1 An Overview of Gas-Assist Injection Molding

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The search for technology to make hollow plastics parts has been ongoing for many years. In 1944, Opavsky patented a technique to inject a gas or liquid into a resin. This technique involved a hypodermic needle. However, the high pressures of injection molding rendered these early techniques unsuccessful. Gas-assist injection molding, as we know it today, was developed in the early to mid 1970s. There appear to be two lines of development: one from early development by Friederich at Rohm in Germany that was patented in 1976 and another that originated from the early foam-molding industry.

The initial development by Friederich resulted from a desire to make hollow-shaped bodies by using a modified injection molding process. Before the development of this technology, two primary means of making hollow components existed. One involved the bonding of two halves that had been produced by injection molding. The welding process could be adhesion or welding. The second means involved blow molding, either ''injection blow'' molding or extrusion blow molding. In injection blow molding, a ''preform'' is injection molded. The 'preform' is inserted into a hollow core in which the 'preform' is heated to the appropriate temperature, after which gas is introduced into the center, producing the desired shape.

Each of these processes has drawbacks. If the components are not mirror images, individual molds must be manufactured to produce each section. The combination of injection molding sections requires fixtures to ensure that the components are held in the proper position until the bond is finalized. The welding process also requires an additional piece of equipment such as ultrasonic or vibrational units to produce the bond.

Ernst Friederich of Rohm GmbH in Darmstadt, Germany, was the first to invent such a process. The initial patent filed in Germany (Germany patent 2501314, issued 1975) stated the process as:

> A method for making a hollow shaped body from a thermoplastic resin by injection molding, which method comprises injecting an amount of molten resin sufficient for the preparation of the hollow shaped body from an injection nozzle into a mold through an injection aperture in said mold, injecting gas under pressure through said injection nozzle and aperture to expand and distribute the molten resin over the interior surfaces of the mold, whereby said hollow shaped body is formed within said mold with a gas-entry opening in said hollow shaped body, cooling the hollow shaped resin body so formed to a temperature beneath the softening point of the resin, opening the interior of the hollow shaped body to equalize the pressure therein with ambient pressure, and then opening said mold to remove said hollow shaped body [1]. Figure 1.1 illustrates the concept.

Potential applications stated in the ''Friederich patent'' were large hollow components such as double-paned windows, skylights, hollow glass bricks, and double-walled lighting fixtures. This patent was issued in the United States, July 18, 1978, as U.S. patent 4,101,617. The original structural foam process was developed at Union Carbide. One of the primary deterrents to expansion in applications requiring surface aesthetics was the swirl pattern on the surface. Continuing work at Union Carbide to overcome this issue, Olabisi developed the structural web process in the late 1970s [2].

In the early 1980s, Hunerberg at Hoover Universal saw the potential for this process

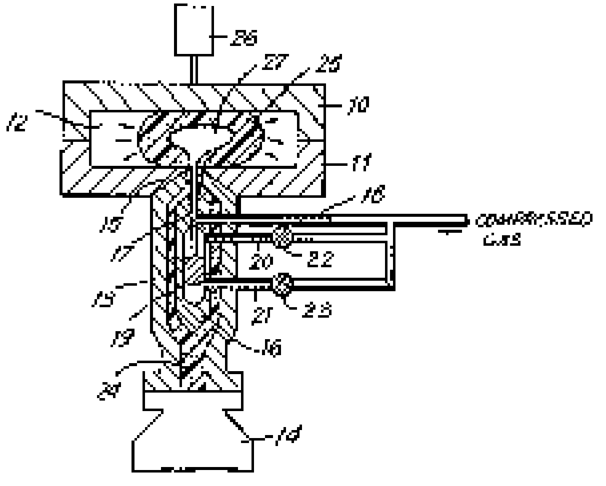

Figure 1.1 United States Patent 4,101,617 (issued July 18, 1978), Figure 1

and worked with Olabisi to adapt the original work as a commercial process. The process, commercialized in the 1980s, was relatively inactive through the late 1980s and early 1990s. Interest has escalated in the last few years, as the interest in gas-assist injection molding has increased.

1.1 Development of Gas-Assist Injection Molding

Outside Germany, developments on producing hollow, injection-molded components initially surfaced around 1980 when a number of foam molders took the next step from producing cellular components to producing components that contained large hollow areas. As mentioned, companies such as Hoover Universal and KMMCO in the United States and Peerless Foam Molders in the United Kingdom were active in developing variations of this technology to compliment their structural foam and to overcome the surface appearance issue.

Only a few people—namely Jim Hendry, Inder Baxi, Eric Erikson, and Steve Jordan—were involved in the early work. The most notable, Jim Hendry, worked on this technology at KMMCO with Baxi and Erikson in the early 1980s. Subsequently, he began consulting with Peerless in the United Kingdom, where he worked with Steve Jordan. Hendry rejoined Baxi at Sajar in the mid 1980s, where work continued on gas-assist injection molding.

Peerless patented its Cinpres I (Controlled Internal Pressure Molding) process in 1983 and began production in 1984. Mike Ladney, president of Detroit Plastics Molding (DPM) became interested in this technology when he observed Cinpres being demonstrated during the 1986 Internationale Messe Kunststoff und Kautschuk in Düsseldorf, Germany. In 1987, Ladney purchased rights to the Friederich patent that had lapsed in Europe, but not the

Figure 1.2 Gas-assist injection molding ''family tree''

United States. At that point, Hendry began working with DPM to further develop gas-assist injection molding technology; as a result, GAIN Technology was formed. Figure 1.2 illustrates the intertwined development of this technology.

By now, a number of European companies were using this technology to produce parts, and the benefits were being recognized. Consequently, a number of machine manufacturing companies, including Battenfeld, Ferromatik, Stork, Engel, and Johnson Controls, began developing variations of the process.

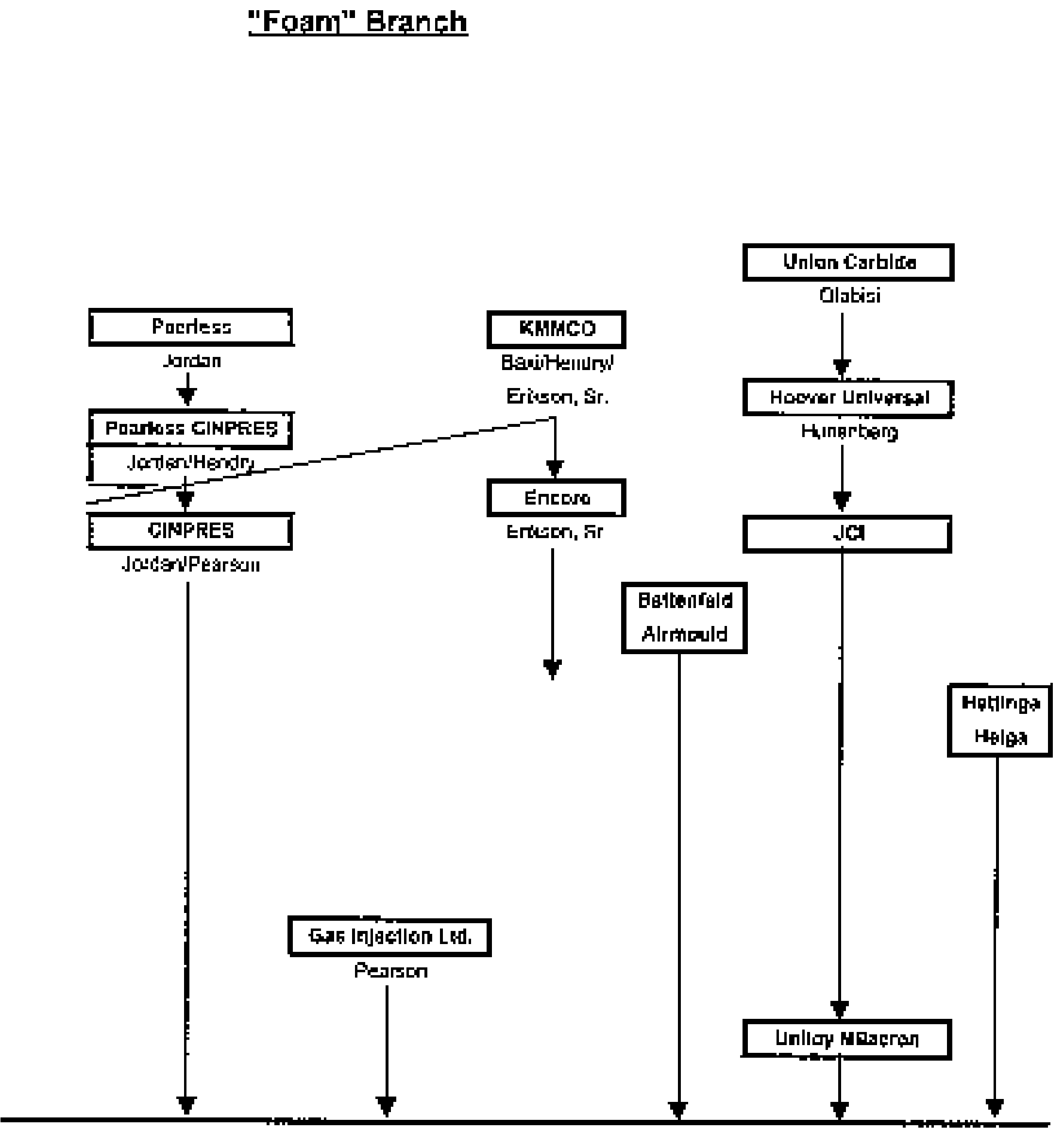

Figure 1.2 Continued

1.2 Legal Aspects

The initial legal shot was fired in 1987, after Ladney acquired rights to the Friederich patent. He filed a suit against Cinpres for inducing its licensees to infringe the Friederich patent in the United States by using the Cinpres I technology. This provided the impetus for the companies involved in this technology to patent as many aspects of the technology as possible. A number of companies including Cinpres, GAIN, Johnson Controls, EPCON, Hettinga, and Sajar have patent coverage. Ladney and GAIN Technologies have been involved with suits and countersuits with Cinpres since 1987. Other companies, such as Battenfeld and their Airmould process, have been peripherally involved.

To use gas-assist injection molding, a license may be required. If so, several options are available: a patent-only license, a development license, and a full manufacturing license. A patent-only license enables the licensee to use the specific patents licensed, but it does not include any application development support or equipment. For OEMs or molders taking the initial foray into gas-assist injection molding, a development license is the first step. This license can be converted into a full manufacturing license.

Initially, license fees plus production royalties were the norm. In some instances, individual molds were licensed. However, licensing agreements have changed significantly. A variety of licensing arrangements exist, and in some cases, specific agreements can be negotiated. The best advice is to review licensing requirements with potential suppliers when you assess the technology and support capabilities.

To select the appropriate technology, it is important to review and understand each of the technologies and the suppliers' capabilities. All have somewhat different approaches and different levels of support. Some such as Cinpres have global support, whereas others are local. Some technologies are specific to equipment such as the multi-nozzle technology that is available only on Uniloy Milacron structural foam equipment. It is recommended that you talk to other people who use gas-assist injection molding technology and obtain their input about the various aspects of using this process.

1.3 Overview

In the plastics processing arena, gas-assist injection molding is a relatively new process that is experiencing rapid growth. Sometimes it is incorrectly positioned as a quick-fix for a problem application. Although it is a variation of injection molding, it is sometimes confused with blow molding. This is because both processes feature parts with hollow sections. One major difference between the processes is in the hollow section content of the part. Gas-assist molded parts have a much thicker wall surrounding a relatively small amount of hollow core. In general, gas-assist molded parts have less than 10% weight reduction in the hollow sections. Blow molding, on the other hand, can result in 80% or more hollow sections.

Gas-assist injection molding involves the injection of a short shot of resin into the cavity. When gas is introduced into the molten material, it takes the path of least resistance into areas of the part with low pressure and high temperature. As the gas travels through the part, it cores out thick sections by displacing the molten material (Fig. 1.3). This molten material fills out the rest of the part. After the filling is complete, the gas becomes the packing pressure, taking up the volumetric shrinkage of the material.

There are two basic types of gas-assist molding: constant volume and constant pressure. For the constant volume process, a cylinder of predetermined volume is

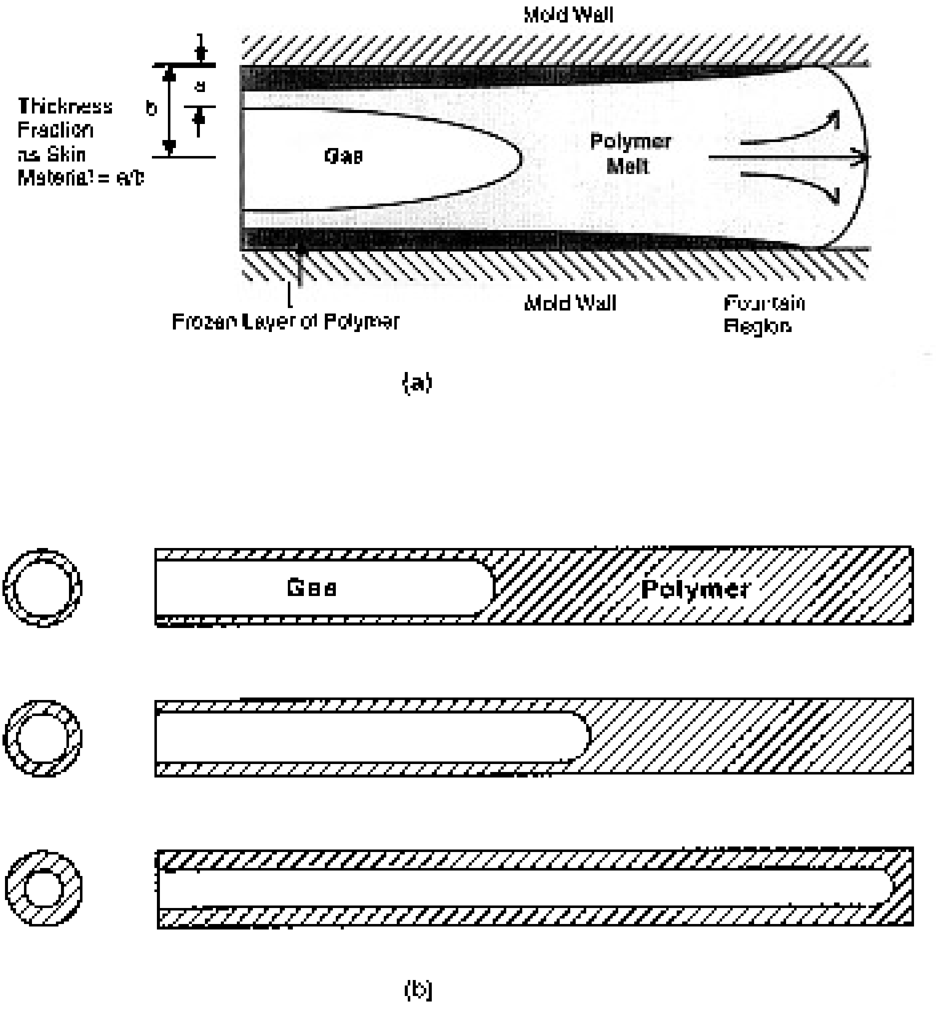

Figure 1.3 (a) Schematic cross-sectional view of a gas channel, showing the filling of polymer melt and gas where the thickness fraction of skin material is defined as the ratio of polymer skin thickness to the half-gap thickness or radius; (b) relation between polymer skin thickness and gas penetration length for a fixed prefilled polymer volume [From *Innovation in Polymer Processing: Molding*, Stevenson, J.F. (Ed.)]

prepressured prior to the gas injection. A piston pushes the gas out of the cylinder into the part. The pressure in the part depends on the ratio of part volume to the cylinder volume. Gas pressure, timing, and piston speed control the profile. Figure 1.4 illustrates the pressure drop-off during the cycle for the constant volume process. For each injection cycle, the pressure must be built up prior to injection.

The constant pressure method functions with gas compressors that build up a reservoir of nitrogen to a predetermined pressure. This reservoir supplies a constant pressure to a series of valves. Pressure profiles are achieved by regulating the gas pressure to the valve

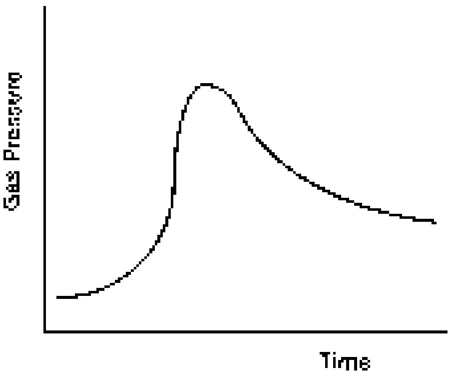

Figure 1.4 Constant volume system gas pressure profile [From *Innovation in Polymer Processing: Molding*, Stevenson, J.F. (Ed.)]

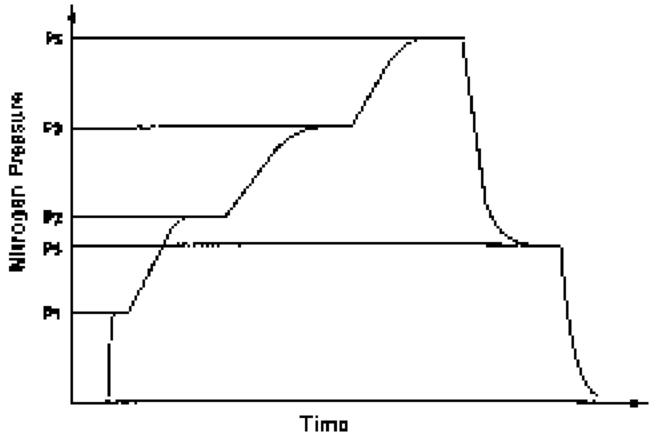

Figure 1.5 Constant pressure system gas pressure profile [From *Innovation in Polymer Processing: Molding*, Stevenson, J.F. (Ed.)]

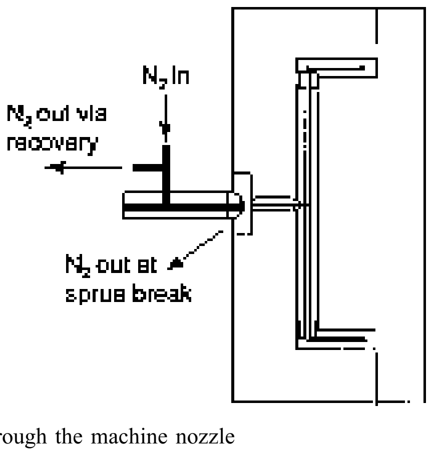

Figure 1.6 Gas injection through the machine nozzle

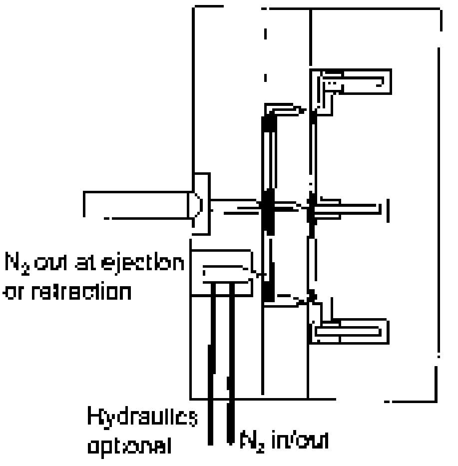

Figure 1.7 Gas injection into the polymer stream

and to the opening of each valve. Figure 1.5 illustrates that the gas pressure can be maintained throughout the molding cycle.

There are two primary options to implement gas-assist molding. These options differ in the location in which the gas is injected into the mold. Gas is injected either through the nozzle or directly into the mold cavity—either in the runner or directly into the part (Figs. 1.6, 1.7, and 1.8). The important difference is that the through-the-nozzle technique requires all gas channels to begin at the nozzle. When the gas is injected directly into the mold, the gas channel may be designed independent of the gate location, provided that the proper material fill pattern is achieved prior to gas injection.

Figure 1.9 illustrates the process whereby the gas is injected directly into the mold.

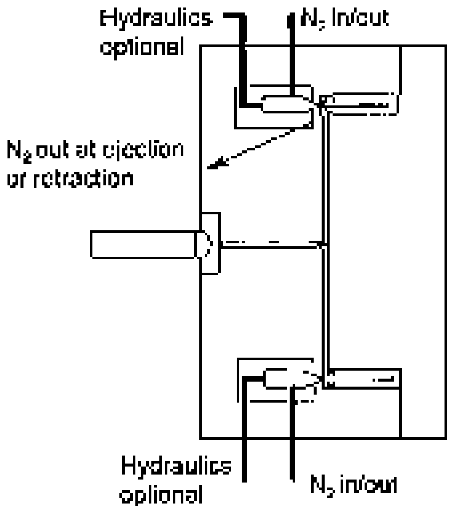

Figure 1.8 Gas injection directly into the cavity

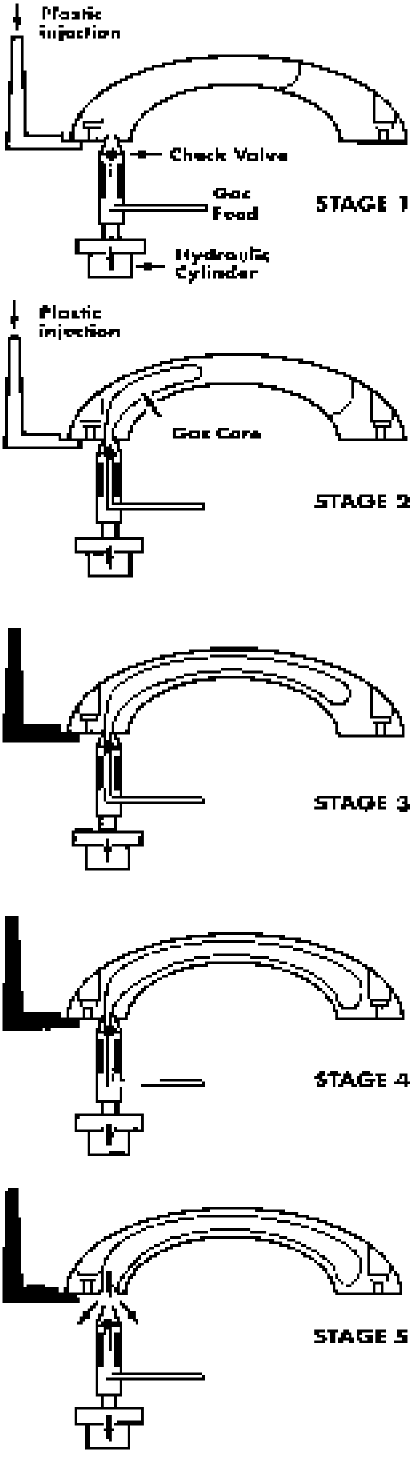

Figure 1.9 Injection sequence for gas injection into mold [From *Innovation in Polymer Processing: Molding*, Stevenson, J.F. (Ed.)]

Material is injected to a given volume (Fig. 1.9, Stage 1); then injection of the gas begins as material injection finishes (Fig. 1.9, Stage 2). The gas fills the component (Fig. 1.9, Stage 3), pressuring it (Fig. 1.9, Stage 4). When the material has become solid, withdrawal of the gas injection nozzle allows the gas to be released (Fig. 1.9, Stage 5) [3].

There are numerous variations on the basic gas-assist process. Two of these are multi-nozzle gas-assist injection molding and a process in which a liquid is vaporized in the melt, producing a gas that forms the channel.

Multi-nozzle gas injection molding uses multiple nozzles to mold large parts for the

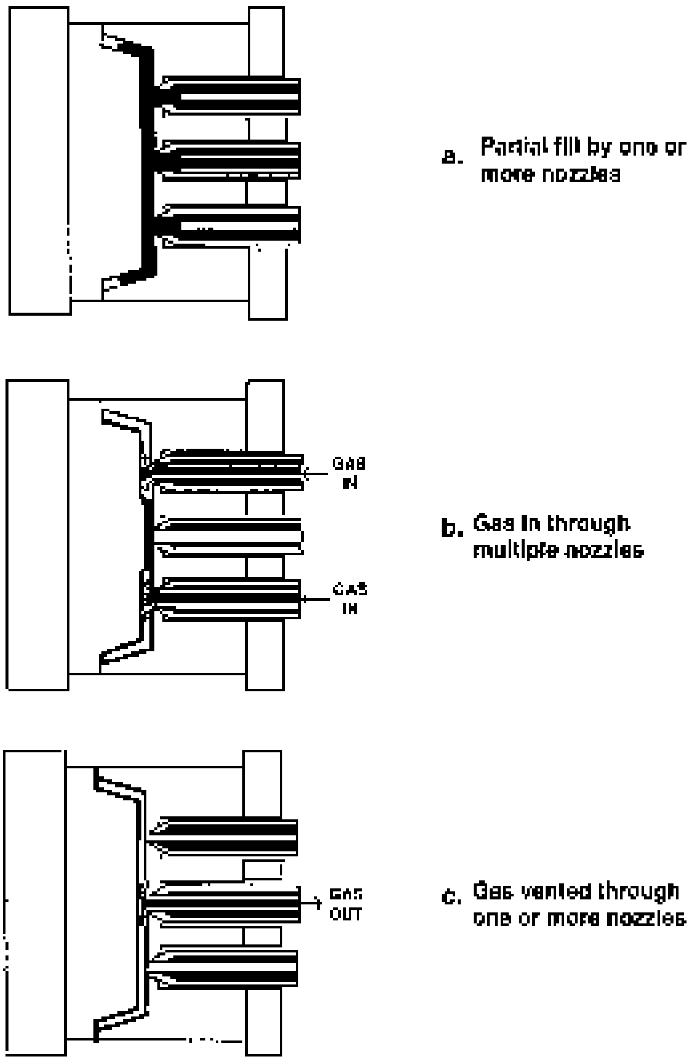

Figure 1.10 Multi-nozzle gas-assist molding: (a) material is injected through multiple nozzles, (b) gas is injected through multiple nozzles to fill out part and hold pressure, (c) gas is exhausted through one or more nozzles

same reasons as structural foam molding. Filling large parts with more than one nozzle reduces the flow length, injection pressure, and cavity pressure. Multiple nozzles can also be used for multiple molds mounted on one common platen, or individual molds can have one or more gas nozzles, depending on part size and flow length requirements. Figure 1.10 illustrates options of multi-nozzle gas-assist molding. Figure 1.10(a) shows resin injection, followed by gas injection in Fig. 1.10(b) and gas venting in Fig. 1.10(c).

Molding multiple parts with different shapes and weights in a single cycle is extremely difficult using single-nozzle gas-assist injection molding due to issues associated with unbalanced flow and fill patterns. Multiple nozzle processing can overcome these problems by permitting each mold cavity to be filled individually with different shot sizes and gas pressures. Machines have been designed and built with up to six shot sequential gas injection control systems [4]. This system allows up to six different molds to be installed on the multi-nozzle machine platen at the same time. Figure 1.11 illustrates molding a 9 kg (20 lb) part and a 2.3 kg (5 lb) part in the same cycle. Some cavities can have multiple nozzles, whereas others have only one nozzle. The machine is programmed to deliver an appropriate amount of material and gas to each cavity sequentially. This technique is claimed to increase machine capacity by 50% or more and is used primarily on large parts—parts weighing more than 2.3 kg (5 lb).

HELGA (Hettinga Liquid Gas Assist) is quite different from previous methods that use nitrogen gas to create the channel. Figure 1.12 illustrates this process. A portion of the required resin is injected into the cavity and is followed by ''co-injection'' of more resin containing a proprietary liquid. Upon coming into contact with the hot melt, the liquid is transformed into a gas, creating the channel. The liquid flow is terminated, and the

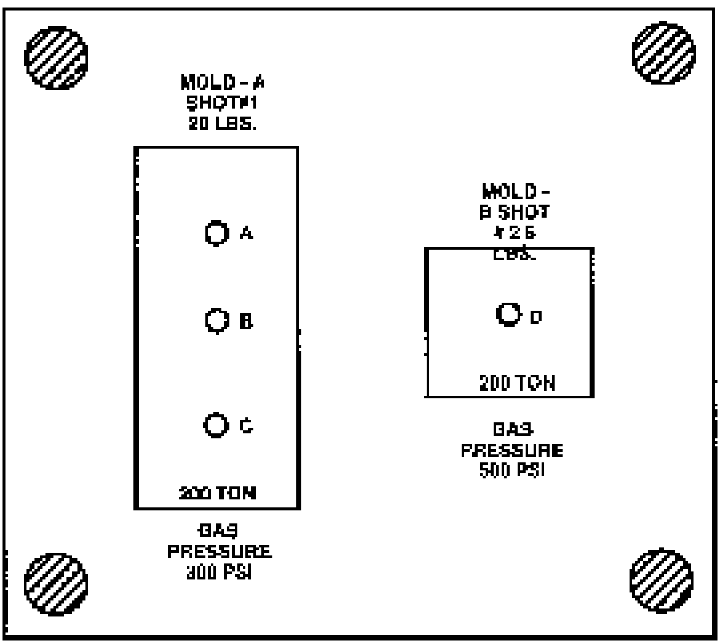

Figure 1.11 Molding multiple parts on a multi-nozzle machine

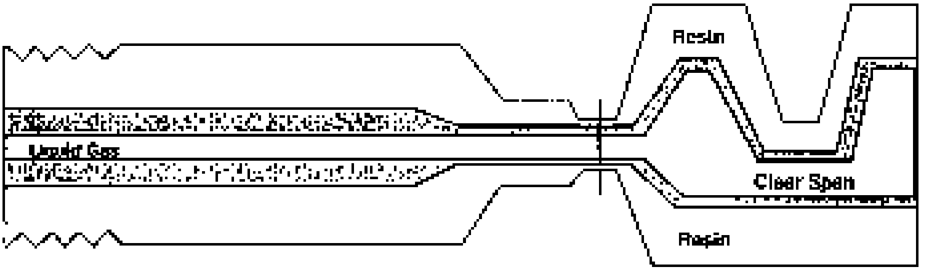

Figure 1.12 HELGA® liquid gas-assist process: Liquid gas is injected into the mold using a special nozzle and then expands to form hollow cores

injection process is completed using resin. The gas is contained within the part and continues to exert pressure outward on the resin minimizing sink marks. When the part cools, the gas deactivates and remains inactive even though the part is heated.

The HELGA process can be applied into the article as well as through the machine nozzle. One advantage in some applications is the fact that there is no open hole where the gas is injected into the part. This is significant in applications where contact with liquid may result in its getting into the part. With the other gas-assist processes, closing this hole(s) requires a secondary operation.

A number of companies hold patents on gas-assist injection molding technology. These patents cover a variety of techniques used to inject gas into the molten material, gas nozzle design, and sequencing. Table 1.1 lists the primary suppliers of this technology. It is recommended that you contact a number of them to review their specific technologies prior to deciding which approach meets your specific needs. Equipment for this technology is available globally. Table 1.2 lists a number of companies that have global capability.

Table 1.1 Gas-Assist Injection Molding Technology Suppliers

Technology provider	System	License requirement
Battenfeld Airmould	Pressure regulation modules	No
CINPRES Ltd.	Multi-valve capability with integral pressure intensification	Yes
Epcon Gas Systems	Multiple valve systems with integral intensification; optional shot control methods	No
Ferromatik Milacron	Airpress III	No
Gas Injection Limited	Pressure regulation modules; external gas-assist	Yes
GAIN Technologies	Through-the-nozzle; multiple valve systems with stand-alone nitrogen generation	Yes
HELGA (Hettinga)	Liquid injection molding	No
Incoe Corporation	External gas systems	No
Uniloy Milacron	Multi-nozzle injection molding based on multi-nozzle structural foam process	No
Nitrojection	Multi-valve systems with intensification capabilities.	Yes

Table 1.2 Gas-Assist Injection Molding Systems and Equipment Suppliers

Alliance Gas Systems	Incoe Corporation
Asahi Chemical Industry (Gas Press Injection Molding, GPI)	Hettinga (HELGA)
Battenfeld (Airmould)	HYDAC
Bauer Gas Systems	Krauss Maffei
Cinpres Limited	Mitsubishi
Engel (Gasmelt)	Nitrojection
Ferromatik Milacron (Airpress III)	Preba
GAIN Technologies	R.F. Topla
Gas Injection Limited	Uniloy Milacron

1.4 Fit of Gas-Assist Injection Molding

Where is gas-assist injection molding being used and why? The most significant advantage that designers see is the added stiffness provided by the hollow channels and sections without adding weight—sometimes even at lighter weight. There are two basic types of gas-assist injection molded components:

— Contained channel gas flow
— Open channel gas flow

Contained channel gas flow parts consist primarily of a single thick section or channel through which the gas must penetrate. Examples of contained channel flow components are handles, arm rests, frames, and tubes. Because the gas has a clearly defined path through which to propagate and no thin-walled sections that must remain gas free, these parts are normally the easiest to process. Figure 1.13 illustrates both contained and open channel flow parts.

Open channel parts consist of a nominal thin wall with gas channels traversing the part similar to traditional injection-molded ribs. Because gas may penetrate into the thin-walled sections of the part (sometimes referred to as fingering), open channel components are more difficult to design and process.

1.5 Advantages of Gas-Assist Injection Molding

Why is the level of interest in gas-assist injection molding so high? The primary reasons are that the ‘‘promised’’ advantages of this process are being delivered. Some of the potential benefits of gas-assist injection molding are:

- Reduced molded-in part stress
- Less warpage

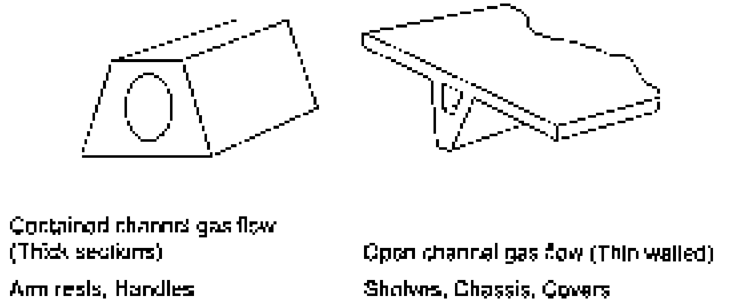

Figure 1.13 Gas channel types (open channel and closed channel): Most gas–assist parts may be divided into two categories as shown above

- Reduced/eliminated sink
- Greater design freedom
- Increased parts integration possibilities
- Improved surface appearance vs. foam (i.e., reduced/eliminated finishing)
- Hollow sections that provide:
  - Easier part filling
  - Longer material flow length
  - Higher stiffness-to-weight ratio
- Reduced cycle time vs. solid sections
- Lower clamp tonnage requirements
- Lower injection pressures
- Reduced tooling costs as a result of replacing hot runner systems with gas channels

Gas-assist injection molding delivers the benefits. As a result, many companies are actively positioning new applications in this technology. As with all processes, a thorough assessment must be made of the component to be manufactured, as well as its required features and volumes, to ensure that the most cost-effective manufacturing process is selected. Force-fitting a process normally does not result in the best solution.

1.6 Disadvantages of Gas-Assist Injection Molding

Some disadvantages must exist; otherwise, the process would have been implemented in a broader scale over a 25-year time period. The first issue is licensing. Table 1.1 lists the principal technology suppliers that require a license to be taken in order to employ their patented technologies. Although licensing scenarios are constantly changing, currently, Cinpres Ltd., Gain Technologies, and Nitrojection require a license. Equipment purchased for either HELGA or the Johnson Controls multi-nozzle process include the license.

Another issue is additional cost. Even if a license is not required, process-specific equipment that ranges from $30,000 to $85,000 is required. These additional costs are incurred by the molder in order to have the capability to manufacture and sell components using gas-assist injection molding. Depending on the license negotiated and the volume of parts manufactured, this fee can range from a few cents/unit to a significant additional cost.

Another source of added costs is the gas used in the process. Except for the HELGA process, nitrogen is the primary gas used due to its inert nature and plentiful supply. In the early stages of developing gas-assist injection molding capability, high-pressure cylinders were used as the nitrogen source. Why? At this point, volumes of nitrogen used are small, the tanks can be located close to the machine, and the cost is low.

As the quantity of parts molded using gas-assist injection molding increases, costs, logistics, and safety issues associated with the nitrogen supply must by addressed. Options to high-pressure cylinders are liquid nitrogen in bulk cryogenic containers and on-site nitrogen generators. Table 1.3 illustrates a study done by Bauer Gas Systems Inc. Based on using 13 cfm (360 l/min) of nitrogen for 24 hours/day, 7 days/week, 50 weeks/year operation [5]. This study showed payback for on-site generation to be approximately one-half year vs. cylinder gas and just under 1 year vs. liquid nitrogen. The point is that nitrogen adds a measurable cost and can have a significant impact on the profitability of a gas-assist injection molding operation.

Gas nozzle design and location are potential issues. With in-article and in-runner gas injection, the gas nozzle location is a critical tool design function. Polymer must cover the gas nozzle prior to gas introduction or blow-out will occur. Proper gas nozzle design and location are critical for optimum manufacturing productivity. Some nozzle designs will foul or plug during the gas injection or venting phase. This results in either maintenance or replacement, either of which will have a negative impact on productivity and cost.

Table 1.3 Nitrogen Gas Cost Study[a] Cylinder/Liquid/Membrane Separator

Requirements:	
Nitrogen flow	13 cfm (360 l/min)
Number of injection points	2
Nitrogen purity	98%
Production Schedule:	
Daily	24 hours
Weekly	7 days
Annually	40 week
	8400 hours

	Cylinder	Liquid	Membrane separator[b] (on site)
Cost ($)/*100 cf* (/3 m^3)	2.89	1.45	1.57
Cost ($)/*hour*	22.54	11.31	1.36
Cost ($)/*year*			
Year 1	189,336.00	95,004.00	89,724.00[c]
Year 2	378,672.00	190,008.00	101,148.00
Year 3	568,008.00	285,012.00	112,572.00
Year 5	946,680.00	475,020.00	135,420.00

[a] Source: Bauer Compressors, Inc.
[b] Membrane Separator capacity 15 cfm (425 l/min)
[c] Year 1 cost includes full cost of generator, $78,300.

1.7 Materials

Most thermoplastic materials are capable of being used in gas-assist injection molding. Table 1.4 lists many of the materials used in gas-assist injection molding. Crystalline materials such as polypropylene, nylon, and polybutylene terephthalate (PBT) may have some advantage because they have a sharp melting point and are low in viscosity, allowing easy gas penetration. Material selection should be based on meeting application performance requirements such as stiffness, strength, performance at use temperature, and chemical resistance. It has been shown that as the polymer viscosity increases, the gas channel wall thickness will increase. This has been demonstrated by GE Plastics for polycarbonate and PBT. Polymer viscosity can be varied by changing the melt temperature during processing. As the melt temperature increases, the viscosity decreases, decreasing the wall thickness of the gas channel. Most material suppliers are working with gas-assist injection molding. They can provide information of the use of specific materials with this process.

Injection-molded thermoset materials have been shown to be capable of being used in the gas-assist process. Work by Battenfeld has shown that laminar flow thermoset materials can be gas-assist molded [5]. By contrast, nonlaminar flow thermosets have not been successfully molded using this technology. The primary reason being that when nonlaminar flow materials are molded, there is very little adhesion between melt and the mold cavity wall. Consequently, material at the flow front is not distributed toward the cavity wall and an uncompressed, low-pressure area is formed resulting in an area of low resistance for the pressurized gas to flow through. Battenfeld's work with nonlaminar flow thermosets demonstrated that the gas does not form a bubble but instead penetrates the flow either directly through the flow front or along the cavity wall/material interface.

The suitability of a number of thermoset resins was studied. Included were phenol formaldehyde, urea formaldehyde, melamine formaldehyde, melamine phenol formaldehyde, unsaturated polyester, and epoxy resins. In general, they found that materials containing inorganic fillers exhibited laminar flow, and gas-assist injection molding was applicable. Those containing organic fillers exhibited solid/shear flow and gas-assist

Table 1.4 Materials Used for Gas-Assist Injection Molding

Acrylonitrile butadiene styrene (ABS)	Polyethylene terephthalate (PET), glass-reinforced
Acrylonitrile butadiene styrene/polycarbonate (ABS/PC)	Modified polyphenylene ether or modified polyphenylene oxide (M-PPE or M-PPO)
Acetal	Polypropylene (glass and mineral grades)
Hi-Impact Polystyrene (HIPS)	Polystyrene
Polyamide (nylon) (unfilled and glass-filled grades)	Polysulfone
Polybutylene terephthalate (PBT) (glass-reinforced grades)	Polyvinyl chloride (PVC)
Polycarbonate	Syndiotactic polystyrene (SPS)
Polyetherimide	
Polyethylene (HDPE)	

injection molding was not applicable. If you plan to use gas-assist injection molding with a thermoset material, it is strongly recommended that you use a prototype tool to assess the compatibility of the material to the process [6].

In addition to weight savings and reduced molding pressures, the potential to reduce flash was found to be a significant benefit of the application of gas-assist injection molding to thermoset materials. Although it has been demonstrated, few if any commercial applications of gas-assist injection molding using thermoset materials are known.

1.8 Design Considerations

Optimizing part design for gas-assist injection molding should focus on three objectives:

- Channel layout optimization
- Channel sizing with respect to the part
- Balancing the polymer fill pattern

Gas channel layout within a cavity involves defining locations for both the gas nozzle and channels relative to the location of the polymer entry into the mold. The gas bubble will follow the ‘‘path of least resistance,’’ that is the path with the lowest pressure, which is typically the highest temperature. A channel or thicker section of a part will usually be of higher temperature than thinner areas due to the larger mass of polymer. The region of the lowest pressure will typically be in the area of the part that has the least amount of packing. As a result, to induce the gas bubble to proceed in the desired path, it is essential to control the resin-filling pattern so that the lowest pressure in the cavity exists near the end of each channel, after the short shot is delivered into the mold. This pressure differential will effectively draw the gas bubble through the channel, pushing the displaced polymer into the unfilled portion of the mold.

Another consideration in gas channel layout is to avoid closed loop channels. Closed loop channels will result in slugs of material in the section of the channel where the gas bubbles converge (Fig. 1.14).

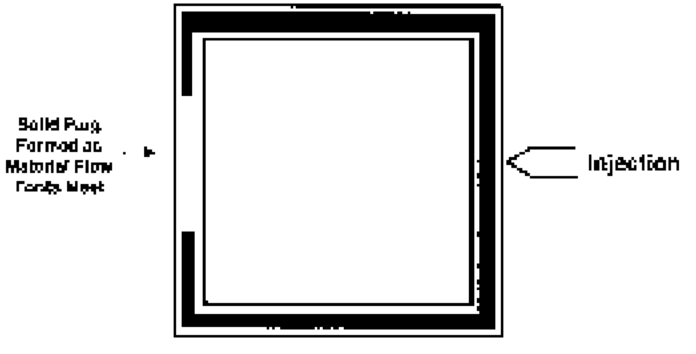

Figure 1.14 Closed loop gas channels

Gas channel size typically begins at a minimum of 2 : 1 to 2.5 : 1 ratio of channel dimension to nominal wall as a lower limit. The upper limit depends on the geometry of the specific part and the location of the channel within the part. Large channels relative to the surrounding wall section may result in race tracking, which leaves the adjacent thin wall section unfilled. Figure 1.15 provides examples of typical gas channel geometry.

Inappropriate gas channel sizing results in several problems uniquely associated with gas-assist injection molding: melt front freeze-off, fingering into the thin wall areas, or gas blow-out. Freeze-off occurs when the gas pressure is insufficient to push the polymer through the available wall section. Because gas pressures are much lower than conventional injection molding packing pressures, flow lengths through thin channels are relatively short. If the last areas to fill are not near the end of the gas channel, freeze-off is not unusual.

Gas fingering typically results when lower cavity pressures are present outside the channel (i.e., when the path of least resistance is outside the channel). Additional causes of fingering can be high melt temperature and early gas injection into the part.

Gas blow-out occurs when the gas bubble propagates through the melt front prior to complete filling of the part. There are two primary causes of gas blow-out: when the short shot of polymer is insufficient to fill the cavity and when the gas is injected into the part prematurely.

Balancing the polymer fill within the cavity is necessary when several channels are involved or when channels diverge within the cavity. During primary gas penetration, the gas bubble displaces polymer within the gas channels to an unfilled area in the cavity. Thus, for parts with multiple gas channels, it is necessary to balance the filling of the gas channels. If some gas channels fill sooner than others, poor gas penetration in these channels will result. One way filling can be properly balanced is by sizing the gas channels. For example, gas channels near the gate would be smaller because they typically fill first, and the gas channels farthest from the gate should be the largest in order to

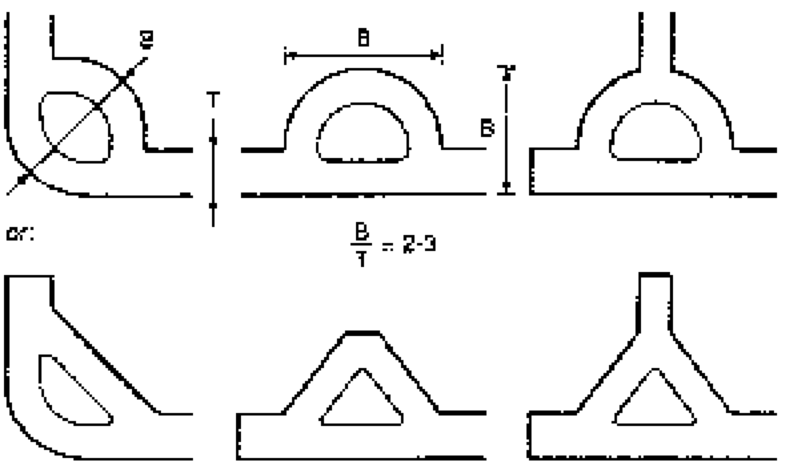

Figure 1.15 Typical gas channel geometries [From *Innovation in Polymer Processing Molding*, Stevenson, J.F. (Ed.)]

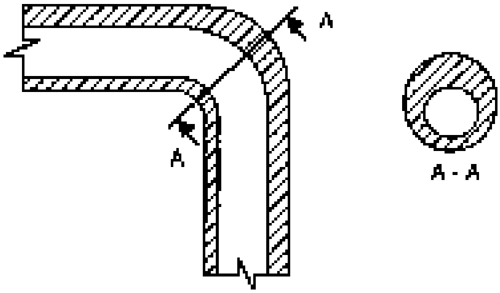

Figure 1.16 Corner thinning design [From *Innovation in Polymer Processing: Molding*, Stevenson, J.F. (Ed.)]

balance filling. A mold-filling analysis can be used in assessing filling patterns in order to balance flow prior to cutting the mold.

Flow around corners of a gas-assist injection molded part must be considered in the design phase to prevent thin inside corners. Gas traveling through a curved channel tends to follow the shortest path through the corner. This means that the bubble will stay to the inside of the corner resulting in an uneven wall thickness. To avoid thinner wall sections on the inside of corners, use as generous a radius on the gas channels as possible (Fig. 1.16).

Parts requiring increased strength or rigidity can be improved by adding ribs to the gas channels or to the nominal wall [7, 8]. A rib is more efficient than gas channels in adding structure to the part and will not contribute to the flow leader effect the way larger channels will. A rib and channel may be combined to produce the benefits of both. Ribs on top of gas channels add greater benefit than traditional ribs because their thickness can be a full 100% of the nominal wall. Figure 1.17 illustrates the addition of ribs to gas channels for increased stiffness.

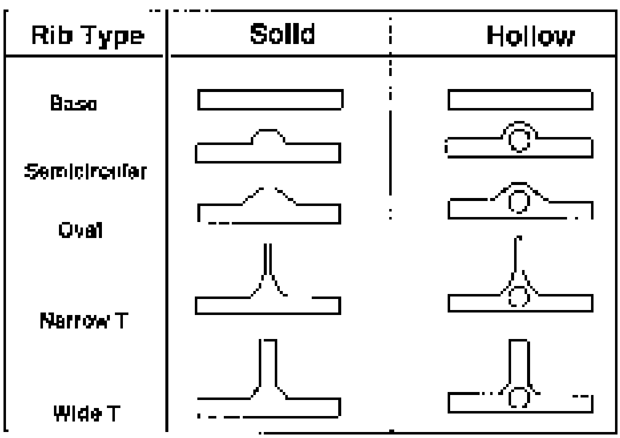

Figure 1.17 Typical rib gas channel geometries

Figure 1.18 Herman Miller Aveon chair molded using the HELGA process [From *Injection Molding Alternatives,* Avery, J. (1998)]

1.9 Applications

Initial applications in gas-assist injection molding were primarily handles, tables, and lawn chairs. As the technology developed and sophisticated design techniques were applied to gas-assist injection molding, the variety and complexity of applications increased. Figure 1.18 illustrates the evolution of the lawn chair to the Herman Miller Aveon chair introduced using the HELGA process. Currently parts ranging from 30 g (1 oz) to 18 kg (40 lb) of material are being manufactured using gas-assist injection molding. The reasons for using this technique are quite different for small parts. Here, tolerance control and warpage reduction could be driving factors. An important consideration for very small components is that payback on the system investment will be difficult; however, as in most cases, weight savings and cycle time reduction will not amortize this cost.

The Chrysler 1995½ minivan exterior door handle, illustrated in Fig. 1.19, is an example of an extension of an early application. The handle/bezels are produced in nylon 6 using Battenfeld's Airmould process. Compared to the benchmarked zinc die-cast model, the number of components in the door assembly was reduced from 22 to 14, the handle unit cost was reduced by $1.30, for an annual $3 million savings. The weight per car was reduced by 0.75 kg (1.5 lb).

An excellent example of the value of using gas-assist injection molding is the Delphi Interior & Lighting Systems' one-piece door module (Fig. 1.20). This module consolidates

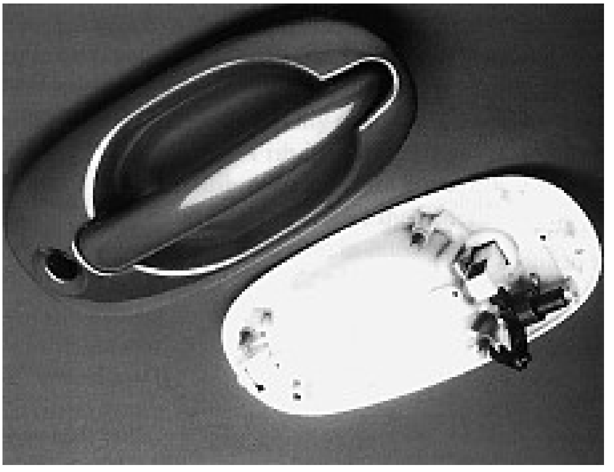

Figure 1.19 Chrysler minivan exterior door handle [From *Injection Molding Alternatives,* Avery, J. (1998)]

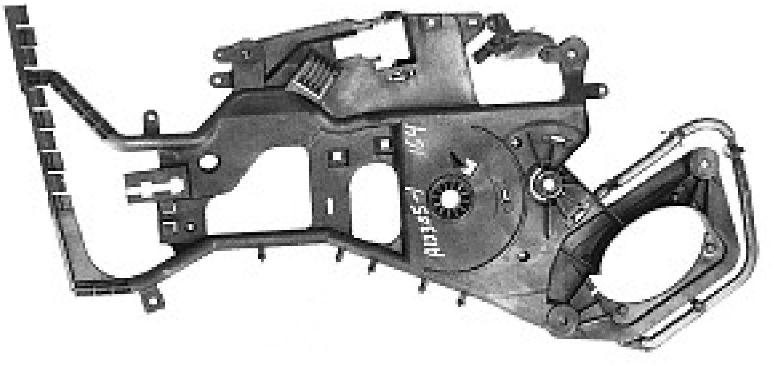

Figure 1.20 Delphi Interior & Lighting Systems door module [From *Injection Molding Alternatives*, Avery, J. (1998)]

as many as 61 parts (window regulator back plate, wire harness attachments, armrest supports, and speaker mounts), which were previously made mostly of metal and required assembly.

Delphi estimates that total system costs with the ''Super Plug'' are 5 to 10% lower than similar door components while the module is about 1.7 kg (3.3 lb) lighter per door. The consolidated component also reduces vehicle assembly time, lowers operating noise, limits corrosion, and enhances recyclability [9].

Figure 1.21 illustrates the unit in use, as it is on GM's 1997 minivan series, including the Chevrolet Venture, Pontiac Trans Sport, Oldsmobile Silhouette, and Opel/Vauxhall Sintra, as well as on GM's retooled Chevrolet Malibu and Oldsmobile Cutlass.

Figures 1.22 through 1.24 illustrate several other applications that employ gas-assist injection molding. Chapter 7 details a wide range of components that are manufactured using a variety of gas-assist injection molding techniques.

Figure 1.21 Delphi Interior & Lighting Systems door module in place [From *Injection Molding Alternatives*, Avery, J. (1998)]

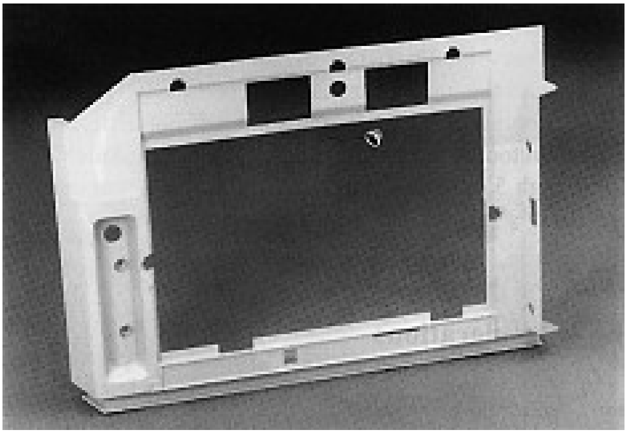

Figure 1.22 CRT bezel [From *Injection Molding Alternatives,* Avery, J. (1998)] (Courtesy of Sajar Plastics)

1.10 Tooling

Gas-assist injection molding is a variation of injection molding. As a result, molds for this process are very similar to those for standard injection molding. Materials are basically the same. Machined tool steel should be used for those applications requiring high-volume production, tight tolerances and good aesthetics. For medium- to low-volume applications, machined aluminum can also be used.

When designing the mold, it is important to know whether a through-the-machine nozzle, in-runner, or in-article gas-assist injection molding process will be used. With in-runner and through-the-machine nozzle techniques, gate size must be large enough to

Figure 1.23 Mobile file demonstrating structural capability of gas-assist molding [From *Injection Molding Alternatives,* Avery, J. (1998)] (Photo courtesy of Cinpres)

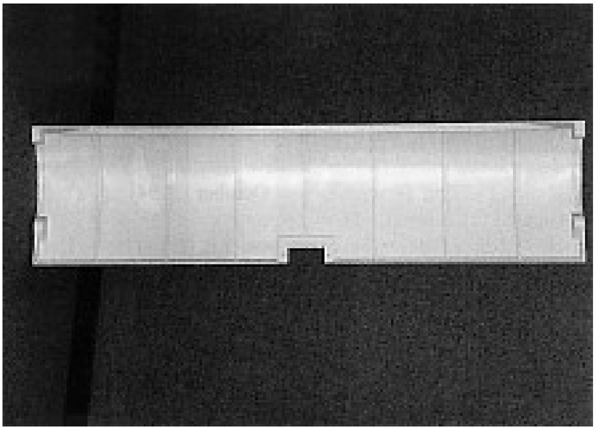

Figure 1.24 Bus overhead cargo door molded using multi-nozzle gas-assist process [From *Injection Molding Alternatives,* Avery, J. (1998)] (Photo courtesy of Horizon Plastics, Ltd.)

prevent gate freeze-off before gas injection. This is particularly important for subgates or tunnel gates that typically are larger than for their injection molding counterparts. Also, edge gates or fan gates should integrate a channel to provide a clear path for the gas into the cavity.

With in-runner or in-article gas injection systems, gas nozzle location is a critical tool design function. Because the nozzle must be included in the mold, cooling line location or other mold functionality could be affected. An additional consideration for gas nozzle location is that it must be located so that polymer will cover it prior to gas introduction. Otherwise, the gas channel will not be developed. Cooling lines, part design, and filling pattern must be known when determining nozzle location.

Hot manifold systems can be used with the in-article gas-assist process. Depending on the gas nozzle location, a valve gate manifold system may be required. If the gas penetrates back into the hot manifold system, it will push molten resin back into the machine barrel. This will result in inconsistent shot size and increased reject rates.

1.11 Developments

As is typical with emerging technologies, modifications and new approaches are developed. This has been true with gas-assist injection molding. On a global basis more than 50 companies are ‘‘suppliers’’ to users of this technology. Many of these suppliers are listed in the appendix. They range from primary technology suppliers and control systems suppliers to gas generation systems and component suppliers.

External gas-assisted injection molding has been available for several years, but it has yet to penetrate the market significantly. Battenfeld, Asahi, Incoe and Gas Injection Limited all offer this technology that is claimed to provide benefits for applications requiring highly aesthetic surface finishes and where conventional ribs or gas channels are not feasible. Limited applications such as Canon Corporations fax machine lower housing (Fig. 1.25) employ this technology.

External gas molding is different because the gas is injected directly into the core side of the mold, not into the material filling the cavity (Fig. 1.26). The mold must be sealed at the parting line and in any ejector pin areas to prevent gas from escaping. The gas creates a layer or ‘‘blanket’’ across the entire sealed surface area or selected sealed areas of the molded part. The gas pressure is held constant, to compensate for the volumetric shrinkage of material during cooling. When the material has cooled to the point when it is self-supporting, it must be vented, either fully or partially. Some remaining gas pressure may be retained for use in assisting part ejection from the mold.

New variations continue to be developed. The latest variant being water-assist injection molding. This process is under development by IKV, the Institute for Plastics Processing,

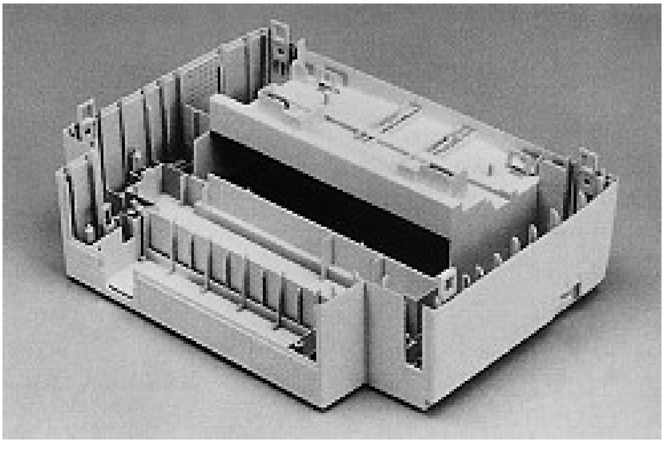

Figure 1.25 Fax machine lower housing (photo courtesy of Canon Corp.)

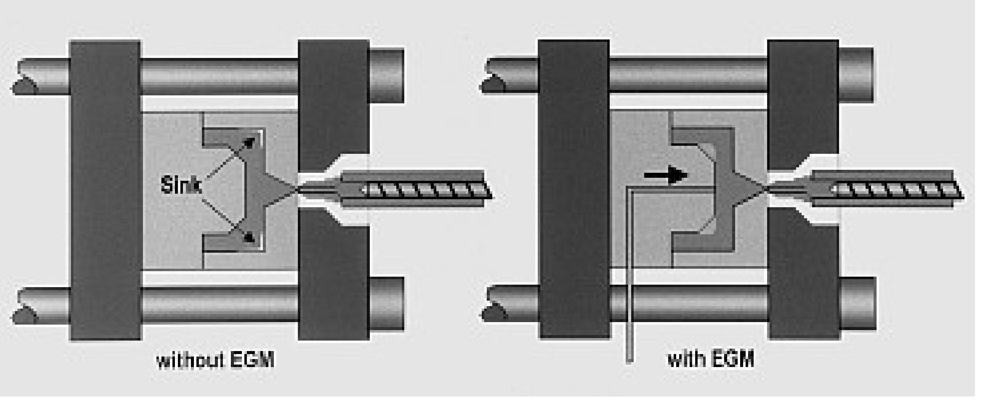

Figure 1.26 External gas molding (EGM)

Aachen, Germany. In the IKV process, cold water is injected into the melt and stays in the liquid phase. Water pressure of 20 bar (290 psi) is required during injection to 150 bar (2176 psi) during the holding phase. The water can be drained from the part while it is still in the mold, or it can be drained off after the part has been demolded [10].

This variation is similar to the HELGA process of Hettinga. In the HELGA process, a proprietary liquid is injected in the nozzle while the resin is being injected. The liquid is vaporized, and the resulting gas pressure forms the gas channel. When the part cools, the gas deactivates and remains dispersed. The liquid does not condense, and it is unnecessary to drain it from the part. Initial thoughts are that the water-assist process is likely to compliment gas-assist injection molding. It is felt to be less suited to coring out flat parts, thin walls, and ribs but is best suited to parts with large-diameter rodlike sections such as automotive ducts. Advantages are claimed to be smoother surfaces of the core walls that would be beneficial in the production of these parts. Two processors are involved in the development of this technology with IKV. It is estimated that it could be in commercial production by 2002.

IKV is also investigating the application of gas-assist injection molding to address several issues related to powder injection molding [11]. The issues are: powder costs, which limit the attainable size of parts economically feasible; the time required for

Figure 1.27 Truck side rear view mirror (photo courtesy of Siegel-Robert, Inc.)

cooling, debinding, and sintering of thick wall parts; and the reduction of internal stress induced by flow effects during the holding phase. Initial investigations by IKV have shown the elimination of orientation due to constant pressures over the flow length of the material. As a result, parts with improved dimensional stability and lower molded-in stress and warpage are produced compared to compact powder injection molded parts. The cost-effectiveness is improved by reducing the amount of material required for a similar part, and because there is increased surface and less material, de-binding and sintering times are reduced.

A test sample used by IKV (a complex tube) demonstrated a 34% reduction in material usage compared to a compact molded powder injection molded part, yet the stiffness was reduced by approximately 10%. The resulting hollow channel part yields a significantly increased flexural strength. Even though this investigation demonstrates that it is possible to apply gas injection molding to powder injection molding, the processability is strongly dependent on the thermal properties of the feedstock. These studies demonstrated that advanced process management is essential to produce powder injection molded parts of high quality. It can also offer some fundamental advantages for existing applications as well as opening new opportunities for future uses.

Efforts such as these will continue as suppliers strive to gain proprietary positions and technology advantages. Some developments will provide value and gain commercial acceptance, whereas others will be impractical to implement or fail to provide cost-effective benefits.

1.12 Future Directions

Gas-assist injection molding is currently a niche process with a limited processor base. The widest acceptance of this technology has been by the automotive industry. This is not unexpected because the need for productivity and cost and weight reduction drive the need for manufacturing innovation.

Realization of the ‘‘promised’’ benefits of gas-assist injection molding in programs properly designed and developed for this process produced a high degree of interest in ‘‘advanced’’ applications by automotive OEM’s and Tier 1 suppliers. The best example to date is the Delphi Interior & Lighting Systems’ door hardware module discussed earlier. Another example of future possibilities for this technology is in Chrysler Corporation’s Composite Concept Vehicle, an inexpensive, five-seat passenger car with an all-plastic exterior; it is being assessed as a potential automobile manufacturing technique for developing countries. The left and right inner and outer panels provide both structural support and decorative finish. The plastic door panels weigh about 15.9 kg (35 lb) and are produced in the development phase using gas-assist and hot-runner molding with sequential valve gating.

The next level of commercial development is to integrate gas-assist injection with other processes such as co-injection molding and overmolding in order to maximize its value. Figure 1.27, a truck side rearview mirror, is produced using gas-assist injection molding to provide rigidity. It is co-injected with an Acrylic styrene-acrylonitrile skin to provide the appearance and weatherability in a single molding operation. This eliminates assembling brackets into the base and painting, both of which are expensive and time-consuming operations.

Until recently the value of gas-assist injection molding has been questioned in tight tolerance, thin-walled applications. Successful applications in CD-ROM player trays and a press-fit layer plate component in a bussed electrical center for automotive electric systems illustrate the use of gas-assist injection molding to thin-walled components. Enhanced dimensional stability in terms of reduced molded-in stress that results in minimized warp is the primary benefit. These applications are discussed further as case studies in Chapter 7.

Where is the future of gas-assist injection molding? Even though it has been demonstrated to be of significant value, its acceptance has been slowed by legal actions and fear of litigation. For this process to become mainstream, progress must be made in several areas.

- The ‘‘knowledge gap’’ must be overcome. Designers must have confidence that their designs can be implemented, and that the value of the process will be realized. The development cycle for components molded using gas-assist injection technology must be no longer than for a standard injection molding or structural foam component.
- Recognition that gas-assist injection is not a ‘‘fix-it’’ for existing problems even though some design issues may be overcome by creatively applying this technology, material, and process. As with any process, a product must be optimally designed for material, design, and process.
- Additional costs of using gas-assist injection must be understood and minimized. These costs (licensing, control systems, gas, nozzles) must be balanced in terms of the potential savings provided by this process. Potential savings include: material usage for a specific application, and reduction of the required press tonnage for a gas-assist injection molded part vs. the press tonnage for the part molded using standard injection molding. This may translate to equipment savings, energy savings, and reduced floor space requirements. All of which may potentially prove a reduction of investment and operating costs.
- Fear of litigation must be eliminated. This is easily accomplished by taking a license from one of the technology suppliers and applying the technology in compliance with the license.

Broader commercialization of gas-assist injection molding may occur via several paths, some of which might be:

- The technology becomes widely understood and low cost to implement. Most designers and molders become knowledgeable and use the technology.
- A group of converters specialize in gas-assist injection molding. Their expertise enables them to develop components quickly and cost-effectively, positioning them as suppliers of choice for gas-assist injection molded components. This is the current situation.
- Captive converters become the largest users of gas-assist injection molding. They have the large volume applications that enable them to amortize the added costs.

Will gas-assist injection molding technology grow or not grow? The challenge is to make it low cost and easy to use. If that state can be achieved, gas-assist injection molding will be widely used and become a major factor in the future of injection molding.

References

1. Friederich, E., German Patent 2501314 (1975)
2. Olabisi, O., United States. Patent 4,136,220 (1979)
3. Beattie, K., Paper presented at Society of Manufacturing Engineers, Automotive Plastics '94 Conference, Detroit, MI, October (1994)
4. Hunerberg, E., Paper presented at SPI Structural Plastics Division Gas Assist Injection Molding Seminar, Detroit, MI, November (1996)
5. Lynch, M., Paper presented at SPI Structural Plastics Division Conference, Irvine, CA, April (1997)
6. Smith, C. *European Plastics News*, June 1993, p. 22
7. Gennari, A., Woods, J.T., Zuber, P.J., Paper presented at SPI Structural Plastics Division Conference, Washington, DC, April (1994)
8. Grelle, P., Dallman, M.A., Kerouac, K.A., Paper presented at SPI Structural Plastics Division Conference, Atlanta, GA, April (1996)
9. Shah, S., Clark, C., Juback, G., Paper presented at SPI Structural Plastics Division Conference, Atlanta, GA, April (1996)
10. Mapleston, P., *Modern Plastics* (1999), pp. 28–29.
11. Michaeli, W., Hopmann, C., *Modern Plastics* (1999), pp. 116–119.

Bibliography

Barton, S., Paper presented at SPI Structural Plastics Division Conference, Irvine, CA, April (1997)
Bergen, J., Simpson, S., Paper presented at SPI Structural Plastics Division Conference, Irvine, CA, April (1997)
Betts, T., Paper presented at SPI Structural Plastics Division Conference, Irvine, CA, April (1997)
Bertacchi, G., Bernhardt, A., *Injection Molding* (1996), pp. 74–75
Caropreso, M., Zuber, P., *Plastics Technology* (1995), pp. 48–52
De Gaspari, J., *Plastics Technology* (1994), pp. 44–49
Eckardt, H., In *Innovations in Polymer Processing*. Stevenson, J.F. (Ed.) (1996) Hanser, Munich, Chapter 1
Galli, E., *Injection Molding* (1994), pp. 35–39
Galli, E., *Injection Molding* (1996), p. 77
GE Plastics, *Gas Assist Injection Molding Design Guide*
Gennari, A., Woods, J., Zuber, P., *Plastics Design Forum* (1994), pp. 21–25
Moore, S., *Modern Plastics* (1994), pp. 52–56
Turng, L.S., In *Innovations in Polymer Processing*. Stevenson, J.F. (Ed.) (1996) Hanser, Munich, Chapter 2
VanHoeck, S., Paper presented at SPI Structural Plastics Division Conference, Irvine, CA, April (1997)