German Advanced Composites
Fast Forward with Innovation

MTI ® Process

MTI® (**M**embrane **T**ube **I**nfusion) is a **V**acuum **I**nfusion **P**rocess utilizing a semipermeable membrane hose for the system evacuation (see the difference to the standard VIP in the animation film on GAC`s website "MTI How it Works"). Semipermeable means that air and gases can travel through the membrane fabric but not resin.

Using other styles of break zones (e.g. peel ply wrapped vac line) they will eventually wet out and resin will be drawn out of the laminate. This won`t happen with the MTI® hose. Even with a thin, slow-curing resin system, the membrane hose creates an absolute barrier between the resin hydraulic pressure and the low pressure of the vent tube, even after resin reaches the MTI® hose, thus allowing the perfect environment to create void free laminates.

This product was specially designed to make the resin infusion process easier and more reliable. It enables the user to achieve high-end results on a par with autoclave systems but with much less investment and expenses in equipment, labor and material. In the following we provide information in terms of the physics behind, the technology and a proper set-up of a MTI® process.

Understanding Vacuum and how to measure it

The atmospheric pressure that we experience on earth is caused by the weight of air above the measurement point and for this reason it varies with the altitude above sea level. The standard atmosphere (atm) however is an established constant. It is approximately equal to typical air pressure at earth mean sea level and is defined as follows:

1 atm = 760 Torr = 29,92 "Hg = 14.7 psi = 101.3 kN/m2 = 1013 mbar = 1013 hPa

In practice, atmospheric pressure at sea level will vary from about 980 mbar to about 1030 mbar. At the summit of Mount Everest atmospheric pressure averages about 300 mbar.

The barometer in our home gives an absolute (atmospheric) pressure. The reading is the pressure above the absolute zero of pressure (or perfect vacuum). The vacuum of an infusion set-up is measured with an analog dial gauge, usually mounted on the vacuum pump or resin catch pot, and the reading is relative to the external atmospheric pressure. This relative measurement is called gauge vacuum and is the pressure difference with the atmospheric pressure as reference point. The vacuum gauge (manometer) works the opposite way to the barometer.

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Thus the absolute pressure in the vacuum bag or resin trap is equal to the current atmospheric pressure minus the gauge vacuum pressure ($P_{abs} = P_{atm} - P_{rel}$). Relative pressure (the gauge vacuum) is the driving force for the resin to get into the part. It is the difference between the atmospheric pressure and the absolute pressure in the bag ($P_{rel} = P_{abs} - P_{atm}$)

That means that in a location such as Florida (sea level with high atmospheric pressure) you get more pressure and can infuse over a longer distance than someone doing infusion in the mountains of Colorado. Weather affects the infusion process in the way that good weather provides higher pressure and bad weather lower pressure.

This means that the residual pressure inside the lay-up may differ from the gauge reading because of changes in atmospheric pressure due to changing weather conditions and altitude variations. For instance at sea level and standard weather (P_{atm} = 29.9 inHg) a gauge vacuum (P_{rel}) of - 25.9 inHg is equivalent to an absolute pressure of 4 inHg. In other words, the vacuum gauge that reads, for example, - 25.9 inHg at full vacuum is actually reporting 4 inHg, or 136 mbar absolute pressure. That is still in the low vacuum range.

For a high quality infusion process we strive to achieve an absolute pressure in the range of 10mbar (0.145psi or 0.295inHG) to 20mbar (0.29psi or 0.59inHG) above the absolute zero of pressure at the pump.

If we want to confirm that a bag has been evacuated to this degree of vacuum, the gauge used to measure this value needs to be accurate in this region.

A conventional analog vacuum gauge, usually mounted on the vacuum pump or resin catch pot will experience inaccuracies of at least ±25 mbar from weather variations alone, plus variations due to the accuracy of the mechanism within the gauge, typically between 1 and 3% of full scale, perhaps another ±30 mbar.

It is apparent that an analog vacuum gauge with a total accuracy of ±55 mbar (1.62inHG) is not an appropriate instrument for measuring an in-bag vacuum of 10 to 20 mbar.

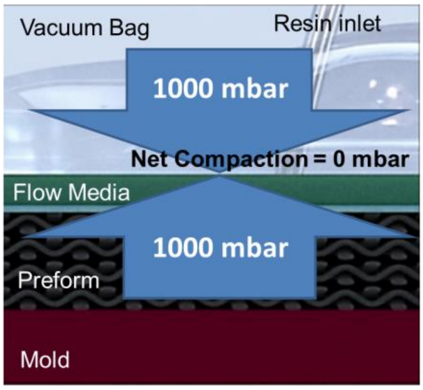
If the purpose of the vacuum infusion process is to produce high-quality parts, we recommend to use a digital absolute pressure gauge. Such a device measures the pressure relative to the absolute zero of pressure and is unaffected by weather or altitude, so you know exactly what is happening inside the vacuum bag.

We have gained excellent experiences with the Made in Germany device Greisinger GDH 200-14 in countless projects. It responds to pressure changes with a resolution of 1mbar down to absolute zero in an instant which does not only save time with setting up the vacuum system and finding leaks. It is also a performance indicator for the quality of the infusion process

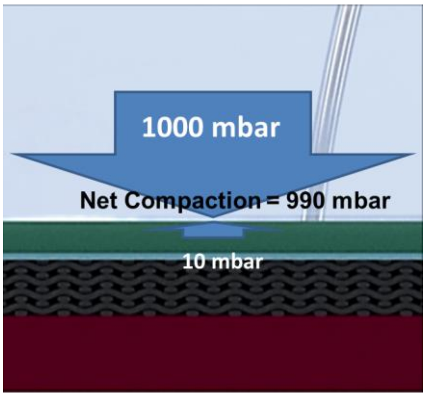
Physics behind the Vacuum Infusion Process (VIP)

In order to understand the physics behind VIP, net compaction, fiber volume, and the effects it has on the quality of the finished composites product, we need to take a closer look into what happens during the infusion process.

The driving force behind VIP is a pressure differential across the fiber preform - which pushes the resin through the layup.

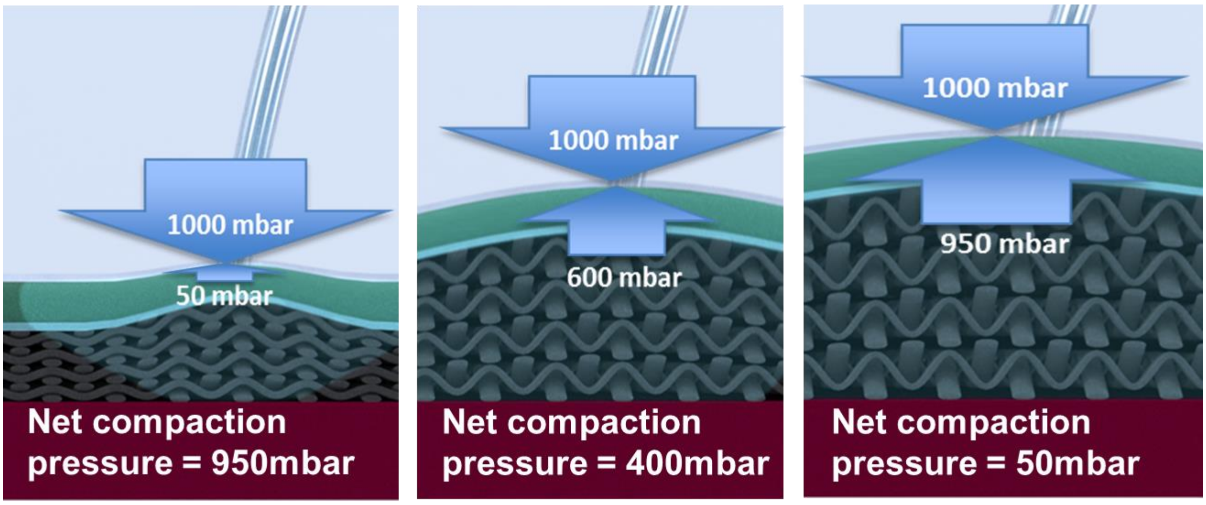


Prior to evacuation the mold, dry preform, flow media and vacuum bag are all in a relaxed state. At this point, the pressure within the bagged system is the same as that outside of the bagged system, namely atmospheric pressure. Thus, the net pressure compacting the dry preform is zero.



After evacuation and prior to resin flow, vacuum has been applied so that absolute pressure in the system is uniformly low (vacuum is uniformly high) and the mold, preform, flow media and vacuum bag are in a compacted state. For a high quality infusion, the goal is to achieve an absolute pressure in the range of 10 mbar inside the bagged system, while 1000 mbar remains outside the bagged system. Thus, the pressure differential is 990 mbar, which is the net compaction pressure upon the dry preform and the force that drives the resin through the laminate.

Once the resin inlet is opened, the resin begins to flow and the pressure of the filled volume approaches atmospheric pressure, since it is connected with the resin reservoir. The rise in pressure inside the bagged system acts against the atmospheric pressure outside the bagged system. The pressure differential is the remaining net compaction upon the preform in the mold, as shown in the diagram below.



This pressure differential will vary depending on a number of factors including the permeability of the dry preform and flow media and the timing sequence of clamping the resin inlet(s) and vacuum lines. With less compaction, more resin can flow into the preform. In traditional resin infusion, this net compaction can approach zero, resulting in laminate relaxation which leads to increased thickness and reduced fiber volume fraction. Thus, achieving a high fiber volume fraction requires compaction of the layup.

Self-regulating MTI® process

A MTI® setup is a closed hydraulic system which means that only air and gases can escape during the infusion process but not resin. Resin stops when it hits the membrane and continues to flow through the rest of the dry fabric, eliminating the need for complex calculations of resin injection points (keeping in mind the overall flow distance that the resin can attain in the particular infusion setup) and also a resin catch container is no longer necessary. Such a self-regulating system provides the perfect environment to create void free laminates.

As soon as the MTI® hose is completely covered with resin, it shuts off the evacuation line by itself. This mainly affects two things.

- Surface quality regarding pinholes - Even with a very thin, slow-curing resin system, the membrane hose creates an absolute barrier, preventing the laminate from bleeding out which would create pinholes on the surface. Pinholes are tiny holes on the surface which cause a tremendous effort with the finish works particularly with cosmetic carbon fiber parts. A “trained eye” can see the difference in regards to part quality even if a clear InMold coating was applied as first layer in the mold.

- Porosity and fiber to volume ratio - It allows the user to adjust or control the net compaction pressure during and after the infusion only through the use of hydrostatic affected by the height difference between the mould cavity and resin source. This affects the porosity of the laminate as well as the fiber to volume ratio.

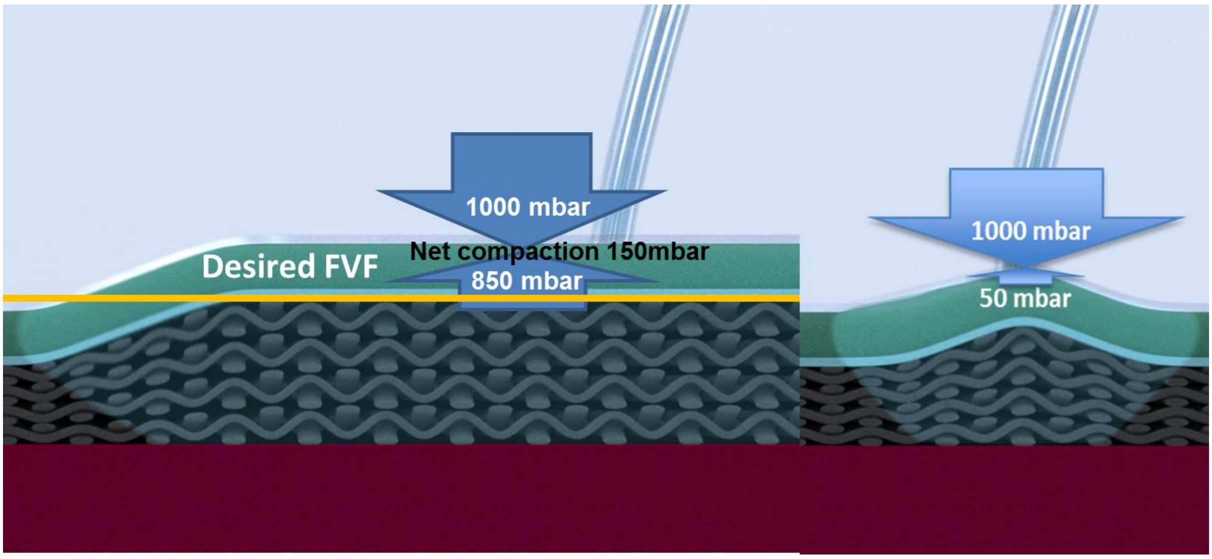
- Unlike the standard VIP where entrapped air bubbles expand to maximum size through the constantly pulling vacuum pump the self-regulating lower system pressure leads to a collapse of possibly entrapped air bubbles. It also affects a possible out-gassing process (as described below)

Controlling net compaction pressure and fiber volume

The MTI® system was especially designed to be self-regulating in terms of resin flow management, leaving less room for failure which increases the ability to repeatedly achieve void-free laminates with a high fiber volume but also to address the compaction and laminate relaxation issue described above. In this regard the MTI® system is perhaps the most simple and cost-effective solution, without dependence upon lengthy training and complicated timing of clamping the evacuation and/or resin inlet lines.

How does it works? As already said a vacuum infusion setup utilizing the MTI® hose is a closed hdraulic system which follows the physical laws of hydrostatic. That means that the In-bag pressure can be easily controlled through a defined resistance within the resin inlet line. By placing the resin source below the mold cavity the pressure in the resin inlet line is reduced by a value that corresponds to the hydrostatic weight of the resin column. One can say that 1m results in app. 100mbar net compaction pressure.

The grafic below illustrates what happens with a height difference of 1.5m. 1000mbar – 150mbar = 850mbar which is then the maximum in-bag pressure in the example below, resulting in a net compaction pressure of 150mbar.



Extraction performance

Unlike a simple spiral wrap the MTI® hose has a microporous sleeve which is characterized by an extraction capacity of 20 liter of air per meter and minute with a pressure difference of 50hPa. This affects the time to pull down the vacuum bag. You need to be accurate with the sealing operation to get the vacuum bag down. In other words **- As long as there is a leak in the system which let more air coming in than the MTI® hose surface is able to extract the vacuum bag will not come down.**

Vacuum integrity or the significance of leaks

Where vacuum bagging can be more tolerant regarding leaks, with vacuum resin infusion leaks in the vacuum system are impermissible. This is because a leak in the set-up will create a line of air bubbles from the origin of the leak all the way to the exit of the lay-up. If the bag and associated parts do not hold vacuum, it will not be possible to produce high-quality products. Resin penetration in the region of this line of bubbles will be reduced with a resulting reduction in structural properties and poor appearance. The great thing about the infusion process is that one can pre-test for vacuum integrity before one shoot the resin.

The existence of vacuum leaks can be checked prior to infusion with a pressure rise test. First be sure there are no leaks in the vacuum pump, resin trap (with MTI® you actually do not need one) and connections to each other. After evacuating the lay-up to maximum vacuum for as long as practicable, close the vacuum line and observe the change in vacuum pressure on the digital absolute pressure gauge connected with the resin feed line. A slight pressure variation is normal but the question is how fast this occurs. A visible movement is easy, go back to the vacuum bag and continue searching for big leaks.

A pressure rise of 3 mbar in 15 min is about the maximum that we accept.

This does not mean there are no leaks anymore but finding them will take a lot more effort depending on the size of the set-up.

An airtight system keeps the vacuum easily without pressure changing even without the support of the vacuum pump. In case of leaking or splitted moulds you can use - in addition to the vac-film sealed on the mold perimeter - an envelope bag which is also evacuated by using a T-connector and a standard vac-line. We recommend to manufacture also the molds with vacuum infusion to ensure the highest possible vacuum integrity with the tools.

As already said, a good vacuum integrity is one of the main factors for the quality of the laminate. A leak results in air being sucked into the lay-up, generating voids in the laminate. This affects the standard infusion process with spiral wrap as well as the MTI® process. But with the use of the MTI® hose another point becomes relevant. After the MTI® hose is completely covered with resin the line shuts itself off and the vacuum pump can no longer compensate any leakages in front of the membrane. In case of leaks the vacuum bag eventually loses its tension, resulting in a poor compaction of the laminate.

Finding and repairing vacuum leaks, especially in resin infusion applications, can be a complex process, involving issues such as mold quality, bag quality, bag connections, bag sealing techniques and vacuum tubing quality. Consumables of good quality may cost more than those of lower quality but the time saving from reduced leak problems is likely to outweigh the material cost saving.

Vapour pressure

Evaporation and sublimation into a vacuum is called out-gassing. All materials, solid or liquid, have a small vapour pressure, and their out-gassing becomes important when the vacuum pressure falls below this vapour pressure. In vacuum systems, out-gassing has the same effect as a leak and can limit the achievable vacuum. To avoid water vapour problems, keep raw materials and the MTI® hose dry during storage and keep the work area as dry as practical.

Another source of vapour may be resin solvents. Particularly polyesters and vinylesters will outgas under vacuum. The level of vacuum for this effect to take place depends on the vapor pressure of the solvents present in these resins. Resin suppliers will be able to advice these vapor pressure and the correct level of vacuum to be applied at the end of an infusion to avoid unnecessary out-gassing of the solvents required for the curing process.

So, the use of specially formulated vacuum infusion resins is not only for low viscosity properties but also to prevent out-gassing problems. Most epoxy resins are quite save in this regard.

To avoid resin vapour problems use an appropriate infusion resin and regulate the vacuum level after the infusion by maintaining a vacuum level slightly poorer than the vapour pressure of the resin solvent. The self-regulating MTI® process supports that (s. above).

Degassing the resin

For smaller parts we recommend to degas the resin for at least 15 min. with less than 20mbar/0.29psi absolute pressure before it is applied to the infusion process. This removes embedded air out of the matrix material (coming in through the mixing process) which could cause voids in the laminate. Air bubbles expand to maximum size within the vacuum athmosphere which is present along the resin flow front. We recommend a slow-curing epoxy infusion resin (pot-life depending on the size of the part to be infused) with a proper viscosity of 300 mPas or lower. The lower the viscosity the better the resin flow through the laminate. Heat lowers the viscosity but also reduces pot-life.

Handling the MTI® hose

The most practicable procedure to pull the MTI® hose out of the bag is to look for and grap the one end in the center of the roll instead of the one ending outside.

Also, take care not to damage the membrane of the hose (e.g. by opening the package with a knife or poor handling in the shop).

Finally make sure one end of the membrane hose is sealed properly (refer to the Instruction Manual - Episode 5 to see how to do that in a simple way with butyl-tape) and the other end is connected and sealed accurately with the vacuum line.

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