Gas Assisted Injection Molding – Process Basics

I. INTRODUCTION

Gas assisted processing is a *process enhancement* to conventional injection molding, implemented to reduce or eliminate productivity problems or product defects which often occur during conventional injection molding. It also enables design options previously not possible with standard injection molding processes. Gas assisted injection molding, or "gas assist" as it is often called, is simply a process *modification* to standard injection molding, and should be viewed as an *option* where the process benefits will afford greater productivity through a) expanded product design options, b) reduced cycle times, c) reduction of molded-in stress, d) reduced product weight, e) lower molding machine clamp tonnage and overall improved injection molding performance. The information below describes the basic methods to gain these benefits, as well as describe some of the methods for implementation, and troubleshooting, when in production.

Gas assist injection molding has been practiced at some level for about 20 years, and there have been substantial improvements, particularly during the past 10 years, for implementation of the technology. These advances range from eliminating gas injection through the nozzle to a vastly improved process with in-article gas injectors, and, has moved beyond from what was originally called gas "volume control" to the current standard, process-pressure control. All-encompassing details of the technology would be outside these basics, so only the essentials will be elaborated upon below.

II. PROCESS DEFINITION

Gas assisted injection molding is essentially the process of injecting nitrogen gas into the still-fluid resin mass as the final injection stage of the injection process, performing basically two functions: 1) a) completion of resin dispersion in the mold cavity following partial resin fill, or, b) evacuation of resin from a fully-filled cavity, and, 2) packing the part *internally*, eliminating all or most of the injection molding machine's packing function. This basically summarizes the entire gas assist process, although process techniques and numerous variations are as broad ranging as injection molding itself. Gas assist applications should each be analyzed for practicality of the adaptation, and the best means to implement gas assist processing to afford the widest processing window.

III. PROCESS METHODS AND VARIATIONS

There are two basic methods of injecting nitrogen gas into the mold cavity following either a short-shot of resin or following a complete resin tool fill: 1) Injection via gas injectors, commonly called "in article," (by far the most effective for most products) and, 2) through the nozzle. The primary focus of this discussion will be on injection through gas injection pins, as through the nozzle is an older and less efficient processing technique.

A) Gas injectors – “in-article”

Gas injection via gas injection pins is the preferred method for gas assist processing since the development of reliable injectors over the past seven to eight years. The advantages of gas injectors over through the nozzle are many, including 1) precision internal cavity pressure control, 2) lower gas injection pressures, 3) the ability to introduce gas into the cavity in several areas with independent timing and pressures. The gas injector location(s) in the tool are as critical as the injectors themselves, and will be addressed in a later section.

B) Through the nozzle

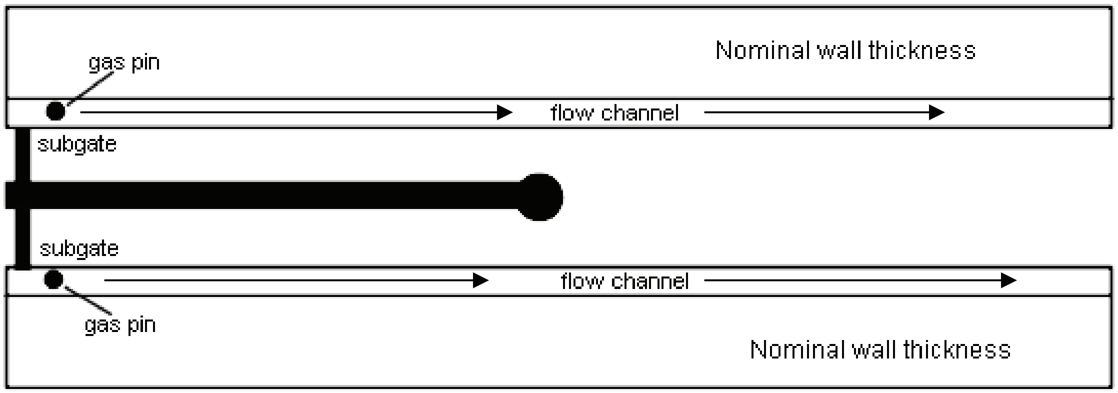
Gas injection through the nozzle was an early method to inject gas into the molded product. “Through-the-nozzle” was widely practiced, due to the simplicity of tool build, but has serious disadvantages. Gas injection through the nozzle requires a higher initial gas injection pressure due to the longer gas flow path, and, resistance of penetration of the gas through the sprue and runner and gate to the article cavities. This method, more importantly *does not* allow for cavity pressure control of the gas once inside the tool cavity. This is a result of the need for a check valve in the gas line just prior to the location of attachment of the gas line to the resin injection nozzle, to prevent resin from entering the gas line. This same check valve *also* prevents *gas* to return through the gas line. With no means for the gas to be vented for pressure reduction, cavity pressure control cannot be achieved with through the nozzle gas injection. This problem could also contribute to gas permeation into the thinner product walls adjacent to the intended gas flow path.

Injection of gas through the nozzle also requires “sprue break” to vent the gas from the mold cavity prior to opening the mold, causing additional wear on the molding machine. Injection of gas through the nozzle is only implemented where no other means is possible for introduction of the gas, or, when the simplicity of center gating and relatively simple gas injection penetration is possible. An example of an application where this may be implemented would be a center-gated polyolefin table top, but with proper engineering support, this is rarely necessary with the currently available gas assist in-article injectors.

C) Gas injector location considerations

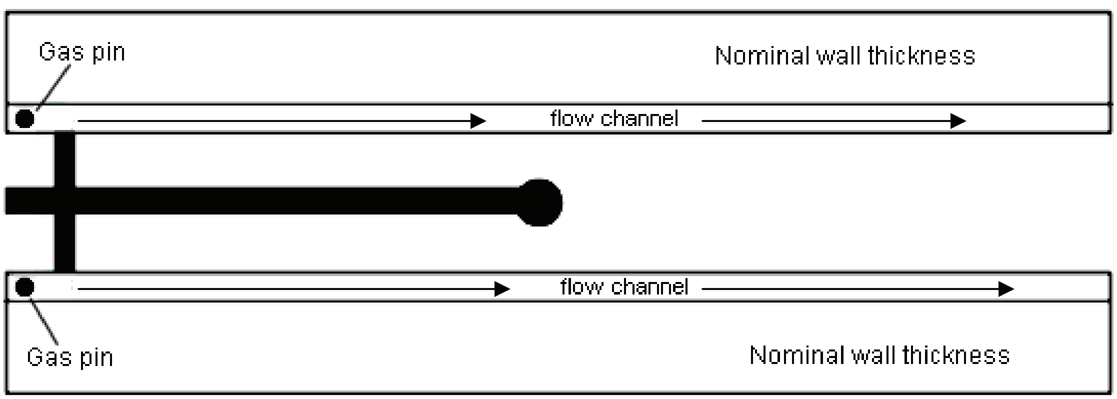
As noted earlier, the location of a gas assist injector is as critical as the injector itself, if not *more* important. Location of the gas injector relative to resin gate(s) and flow channels is critical to maintaining a consistent process. A few problem implementations and recommended corrections are shown on the following pages:

Example 1: Problematic implementation
Gas injectors shown *downstream* from resin gate, in flow path



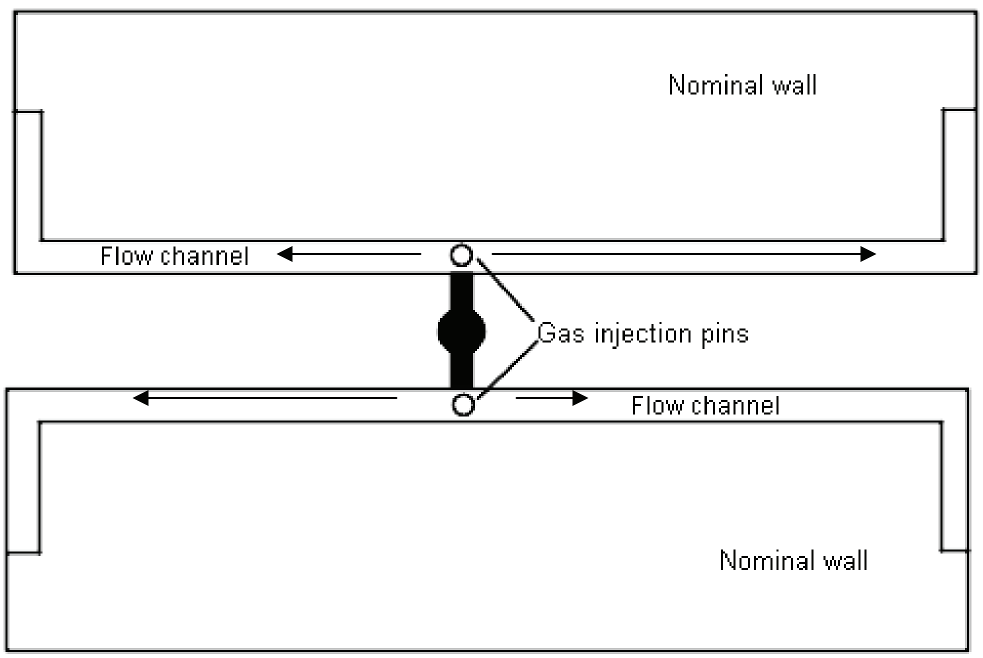
Gas pin is "downstream" from gate, causing plugging of pin and shear in the resin

Example 2: Recommended Implementation
Gas injectors *upstream* from resin gate, “behind” flow path



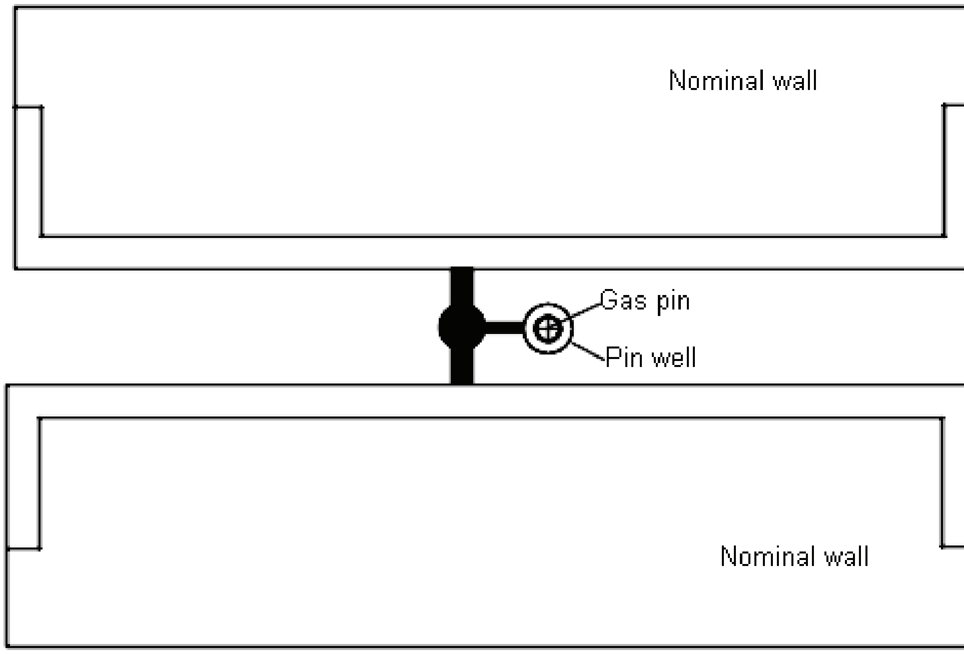
Gas pin is "upstream" from gate, eliminating plugging of pin and shear

Example 3: Problematic implementation
Gas Injectors located in-line of resin flow path



Gas injection pin in line of resin fill - causes plugging and shear

Example 4: Recommended Implementation
Gas pin located in pin well, avoiding direct resin flow path



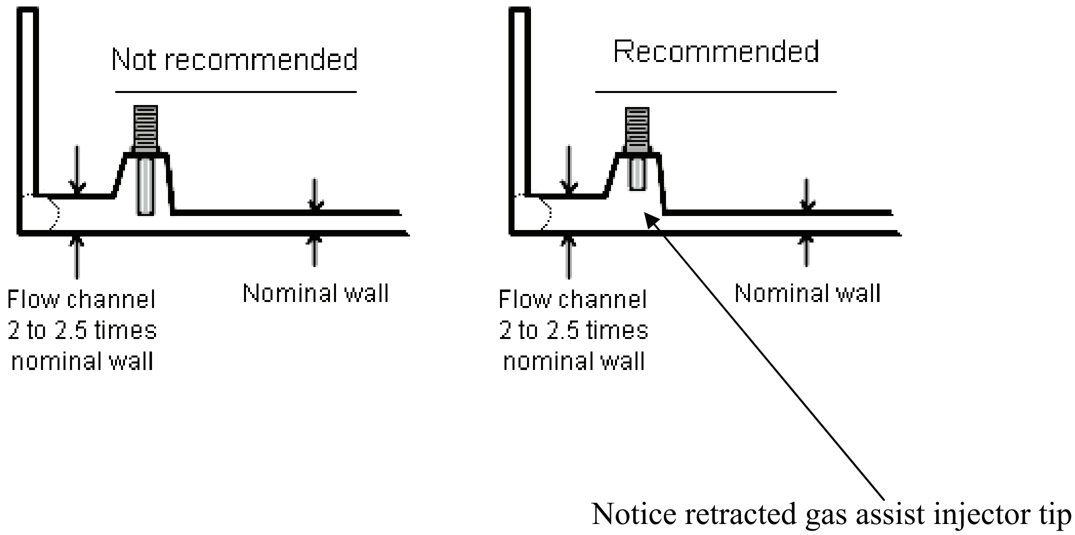
Gas pin in pin well allows injection of gas through gate,
while eliminating plugging and shear

The examples of problematic implementation and recommendations shown above are only a couple examples of an infinite variety of gas injector placement methods, but the principals remain the same. *Never* locate a gas injection pin "downstream" from a resin gate, as direct impingement of resin on the injector will cause plugging of the injector, as well as introduce shear from the heat generated from the interruption of resin flow over the surface of the gas assist injector. These two characteristics actually enable each other, i.e., shear will increase the likelihood of plugging, and direct impingement causes shear.

Gas injectors are also commonly located in an "injector boss" integral to the molded product. The following diagram (Example 5) first shows a common condition where the injector has a tendency to plug, due to the flow of resin over the injector tip. (This condition is shown on the left side of the diagram.) Note that the gas injector extends deeper into the boss in this example putting the tip of the injector in the resin flow path, which will likely plug the injector very quickly.

The right hand side of the diagram in Figure 5 shows the same basic cavity configuration, with the tip of the injector extending *into the boss* but not into the resin flow path. With the tip of the injector "retracted," (in effect in a lower pressure area of the cavity), the potential for plugging of the gas injector is greatly reduced.

Example 5: Gas injector located in integral boss



IV. Partial cavity fill (short shot) vs. EVACUATION METHOD TECHNIQUES

A) Partial Cavity Fill Methods (also known as "short shot)

The basic processing technique in the majority of gas-assisted injection molding applications is to displace a short-shot of resin in the tool cavity and via flow/gas channels (and from thicker sections of the molded product) to last-to-fill areas in the tool cavity. The "last to fill" areas in the cavity function as a "reservoir" to receive the resin being displaced or moved from the thicker areas of the tool cavity. The evacuated area of the cavity from which resin was displaced allows the injected gas to uniformly pack the molded part, affording reduced cycle times and reduced stress. Reduced stress eliminates or greatly reduces warp. The combination of these characteristics contributes to faster cycle times, higher quality, more uniform production, reduced weight, and greatly enhances design options.

B) <u>Evacuation Methods</u>

It is occasionally necessary to completely fill and apply a short period of packing prior to the injection of gas. Some resin can be subsequently evacuated to afford similar advantages as described above, but most often this is performed to improve the molded parts surface quality. This condition should be avoided except when absolutely necessary, as it results in more complicated tooling, increased resin consumption.

This technique is utilized most often when product design does not take into consideration process capabilities, or when part design dictates less than optimum processing. Conditions most often contributing to this need are:

1) Gas/flow channels that extend to the very last-to-fill sections of the tool cavity,

2) Unpainted parts molded in a resin that are susceptible to the appearance of "hesitation lines," exhibited by a defect on the appearance surface of the molded p[art where the resin flow "stalled" prior to the gas pressure continuing the resin flow in the cavity. (With "in article" gas injection and recent generations of process controls, this is not as frequently necessary.)

3) Channels designed into the product that run parallel and in close proximity, resulting in competing internal pressures. (Sequential gas injection)

The fill and evacuate method must be enabled by closing off the resin evacuation point from the tool cavity commonly by means of a pin which is retracted after the start of gas injection. Note that with this technique, there are *many* optional methods to implement the evacuation, some of which are proprietary. A short-shot technique with resin evacuation gives variable results and should be avoided!

V. INJECTION MOLD CONSIDERATIONS

Gas assist processing is successfully performed on all configurations of tooling, i.e., single and multiple cavities, center gated tools, cold runner tools and hot runner manifold tools, sometimes with sequential gating. This section discusses general issues specific to several tooling methods, and the concerns that need to be taken into consideration for each of these options. It is important to note while discussing tooling considerations that the gas injection portion of the process usually cannot be modified to correct an "out of balance" or improper resin fill. Gas distribution in a molded part is strongly based upon initial distribution and viscosity of the resin, and usually cannot be corrected by modifying gas pressures or timing if resin distribution is the problem. Critical elements for successful implementation are resin fill pattern and consistency, and relation of the resin gate to the gas injection points. As noted earlier, the gas provides only two basic functions in the gas assist process; a) completion of resin distribution and b) internal packing of the part rather than packing from the molding machine screw. For this reason, a short-shot of resin in the cavity *must* be balanced and repeatable to allow the gas to *complete* an even distribution of the resin from the flow channels or thicker sections of the cavity.

A) Center gated and cold runner tools

Center gated tools will frequently have a gas injector boss integral to the molded product similar to as shown in Example 5, or occasionally, will be gas injected through the nozzle (not recommended). A high level of consideration must go into the product and tool development to assure that the resin, whether in a center gated tool or from a cold runner, will distribute consistently so the gas may perform its two basic functions efficiently. In a center gated tool, it is difficult and expensive to change gating after the tool has been built, so particular caution must be exercised so that the short-fill of resin into the tool will leave the last to fill areas of the tool available for receiving the resin that will be evacuated from the flow channels upon gas injection.

It is somewhat simpler to modify a cold runner tool to change the balance of resin fill, but care must still be taken when determining the resin fill patter relative to the gas injection point or points. Cold runner tools may be modified or built to the standards shown in examples 2, 4 or 5, or, injected through the nozzle. Please note that with gas injection through the nozzle on multiple cavity tools (or as shown in figure 4,) the short-shot of resin must partially fill each cavity equally! An unbalanced fill of cavities will result in 1) some cavities exactly as desired, 2) some cavities full with little or no gas penetration, and, 3) some cavities with insufficient resin, resulting in a gas "blow-out." Balancing the cavity fill from a cold runner tool is as simple as adjusting the gate sizes to equally fill the cavities, verified by short-shooting the tool and weighing each part. Please note however that in normal molding conditions, factors other than gate size can affect balance of cavity fill. These factors include tool temperature, venting, resin viscosity, and even orientation of the tool in the molding machine. Successful implementation of gas injected through the cold runner has been achieved on tools with eight cavities, and in limited circumstances, sixteen cavities, but this is not recommended as standard practice. When attempting to balance and maintain uniform resin fill for eight or sixteen cavities, the in-production process parameters become too narrow to efficiently meet production consistency. This technique is possible to achieve, but is usually implemented in non-critical applications such as low-line consumer product handles.

B) Hot runner manifold tools

Hot runner manifold tools are frequently used with gas injection, but the considerations for tool build are different than with cold runners or center gated tools. Hot runner tools allow for precise placement of resin gates, enabling superior control of resin distribution, particularly when gate valves are employed. It is now common to use sequential gating to control the progress of the resin in the cavity, and to control, with precision, resin distribution to individual cavities. Note that when using a hot runner tool that it is necessary to use valve gates to prevent gas from entering the runner. As the gas travels in the tool cavity, it flows toward the lowest pressure area available. With a flow channel in close proximity to a gate from a hot runner, it is *necessary* to utilize a valve gate to prevent the gas (and resin) from entering the runner.

It should be noted that with gas assist processing that it is often unnecessary to use a hot runner mold. Flow channels built into a relatively thin wall product act as <u>integral cold runners</u> or insulated runners, allowing for far greater than typical resin flow lengths. This is dependent, however, on the specific resin flow characteristics and flow channel design and length.

C) Mold maintenance

Mold maintenance is normally reduced with the gas assist process. Because clamp tonnage is reduced with gas assist processing, it is common to experience less maintenance to tools due to the reduced cavity pressures. This characteristic reduces wear on lifters and even on the parting line. Re-spotting frequency should also be reduced with gas assist processing.

D) Tooling materials

It is often possible to use less robust mold materials with gas assist processing. This determination is highly dependent upon resin and production volumes, but aluminum is a potential option for some programs. For prototyping, epoxy or other non-metallic materials can often be selected, providing the gas assist techniques are applied properly to reduce cavity pressures and machine clamp needs. “Soft tooling” should be built with stop-blocks in all cases.

VI. GAS ASSIST SYSTEMS AND CONTROLS

Gas assist systems are available in a wide variety of configurations, consisting of various pressure control methods systems, plus a wide assortment of options for nitrogen supply. The following section will address today’s most common equipment configuration, i.e., pressure control systems receiving nitrogen gas from nitrogen generators or from nitrogen cylinders.

A) Controllers

The most flexible and efficient gas assist controller systems available today are “pressure control” systems. These systems have advanced pressure control capabilities allowing precise cavity pressures during the resin-fill completion stage and during the pack and hold phase of the process. Cavity pressure control is only possible with “in article” gas assist processing.

Typical controllers range from one to four points of gas injection control, and have several stages of pressure and time settings available, ranging from 6 to 8 stages, plus a “delay” setting, i.e., the time delay after resin injection and prior to the gas injection phase. An additional control parameter available on the better controller systems is called pressure “ramping,” where there is a selectable time for gradual transition from one pressure and time setting to the next. A typical page of an operator’s control screen would appear as shown in Table 1:

Table 1: Typical Gas Assist Operator’s Controller Screen

	Pressure (in **bar,** or psi)	Time (in seconds)	Ramp (in seconds)
Delay	- - - -	1.00	- - - -
Stage 1	80	4.00	4.00
Stage 2	125	8.00	2.00
Stage 3	100	4.00	4.00
Stage 4	68	6.00	2.00
Stage 5	20	2.00	0

The above “typical” gas injection time and pressure profile is presented as an example of a routine process setup. Every tool has its own process profile for the gas assist phase for each gas injection point, in the same way that the tool will have its own resin injection process profile. A process setting page similar to the above should be available for each controller valve/point of gas injection in the tool.

Pressure ramping: Pressure ramping is normally provided as a means to *precisely* control cavity pressures during gas pressure transitions. This is a benefit for several reasons, but the most critical are to prevent gas penetration into thinner or non-gas sections of the molded part during the cooling stage, and to prevent resin from being drawn back toward the gas injection point during gas decompression. As discussed earlier, the gas performs *first* the function of completing distribution of resin. As the resin in the tool cavity cools, it shrinks considerably. If a higher than necessary gas pressure is maintained in the cavity while the resin is cooling (and during corresponding shrinkage) gas could penetrate into thinner areas where it would be detrimental to the final product. Profiling the gas pressure downward can prevent this undesirable penetration from taking place.

In the above example, note that the overall gas process profile time is 25 seconds, and *does not* include the time elements for pressure ramping. The reason for this non-cumulative time is important. A process can be optimized with delay, time and pressure settings, but the product may be slightly less than desired due to the characteristics described above. With the ramping time being included *within* the overall timing sequence, pressure ramping can be modified without the need to change individual pressure stage timing. This is normally accomplished with the ramp-time setting 'getting its time" from the subsequent pressure phase. In the above example:

Phase 1 shows a ramp time of four seconds. These four seconds of time are *part* of the *time setting* for stage *two*. With this capability, you can then change the ramp setting to best suit the total process *without* changing the overall gas process cycle time.

Pressure ramping can be used to ramp pressure settings *up* as well as down. The are a limited number of instances where the initial pressure setting may be zero, and a two to six second of ramp time *up* to the second stage pressure setting (or between any two stages of pressure). This is not a common setup, but is helpful where initial gas injection must be *early* in the gas sequence and *gradual*ly build pressure to allow for evacuation of a heavy mass of material. In this example, without ramping pressure *up*, an initial medium to high gas injection pressure would cause the gas bubble to *rapidly* penetrate the heavy section, creating a *small* gas path while removing minimal resin from its flow path.

B) Nitrogen supply

Nitrogen furnished to gas assist controllers is available from three basic sources; gas cylinders (bottles), nitrogen generators, and bulk liquid nitrogen supply systems. For many years the most common means of nitrogen supply was gas from cylinders, but this became impractical as gas assist processing grew to multiple installations. Typical cylinders contain 8.5 cubic meters of nitrogen (300 SCF) and are delivered at a pressure of approximately 170 bar. Nitrogen gas from bottles has a net cost of from $9.00 to $12.50 US per 8.5 cubic meters (300 cubic feet). Additional costs often not taken into consideration by many molders are the costs for storage of cylinders and changing the cylinders during production, incoming freight and demurrage for the cylinders while they are in the molders plant, plus safety concerns while handling 2,500 to 2,800 psi bottles. These issues created the demand for reliable nitrogen generating systems.

Nitrogen generator membrane and compressor technology has developed substantially over the past few years, affording cost savings as much as 80*% lower* than nitrogen gas from cylinders. Bulk liquid nitrogen storage systems are also more economical than bottles, but usually entail a more complicated storage and pressurization system. With the proper compressor, however, bulk liquid nitrogen is the most cost effective for gas assist processing when consumption is 2,000 SCF or more per day.

The nitrogen supply pressure to the gas assist controller does not need to be 500 to 680 bar as is commonly believed, but only high enough to adequately furnish gas to the process without the supply pressure dropping below the process pressure during each gas assist processing cycle. The consumption of gas is based solely on volume, i.e., one cubic liter of gas is the same amount of gas whether at 10 bar or 500 bar, only the size of the "cube" changes. When the gas is injected into the melt during production processing, it is critical that the stored gas pressure does not drop below that of the peak process pressure. Recovery time for the stored gas should not take considerable time, and in fact, with the proper relative pressure of the stored gas, some production setups may not require any pressure recovery time between gas injection cycles. A general "rule of thumb" is to maintain the gas storage pressure approximately 50% to 75% higher than the process gas pressure.

This needs to be elaborated upon for practical implementation. Note the above comment that a volume of gas is a volume of gas – pressure is irrelevant. However, a process pressure may be 270 bar (4,000 psi) but the *void* created by the gas is relatively small. Although the pressure is high, the *volume of gas* is small. Recovery will be quick. In this scenario, it would *not* be necessary to store gas at a pressure of 400 to 540 bar. Alternatively, a gas process pressure of 68 bar (1,000 psi) with a void of 2 liters would be an *exceptional* amount of gas, based upon the large resulting void. This scenario would require a *higher* ratio of stored gas pressure to process pressure, in order to prevent the storage pressure from dropping below the required process pressure during the gas injection cycle. Keep in mind that the gas in the feed line and gas paths in the tool are also consumed during each molding cycle, and needs to be added to any calculations for gas consumption.

VI. SYSTEM INSTALLATION AND CONNECTIONS

Each process control provider will have its own preferred method for connection to the injection molding machine, but the following details are most common. At this time there is no common industry standard for interfacing the gas injection equipment with the molding machine, but simplicity and reliability has resulted in the following typical interface:

The operational standards for the majority of gas injection controllers are: 1) cycle start, and 2) cycle reset. Cycle reset is to establish the breakpoint between cycles and to reset the gas injection controller system for the next gas injection sequence, and cycle start is to establish the set point to initiate the gas injection sequence. Both signals are sent from the molding machine as simple dry contacts to the gas controller, with the gas controller reading the signal to initiate that signal's function. Analog or digital signals are rarely necessary for the controller – molding machine interface.

A) Cycle reset

Cycle reset is commonly read from the condition “clamp closed,” and is a continuous signal. As long as this signal is maintained, the gas injection controller will be enabled, awaiting the start cycle signal, and is maintained throughout the gas injection cycle. To enable the reset function and to afford a safety factor, this signal is uninterrupted during the molding cycle; if the signal is broken during the gas injection cycle, the cycle ends, and the controller is reset for the next process sequence.

B) Cycle start

Cycle start is another “dry signal” (closed contact) typically initiated from “end of shot” for the resin injection phase. Cycle start may also be initiated from *start* of the resin injection sequence, but this creates additional process complexity, as it is common to develop the overall gas assist molding process tuning the *resin* injection phase, which could often require adjustment of the gas sequence *every* time the resin injection phase is modified. For this reason it is recommended that cycle start be initiated from the end of the resin injection sequence. Please note that the start signal does *not* need to be a continuous signal, it is a “trigger” to initiate the delay and subsequent gas injection pressure and timing sequences.

A variation on the cycle start signal method is when utilizing sequential gating. With sequential gating, it is usually necessary to initiate one or more of the gas injection points *prior* to completion of the resin injection sequence. In this example, the start signal may occur at the start of resin injection, with the gas injection delay setting being used to start the gas injection profile for each gas injection point during the resin fill. This setup is somewhat more complicated than a simple “end of shot” method, but with proper setup, this technique affords very creative possibilities on hot manifold tools with sequential gating. As previously mentioned, it is important to employ valve gates when using sequential gating or hot runner tools. Valve gates will also enable a precise amount of resin to be delivered from the corresponding gate to accommodate the gas injection details for that area in the injection mold.

Most controller systems require additional signals necessary for safe system operation, such as for closure of the purge shield and closure of the operator safety gate. These signals only *enable* the gas injection process, and do not contribute to control of the process. These signals are usually dry contacts also, sent from the molding machine to the gas assist controller, and are signals that must be maintained during the full process cycle.

C) Nitrogen gas to process connections

The gas assist process controller needs (1) gas feed line to the mold for each gas injection point in the tool. It is important to note that the length of the gas line to the mold or nozzle is important in the gas assist process for two reasons: 1) Gas in the feed line to the tool is also consumed during each molding cycle. The longer the gas line, the more gas consumed. 2) If the gas feed line to the tool is excessively long, the time for pressure to reach the tool may also be longer than expected, possibly complicating the gas injection process. As an example, a setup with a 10 foot gas feed line to a tool may be used, and a month later at a different molding machine, a 25 foot feed line could be utilized. This could necessitate a change the gas profile setup, as delay in delivery of gas to the tool cavity may occur with no changes being made at the gas controller!

When utilizing gas injection through the nozzle, only one gas injection output valve is necessary. Flexible high-pressure gas lines are in common use, with thermoplastic insulation on the outside of the gas line. It is not recommended to use this type of gas line in close proximity to the resin injection nozzle, as high nozzle temperatures can damage the gas line. In this scenario, it is recommended that a short section of high-pressure stainless steel gas line be connected to the flexible gas line in the area before attachment of the line to the injection nozzle.

When injecting gas "in article," the gas lines will be connected directly to the exterior of the mold. In this setup, the flexible style gas lines may be directly connected to the tool, as no high temperature areas will be near the connection(s). Again, it is important to use the shortest gas lines possible, as all of the gas in the gas lines will be consumed during each gas injection cycle.

VII. PROCESS STARTUP

New tool process startup is perhaps the most subjective element of the entire gas assist process. As with every new or converted tool, process engineers use their experience on previous programs to predict the approximate control parameters for the new tool. This same procedure is necessary with a gas assist tool, with the added complexity of the gas injection sequence. Every tool is different, and many tools will run different when transferred to a similar but different molding machine. Explicit direction is not possible and outside the scope of this essay, but the following procedure is recommended to get "90 % there."

A) On any new or converted tool startup, do not begin the startup with the gas injection sequence enabled. Except for unusually large voided products, start the process with molding the product solid. This will enable you to determine exactly what you are working with, with respect to gating, resin fill speeds, evaluation of gas injection point to resin gate, tool temperature settings and process parameters for the resin being molded. Note that the majority of process parameters for a successful gas assist program are with the resin injection details; the gas injection details should be thought of as the finalization of the process, not the core process.

B) After evaluating the product with a full cavity fill of resin, estimate the intended void in the gas assist part. A thin wall product will require a cavity fill of approximately 95 to 98% or more for gas assist production. A heavier wall part, such as a tubular handle or a very thick geometry product may result in a resin fill percentage as low as 50%! After achieving the full cavity fill as described in the above section, decrease the shot size to get "near" where you might expect the resulting cavity fill percentage to be.

1) On a thin wall part, this may be simply decreasing the shot size in *very* small increments, and enabling the gas injection sequence. The initial gas injection pressure may be anywhere from 21 bar (300 psi) to 270 bar (4,000) psi or even higher; this initial recommendation should be provided by your gas assist technology supplier. For the purpose of this general recommendation on a thin wall part, let's start the process with a delay of 1 second

and an initial injection pressure of 68 bar (1,000 psi). Start the molding sequence with these parameters, with a shot size reduction of ½% to 1% of the full cavity shot size. After removing the part from the mold, you will notice one of three possible results. It will be necessary to cut the part in the areas of the flow/gas channels for evaluation: a) upon cutting the part, you notice that the cavity is full, resin distribution is complete, but the flow channels are not evacuated. Reduce the shot size on the next shot. B) the resin fill is not complete, and the gas "blew out" of the resin in the last to fill areas of the cavity. Increase the shot size slightly. c) the resin completed fill in the cavity, the gas penetrated the flow/gas channels, and you have a perfect part. 99.9% of the time examples a) or b) will be the result! There are many variables to be addressed for examples a) and b), but these will be addressed in the trouble shooting section later in this paper.

2) On a very thick product such as a tubular handle or very thick geometry product, following the initial full shot fill, reduce the resin fill percentage to about halfway between what the full shot size was and what you estimate the eventual actual percentage of fill will be. (There is no need to guess "close" to the actual percentage, as this will be likely impossible without lengthy hands-on experience in gas assist tool startup.) With the same resin injection parameters used for the full cavity fill, set the shot size as noted above. With thick, tubular cross section products, the gas injection pressures necessary will be *far* lower than with thin wall products. It is common now to see products with 25 mm to 50 mm cross sections to be in production with gas injection pressures as low as 17 bar (250 psi.)

Inject the resin as above and enable the gas injection sequence, but now with a heavier wall product, delay time necessary could vary greatly based upon the resin selection, specific part geometry and tool surface, i.e., polished, grained, class A or a non-appearance product. Start this sequence with 1-second delay, and with an initial gas pressure of 68 bar (1,000 psi). Remove the part from the tool and examine the results. In the same manner as with a thin wall part, the results may be a short-shot with the gas blowing out of the plastic or a part that has been pressurized with the gas, but is far too thick in the majority of the cavity. Increase or reduce the shot size as necessary.

It is important to note at this point that the objective of a successful, repeatable and efficient gas assist process is to attain the a) lowest part weight, b) fastest cycle time, and c) the lowest gas processing pressure. To go into lengthy detail of process development for specific applications would be outside the scope of this paper, and would be literally impossible with all of the variables of resin, part geometry and molding machine variables. Various conditions and possible remedies for observed conditions are summarized in the troubleshooting charts on the following pages.

VIII. PROCESS TROUBLESHOOTING

Table 2: Thin Wall Product Troubleshooting

Problem	**Cause**	**Solution**
Resin not completing cavity fill – gas making penetration in channels	Mold temp. too low, causing resin "freeze-off"	Increase mold temperature
	Resin temp. too low	Increase barrel or nozzle heat per resin specifications
	Gas pressure too low	Increase gas injection pressure
	Excessive delay in gas injection	Reduce gas delay setting
Resin completing cavity fill, gas not penetrating flow channels	Resin shot size too large	Decrease shot size
	Flow channels too large or too long – allowing premature resin fill in last to fill areas of cavity	Decrease extent/length of flow channels or size (cross section) of flow channels
Resin not completing cavity fill, gas "blowing out" of short shot	Resin shot size too small	Increase shot size
	Gas injecting too early	Increase gas delay time
Resin fill cannot be completed, with or without gas injection enabled	Flow channels too large and/or too long, creating pressure trap	Reduce flow channel length or cross section
	Mold too cold	Increase mold temperature
	Resin too cold	Increase melt temperature
Gas penetrating nominal wall	Insufficient gas delay	Increase gas delay time
	Tool too hot	Decrease tool temp.
	Flow channels too small relative to nominal wall	Increase flow channel cross section
	Resin too hot	Decrease resin temperature

Example 6: Thin Wall Product Flow Channel Design

The following graphics represent acceptable flow channel cross-section designs, as well as commonly observed problematic channel designs.

Figure 7: Preferred Flow Channel Geometry

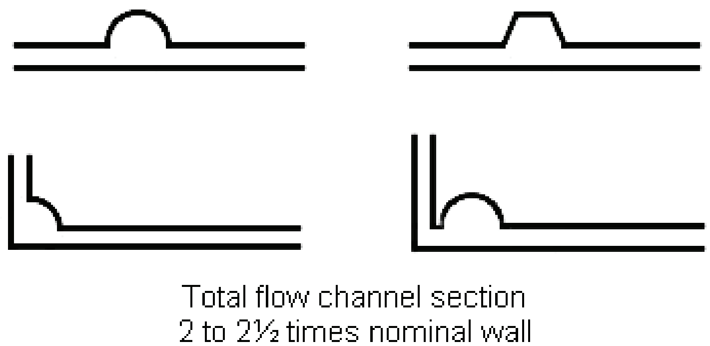
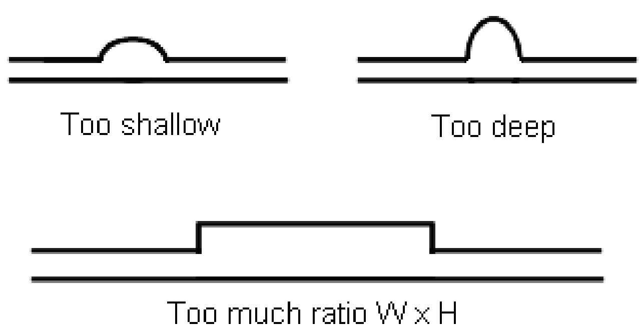


Figure 9: Problematic Flow Channel Geometry



In Figure 9 examples, the following conditions will occur with each respective design:

Too shallow – gas will be more likely to penetrate the nominal wall, as the pressure differential between the flow channel and nominal wall will be too low to confine the gas.

Too deep – this type of channel tends to cause excess resin fill toward the end flow channel, and causes difficulty in filling the nominal wall near the start of channel. The result is gas trapping in the tool, with gas penetrating the nominal wall and *not* in the flow channel. Unnecessarily high gas pressures are also experienced in attempt to displace the oversized channel.

Too much ratio W x H – this cross section will not be displaced by gas uniformly; the gas may tend to “wander,” creating variable channel evacuation. Some of the channel is likely to be solid in the thickest section, causing excessive cycle times and possible surface defects. Repeatability will also be very difficult.

An occasional problem occurring in thin wall applications is that the intended function of the gas is to displace long channels along the edges of the molded product, to facilitate mounting surfaces. These surfaces/flow channels tend to extend to the end-of-fill of the molded product. This condition requires a fill and evacuate method, with additional process parameters for actuating pins which will first block the point of resin evacuation, which can be opened following gas injection.

Another complication is parallel channels within close proximity. Parallel channels will "compete" with respect to internal pressures, with one channel almost always becoming dominant in pressure, evacuating the resin in *that* channel and forcing that resin into the lower pressure channel. Consequently, the lower pressure channel fills with resin displaced *from* the dominant channel, resulting in unbalanced and unequally evacuated flow channels. This can condition contributes to sink marks, warp, long cycle times and non-acceptable processing conditions.

These conditions are usually avoidable, as alternative methods for product design, tooling design and resin selection are available to employ efficient molding conditions. Numerous options are available when these conditions are present, but such details are specific to each product design.

Table 3: Tubular and Thick Wall Product Troubleshooting

Problem	Cause	Recommended Adjustment
Inadequate cross section void	Excess resin	Decrease shot size
	Inadequate gas delay time	Increase gas delay time
	Too high initial gas pressure	Reduce initial gas pressure or ramp pressure *up*
Unbalanced or inconsistent void – void off center of product	Improper tool orientation in molding machine	Set tool orientation to inject gas upward rather than horizontally
	Gas injection point off center of mass of desired void	Change gas injection point to center of mass of desired void
	Resistance/surface tension of resin is insufficient for gas displacement or distribution	Convert process to fill-and-displace method
Product shows surface defect at location of end-of-fill, or short-shot resin portion of fill	Excess gas delay time after resin injection	Reduce gas delay timing
	Tool temp. too low	Increase tool temp.
	Resin is overly susceptible to appearance problem when resin fill "stalls"	Sample alternate resins
	Resin begins to cool prior to being displaced or distributed by gas	Convert process to fill-and-displace method
Gas penetrates outside channel in thick nominal wall product	Inadequate differential between flow channel and nominal wall	Examine extent and size of flow channels relative to wall thickness and flow length – revise channel cross section, length of channel or number of channels
	Resin to hot to create adequate resistance	Increase gas delay time
		Reduce mold temperature

Table 4: Gas Pin/Injector Troubleshooting

Problem	Cause	Recommended Adjustment
Gas pin(s) plugging upon resin injection	Resin in direct path of resin fill pattern	Relocate gas pin out of direct flow path of resin
	Gas pin extends too far into flow channel or gas pin boss	Use shorter pin length or extend depth of gas pin boss
	Gas pin vents too large for intended resin viscosity	Reduce gas pin vent size; add additional, smaller vents if necessary
Gas pin(s) plugging during gas venting	Resin not solidified adequately – molten resin being drawn toward pin during vent	Extend time of low pressure gas hold
		Add or increase ramp time to decompression stage
		Reduce tool temperature
	Excess resin at end-of-fill of flow channel	Reduce resin shot size
Gas pin/injector shows excessive wear	Injector in direct path of resin fill	Relocate gas pin out of direct flow path of resin
	Gas pin material too soft for reinforced resin	Convert to hardened steel injection pin
Gas pin/injector not sealing in molded part	Too little surface for resin to seal on pin surface	Increase length of gas pin
	Resin too "fluid" around pin area	Increase gas delay time
		Decrease tool temperature
		Reduce gas injection pressure
		Add undercut to base of pin shaft (pat. pending)
Gas pin/injector causes surface appearance problem on class A surface opposite pin	Impingement of gas on class A surface	Revise pin to side-discharge style

Table 5: Gas Injection System and Process Troubleshooting

Problem	Cause	Recommended Adjustment
Excess gas consumption	Leakage in connection to mold or pin assembly to tool	Locate and correct leak
Gas supply pressure drops below process pressure upon gas injection	Inadequate gas pressure or volume available to process	Increase gas supply pressure or storage vessel volume
Gas supply pressure drops below process pressure during hold phase (this condition is normally observed on the "system pressure supply" gauge)	Gas is leaking from product ("blow out")	Increase shot size or revise resin distribution pattern
	Gas leaking from pin assembly	Tighten/seal gas pin assembly into tool
	Gas leaking around pin, between resin and pin	Increase delay
		Reduce initial gas pressure
		Increase pin length
		Use "undercut" at base of pin
Gas penetration into product varies over time	Changes in resin viscosity	Maintain uniform resin supply/regrind percentage
	Mold temperature fluctuation	Correct tool temperature control
	Resin melt temperature variation	Examine and correct barrel/nozzle heat variation
	Gas supply varies to gas assist process controller	Maintain consistent gas supply pressure and volume
All process conditions constant, no gas in part	Gas pin plugged	Clean or replace gas pin
		Relocate gas pin
		Revise gas pin design to eliminate cause of plugging
	Signal(s) to gas controller not being actuated	Test signals to controller and correct missing signal condition

IX. EMERGING PROCESS DEVELOPMENTS

A. Multi-temperature Gas Injection

Multi or variable gas temperature processing is a patented technique (5,728,325) developed to assist production needs where resin flow length capabilities or excessive cooling times may be experienced with conventional gas assist processing. With this technique, auxiliary gas temperature control is added typically downstream from the gas assist process controls, which can either heat the nitrogen gas prior to injection into the melt, chill the nitrogen gas prior to injection, or in some limited cases, a combination of both.

1. Heated gas

With high viscosity resins and/or in thin wall products where minimal flow channels are permissible, resin can cool or "freeze-off" prematurely, inhibiting its continued flow to the last to fill areas in the tool cavity. Heated gas functions as an *aid* to maintaining the resin temperature internally in the flow channel, without changing other processing parameters such as resin injection speed and tool temperature. There appear to be few applications where this technique is beneficial, however.

The *sequence* of using a heated gas may be modified in process, by partially exhausting the gas following the initial packing phase, or, the "first phase" gas may be maintained during the entire cooling cycle. When accelerated cooling is necessary, the heated gas can be vented at the same gas injection point from which the gas was introduced, or, a secondary injection point may be present in the tool to exhaust the heated gas, aided by the introduction of an ambient temperature or chilled gas from the first injection point.

2. Chilled gas

With the proliferation of gas assist processing in general, many design options are possible for injection molded products with cross sections that were never before possible. Successful products have been put into production with cross sections that are as large as three to four inches thick! (Please do not interpret this as an option or recommendation for designing parts of these dimensions!) With cross sections of this size, it is common to experience a resulting wall thickness, after gas injection, of one-half inch or more. Although the internal gas pressure maintains sufficient internal packing to produce a mechanically sound part, and while appearance considerations can be maintained for non cosmetic parts, cooling cycles are *extremely* long. A resulting wall thickness of this magnitude, even though gas injected, will experience a cooling time similar to a part of this thickness molded conventionally.

The chilled gas option is a means to substantially reduce the cooling cycle, while maintaining all other processing parameters. The chilled gas can be implemented by either utilizing the chilled gas as the initial gas injection phase, or, by injecting ambient temperature gas, reducing the first-phase gas pressure and following the first-phase gas with the introduction of the chilled gas. The temperature of the chilled gas itself may not significantly change the basic gas injected processing control parameters; it simply aids, to a substantial degree, the internal cooling of the product and increases overall production yield.

B. Multi-fluid and water injection

Multi-fluid gas injection is a technique where two fluids are used for a) completing fill of the resin in the tool cavity, and, b) rapidly accelerating the cooling stage with the second fluid phase. For some applications, the first-phase fluid will be nitrogen, as is standard with conventional gas injection. The second phase is the injection of a second fluid, this being a liquid (usually water) for the purpose of reducing the cooling cycle. It is most common for the second-phase fluid to be followed by a third sequence, nitrogen or simply air, to evacuate and dry the product internally.

Water is also used as the first-phase fluid, but, as water/moisture can cause splay or other surface defects in a molded part, it is critical to provide enough flow and pressure to prevent the water form turning to steam, or "gassing off" prior to packing. By utilizing the sequential fluid injection, the desired production characteristics are achieved during the first phase, accelerated cooling is achieved during the second phase, and water evacuation is achieved during the third phase, as is necessary to prevent problems during down-line assembly and/or painting.

The Multi-fluid injection process is implemented most efficiently with multiple points of fluid injection, commonly two. Specialized multi-fluid injectors are available that enable both fluids to be injected from the same injection point. Multi-fluid gas injection can decrease cycle times up to 75% where cycles as long as three to four minutes may be currently experienced.

Summary:

There is a wealth of knowledge available about process feasibility product adaptation, part design and tool design available in the marketplace. Lean on your technology and system provider for support, or employ an experienced engineering consultant that has successfully implemented programs similar to yours!

AEGIS Consultants, Inc.

4701 Shore Drive, Suite 103, Virginia Beach VA 23455 USA
757-271-9927 e-mail: engineering@gaspins.com

gaspins.com