A STRATEGY FOR THE DESIGN OF GAS ASSISTED INJECTION MOLDED PARTS

Peter Zuber and Anthony Gennari
GE Plastics GE Plastics

ABSTRACT

Molded parts designed for the gas assist process require the proper gas channel layout relative to part geometry and gate configuration. This is particularly true of thin walled parts with thick channels that act as a conduit for gas penetration. Many parts designed without using the basic principles specified herein have resulted in moldings with poor gas penetration and/or undesirable penetration of gas into thin wall areas. Poor gas penetration results in parts which are warped or display excessive sink since the large channels are not cored out. Penetration into the thin walls affect surface appearance and severely degrade impact performance of the part. A strategy using estimated melt front advancement and cavity channel balancing has been developed for designing gas assisted injection molded parts. Results from various molding trials indicate that this strategy is successful.

INTRODUCTION

Gas Assist Molding

The gas assist process is an extension of the traditional injection molding process. Polymer is injected into a vented cavity with the mold closed. A given volume of polymer is injected such that a short shot results at the end of polymer injection. This polymer injection phase is then followed by the injection of nitrogen gas into the cavity. The nitrogen gas is typically injected at pressures ranging from 0.5 - 30 MPa (70 - 4500 psi). Although other gases may be used, nitrogen is well suited for this technique because of its inert nature and general availability. The process sequence may be summarized as follows:

1. Clamp mold
2. Inject polymer to a short shot
3. Inject high pressure gas
4. Hold gas while cooling
5. Vent gas
6. Eject part

The addition of gas into the cavity acts to "core out" the thick sections of the part. The path which the gas travels through the part is pre-determined by the geometry of the part and the filling pattern. It is important to note that the gas will follow the path of least resistance, which means the gas will travel in the direction of the highest temperature (low viscosity) and lowest pressure. This must be kept in mind when designing a part which incorporates gas channels.

Since the gas assist method is a "short shot" process, the part is not packed out during the polymer injection phase like traditional injection molding. Packing is instead provided by the pressure within the part via the gas bubble. This yields a part with lower stress and stress gradient, however, it also requires that the gas bubble penetrates the channels effectively in order to provide sufficient packing. By understanding the geometry and process conditions desirable for gas assist processing, a well designed gas assisted part may be produced.

In addition to the usual injection molding process variables, gas assist adds additional variables to the process. These process variables are.

- Gas timing
- Gas pressure profile

The addition of more variables to the process makes gas assisted molding less stable than the traditional process This implies a greater "learning curve" is required to master the gas assist process. For this reason, it is recommended that gas assist be employed only when the benefits of the process can not be realized using traditional injection molding.

PROCESS BENEFITS - Many benefits have been claimed by those familiar with gas assist molding. It is important to remember that the process may be used to realize only some of these potential benefits for any particular part. Different parts have different requirements, therefore, gas assist may be employed for different reasons. Some of the potential benefits are listed below :

- Enhanced flow due to the use of large flow leaders (channels).
- Reduced cycle time over injection molding if thick sections are required.
- Improved surface over injection molding with thick sections (Reduced sink).
- Reduction in required clamp tonnage.
- Reduced part warpage over traditional injection molding.
- Uniform packing/reduced stress over injection molding.
- Reduced weight in some parts.
- Greater design freedom for injection molded parts.

Gas Assist Process Methods

There are many vendors which can supply equipment for gas assisted injection molding. The gas gating methods used by these vendors may be divided into two categories :

- Through the nozzle gas gating
- Direct gas gating into the cavity

Either one of these techniques may be used to produce excellent gas assist parts when used properly. The important difference is that the *through the nozzle* gas gating method requires that all gas channels begin at the nozzle. When the *direct gas gating* into the cavity method is used, the gas channel may be placed into the cavity independent of the gate location provided that the proper fill pattern is achieved prior to gas injection.

The method of controlling the gas process variables is also different between hardware vendors. Most machines control pressure directly and allow the operator to ramp the pressure within certain time domains Other machines such as CINPRES® use a cylinder of constant volume which is pre-charged to an adjustable initial pressure. A piston in this cylinder is adjusted to a constant velocity which drives the gas into the cavity. Generally this method does not result in a constant pressure profile. Experience with both systems has shown that the two methods may be controlled to yield equivalent parts.

TYPES OF GAS ASSIST PARTS

Most gas assisted injection molded parts may be categorized into two types :

- Contained channel gas flow
- Open channel gas flow

Examples of *contained channel flow* parts are tubes, arm rests, handles and frames. These parts consist merely of a single thick section or channel through which the gas must penetrate. Figure 1 displays a cross section of a part used as a structural frame. This is a good example of *contained channel gas flow*. Contained flow parts are generally the easiest to gas assist mold because the gas has a clearly defined path by which to propagate and does not have thin walled areas which must remain gas free.

Examples of *open channel flow* parts are access covers, panels, shelves and chassis. These parts consist of a nominal thin wall with gas channels traversing the part similar to traditional ribs. Figure 2 displays a printer chassis which is a good example of *open channel gas flow*. These parts are more difficult to design and process because the gas may not just flow through the channels but can penetrate into the thin walled regions of the part creating undesirable "cracks" or surface read through. Other problems such as "freeze off", "fingering", "blow out" or insufficient packing may also result if the part is not designed or processed correctly. These parts must be designed such that the gas "cores-out" all the channels without penetrating into the thin walls.

The main focus of this paper will deal with *open channel flow* type parts since these are the most challenging parts to manufacture using the gas assist process.

GAS ASSISTED MOLDING PART DESIGN

The path of gas entering a cavity can not be controlled by process but will only respond to the reaction forces acting upon it. The gas will follow a pre-defined path (path of least resistance) determined by the part design and polymer fill.

The three main objectives when designing a part for gas assist molding are to :

1. Obtain the proper *layout* of gas channels throughout the part,
2. *Balance* the polymer fill through the part,

and,

3. *Size* the channels properly with respect to the part.

Parts which have been designed with these objectives in mind will yield well filled and well cored-out parts. The parts considered in this procedure are the *open channel flow* type parts defined above. Only these types of parts will be examined below since they are considered more difficult to design and process than the *contained channel flow* parts.

Gas Channel Layout

The *layout* of gas channels within a cavity involves defining locations for the gas channels and gas nozzle relative to the sprue or gate (if a *through the nozzle* gas system is used, then the location of the gas nozzle is fixed with the sprue).

The "path of least resistance", which the gas bubble will follow, is the path which has the lowest pressure and highest temperature. A channel, or any thick region of a part, will generally always be of higher temperature than thin areas due to the larger mass of the polymer (relative temperature within the cavity is also a variable which can not be controlled). The region of lowest pressure, however, will be in the direction of the melt front or areas which have minimal packing. It is, therefore, **the cavity pressure (or filling pattern) which must be controlled and most governs the path of the bubble**.

The relative difference in pressure between the gas and the polymer surrounding it is the driving force which determines the path of the bubble and, therefore, the effectiveness of the process. This implies that the main design objective is to set up a filling pattern within the cavity in which the lowest pressure exists near the end of each channel after the short shot is delivered The only way of assuring that this condition exists is to **position the channels such that they end near the last areas of the cavity to fill**. Since the pressure at the melt front is zero (and is greater than zero in the filled portion of the cavity), this situation will act to draw the gas bubble along the channel while remaining contained within the channel The displaced polymer within the channel may then fill the remaining unfilled portion of the cavity at relatively low pressure since it need not push the polymer a large distance through the thin wall. Filling at lower gas pressure also reduces the possibility of gas "fingering". "Fingering" is unwanted gas penetration into the thin walled region of a part

The challenge in accomplishing this objective is that the addition of channels into the cavity will disrupt the filling pattern and affect the location of the last area to fill. The recommended approach is to start with channels which are relatively small to minimize this effect (refer to the section on GAS CHANNEL SIZE). By having channels which end near the last points to fill, the bubble will most effectively core-out the channel as desired and complete the filling of the cavity.

Another way of accomplishing this objective with parts which have large thin walled regions without channels is to gate the polymer into the thin wall instead of gating into a channel. This will reduce the effect of "race tracking" of the polymer down the channels and assure that the thin walled areas are filled.

Another rule to keep in mind is to avoid closed loop channels if complete coring is required Closed loops will result in "slugs" of material in the channels where the two gas bubbles converge together The channels should also be oriented somewhat in the direction of the melt flow. "Zig-Zagging" of a channel will not enhance flow in the part and may also lead to gas "fingering".

Balancing Of Polymer Fill

When a cavity requires many channels, or when channels diverge within the cavity, it will be necessary to "balance" the channels such that the part fills evenly. Uneven filling of the part will result in some channels filling sooner than others and the resulting short shot pattern will not yield a situation in which the end of all channels are near the last area of the part to fill, as described above This situation will result in the gas seeking the low pressure path by traveling down the unfilled channels while not penetrating the channels which are filled Remember that for *primary gas penetration*, the gas bubble must displace the material within the inner channel. If some channels are filled before gas introduction, then there is no space to displace this material and, therefore, the channel will remain solid or have only *secondary gas penetration*.

This problem may be avoided by sizing the channels such that the **shorter channels, relative to the gate, are smaller than the longer channels** This is required to prevent the shorter channels from filling up prior to gas introduction. The balancing of fill through channel sizing is only effective to a limit however. It has been shown in extremely large parts that variation and channel dimension may be such that the small channels at their minimum (2.1) and the large channels at their maximum (6:1 for this part, see section on GAS CHANNEL SIZE) still is not enough to balance the filling. In these cases, multiple drops of polymer can be added. By using more drops, the flow is somewhat balanced before channel sizing, therefore, less channel size variation will be required.

The *direct gas gating into the cavity* technique is more forgiving in these instances because the gas is gated directly into the cavity. This allows the gas pressure and timing to be independent of the polymer injection and timing.

The determination of last areas to fill and the assessment of channel filling patterns is where the application of mold filling analysis is most beneficial. The analytical model of the process can determine how the channels fill. The channel sizes may then be easily adjusted to balance the flow analytically before the tool is cut.

Gas Channel Size

Many myths have circulated regarding the relative size of a gas channel with respect to the nominal wall thickness. A lower bound is required in order to give the gas a well defined path to travel. A 2:1 ratio of channel dimension to nominal wall is typically used as a lower bound for channel size although the nominal wall thickness has been used successfully in some designs. The upper bound, however, depends on the geometry of the given part and position of the channel within the part. Large channels present a problem in that the polymer will "race track" through them and leave the adjacent thin walled areas unfilled If, however, the thin areas adjacent to the channel can be filled (by adding polymer drops or additional channels), then the gas channel may be quite large

The main design rule, as stated above, is to **position the channels such that they end near the last areas of the cavity to fill**. This becomes a challenge since the addition of channels into the cavity will disrupt the filling pattern. The recommended approach is to start with channels which are relatively small to minimize this effect ($\approx$ 2.5 nominal wall). Any size channel will generally yield most of the benefits offered by gas assist with the exception of added rigidity to the part. This issue is usually dealt with by adding ribs to the gas channels. A rib is a more efficient method of adding structure to the part than a gas channel. A rib and channel may also be combined to yield the benefits of both.

The problems which may result if this main design principle is not satisfied are "freeze off" of the melt front, gas penetration or "fingering" into the thin walled areas, or gas "blow out".

Freeze off will occur when the gas pressure is insufficient to push the polymer the required distance through the thin wall. This most often occurs if the condition of having the last areas to fill near the end of the gas channel (as discussed above) is not satisfied. Gas pressures are generally much lower then conventional packing pressures so flow lengths from the channel will be relatively short.

Gas "fingering" has many causes. It results when lower cavity pressures exist outside the channel rather than within the channel (path of least resistance). One example is if the "race tracking" of the polymer down a channel is such that a high melt front angle develops. This will result in the low pressure area or melt front being adjacent to the gas bubble rather than in front of it. In this case, the gas will leave the channel and penetration or "fingering" through the thin wall will result (see figure 3) It will be necessary to reduce the channel size or add flow leaders in the thin wall area to reduce the melt front angle at the channel. Fingering has also often been observed near a gate area where back filling may occur. A fan gate may be required to reduce this effect. Fingering is significantly influenced by process conditions. A high melt temperature or early gas gating can lead to fingering even in a properly designed part.

Gas "blow-out" is when the gas bubble propagates through the melt front before the part is full (see figure 4). It has two primary causes. Gas blow-out may occur during processing if the magnitude of the short shot is less than is required. The simple solution here is to increase the short shot until blow-out no longer occurs. The more troubling cause of gas blow-out is when it results from an improper cavity filling pattern. Blow-out will occur for the same reasons as gas fingering only the fingering leads to the melt front before the part is full. To prevent this from occurring the magnitude of the short shot may be increased, however, in this case the resulting full part will have channels which are only partially cored-out resulting in a part which may never realize the full benefits of the gas assist process.

CHANNEL DESIGN PROCEDURE

The gas assist design procedures discussed above are summarized in the procedure listed below. This procedure is provided merely as a guideline Each part presents its own unique issues which must be dealt with individually ·

1. Determine what benefits need to be realized by using the gas assist molding process (i e added structure, enhanced flow).

2. With these benefits in mind, determine approximately where the gas channels must be located relative to part geometry. Remember that the end of polymer fill must occur near the end of the gas channels.

3. Identify the best gate or sprue location(s) relative to the part geometry and channel locations. Keep in mind that the part should fill evenly

   The following steps (4-8) may be accomplished by trial and error durring molding. This method, however, can be more costly and time consuming.

4. Perform a mold filling analysis Start by using uniform gas channel dimensions (2-3 times nominal wall recommended). Gas channels may be modeled as part runners

5. If the part has multiple gas channels, or the channels diverge within the part, then adjust the channel dimensions such that gas channels fill nearly evenly. Longer gas channels should be slightly less full since more material will be displaced in these channels

6. Iterate on steps 4 and 5 until the optimum filling pattern is achieved. Movement or the addition of channels may be necessary.

7. Consider the distance and location between the last areas to fill and the end of the gas channels. A relatively large channel leads to a "race tracking" effect and the thin areas may not fill out. Reduce channel size if necessary or add flow leaders to difficult areas

8. If the flow balancing leads to a variation in channel sizes which is undesirable, then the addition of extra polymer drops into the cavity may be considered. The filling pattern may be tailored using these extra drops so that the variation in channel sizes is reduced. Repeat procedure starting at step 4.

EXAMPLE

The example below illustrates the procedure used to design a large structural panel. This application is proprietary at the time of this publication so details of the design have been intentionally obscured in the figures. The perimeter of the part in the photos and analysis have been intentionally clipped.

<u>PART DESCRIPTION</u> . A large structural panel (≈ 1100 mm x 900 mm). The part has 3.8 mm nominal wall thickness.

<u>Step 1</u> - Identify benefits of the gas process for this part.

1. Enhance flow/Reduce clamp tonnage (over injection molding).
2. Reduced weight.
3. Add structure to the part.
4. Improved surface.

<u>Step 2</u> - First cut of channel layout

1. The primary concern is part structure (stiffness, strength).
2. Closed loops must be avoided to minimize cycle time
3. Large area to fill

The channel layout is shown in figure 5.

<u>Step 3</u> - Identify the best drop location(s).

1. The part must fill evenly.
2. Many channels/ribs needed for increased structure.

One drop chosen in center of panel for first iteration

<u>Step 4</u> - Preliminary analysis shown in figure 6. Uneven polymer filling will result in poor gas penetration.

<u>Step 5&6</u> - Final iteration performed. Results shown in figure 7. Balanced polymer flow will result in good gas penetration. Short shots are shown in figures 8 and 9. These short shots show a reasonable correlation with the analysis, however, the filling is not as even as predicted

<u>Step 7&8</u> - Two drops considered for production. Results shown in figure 10.

ACKNOWLEDGMENTS

The authors would like to acknowledge Andy Poslinski and Peter Oehler for their gas assist research support to GE Plastics.

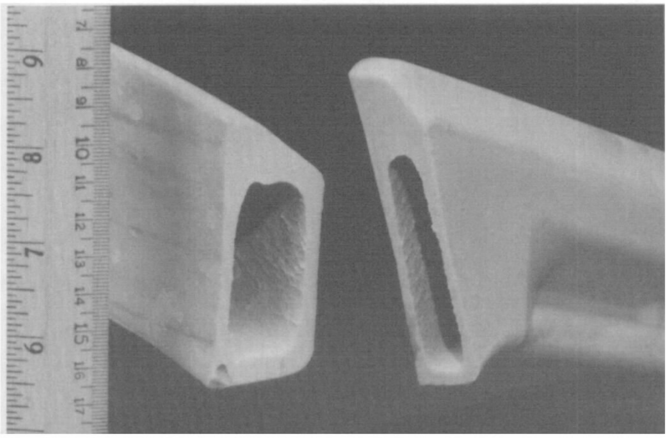

Figure 1 : Example of a "contained channel gas flow" part

Figure 3 : Example of gas "fingering"

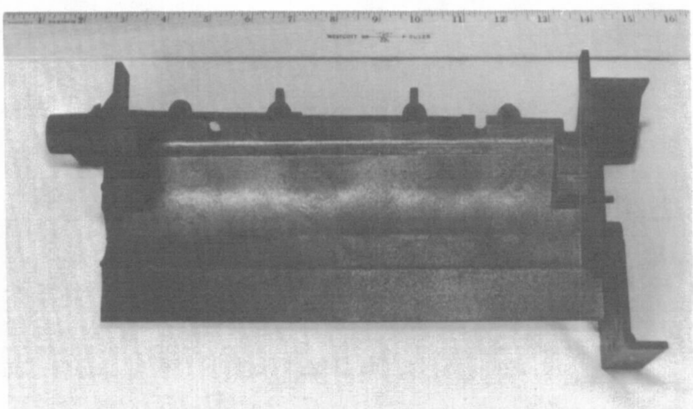

Figure 2 : Example of a "open channel gas flow" part

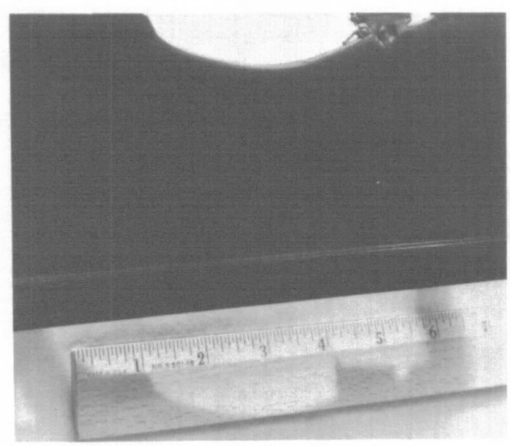

Figure 4 : Example of gas "blow out"

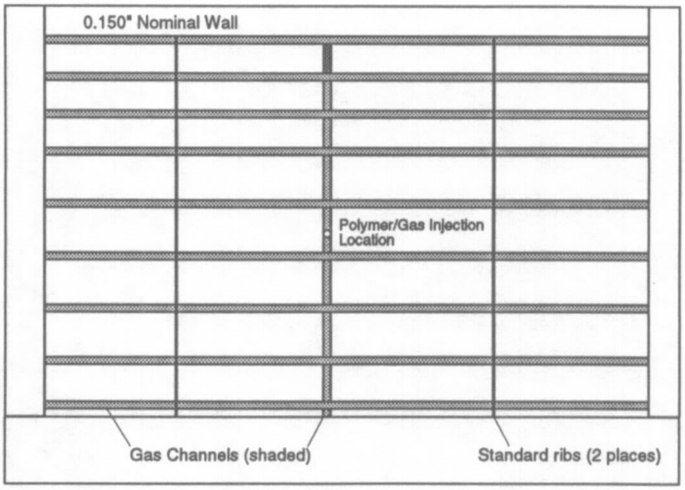

Figure 5 : Gas channel layout for example problem

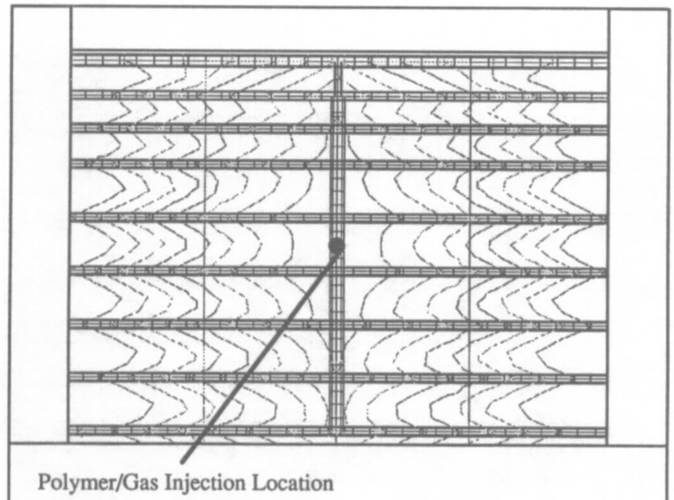

Figure 7 : Final design iteration (even filling)

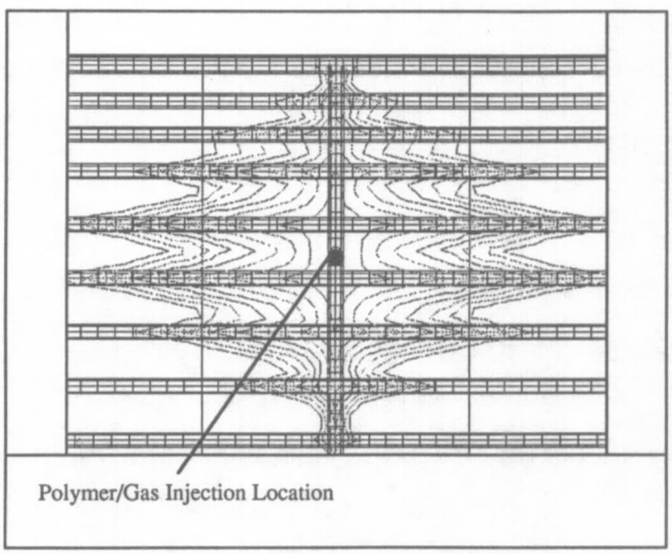

Figure 6 : Preliminary filling analysis (equal size channels)

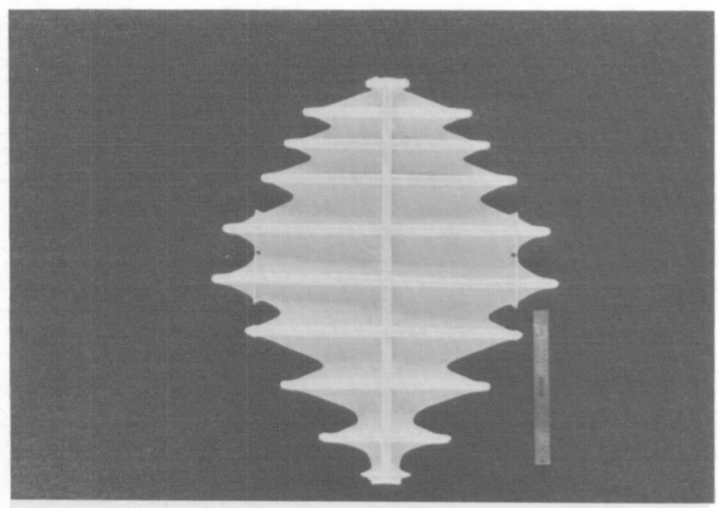

Figure 8 : Short shot of the example part

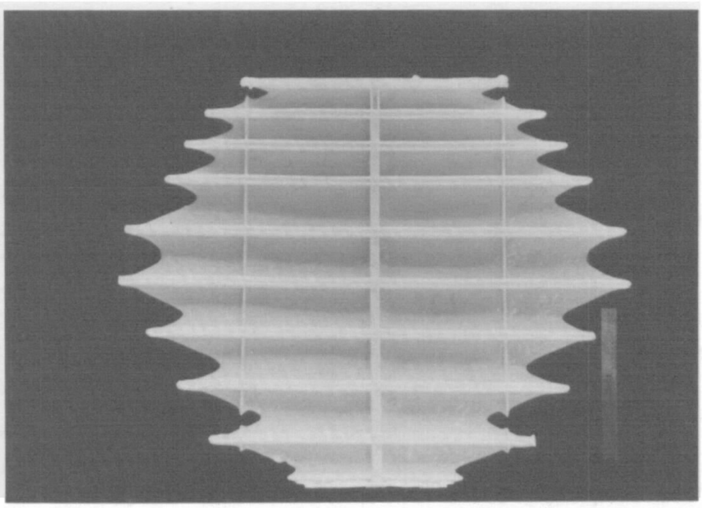

Figure 9 : Short shot of the example part

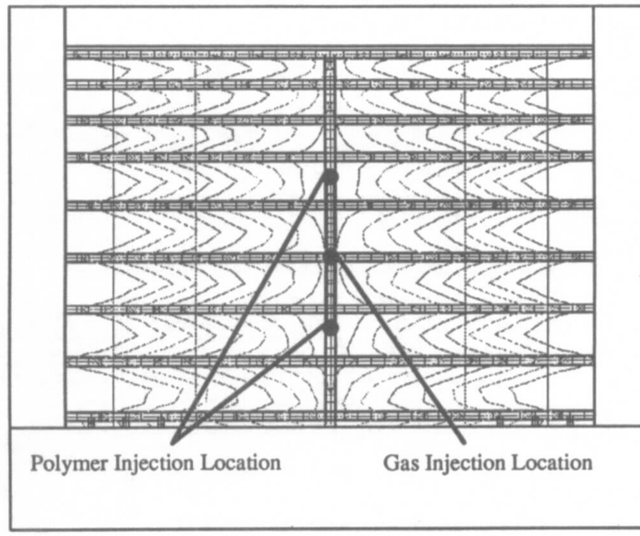

Figure 10 : Production version with two drops

Peter Zuber graduated from Northeastern University in 1981 with a BSME degree. In 1982 Peter completed his MSME from Massachusetts Institute of Technology. Upon graduation, Peter entered GE Aerospace on the Edison Engineering Program. After successfully finishing the Edison Program, Peter began full time work at GE Aerospace, until 1989 when he began employment with GE Plastics as a CAE Structural Analysis Engineer - Technology Development. In 1982 Peter became an Advanced Injection Molding Processes Engineer, specifically Gas-Assist Molding, at the Polymer Processing Development Center.