# Separating Bubbles By Superficial Capillary Flow

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**SUMMARY:** In an earlier analysis [1], it was found that using bubble film is the best method for removal of volatile components and dissolved gases. The bubble film thickness may reduce to around 0.1 μm before break up and this allows diffusion at molecular level without nucleation. Formation of bubble film on the other hand, can provide a larger diffusion surface area. At one end, the bubble is playing an important role in removing the volatile component and dissolves gaseous and at another, the bubble itself is the problem and very difficult to eliminate. The separation of bubbles by means of capillary superficial flow process is found to provide a possible solution to get bubble free resin mixture prior before infusion. Therefore the process of mixing, degassing, bubble straining and infusion can be carried out concurrently to form a continuous supply system.

The paper develops the above work being undertaken at the University of Strathclyde to seek to reduce the formation of bubbles in the resin infusion manufacture of composite structures.

**KEYWORDS**: bubble film, volatile component, dissolves gaseous, capillarity, imbibition, drainage, infusion, degassing.

## INTRODUCTION

Developments in the field of advanced composite materials over the past decades have significantly altered their current and future potential role in structural applications. Composites offer structural designers materials of higher strength, stiffness and lower distortion than previously available engineering materials. Epoxy resin composites are one example of such a material. These composite systems are finding widespread use in the transportation, marine, aerospace and even sporting goods industries. As these structures are becoming more optimized, in order to reduce weight and material cost, the requirement on mechanical properties are increasing in terms of performance and consistency.

Vacuum infusion is one of the manufacturing techniques used to give increased performance. It is suitable for large load carrying composites and sandwich structures. The vacuum infusion process virtually eliminates styrene emissions, making for a cleaner and healthier workplace.

This process not only improves the air quality, but also reduces non-construction solid waste products significantly. Resin infusion under flexible tooling (RIFT) is a variant of vacuum driven resin transfer molding in which one of the solid mold faces is replaced by a polymeric film. One variant of the process is known commercially as SCRIMP

During the manufacture of composite components by resin infusion bubbles may develop during mixing due to air entrapment, local pressure variation and out-gassing of volatile components and dissolved gases. Bubble problems during composite impregnation results in higher void content. The void content distribution in the final laminate leads to inhomogenous problems in impregnation. Bubbles in a viscous fluid are very difficult to eliminate. It is possible to bring a bubble closer to the surface for diffusion but viscosity governs the drainage on the bubble film; therefore, smaller bubbles take a longer time to break up.

## THE FLUID AND BUBBLE

The fluid on this occasion is epoxy resin RSL 135i (viscosity 1100 mPas) and amine type hardener RSH 137i (viscosity 50 mPas) supplied by PRF composite. The mixture of 33g hardener for 100g of resin as recommended by the supplier at 25 $^0$C giving a viscosity of 200 mPas. During the pouring of the resin, there are always some entrained air bubbles. The big bubbles (over 1 mm in diameter) rise easily to the surface and take a few seconds to clear. The small bubbles (less than 1 mm in diameter) move much slower to the surface. Theoretically, the terminal velocity [4] of the rising bubble can be represented as

$$U = \frac{2}{9}\frac{\rho g r^{2}}{\mu} \tag{1}$$

The same things also happen during pouring of the hardener, being much less viscous than the resin, the bubble releases to the surface almost instantly. Since the resin is much heavier and viscous than the hardener, the two remain separated like water and oil. The stirring action to mix the resin and hardener creates more bubble and also much smaller bubble (dust like particle).

During the degassing process, the bubbles grow bigger in size and rise to the surface easily as buoyancy forces predominant. While the bigger bubbles disperse on to the surface, the much smaller bubbles only rise slowly to the surface. The pressure variation does not have any effect on the terminal velocity of a rising bubble. These smaller bubbles may take hours to rise to the surface.

It is essential to have bubble free resin before vacuum infusion starts. If the infusion starts immediately after degassing, the unreleased bubbles may migrate into the lamination. During curing, the shrinkage of the resin will pull the bubble surface in between the fiber tow creating higher void content. Therefore, the degassing time needs to be extended to allow the bubbles to clear the resin

## THE FILTERING MEDIUM

The filtering medium used in this experiment is made of woven fine fibers. It is supplied in sheet form and the pore size is very fine, the estimated range being from 50 to 100 microns distributed randomly. The thickness is about 2 mm. Each fiber is so thin that it can only be seen in a microscope, which can magnify at least 1000 times [6]. In just one square centimeter of the woven cloth, the fiber passes over itself 30,000 times (which means that each gram of the cloth contains 39,000 meters). It is almost unimaginable. The cloth feels smoother and softer than the finest terry. Rather than using fine mesh this woven micro fiber cloth was considered to be appropriate since the bubble size developed in the experiment varies from dust like particles.

## IMBIBITION AND DRAINAGE

In the studies of multiphase flow through porous medium [2], it is shown that capillarity governs most of the permeation process. The present of bubbles represents the non-wetting fluid, and the resin mixture therefore may be termed wetting fluid. The movement of these wetting and non-wetting fluid in between the solid medium by means of superficial capillary flow cause imbibition and drainage.

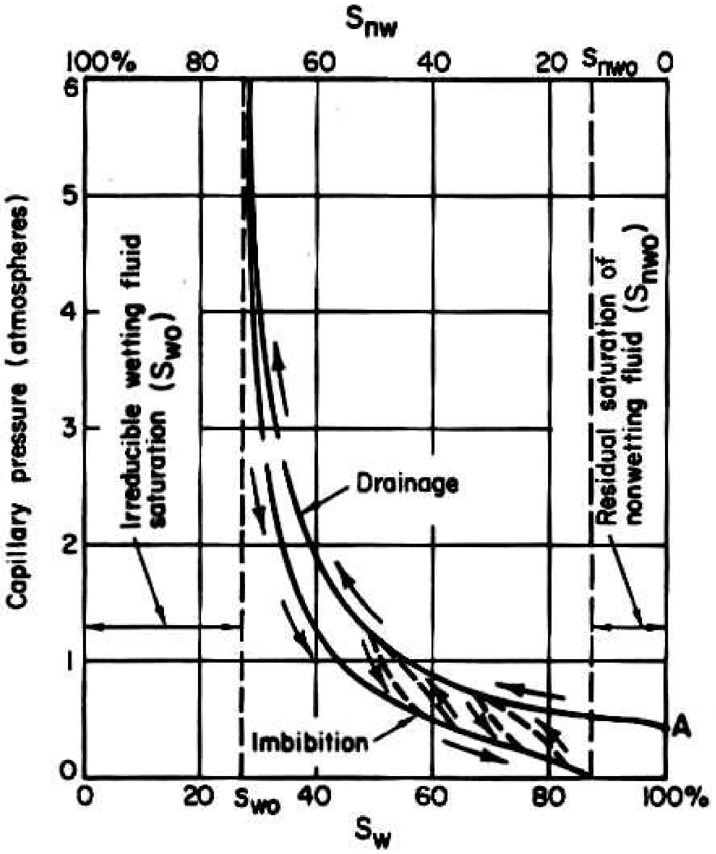

Figure 1: Typical capillary pressure – wetting fluid saturation curves illustrating hysteresis [2].

Due to the complexity of random configuration in natural porous mediums [5], capillary tube has been taken in most experiments as to ideally represent the actual mono-system. For a single bubble of non-wetting fluid to be forced in to a capillary (to promote drainage), slightly higher pressure needs to be induced compared to the process of imbibition by the wetting fluid that takes place naturally by the capillary pressure. With reference to figure 1 in unsaturated flows, Snwo indicates the amount of entrapped air that is the non-wetting fluid. At Snw ≤ Snwo, the non-wetting fluid ceases to flow.

Bond in 1928 [3] proposed a simplified formula for a critical diameter at which a gas bubble or liquid droplet is midway between rigid and fluid state:

$$d_{cr} = 2\sqrt{\frac{\sigma}{\Delta \rho g}} \tag{2}$$

For epoxy resin surface tension $\sigma$ = 32 dyne/cm (32 x $10^{-3}$ N/m) and resin density $\rho$ = 1.1028 g/cm$^3$ (1102.8 kg/m$^3$) and taking g = 9.813 m/s$^2$, the bubble critical diameter $d_{cr}$ = 0.003439 m (3.439 mm). Therefore, considering bubble diameters lower than this critical diameter (e.g. 1 mm to dust like particle) they are as rigid as can be theoretically accepted.

To explain what happens to the bubbles (as they cannot pass through the woven cloth), the following equation drawn from Young-Laplace equation should be able to verify the condition. Pressure P inside a bubble [4] of radius r is given by

$$P = \frac{4\sigma}{r} \tag{3}$$

The pressure inside a small bubble is greater than that inside a large one. When small and large bubbles are connected, the smaller ones inflate the larger and collapse. Therefore, the result of the coalescing bubbles that cannot penetrate through the filter will increase in buoyancy properties to rise and diffuse to the surface.

## RESULT AND CONCLUSION

A simple experiment has been carried out to verify the above theoretical approach. A bubbly resin was poured in to a cup-like container, made of the woven micro fiber cloth, placed in a vacuum pressure at 90 mbar. The excess resin which permeated through the filter was collected at the bottom of the vacuum chamber. It was found that the collected resin contained no visible bubbles. However, there was a small amount of dust like particles present. These dust like particles diminished as the vacuum pressure was relieved.

For the conclusion, bubbles created during mixing, transferring and degassing can be separated using a porous medium (fine fiber filter) due to superficial capillary flow. Therefore, bubble free resin can be produced, prior to the vacuum infusion process without waiting for the bubbles to clear by themselves, which consumes a longer period of time.

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