

# Vacuum Impregnation System Technology

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In the November 2012 issue of DCE, we discussed the basics of vacuum impregnation, the essential fundamentals and variables in establishing a vacuum impregnation program. In the January issue, we took a deeper dive into one of the selection variables, the impregnation process types used to seal a casting. In this issue we discuss vacuum impregnation system technology or “hardware” used to impregnate the parts. The first section of the article, the Equipment Overview, describes the four (4) basic common tasks performed by an impregnation system. The Overview also provides detailed information on the variety of ways those tasks can be accomplished in a generic system.

The second section, System Selection, enables the reader to explore specific requirements and production goals for their impregnation system installation. Additionally, this section introduces and describes the design elements of the two (2) major categories of impregnation hardware. Correlating the specific requirements and goals for the impregnation system with the basic design elements of each of the major categories of impregnation equipment will help develop an impregnation system strategy and selection.



Figure 1 – Continuous Flow Impregnation System.

## Equipment Overview

All impregnation systems accomplish the same four (4) basic tasks:

1. **Penetration** of the casting porosity/leak paths with liquid impregnation sealant.

2. **Recovery** of excess impregnation sealant from the tapped holes, cavities and the outside surfaces of the casting.
3. **Cleaning** or washing of the component’s surface and features where sealant is undesirable.
4. **Polymerizing or “curing”** of the liquid sealant which has been trapped or impregnated within the casting walls or structures of the part.

In general each task is handled by an independent module. Taken together, these modules make up the impregnation system.

### 1. Impregnation Chamber Module (Autoclave, Pressure Vessel, Vacuum Vessel)

The goal in this module is to force the liquid impregnation sealant inside the porous casting walls and **penetrate through the leak paths** into the accessible porosity within the casting. Generally the impregnation chamber is a round vessel with a cover. If positive atmospheric pressure is used in the vessel, it is important to comply with the appropriate closure and safety technology as well as required technical certifications. Access to the chamber may be either the vertical (top loading) or horizontal (front loading) axis.

The impregnation sealant is handled in the chamber in several ways. In a “wet vacuum” system the sealant is loaded directly into the chamber and remains in the chamber at all times. Parts are placed directly into the chamber and immersed in the sealant at the beginning of the process. Conversely, in a “dry vacuum system,” the chamber is empty and parts are loaded directly into the empty chamber while the sealant is contained in a separate reservoir, which is adjacent to the chamber and connected to the chamber with a transfer line and valves. After applying a vacuum to the dry chamber loaded with parts, the transfer valve is opened and the impregnation sealant is drawn from the separate reservoir filling the chamber. The return of the impregnation sealant is accomplished by either letting it flow directly back into the reservoir below or by pressurizing the chamber and pushing the sealant back into the reservoir.

Some chambers suspend the part or load above the level of the stored impregnation sealant. While the part is suspended the dry vacuum is drawn. When the appropriate vacuum level is reached, the part is automatically immersed into the sealant contained in the chamber. Thus, the part is transported to the sealant and not the other way around. The advantage of this is the elimination of the separate reservoir and the corresponding

amount of required hardware and floor space. Reduction of cycle time is another advantage because lowering/lifting the part can be done much faster than transferring the sealant in and out of the chamber.

In addition to handling the impregnation sealant, the chamber's main function is to provide the energy needed to force the impregnation sealant into the leak paths within the casting walls. The actual impregnation cycle provides the vacuum and in some cases the positive pressure to complete this essential task. Before any sealant can be drawn or pushed into the porosity the air in that porosity must be completely evacuated. This is accomplished by exposing the castings to a deep industrial vacuum terminating at a predetermined endpoint.

The connected vacuum pump should be big enough to quickly evacuate the chamber in order to reach the desired vacuum level. The end result is what counts, not the pressure profile. The desired vacuum value should be at least 10 mbar although deeper vacuum levels are frequently specified. When the specified vacuum level is met, the parts are covered with the sealant using the methods described earlier. Once the parts are covered, the vacuum is released, allowing the sealant to penetrate into the now empty porosity through the available leak paths within the castings. In the most robust Dry Vacuum/Pressure systems (DVP) the chamber will then be energized with positive pressure (6.8 bar) to increase penetration and force the sealant deep into the casting walls.

At this point the castings are impregnated with liquid sealant and the chamber is returned to atmospheric pressure. Normally, the chamber module is fully integrated with PLC controls moving the chamber through the various steps in the cycle, ensuring process control without operator intervention.

Finally, temperature control is very important as well. When using anaerobic sealants this is absolutely critical. When using thermosetting impregnation sealants (especially recyclable sealant), constant monitoring of the sealant temperature is required to prevent mass polymerization. Planning for adequate refrigeration, especially in non-climate controlled facilities, is of utmost importance to ensure the impregnation sealant will constantly be kept at the manufacturer's recommended temperature.



Figure 2 - Continuous Flow Impregnation System.

## 2. Recovery Module (Drain Station, Centrifuge)

In this module, the excess impregnation **sealant is recovered** from surface areas, bores, water jackets, tapped holes and other places where it accumulates. At this point this excess impregnation sealant is still in its original state. It has not been exposed to or emulsified in water and doesn't require any treatment or chemistry in order to be re-constituted. Recovered sealant at this point is immediately available for re-use after it is collected by the recovery module. The goal is to recover as much of the impregnation sealant as possible at this stage of the process. This will help both control costs and improve the performance of the two remaining downstream tasks - part washing and curing.

The most basic systems recover the impregnation sealant by simply letting it drain off the parts and process fixtures or baskets. With this design much of the residual impregnation sealant on the parts drains off, but it is not the most effective since some the residual sealant in the water jackets, tapped holes and elsewhere may not drain effectively.

A better alternative for sealant recovery is a rotating or manipulated drip drain. With this method the batch of parts is rotated around its Z-axis in either a timed or continuous cycle. This mechanical manipulation increases sealant recovery allowing areas to drain that couldn't before because of their position. Still even with this method some impregnation sealant is left behind on the surface, in threads and deep tapped holes.

Using a centrifuge is the most effective method for recovering residual sealant. In this recovery module design, the payload is subjected to elevated rotational speed. Centrifugal force is used to remove and recover unused sealant. Working in conjunction with the vessel module, the unused, captured sealant is easily returned to the vessel or reservoir immediately ready for re-use on a future impregnation cycle.

When parts are secured with custom fixtures or special mounting clips, rotational speed and thus effectiveness can be increased (e.g.: 250 rpm). Now, the recovery of residual sealant can be maximized. This option is a design element on front loading systems that are equipped with standard baskets (600 x 400 x 300 mm). At this increased rotational speed, it is possible to almost completely recover all excess impregnation sealant from the payload. However, it is extremely important that the rotating parts be properly fixtured to avoid part-on-part contact and damage.

As mentioned before, effective sealant recovery is a very important task for the impregnation system. Improving sealant recovery immediately reduces operating cost with the conservation of raw materials (sealant). Likewise, stripping the impregnated parts of unused, residual sealant improves the performance of the downstream wash function, which leads to a cleaner, problem-free cure process. Dollars invested in increasing sealant recovery will be quickly recouped with the reduction in the cost of raw material and the improvement of overall system performance.

Some impregnation system technologies eliminate this module and task and instead allow parts saturated with impregnation sealant to move directly to the wash module. This is where the unused sealant is emulsified in the wash water which has been treated with additional chemistry in order to promote the flocking or separation of the sealant from the emulsion. Parts processed with this technology are always washed in water laden with emulsified sealant



Figure 3- Continuous Flow Impregnation System.

and other chemicals. In addition, the emulsified sealant cannot be immediately reused but instead must be separated or flocced from the wash water emulsion in yet another module and then “reconstituted” with additional chemistry in order to be recovered for reuse.

Both approaches result in the recovery of the unused residual sealant. However, recovery prior to emulsification provides for immediate re-use of the raw material, coupled with no additional chemicals, testing and variation.

### 3. Wash/Rinse Module (Surge Station, Roll Rinse, Pump-Over or Cascade Washer)

The purpose of the Wash/Rinse Module is to remove any unwanted, residual sealant from the casting surfaces, tapped holes and features prior to polymerization in the final Cure Module. Washing or **cleaning complex castings** is not a simple or easy task. Many companies specialize in parts washing technology. Effectively removing residual impregnation sealant provides additional challenges beyond normal part washing. Poor parts washing is the primary failure mode for impregnated parts.

There are three factors to consider prior to an evaluation of the variety of mechanical methods used to wash parts. First, from the discussion on sealant recovery, it was determined that maximizing the removal of unused sealant PRIOR to washing results in both greater raw material savings AND a cleaner, downstream washing process. Second, instituting and maintaining procedures and practices that promote the cleanliness of the wash water used in the cleaning process will improve overall wash performance. Finally, incorporating impregnation sealants that are formulated to deliver and promote increased emulsification and cleanliness will result in the cleanest castings moving forward into the manufacturing stream. These considerations should be made independently from but in conjunction with the mechanical design used in the wash/rinse module.

Mechanically, the most basic wash modules start with the simple immersion bath. The impregnation basket is lowered in and out of the washing agent (usually water) in a tank. The impregnation sealant is sheared from the part as the components break the surface of the water. This step may be repeated numerous times. The work can be performed by a surge cylinder/platform or with a hoist.

This option is the simplest way to wash excess sealant off the surface, but the stationary surge tank only provides minimal cleaning action. Often satisfactory results may only be accomplished by increasing the wash cycle time, reducing throughput and increasing costs.

Adding a clockwise and counter-clockwise roll to the stationary, surge wash module improves the washing of tapped holes and machined features, especially on highly machined parts. However, care must be taken to protect the parts from damage caused by the increased motion and manipulation in the module. In addition, design, engineering and build costs increase significantly as these types of complex features are incorporated in the wash/rinse module, especially in larger units.



Figure 4 - Batch Process Vacuum Impregnation System.

The best cleaning result is achieved by setting the washing agent as well as the impregnation batch of parts in motion. This is known as the spray-flood or cascade technology which takes advantage of the Rhönrad Principle. This Principle is very common in water-based cleaning of components and has been used successfully for many years. Almost all modern cleaning systems are based on this proven technology. Therefore, it also makes sense then to adapt and use this effective technology in the wash/rinse module design.

In this process, the batch of parts to be washed is rotated around its Z-axis, and the water is sprayed over and through the batch, shearing or cutting the impregnation sealant from the surface and complex features. The wash water is pumped in from an external tank and fills the wash tank until the desired fill level is reached. The level can vary depending on the component's geometry and can range from a half-filled tank to a full tank. While the system is pumping and moving the water, the wash water can be filtered to remove solids and wastes, preventing them from being re-deposited on the castings.

Finally, rinsing and draining of the residual wash water takes place in a separate tank in larger systems or in smaller units within the wash module tank using the clean rinse water to serve as make-up water for the unit.

Choosing the most appropriate wash/rinse module technology will most likely be mainly part-dependent. Part size, machining status, pack method and upstream and downstream processes must all be considered prior to selecting the design elements for the wash/rinse module in the impregnation system. Failure to identify and address critical wash/rinse requirements increases manufacturing risks and can be dif-

difficult to overcome in day to day operations, resulting in added handling, inspection and containment costs. Proper planning, analysis and advanced testing will control and eliminate those risks, resulting in a repeatable, quality process.

#### 4. Cure Module (Cure Tank, Cure Oven, Cure Station)

In this module, the liquid sealant trapped inside the porosity and leak paths of a component is transformed into a solid state, moving from a liquid to solid polymer. With all thermal cure sealants this is done by exposing the castings to an elevated temperature for a prescribed period of time. Heat energy is the key component and can be delivered through several module design elements. In most systems, the cure module uses a hot water (90 degrees Celsius) bath to provide the heat needed to trigger **the polymerization of the sealant**. The transfer of heat in water is very uniform and fast and parts will frequently “flash dry” allowing them to move quickly into the manufacturing stream. Other module designs utilize large continuous hot air ovens to provide the heat source needed to initiate polymerization.

When anaerobic sealants are used the polymerization of the sealant is not initiated by heat but is a chemical reaction which takes place over a much longer period of time. Although this at first appears to offer a significant advantage, controlling the chemical reaction can be problematic and presents the potential risk of the mass polymerization of the entire inventory of in-process raw material.

The technology used in impregnation systems is not complex. Four (4) tasks are performed, (penetration, seal-

ant recovery, washing and curing) usually by four independent modules. A variety of hardware designs are available to accomplish these tasks. Capital costs, operating costs, functionality and risk must all be considered. Some decisions may be part-dependent or dependent on other variables upstream or downstream from the impregnation process. With this in mind, the second section, Impregnation System Selection, discusses some of the variables which should be considered in the selection of impregnation system technology and describes the two major groups of impregnation system technology in use today.

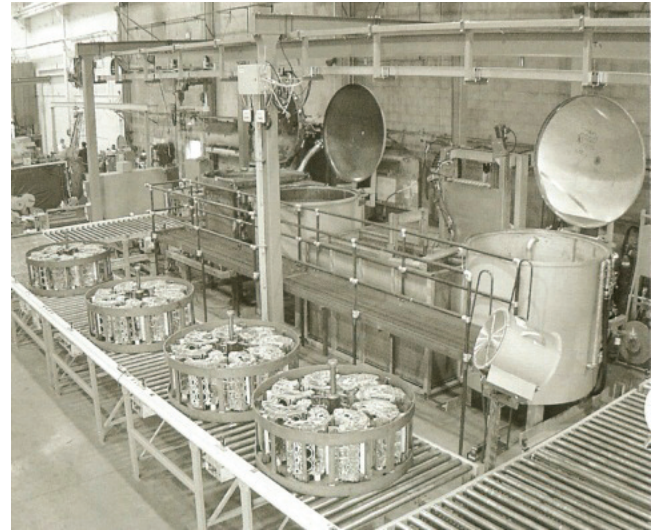


Figure 5 - Batch Process Vacuum Impregnation System.

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## Impregnation System Selection

Since the System Overview indicates that the technology selection is both part-dependent as well as dependent on other factors within the manufacturing stream, exploring the specific requirements and specifications for individual applications is a critical first step in any impregnation system evaluation. As a result, manufacturers must ask themselves:

### What are the characteristics of the components to be impregnated?

1. How many components need to be impregnated daily, weekly and annually?
2. What are the components' dimensions?
3. What are the components' weights?
4. From which materials are the components made (aluminum, iron, zinc, plastic)?
5. What is the machined status of each component (non-machined, partially machined, finished machined)?
6. What are the components' leak rates and porosity status?
7. Where do you anticipate difficulties or challenges with the impregnation process?

### What is your production schedule?

1. Working hours per day?
2. Working days per week?
3. Working days per year?
4. Number of shifts (per day/week/month/year)?

### How should the impregnation process be integrated into the overall manufacturing process?

1. Is the system integration to be on-line or as a separate off-line unit? How are the components manipulated, handled or transported in house (individually, in multiples (batches), as unique sets)?
2. What are the dimensions for the optimum part carrier calculated by size and weight?
3. Which processes are upstream of the impregnation (machining, washing, drying, testing) and which are downstream (electroplating, pressure testing)?
4. What batch sizes are needed before & after impregnation?
5. Which TAKT time must be met?

### What are the performance expectations for the impregnation process?

1. What sealing rate is expected from the impregnation system?
2. After impregnation must parts be immediately available for testing or downstream processing?
3. Will any part-on-part contact contribute to handling damage that will be unacceptable?
4. Are there specific cleanliness criteria that must be met?
5. Are there specific appearance criteria that must be met?

Armed with this information manufacturers can begin to establish what impregnation technology best suits their individual application. From the Equipment Overview



*Figure 6 – The top loading or batch system is the most common type of impregnation system in practice today.*

section, design elements for the four (4) individual system modules can be identified that will meet the specific application requirements.

For the most part, impregnation technology and the associated module design elements can be grouped into two (2) major impregnation equipment classifications.

### 1. Batch Systems - Top Loading Vacuum Impregnation Systems

The top loading or batch system is the most common type of impregnation system in use today. In this type of system, many parts are aggregated into batches and packed individually into baskets, which then pass through the various steps of the process. Batch systems range in size from 24" diameter units to very large systems that exceed 96" in diameter. Increased production volumes are met by increasing the size of the system. Economies of Scale are gained at first but careful evaluation demonstrates that as the systems grow other elements of production suffer. All batch systems require significant infrastructure such as hoists, gantries and/or pits due to their overall size. Larger systems require both pneumatic and hydraulic pressure to operate cylinders and valves. Individual loads can be large, but cycle times for each module or task can be exceedingly long. Material handling requirements are high, and individual part quality and repeatability may vary. Inspection requirements are high.

As size increases, individual design elements discussed in the Equipment Overview become more and more difficult to effectively and economically implement. Centrifuging and roll rinsing large baskets may not be a viable option. Transferring enough sealant to fill the approximate 540,000 cubic inches of a vessel that is 96" in diameter and 76" tall may not be practical.

In the same way valuable resources such as floor space and labor may be scarce. Aggregating parts into large batches creates excessive WIP and extends supply lines. Top loading units depend on batch processing which may not match the upstream and downstream manufacturing processes.

Batch systems have few limitations with regard to component size and weight, which is the primary reason these systems are utilized by out-source impregnation subcontractors. Other than their use in subcontractors' facilities, batch systems have a limited application in OEM manufacturing systems.

For the most part top loading batch systems offer:

#### Advantages

- Flexibility in range of part sizes and shapes
- Ability to process very large, heavy components



Figure 7 – The more recent lean front-loading system.

- Capable of impregnating high quantity of raw (non-machined) castings where part-on-part contact is not an issue

#### Disadvantages

- High requirements for floor space, labor and infrastructure
- Difficulty in handling fully machined, drilled and tapped components
- High risk associated with part washing and rinsing
- Increased need for inspection to insure quality

## 2. Lean - Front Loading Impregnation Systems

The lean, front loading system is a more recent technology than the larger batch units. These systems are cellular or lean in design, focused on conserving valuable resources including labor, power and floor space while being more ergonomic than batch systems. The individual modules are loaded from the front, eliminating the need for overhead hoists and cranes. These systems impregnate smaller size batches or single components per impregnation cycle. This allows for reduction of individual module cycle times as well as increased mechanical manipulation assisting in the accomplishment of the four basic tasks of the impregnation process.

In general, lean, front loading equipment uses smaller modules with little or no supporting infrastructure. Front loading systems can occupy as little as 86 ft<sup>2</sup> of floor space and utilize conventional basket dimensions (e.g.: 600 x 450 x 350 mm), which can be adapted to meet specific part dimensions, if required.

Front loading impregnation system can be designed for either manual or fully robotic operation, eliminating labor while reducing part handling damage.

Front loading systems offer:

#### Advantages

- Smaller, self-contained modules requiring less floor space and infrastructure
- Increased throughput through faster cycle times with lower end points in vacuum and positive pressure
- Smaller payload or single part handling with improved mechanical manipulation of parts promoting enhanced sealant recovery and washing
- More repeatable processing reducing the need for inspection
- Lower in-process sealant requirements resulting in better control of raw materials

#### Disadvantages

- Inability to process larger, heavier parts in excess of 60 Kg.
- May require custom fixtures or tooling to secure parts during processing

As mentioned before, front loading systems can be fully integrated using robotic support for all part handling and transfers between modules. This type of Continuous Flow Impregnation (CFI) technology provides additional features and benefits not available in manual equipment.

The CFI technology is fully self-contained for quality with the robot and PLC working together to ensure that parts do not leave the cell if they have not met all of the pre-determined process parameters. Likewise, the use of robotics shortens cycle times, improving overall TAKT time and production volumes. At the same time robotic handling provides for repeatable processing while controlling handling damage.

The CFI technology offers manufacturers and OEMs the opportunity to completely integrate the impregnation process into their overall production line eliminating labor, reducing WIP and controlling costs. Existing cells deliver over 240,000 cycles per year operating 24/7. They are ideally suited for larger powertrain installations where uniformity and repeatability are essential to part quality and delivery is paramount. Higher volumes, expansion or ramping production can be met by integrating duplicate cells.

While greatly condensed, hopefully this overview provides a better understanding of vacuum impregnation technology and hardware. Coupled with earlier articles on the basics of vacuum impregnation and the three commercially viable impregnation processes, this article attempts to provide more information on vacuum impregnation as well as a better understanding on how to evaluate vacuum impregnation for your specific application.

If you have any questions, please contact Godfrey & Wing at 1.800.241.2579 or visit [www.godfreywing.com](http://www.godfreywing.com).

Table 1 – Top Load vs. Front Load Vacuum Impregnation Systems.

System	Workload Size	Process	Cycle Time	Use	Labor	Floor Space Requirement
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
Front loading system	Rectangular tote size of 300 mm x 400 mm x 800 mm	DVP or DV	240-540 seconds	Specialized, similar parts, large and small	Low	Low
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 and small	Low to None	Low - less than 600 square feet