained during mixing operations. Soon this violent "boiling" subsides and gives way to a slow "simmering". This "simmering" will continue indefinitely in a container filled several inches deep with resin and is caused by the very slow rise of air bubbles in the resin to the surface. Even at pressures less than 1 mm Hg, tiny bubbles (several mils or less in diameter) may never exit without agitation or stirring to bring them to the surface.[1] Evacuation in a thin film or by thorough, prolonged agitation of deeper containers is the most effective means then of rapidly and completely degassing resin under vacuum.

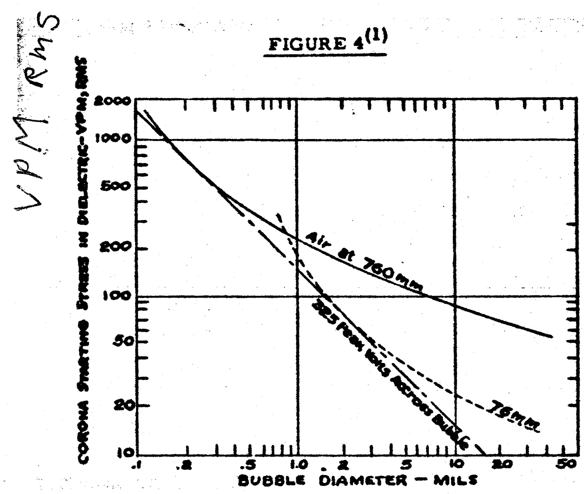
= 1 Torr

Lower Viscosity = Bubble rises faster.

Since air removal is so dependent upon resin depth, thorough degassing before casting and then pouring or flooding under vacuum is desirable. Degassing may be effectively accomplished with agitation or in thin film form at moderate pressure (5 - 10 mm Hg). Casting and impregnation may then be carried out at even lower pressure (1 mm Hg) in a matter of seconds to a few minutes by pouring under vacuum, and returning the casting to atmospheric pressure when the unit is filled with resin. Subsequent pressurizing assists in forcing the impregnant into small crevices and very tight, fine wire windings.

Since very small bubbles are so difficult to remove from a resin and in most instances many never are, the effect of bubbles on the performance of the resin as an insulator is of concern. One of the important factors that determines corona starting voltage, for example, is the shape and size of voids in a casting. Figure 4 is a plot of the calculated minimum corona starting stress versus bubble diameter in a dielectric.

FIGURE 4[1]



Solid curve: Electric stress in a semi-infinite dielectric which can produce corona in bubbles of various sizes for materials of high dielectric constant. The corona starting stress increases with decreasing dielectric constant and is 25% higher than the chart value for k = 2. Dashed curve: Corona starting stress for air filled bubbles at 76 mm pressure. Chain-dashed line: Corona should not start for combinations of stress and bubble diameter to the left of this line regardless of pressure in the bubble.

Parrellel plate?

Normally, operating electric stresses in insulation are not much more than 50 volts/mil. At this stress level, corona should not occur in bubbles under 3 mils in diameter. This premise is substantiated in practice. With proper design and selection of insulating materials, high voltage devices cast in resin operate corona free. Vacuum processing in the 1 - 5 mm Hg is commonly used for such devices. It is interesting to note that insulation failure caused by corona due to voids is almost always traceable to a gap or cleavage plane in the casting, gassing from incompatible insulations, or an improper processing cycle – not minute bubbles left after thorough evacuation.

EQUIPMENT CONSIDERATIONS

Evacuation at pressures in the low mm Hg range means <u>some</u> volatile loss of the resin system. Before installing a vacuum pump for use in a resin processing area, the user should be sure that the pump has been designed to handle a reasonable amount of volatiles. A trap should be installed between the pump and the resin processing tanks to prevent accidental resin entry into the vacuum lines and pump. Where large volumes of resin are being evacuated, a cold trap is desirable to remove volatiles. Dry ice or an old electric freezer unit are effective in a condenser trap. The pump should be equipped with a gas ballast feature to minimize pump oil contamination and possible damage. Capacity of the pump should be adequate so that rapid evacuation of the processing equipment is possible. Small, low capacity pumps should be avoided for production use. Such pumps are designed for laboratory or other intermittent duty. They run hot when pumping a large volume of air and in the presence of volatiles are susceptible to oil contamination and freeze-up.

[1] Murray Olyphant, Jr., Corona and Treeing Breakdown of Insulation Progress and Problems – Part 1, *Insulation*, Feb., 1963, pg. 35-40