

# Resin Infusion Technology: Part 3 – A Detailed Overview of RTM and VIP Infusion Processing Technologies

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This is the final of three parts covering “resin infusion technology”, a composites processing method that has continued to grow in popularity while at the same time encompassing a wide variety of manufacturing versions for both aerospace and commercial markets. The January-February 2007 issue of the SAMPE Journal focused in Part 1 on various industry highlights and the time frame over which various supporting technologies entered into the resin infusion processing technology growth. In the May-June 2007 issue, Part 2 covered a bit of the process definitions and industry variations where RTM (resin transfer molding) and VIP (vacuum infusion molding) are encountered. The distinction between the RTM (pressure feed) and VIP (vacuum draw) processes were elaborated upon.

This particular discussion provides the interested reader with more detail on process advantages, disadvantages, comparison of processes and details on significant parameters affecting the process. Most of the tables are self explanatory so voluminous text discussion is not necessarily warranted here. The interested reader is also provided with several key references at the end of this part for future reading on the subject. Needless to say, SAMPE’s symposia and technical conferences over the past 15 years or so have been filled with a very large number of technical papers on the subject matter and the interested reader is certainly encouraged to look through any of the SAMPE Proceedings ([www.sampe.org](http://www.sampe.org)). Subjects pertinent to the resin infusion technology area will typically be: resin infusion, RTM, VARTM, VIP, SCRIMP, RFI, preforms, textiles, infusion resins and flow media.

Table 1 highlights the various advantages and disadvantages of pressure-feed RTM processing. There are some distinct differences in RTM processing for aerospace applications that are different from commercial applications. The reference by Kruckenberg and Rowan is very good in pointing out aerospace RTM processing steps and attributes.

(Continued on page 2)

**Table 1.** RTM-type process advantages and disadvantages.

<i>Advantages</i>	<i>Disadvantages</i>
<ul style="list-style-type: none"> <li>• Best tolerance control since tooling controls dimensions</li> <li>• Class A surface finish possible from tool</li> <li>• Surfaces may be gel coated for better surface finish</li> <li>• Smooth finish on both surfaces possible</li> <li>• Cycle times can be very short</li> <li>• Molded-in inserts, fittings, ribs, bosses and reinforcements possible</li> <li>• Low pressure infusion operation (usually less than 100 psig)</li> <li>• May increase post-infusion process pressure to higher level (say 200-300 psig)</li> <li>• Prototype tooling costs relatively low</li> <li>• Volatile emissions (e.g. styrene) controlled by closed mold tooling process</li> <li>• Lower labor intensity and skill levels</li> <li>• Considerable design flexibility: reinforcements, lay-up sequence, core materials, inserts and mixed materials co-cured in place</li> <li>• Mechanical properties comparable to autoclaved parts with low void contents (&lt;1%)</li> <li>• Part size range and complexity makes RTM appealing</li> <li>• Near net-shape molded parts with little trim required</li> </ul>	<ul style="list-style-type: none"> <li>• Mold and tool design critical to part quality</li> <li>• Tooling costs can be high for large production runs</li> <li>• Mold filling permeability based upon limited permeability data base</li> <li>• Mold filling software limited or still in development stage</li> <li>• Preform and reinforcement alignment in mold is critical</li> <li>• Production quantities typically range from 100-5000 parts</li> <li>• Requires matched, leak-proof molds</li> </ul>

*Adapted from Benjamin and Beckwith Reference*

Table 2 expands upon the brief Part 2 discussion of RTM and VIP processing similarities and differences. At the same time, there are numerous “subgroups” to these, essentially key two families and therefore a discussion of (a) resin film infusion (RFI), (b) expansion RTM and (c) SCRIMP or SCRIMP-like VIP is covered in this same table. I added the term “SCRIMP-like” because a large number of composites companies utilize very similar features of the licensed SCRIMP process to avoid licensing, patent issues and such. Substitutions for resin flow tubing using sliced tubing, slotted tubing, spiral wrap electrical connector tubing, and similar processing innovations are common. Flow media, ranging from simple wire or plastic screen materials to “burlap” mat is also a common practice. The author is not suggesting patent or licensing infringement and only points out what appears to be common practice within the current composites industry.

**Table 2.** Comparison of various RTM and VIP molding processes.

<i>Processing Terminology</i>	<i>Process Attributes or Features</i>
Resin Transfer Molding (RTM)	<ul style="list-style-type: none"> <li>• Developed from urethane technology</li> <li>• Resin injected into matched mold under pressure</li> <li>• Excellent surface finishes on both surfaces</li> <li>• Can obtain high fiber volumes (55-65%)</li> <li>• Process called Co-Injection RTM (CIRTM) uses different resin systems during process</li> </ul>
Vacuum Infusion Processing (VIP)	<ul style="list-style-type: none"> <li>• Often termed Vacuum-Assisted RTM (VARTM or VRTM)</li> <li>• Vacuum pulls liquid resin into preform (no applied pressure)</li> <li>• Single-sided tool normally used with vacuum bagging technology</li> <li>• Requires lower viscosity resins</li> <li>• Excellent surface finish on tool side only</li> <li>• Tooling less expensive than RTM</li> <li>• Lower fiber volumes normally obtained (45-55%)</li> </ul>
Resin Film Infusion (RFI)	<ul style="list-style-type: none"> <li>• Resin “film” placed in bottom of tool and autoclave heat/pressure cycle used to melt and force resin into preform</li> <li>• Resin “film tiles” normally based on prepreg B-staged formulations</li> <li>• Normally requires matched die tools for complex parts</li> <li>• Several industry variations exist:                             <ul style="list-style-type: none"> <li>○ Resin Liquid Infusion (RLI) in which liquid resin replaces resin “film” sheets in tool bottom</li> <li>○ SPRINT™ in which resin layers are interspersed in the preform lay-up and flowed during heat up</li> </ul> </li> <li>• Capable of producing high quality parts depending upon tooling</li> </ul>
Expansion RTM	<ul style="list-style-type: none"> <li>• Thermal Expansion RTM (TERTM) uses matched die with internal core that expands to provide pressure after RTM infusion of preform</li> <li>• Rubber-Assisted RTM (RARTM) uses silicone rubber tooling inserts which expands upon heating to provide pressure intensification within the tooling cavity after RTM infusion of the preform</li> </ul>
SCRIMP™ or “SCRIMP-like” VIP	<ul style="list-style-type: none"> <li>• Seeman’s Composite Resin Infusion Molding Process (SCRIMP™) uses a proprietary infusion tubing and media to speed resin flow and thickness infusion of the resin</li> <li>• “SCRIMP-like” VIP processes use various <u>commercially available</u> “flow media” to achieve results similar to the SCRIMP™ process</li> </ul>

*Adapted from Benjamin and Beckwith, Campbell References*

Table 3 really starts to get into the “nitty gritty” of what processing variables are important in RTM and VIP manufacturing. There are obviously a number of important factors and each one plays an important role in how one decides what works best to their advantage. Understanding their effects means that one can more consistently control the process every time to ensure good parts are made repeatedly.

**Table 3.** RTM and VIP processing variables and their effects.

(Table 3 continued on page 4)

<i>RTM or VIP Process Parameter</i>	<i>Potential Effects on Processing or Structure</i>
Resin Viscosity	<ul style="list-style-type: none"> <li>• 50-1000 cps typical flow processing range</li> <li>• Processing at 10-100 cps at higher temperature also typical</li> <li>• Higher viscosity – preforms often hard to wet out</li> <li>• Lower viscosity – more rapid infusion may leave dry areas and voids</li> </ul>
Resin Pot Life	<ul style="list-style-type: none"> <li>• Too short – resin fails to completely fill preform</li> <li>• Too long – process cycle lengthened unnecessarily</li> </ul>
Resin Injection Pressure	<ul style="list-style-type: none"> <li>• Helps drive resin into mold and preform</li> <li>• Applied too fast – may move preform out of position within mold</li> <li>• Too high a pressure may cause “fiber” wash of preform</li> <li>• Too high – may damage mold, tooling or “blow seals”, causing damage</li> <li>• Too low – cycle times very long</li> <li>• Too low – resin could gel during fill period</li> </ul>
Resin Injection Vacuum Level	<ul style="list-style-type: none"> <li>• 20-28 inch Hg typical process range</li> <li>• Helps pull resin into mold and preform</li> <li>• Aids in reducing void content through part</li> <li>• Assists also in holding mold halves closed</li> <li>• Aids in removing moisture and volatiles</li> </ul>
Multiple Injection Ports	<ul style="list-style-type: none"> <li>• Commonly used to ensure more complete wet-out of preform structure</li> <li>• Sometimes used sequentially to fill long or large area parts (e.g. “pumping” action)</li> </ul>
Internal Rubber/Elastomeric Tooling	<ul style="list-style-type: none"> <li>• Rubber/elastomeric inserts have very high expansion (high CTE)</li> <li>• Often called “pressure intensifiers”</li> <li>• Used to provide internal compaction pressures</li> <li>• Higher fiber volumes (&gt;65%) achievable</li> <li>• Very low void contents typical (&lt;&lt;1%)</li> <li>• Tooling <u>must</u> be much more robust to handle induced pressures</li> </ul>
Closed Mold Pressurization	<ul style="list-style-type: none"> <li>• <u>Infusion</u> pressures usually below 100 psig</li> <li>• Pressure often increased to 100-300 psig range <u>after</u> resin wet-out</li> <li>• Decreases “microvoids” by collapsing “bubble cavities”</li> </ul>
Fiber Sizing or Coupling Agents	<ul style="list-style-type: none"> <li>• Sizing or coupling agent chemistry must be compatible with selected resin</li> <li>• Sizing level (if too high) can reduce resin flow (lowers effective permeability)</li> </ul>
Preform, Reinforcement Integrity	<ul style="list-style-type: none"> <li>• Loose preforms (chopped fiber, lightly tacked layers, low fiber volumes, etc.) tend to “wash” and move around the mold cavity</li> <li>• Tight preforms (braids, stitched, fabrics, textiles, etc.) tend to maintain shape and integrity</li> </ul>
Fiber Volume	<ul style="list-style-type: none"> <li>• Resin flow permeability inversely proportional to fiber volume</li> <li>• Higher fiber volumes (&gt;60%) requires more work, energy and time to wet-out preforms</li> <li>• Commercial market – usually 25-55 vol%</li> <li>• Aerospace market – usually 50-70+ vol%</li> </ul>
Core Materials	<ul style="list-style-type: none"> <li>• Foam core and balsa core materials used extensively</li> <li>• Open cell and honeycomb core materials require</li> </ul>

**Table 3.** Continued from page 3

	<ul style="list-style-type: none"> <li>method for preventing resin flow into cell structure</li> <li>Closed cell cores typically have some inherent resin path to opposite sides (flow media, cross-cuts, pore holes, etc.)</li> </ul>
Molded-in Inserts and Fittings	<ul style="list-style-type: none"> <li>Inclusion and co-curing entirely possible with RTM and VIP processes</li> <li>Resin flow around these can leave dry areas and voids</li> </ul>

*Adapted from Benjamin and Beckwith Reference*

Table 4 pertains to “preform” options. All fiber reinforced composites have some degree of “fiber” inherent within the structure. With RTM and VIP, the key structural component is the “preform”. By definition the preform is that fiber reinforced structure (dry) that is designed to be inserted within the mold or tooling, and is further designed in such a manner as to carry the structural, thermal, and physical loading of the eventual cured composite structure. The preform may be made in a variety of manner but the desired preform will be governed by economics, structural requirements, physical and thermal needs, complexity – and a wide variety of other factors.

**Table 4.** Preform options – their advantages and limitations with RTM or VIP.

<i>Preform or Textile Process</i>	<i>Advantages</i>	<i>Limitations</i>
Chopped, Spray-up Materials	<ul style="list-style-type: none"> <li>Low cost preform approach</li> <li>Low-to-moderate in-plane properties</li> <li>Lower fiber volumes</li> <li>Several variations (short chopped fiber spray-up, P4 glass process and P4A carbon process)</li> </ul>	<ul style="list-style-type: none"> <li>Lower mechanical properties</li> <li>Commercial performance range applications</li> </ul>
Low Crimp Uniweave	<ul style="list-style-type: none"> <li>High in-plane properties</li> <li>Good tailorability</li> <li>Highly automated preform fabrication process</li> </ul>	<ul style="list-style-type: none"> <li>Low transverse and out-of-plane properties</li> <li>Poor fabric stability</li> <li>Labor intensive ply lay-up</li> </ul>
2-D Woven Fabric	<ul style="list-style-type: none"> <li>Good in-plane properties</li> <li>Good drapeability</li> <li>Highly automated preform fabrication process</li> <li>Integrally woven shapes possible</li> <li>Suited for large area coverage</li> </ul>	<ul style="list-style-type: none"> <li>Limited tailorability for off-axis properties</li> <li>Low out-of-plane properties</li> </ul>
3-D Woven Fabric	<ul style="list-style-type: none"> <li>Moderate in-plane and out-of-plane properties</li> <li>Automated preform fabrication process</li> <li>Limited woven shapes possible</li> </ul>	<ul style="list-style-type: none"> <li>Limited tailorability for off-axis properties</li> <li>Poor drapeability</li> </ul>
2-D Braided Preforms	<ul style="list-style-type: none"> <li>Good balance of off-axis properties</li> <li>Automated preform fabrication process</li> <li>Well suited for complex curved parts</li> <li>Good drapeability</li> </ul>	<ul style="list-style-type: none"> <li>Size limitation for off-axis properties</li> <li>Low out-of-plane properties</li> </ul>
3-D Braided Preforms	<ul style="list-style-type: none"> <li>Good balance of in-plane and out-of-plane properties</li> <li>Automated preform fabrication process</li> <li>Well suited for complex shapes</li> </ul>	<ul style="list-style-type: none"> <li>Slow preform fabrication process</li> <li>Size limitation due to machine availability</li> </ul>
Multiaxial Warp Knit	<ul style="list-style-type: none"> <li>Good tailorability for balanced in-plane properties</li> <li>Highly automated preform fabrication process</li> <li>Multi-layer high throughput material suited for large area coverage</li> </ul>	<ul style="list-style-type: none"> <li>Low out-of-plane properties</li> </ul>
Stitched Preform Structures	<ul style="list-style-type: none"> <li>Good in-plane properties</li> <li>Highly automated fabrication process provides excellent damage tolerance and out-of-plane strength</li> <li>Excellent assembly aid</li> </ul>	<ul style="list-style-type: none"> <li>Small reduction in in-plane properties</li> <li>Poor accessibility in complex curved shapes</li> </ul>

*Adapted from Campbell*

Resin characteristics are hit again in Table 5 because resin parameters are very important to infusion processing. Processing modeling and simulation is controlled by fluid flow in porous media – e.g. D’Arcy’s Law in particular. The important parameters typically being viscosity, temperature, working time (pot life, gel time) and permeability (actually a preform aspect more than resin aspect).

**Table 5.** Resin characteristics for infusion processing.

<i>Resin Parameter</i>	<i>Pertinent Characteristics Desired</i>
Viscosity	<ul style="list-style-type: none"> <li>• Flow viscosity must be low enough to rapidly wet-out preform</li> <li>• Viscosity should be in 50-1000 cps range</li> <li>• Viscosity comparisons (77F):               <ul style="list-style-type: none"> <li>○ Water = 1 cps</li> <li>○ Blood, Kerosene = 10 cps</li> <li>○ 30wt Motor Oil = 150-200 cps</li> <li>○ 40wt Motor Oil = 250-500 cps</li> <li>○ Honey = 2000-3000 cps</li> </ul> </li> </ul>
Pot Life or Gel Time	<ul style="list-style-type: none"> <li>• Must be sufficient to allow <u>complete</u> wet-out of entire preform</li> <li>• Too short – resin stalls out and leaves dry areas</li> <li>• Too long – unnecessary cycle time duration</li> </ul>
Temperature Controls	<ul style="list-style-type: none"> <li>• Higher temperatures can:               <ul style="list-style-type: none"> <li>○ Decrease resin viscosity initially</li> <li>○ Shorten infusion time too much</li> <li>○ Speed up cure reaction</li> <li>○ Decrease time to 1000 cps limit</li> </ul> </li> <li>• Temperature controls (heating) can be placed upon:               <ul style="list-style-type: none"> <li>○ Mold cavity</li> <li>○ Resin mix bowls</li> <li>○ Incoming resin lines</li> <li>○ All of the above or only certain regions</li> </ul> </li> </ul>

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Flow media, as a result in the SCRIMP patents that were generated in the late 1980's and early 1990's, play an important part in getting resin to quickly flow 'into the structural preforms and wet out the surrounding fibers. Table 6 discusses several variants that have cropped up in recent years within the infusion industry.

**Table 6.** Flow media enhancement for infusion processing.

<i>Flow Media Type or Approach</i>	<i>Generally Observed Effects</i>
"Omega" Tube or Perforated Tubing	<ul style="list-style-type: none"> <li>• Open side of Omega tube allows rapid resin flow through tube and lateral flow across surface of preform</li> <li>• Perforated holes in tubing acts in same manner</li> <li>• Spiral cable wrap also typical substitute</li> </ul>
Screen Materials	<ul style="list-style-type: none"> <li>• Rigid and semi-rigid screen materials used to increase permeability for resin flow between layers</li> <li>• Materials of choice: plastic mesh, window screen, Burlap</li> </ul>
Double Vacuum Bagging	<ul style="list-style-type: none"> <li>• Resin infused with secondary bagging layer pulled off preform surface (creates higher permeability and lower fiber volume initially)</li> <li>• Vacuum eventually applied across preform to remove voids and provide compaction <u>after</u> resin infusion completed</li> </ul>
Perforated, Slotted Cores	<ul style="list-style-type: none"> <li>• Core perforations or cross-cut slotting (saw cuts) in core material</li> <li>• Creates z-direction resin flow to opposite sides of core for complete wet-out</li> </ul>