

Impregnation Systems

The Basics of Vacuum Impregnation

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Many companies from very different industries - automotive, defense, aviation, industrial OEMs - allow vacuum impregnation of their parts. Numerous companies even operate one or more vacuum impregnation systems in-house as it is an integral part of their manufacturing system.

The ultimate goal of vacuum impregnation is to seal leak/migration paths, known as porosity, without impacting the functional, assembly or appearance characteristics of a part. Functional characteristics include the ability for fluids or gasses to flow only where needed in order to enhance in-service performance of the component's design. Assembly characteristics, which must be maintained, include performance of tapped holes, the integrity of mating and sealing surfaces, the elimination of residual internal contamination in water jackets, sockets, surfaces, and dimensional areas. Appearance characteristics include oxidation and discoloration.

Vacuum impregnation is governed by Military Standard MIL-STD-276A as well as numerous proprietary and customer specifications.

The vacuum component of the process removes the air that occupies the porosity in cast or pressed metals. The impregnation component of the process fills the void with a durable and stable material that seals the porosity. These materials can be methacrylate monomers, silicates or epoxies.

In general, vacuum impregnation is a four step process.

1. In the **Impregnation Chamber** (also known as an autoclave, pressure vessel or vacuum vessel) air is evacuated from the porosity in the part by using a deep vacuum. The evacuated leak path is filled with sealant by covering the part with the sealant and applying pressure. It is important to note that more energy is required to penetrate the porosity with sealant than to evacuate the air.
2. In the **Recovery Station** (also known as drain station, centrifuge) excess sealant is recovered for reuse.
3. In the **Wash/Rinse Station**, residual sealant is washed from the part's internal passages, taps, pockets and features where sealant is undesirable.
4. In the **Cure Station**, the sealant, impregnated into the walls of the part, is polymerized in the leak path.

However, what is often overlooked is that a successful impregnation program is a combination of process type, manufacturing system and sealant and that the combination will determine the success or failure of the vacuum impregnation process. Every part requires more or less its own combination of the various options to achieve the best result. Not every sealant is suitable for every part

just as not every process is suitable for every part. Each process, system and sealant has pros and cons, and it is important to choose the combination that presents the lowest risk to achieve the customer's goals.

Vacuum Impregnation Selection Variables

There are three selection variables to consider when using vacuum impregnation:

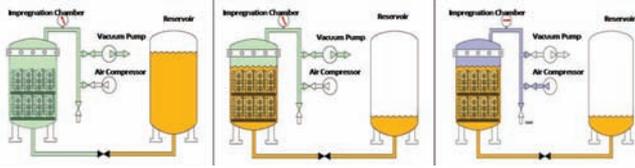
- Process
 - Dry Vacuum & Pressure (DVP)
 - Dry Vacuum (DV)
 - Wet Vacuum (WV)
- System
 - Batch System
 - Offline
 - External
 - Lean System
 - Online (Continuous Flow)
 - Front Loading
- Sealant
 - Anaerobic
 - Thermosetting
 - Recyclable
 - Recoverable

Processes

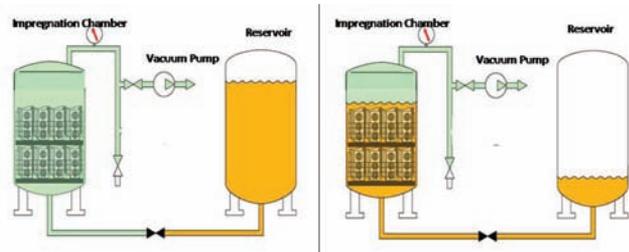
As mentioned above, there are three vacuum impregnation processes:

- Dry Vacuum and Pressure (DVP),
- Dry Vacuum (DV) and
- Wet Vacuum (WV).

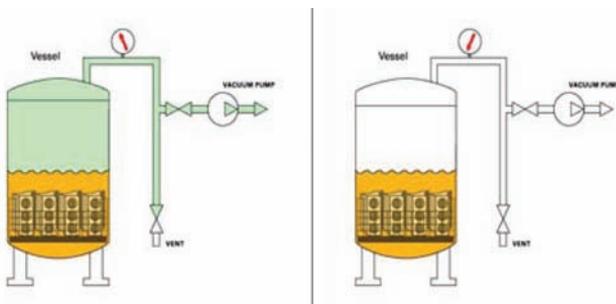
Dry vacuum and pressure impregnation is the most robust and thorough method of impregnation. It is used when a casting or component's sealing requirements are demanding, when parts have a design that makes them difficult to seal or if the part is high in value. Dry vacuum and pressure is the preferred method for impregnating parts and components manufactured for the automotive, aerospace and defense industries.



Dry vacuum impregnation is a method to seal simple porosity and leak paths. However, since it lacks the final pressure stage (which allows for sealant penetration), it requires longer cycle times and is less effective than DVP.



Wet vacuum impregnation is suitable to seal large, through porosity and leak paths. It is less consistent in its sealing effectiveness, but it is the preferred process to seal powdered metal parts and electrical components due to the large and open nature of the porosity. Because the wet vacuum process does not require a certified pressure vessel, a sealant reservoir and transfer line, it is a low-cost option, but it is limited in its application.



Systems

The second variable in the vacuum impregnation selection process is determining what type of system will best meet your needs - a batch system, cellular/lean or a continuous flow system. This depends on the material being impregnated, handling, access and whether a manual or automated system is preferred.

A summary of each type of system is included in table 1 below.

The **top loading or batch system** is the most common type of impregnation system and has remained unchanged for 50 years. Parts to be processed are aggregated into the impregnation vessel, which then passes through the various steps of the process. Due to high packing density and system size, a longer rinse cycle is required to perform the process and ensure all residual impregnation sealant is thoroughly washed off the components. These systems have few limits with regard to component size and weight and are the primary reason these systems are utilized by impregnation subcontractors. Other than their use in subcontractors' facilities, batch systems have little or no applications in modern OEM manufacturing systems.



Figure 1 – Batch Process Vacuum Impregnation System.

Table 1

System	Workload Size	Process	Cycle Time	Use	Labor	Floor Space Requirement	Automated or Manual
Top loading batch system	24-96 inches in diameter; working depths of 12-120 inches	DVP, DV or WV	20-40 minutes	Jobbing and processing hundreds of unique parts large and small	High	1,000 to 10,000 square feet, including storage and support equipment	Manual
Front loading system	Rectangular tote size of 300 mm x 400 mm x 800 mm	DVP or DV	480-540 seconds	Specialized, similar parts, large or small	Low	Low	Manual or semi-automated
Continuous flow system	Rectangular tote size of 300 mm x 400 mm x 800 mm or direct part handling	DVP or DV	90 seconds	Specialized, similar parts, large or small	Low to None	Low - less than 200 square feet	Automated



Figure 2 – High Value / Low Volume Impregnation System.

The lean **front loading system** represents modern technology. These systems are cellular or lean in design, focused on conserving resources including labor, power and floor space while being very ergonomic. The individual stations are loaded from the front, eliminating the need for overhead hoists and cranes. These systems impregnate smaller load sizes or single components per impregnation cycle. This allows reduction for efficient and effective process times and the cleanliness of the components is much better than with the top loading system. The only limitation is component size yet these systems can handle the largest V-8 engine blocks and transmission cases.



Figure 3 – Continuous Flow Impregnation System.

The new **Continuous Flow Impregnation (CFi) System** takes it one step further. This impregnation system is front loading as well, but with help from a robot. This impregnation process is extremely “pure” and has a cycle times of less than 95 seconds. Individual part handling leads to many process improvements, such as shorter cycle times, better rinse results without risk of contamination, damage or discoloration. Furthermore, each part passes through an identical process, and process parameters can be directly associated with a particular part (tracking).

Sealants

Choosing which sealant type is the final variable of an impregnation program. There are three types of impregnation sealants:

- Anaerobic,
- Thermosetting recyclable and
- Thermosetting recoverable.

Anaerobic sealant cures at room temperature and relies on metal ions to catalyze the sealant and is primarily used with wet vacuum impregnation systems. This sealant is best-suited for powdered metals, insert/overmolded components and cables. When using anaerobic sealant, components must cure for up to 48 hours prior to a pressure test. The sealant has a short pot life and becomes unstable once initiated in the impregnation chamber. Anaerobic sealant requires constant refrigeration and aeration and special or dedicated drain systems for the elimination of the sealant and effluents.

Thermosetting recyclable sealant cures in hot water or at an elevated temperature. This sealant is best-suited for powdered metals and castings. When using thermosetting recyclable sealant, components may be pressure tested immediately after the cure stage after they are cooled, and less wash water is required. The sealant has a short pot life as it becomes contaminated with minerals, water and solids thus decreasing the recovery of the castings over time. Due to this uncontrollable change of the ingredients, it has a higher risk of mass polymerization.

Thermosetting recyclable sealant requires constant refrigeration and enhanced testing techniques to keep the sealant within the required range. When using this sealant the high operating costs (e.g.: long degassing process) and the high VOC emissions, as well as the issue of migration or sealant bleed-out have to be taken into consideration. The sealant may need to be disposed of every six to twelve months as recycled contamination builds in the system.

In addition to the sealant, further chemistry (wash water conditioners, sealant additives, inhibitors) is required to recycle the sealant out of the wastewater stream. The recycling process requires constant monitoring of all system and impregnation sealant parameters.

Thermosetting recoverable sealant also cures in hot water or at an elevated temperature. This sealant is best-suited for powdered metals, castings, cables and graphite parts. When using thermosetting recoverable sealant, components may be pressure tested immediately after the cure stage after they are cooled. The sealant is recovered in the centrifuge so the unused sealant remains pure. With a long pot life, the sealant remains in its original condition during and after recovery. When using this sealant, there is the issue of migration or sealant bleed-out, as with the recyclables. Wastewater-free systems are available.

MIL-I-17563C

It is important to note that regardless of the sealant type selected it should be tested to MIL-I-17573C and listed on the most recent issue of the US Department of Defense (DOD) QPL -17563.

MIL-I-17563C defines a series of tests that must be conducted under the auspices DOD to demonstrate a sealant is suitable for use. It includes testing samples immersed in several types of media (such as gasoline, fuel, sulfuric acid (18%), oil, water, etc.), along with temperature changes and pressure tests. After testing, the defined samples cannot leak and have to fulfill additional criteria. The MIL requirements exceed most testing criteria of OEMs and may be used to eliminate the need for further OEM testing.

This standard is currently the only universal specification applicable to impregnation sealants that is accepted by all manufacturers and used as a reference. Once listed, manufacturers cannot change composition of their sealants without approval from the DOD.

Unfortunately there is not just one solution for every part. For this reason, careful consideration should be given to what information will be specified by OEM specifications or drawings. Naming an impregnation sealant on the drawings will do little to guarantee the sealing quality because the process might not be correctly configured for the particular component. What should be specified is the process and system combination that will lead to the best opportunity for success and that the sealants listed on the Military Specification are acceptable alternatives.

While greatly condensed and simplified, we hope this overview provides you with a better understanding of vacuum impregnation processes, sealants and systems.

If you have any questions, please contact Godfrey & Wing.

Summary

There are three key components to vacuum impregnation - the process, the system and the sealant. Ask yourself:

1. Which **impregnation process** provides the highest opportunity for sealing a leak path at the lowest risk?
2. Which **manufacturing system** integrates into your parts' overall manufacturing flow?
3. Which **impregnation sealant** provides the lowest operating risk given the component being impregnated; the upstream and downstream processes; and the impregnation process selected?

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