



German Advanced Composites is headquartered in the USA and recognized for its expertise aiding customers to streamline composite production processes. World Champions such as the Miss Geico offshore racing team benefit from our hands-on on-site training courses, project support and materials for the Vacuum Infusion Process that makes the difference between a good and a world class business. And now you can too! In the following we provide information about the physics behind membrane supported vacuum infusion process.

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MTI[®] Process

MTI[®] (**M**embrane **T**ube **I**nfusion) is a **V**acuum **I**nfusion **P**rocess utilizing a semipermeable membrane hose on the vacuum port system side (see the difference to the standard VIP in the animation film on GAC`s website "[MTI How it Works](#)"). Semipermeable means that only air and gases can pass the membrane fabric during the infusion process 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, thus allowing for maximum process control.

The MTI[®] hose was developed to enhance the productivity, reliability and quality of composite manufacturing processes utilizing the resin infusion technology. It enables the manufacturer to achieve high-quality results on a par with autoclave systems but with much less investment and expenses in equipment, labor and material.



Controlling the compaction of the laminate during the resin infusion process is decisive if manufacturers aim to, repeatedly, produce high-quality composite products that are characterized through an optimal fiber volume fraction.

The MTI[®] valve was designed to address particularly this process. When plugged into the resin line it automatically keeps the in-bag pressure in an optimal range - reliably and repeatedly.

In the following we provide information regarding the physics behind vacuum infusion in general, the MTI[®] technology and a proper set-up.

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:

$$1 \text{ atm} = 760 \text{ Torr} = 29,92 \text{ "Hg} = 14.7 \text{ psi} = 101.3 \text{ kN/m}^2 = 1013 \text{ mbar} = 1013 \text{ hPa}$$

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 which means that the reading is the pressure above the absolute zero of pressure. The vacuum of an infusion set-up is usually measured with an analog dial gauge, 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 is a manometer and works the opposite way to the barometer.

Thus the absolute pressure P_{abs} in the vacuum bag or resin trap is equal to the current atmospheric pressure P_{atm} minus the gauge vacuum pressure P_{rel} ($P_{\text{abs}} = P_{\text{atm}} - P_{\text{rel}}$). Relative pressure 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 ($P_{\text{rel}} = P_{\text{atm}} - P_{\text{abs}}$)

In a location such as Florida (sea level with high atmospheric pressure) one can achieve a higher relative 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 P_{atm} and bad weather lower P_{atm} .



For instance at sea level and standard weather ($P_{atm} = 30$ inHg/1000mbar) a gauge vacuum of 27 inHg (P_{rel}) is equivalent to an absolute in-bag pressure of 3 inHg. In other words, the vacuum gauge that reads, for example 27 inHg is actually reporting 3 inHg/100 mbar P_{abs} .

Whereas the value of P_{rel} has an impact on the maximum flow distance of resin through the laminate P_{abs} is a parameter for the amount of air that is left in the system. The higher that value the more air is left and the more voids can arise during the infusion process. In the example above the gauge vacuum of 27 inHG (P_{rel}) and in-bag pressure of 3 inHG (P_{abs}) indicates that 10% of air is left in the bagged system. For a high quality infusion process we strive to achieve the lowest possible P_{abs} , at least in the range below 20mbar (0.29psi or 0.59inHG), the lower the better.

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 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.

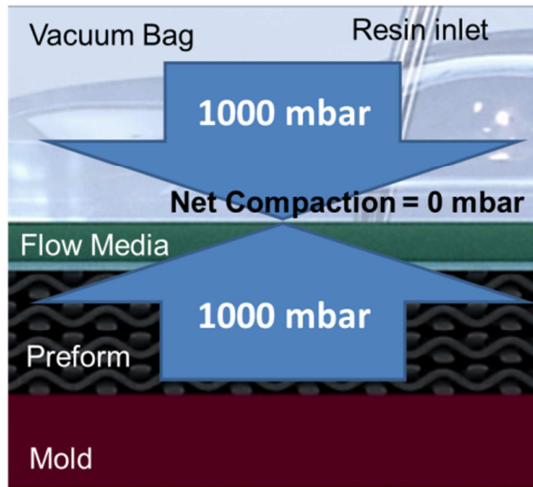
For the measurement of such values we recommend to use a digital absolute pressure gauge.

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 perfect performance indicator for the quality of the infusion process.

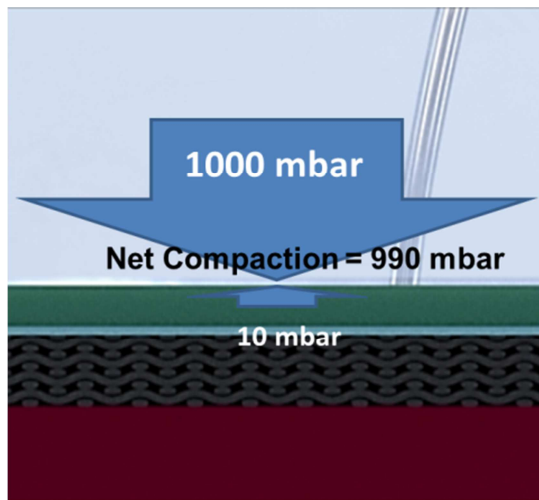
Physics behind the Vacuum Infusion Process (VIP)

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.

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

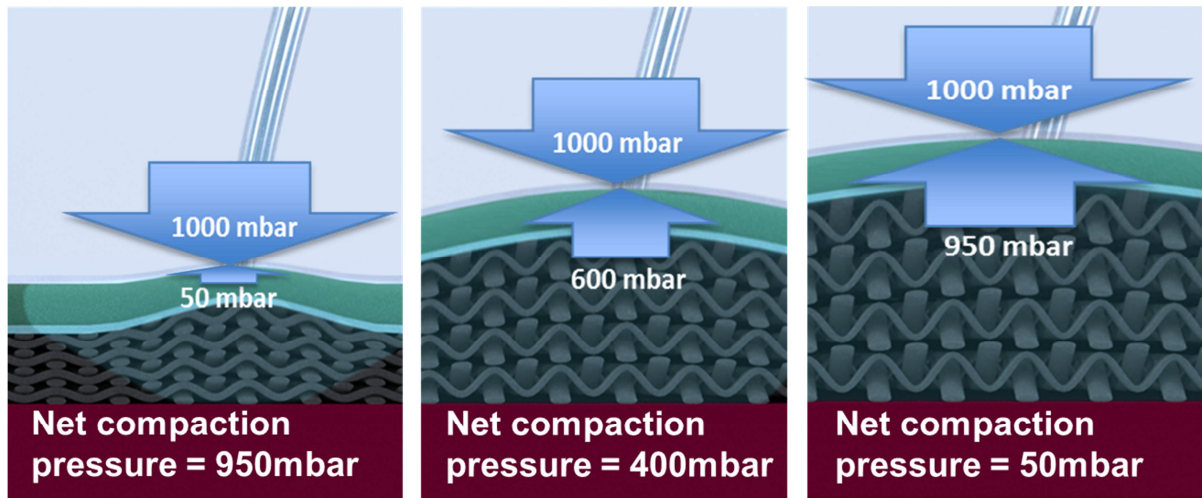


Prior to evacuation the mold, dry preform, flow media and vacuum bag are all in a relaxed state. At this point, the pressure within the bagged system is the same as that outside of the bagged system, namely atmospheric pressure. Thus, the net pressure compacting the dry preform is zero.



After evacuation and prior to resin flow, vacuum has been applied so that absolute pressure P_{abs} in the system is uniformly low (vacuum is uniformly high) and the mold, preform, flow media and vacuum bag are in a compacted state. With 10 mbar inside the bagged system and 1000 mbar outside the bagged system 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 via the resin inlet line to the resin reservoir which is open to atmosphere. 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

The MTI[®] setup is a closed hydraulic system which allows only air and gases to escape during the infusion process but not resin. Resin stops when it reaches the membrane and continues to flow through the rest of the dry fabric, eliminating the need for a complex vacuum port system, thus a resin catch container is also no longer necessary. Such a self-regulating system provides the perfect environment to create void free laminates.

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

- Fiber to volume ratio and thickness - 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 mold cavity and resin source. This affects the fiber to volume ratio as well as the thickness of the laminate.
- Unlike the standard VIP where entrapped air bubbles expand to maximum size through the constantly pulling vacuum pump the lower pressure of the MTI[®] system leads to a collapse of entrapped air bubbles. This affects positively the porosity of the laminate as well as a possible outgassing process (as described below)



- Surface quality with cosmetic carbon fiber parts - Even with a very thin, slow-curing resin system the membrane hose creates an absolute barrier, preventing the laminate from bleeding out which would result in the formation of pinholes. Pinholes are tiny holes on the surface which cause a tremendous effort with the finish works particularly with cosmetic carbon fiber parts.

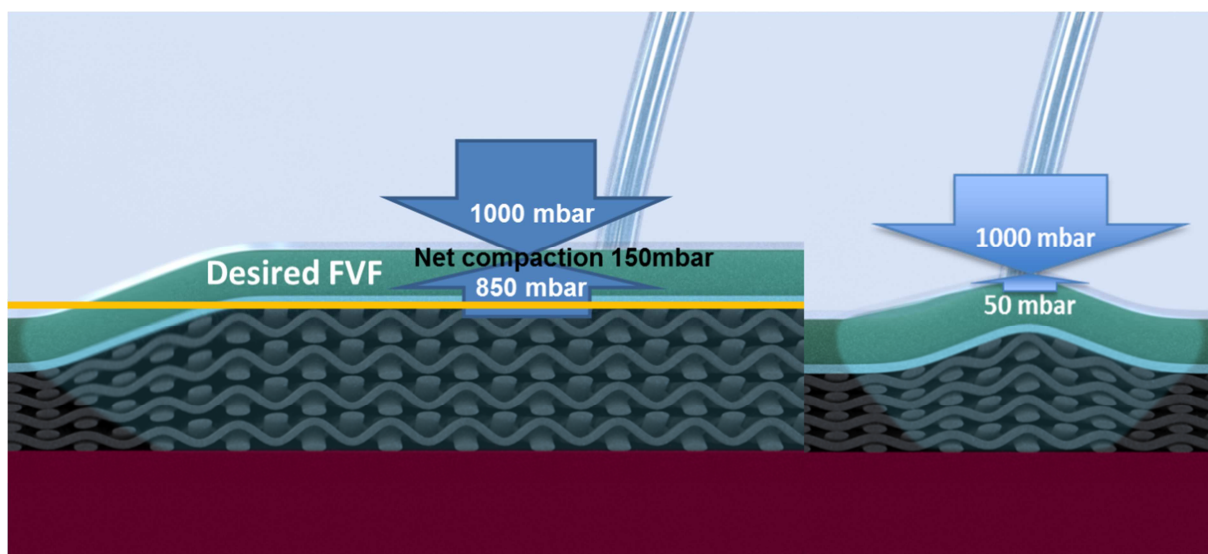
Controlling compaction pressure and fiber volume fraction

The MTI[®] system is self-regulating in terms of resin flow management which increases the ability to repeatedly achieve void-free laminates with a high fiber volume but also addresses 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 work?

Because the MTI[®] system is a closed hydraulic system it is easy to utilize the physical laws of hydrostatic to control the In-bag pressure only through a reduction of pressure in 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 pressure of the resin column. In the metric system a liquid column of 10 m results in 1000mbar pressure force.

The graphic below illustrates what happens with a height difference of 1.5m. $1000\text{mbar (P}_{\text{atm}}) - 150\text{mbar (hydrostatic pressure resulting from 1.5m resin resin column)} = 850\text{mbar (in-bag pressure)}$ resulting in a net compaction pressure of 150mbar during the infusion process.





MTI[®] valve

The MTI[®] valve was developed to simplify the controlling of laminate compaction and fiber volume fraction. Using the MTI[®] process, the MTI[®] valve is simply plugged into the resin feed line. It is designed to reduce the pressure within the resin inlet tube by 150mbar which in turn keeps the net compaction pressure in a range which is decisive to achieving an optimal fiber volume fraction.

Recommendation – With the leak check make sure you clamp the resin line between MTI[®] valve and resin source and not between MTI[®] valve and mold. For maximum vacuum integrity we recommend to seal the connecting points (MTI[®] valve/resin line) with butyl tape.

Evacuation performance

The permeability of the membrane was optimized to act as a reliable resin barrier but at the same time to ensure that gases arising during the infusion process get drawn out properly. This compromise of course affects the time to pull down vacuum via the MTI[®] hose. To expedite this process we recommend to use a resin inlet port for the evacuation process as well as for finding possible leaks before switching to the MTI[®] hose port.

Vacuum integrity or the significance of leaks

Where a wet layup with 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 a 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 5 mbar (0.147inHG) in 5 min is about the maximum that we accept for high-quality carbon fiber laminates.



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

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

As already said, 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 saturated with resin the line shuts off itself and the vacuum pump can no longer compensate any leakages in front of the membrane.

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 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 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 atmosphere 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 get the MTI[®] hose out of the bag is to grasp the one end in the center of the roll instead of the one ending outside. Pull out the hose carefully to avoid ending up in a mess.

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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