Injection-mold venting: the hidden processing parameter

Volatiles emitted in increasing quantities by the newer materials often cannot be adequately vented by traditional means. Peripheral and water-line venting are effective alternatives.

By Paul E. Allen
Logic

The need to vent molds arises because of something we are too apt to forget—the entrapment of air in mold cavities as the mold halves close. There is, however, another gas that has to be dealt with, and its source is the plastic melt itself. Nonaqueous volatiles, or NAVs, as they are called, are given off when plastic resins are heated to processing temperatures. Finally, if a resin has not been adequately dried before being fed to the hopper, still another gas is given off—steam.

In the early history of injection molding, NAVs were not much of a problem. Polystyrene, the predominant resin used at the time, gives off very little gas at normal processing temperatures. But as newer resins came along—polypropylene, polyethylene—which give off larger volumes of gases, the problem of effective venting was emerging. The problem was soon even further complicated by the introduction of the engineering resins, polycarbonate and acetal, which give off gases in even greater volumes. Today, with the ever-increasing use of fillers and neutralizers, new pigments, and additives to retard fire and smoke, UV degradation, microbial attack, and so on, NAVs are being released during molding in quantities never encountered before. It is for this reason that proper venting is so much more critical than it was just a few years ago. For unless these gases are permitted to escape from the mold, they become compressed and generate temperatures high enough to cause molding problems.

Improper venting

Probably the most familiar effect of improper venting is the "gas burn," which generally is a small black spot on the plastic part. The black is a thin carbon deposit where the plastic was literally burned, that is, oxidized due to the very high temperature of the compressed gases trapped in the last portion of the mold to be filled. If this thin film of carbon were scraped off, it would often reveal unharmed plastic beneath it, but in worse cases the burn goes much deeper, sometimes deep enough to be visible on the other side of the part. (Not only can the plastic part be burned, but the mold can be damaged by gas compression. The chemical action of the gases at high temperatures can actually etch away the steel at a spot where burns continue to be generated.)

Improper venting also gives the molder trouble with short shots, both indirectly and directly. Gas compression can directly result in shorts because, all other conditions remaining the same, the added resistance of a pocket of compressed gases in the cavity will slow down the fill rate, thus allowing the melt front to cool more before the part is full. Being cooler, its viscosity will be higher, and more pressure will therefore be required to fill the part.

Generally, however, shorts are encountered in a poorly vented mold because the molder tries to fill it more slowly to avoid the burns, and the melt front cools before the cavity is filled. Improper venting can also cause flash in certain cases. Indeed, it always tends to increase flash. The thin-walled, round, flat part shown in *Fig. 1* was nearly impossible to fill without flashing the parting line, even though it was running in a press that provided more than enough clamp force. Theoretically, the mold *could not* be flashed, but it flashed nonetheless.

We hypothesized that the gases inside the cavity were not being effectively vented, but instead were blowing out all around the parting line. Thus, the mold was opened enough to permit the melt on reaching the parting line to follow the gases out and generate flash. It should be added that filling time had to be extremely short because of the thin-wall section, and that it was nearly impossible to stop injection precisely when the mold was full. Yet after venting was increased the problem was greatly reduced.

The following illustration will explain the mechanism by which, at a given pressure, gases can blow a mold that the melt cannot. Suppose we are running a mold with a projected area of 50 square inches in a 500-ton press. The effective clamp pressure is therefore 10 tons per square inch. Assume that an injection pressure of 10,000 pounds per square inch (5 tons per square inch) is required to fill the cavity. The total force presented by the plastic at this pressure would therefore be 250 tons (5 tons per square inch X 50 square inches), only half the force needed to match the clamp force, let alone blow the mold.

Now suppose the gases inside the mold were not vented properly and, with 5 tons per square inch of pressure behind them, found a small im-

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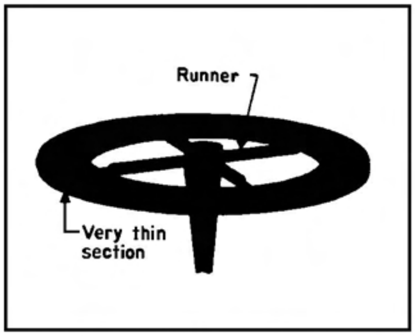

Figure 1. Thin-walled cylindrical part flashed because of inadequate venting.

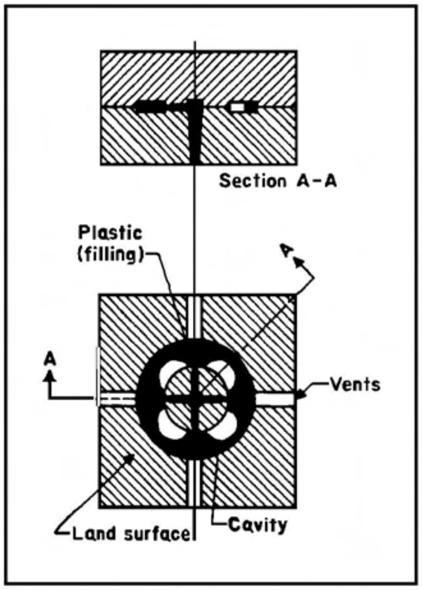

Figure 2. Pockets of trapped gases force the mold halves sufficiently apart to create flash.

perfection in the land surface through which to escape. This would, of course, only be possible for the gases to do, and not the melt, due to the extremely large difference in viscosity. Once they have found their outlet, they will rapidly exit the cavity and spread out between the entire interface of the mold halves. The effect of this is to enlarge the projected area with a cushion of gases to include the entire area of the mold (assuming a mold without raised land surfaces). If the mold were 36 inches square, its overall area would be 1296 square inches, and with a layer of gases spread evenly between both mold halves (a simplistic assumption), we would be dealing with a force of 6480 tons (5 tons per square inch X 1296 square inches = 6480 tons). Clearly we have discovered a mechanism that is capable of blowing open the clamp. It is very important to note here, however, that we have very greatly oversimplified the case, but we merely want to illustrate the concept, although we do hope to have given the hypothesis some degree of plausibility. *Figure 2* is a drawing of the mold that makes the part that is shown in *Fig. 1.* We hypothesized that in this case the gases did not spread out along the entire interface, but were trapped in the center of the part.

There are two more molding problems related to venting: plateout and oil-like deposits. Plateout is a film-like deposit of chemical solids on the cavity; it originates from the plastic It leaves a cloudy mark on plastic parts if it is not cleaned off periodically, and it is often seen on crystal polycarbonate parts. Plateout can be lessened or eliminated in many instances by much better venting.

Oil-like substances (often referred to as oils) are usually found near the vents, and often become built-up and gummy enough to plug them up. Again, with adequate venting the problem of oil deposits would have been lessened or eliminated. Oil deposits result from temperature instability (overheating).

Figure 3 shows a production mold running polypropylene that exhibited a tendency to collect oil deposits near the vent, which eventually became plugged up and had to be cleaned. Venting is by a pin in the stationary mold-half. The core is not actually cooled; the nearest cooling-water channel is at its base. Therefore, the core became quite hot when the mold was run, and allowed the melt front to stay too hot as it flowed by. This helped produce excess volatiles, including oils, to the point where the vent became plugged. There are other causes for oil buildup—most of it comes from the heat generated by the compression of gases and plastics.

The problem was a vicious circle: as the vent became more plugged with oils and its effectiveness was reduced, less gas was vented, more compression generated, more heat added to the core, which allowed the melt front to get even hotter, therefore, adding even more gases to the mold, more compression, more volatiles, more oils —and so on.

Traditional venting?

Until now the only way to allow gases to escape from a cavity was to provide a channel between the cavity and the outside of the mold. Primarily, all successful venting efforts have been variations on only two methods.

The most common of these methods is to grind a small vent channel in the land surface around the parting line (*Fig. 4*). It is thick enough for the gases to escape, but too thin for the plastic to enter and flash. Channel thickness may range from 0.00025 to 0.0015 inch, depending on the resin. Vents are placed wherever a burn is anticipated. Sometimes molds are built without vents, run to determine where burns do occur, and vented there.

The other method successfully used for the last several years is to vent the cavity by ejector pins. Small flats ground on the end of the pin provide escape routes for the gases. It is costlier and more difficult than to grind vent channels in the land surface. Sometimes ejector pins are even put in a mold for the sole purpose of venting and are not required for ejection at all.

The need to vent the runner as

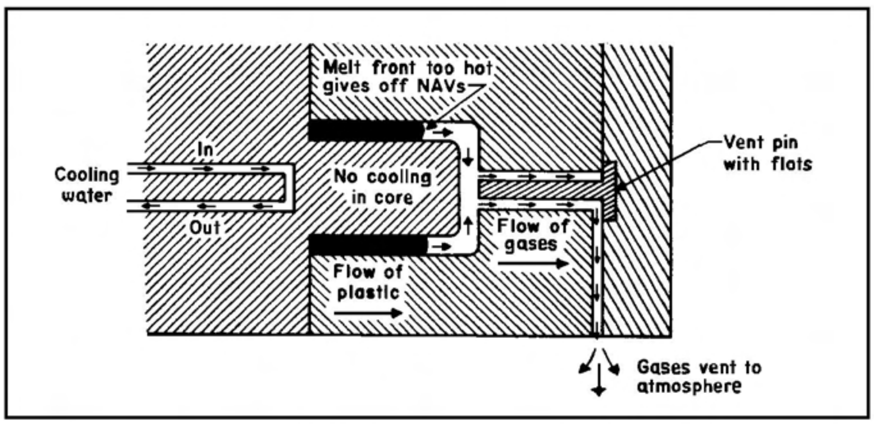

Figure 3. Small vent pin would plug up with oils given off by too many NAVs. With cooling in core, NAVs would be given off.

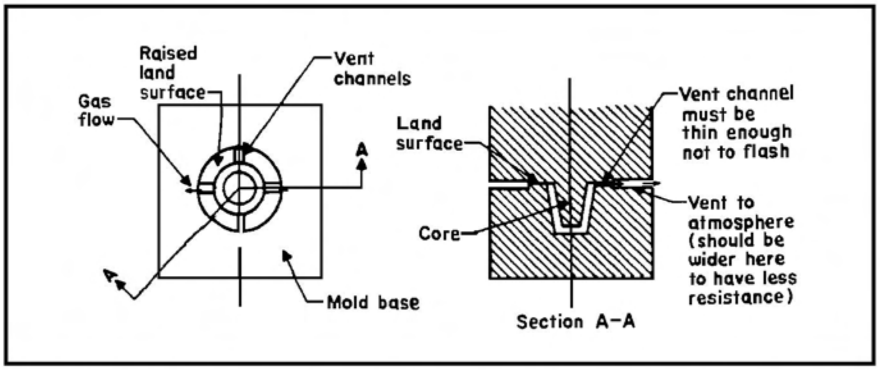

Figure 4. Conventional vent channels ground into land surface around parting line must be too thin to flash.

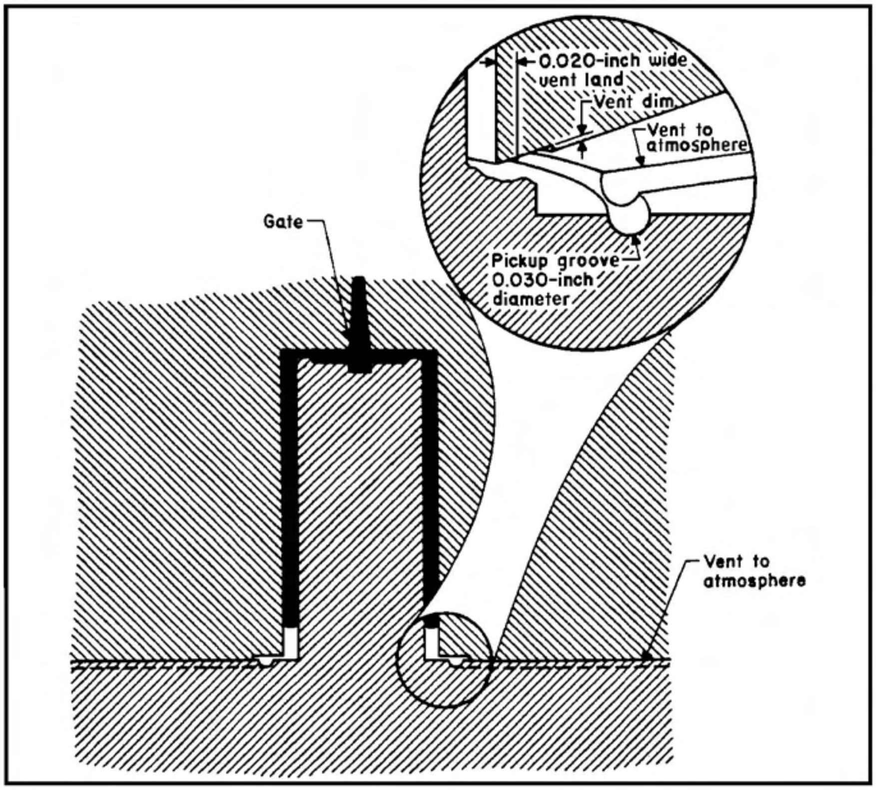

Figure 5. Venting around entire parting line increases effective venting area. Parting lines do not touch.

well as the cavity has been recognized, and will be discussed later.

Limitations of traditional venting?

Despite advances in venting, burns and shorts due to gas compression remain a problem for the molder. The two main limiting factors associated with venting channels and ejector pins are:

- Both are fixed in position: once a venting channel or an ejector pin is in a mold, it is there to stay without generally extensive retooling.
- Both provide relatively little venting area. Sometimes they do not reduce gas pressure enough to eliminate the problem entirely.

These two limitations become obvious after a new vent channel is ground in the mold, or a new vented ejector pin is placed where parts are burning, when the discovery is made that the burn has been eliminated there but occurs somewhere else!

Another limitation is that the location and size of vent channels and vented ejector pins usually must be determined by trial and error. Although we can frequently anticipate where they are needed, we are often not sure until the mold is run. This is not really a great problem, unless a vent is needed where it would be difficult or impossible to put one, using conventional methods.

Better mold venting

The way to better venting is to overcome the limitation of traditional venting techniques—small size and fixed location. One way to immensely increase the effective area of a vent is to vent around the entire parting line *(Fig. 5). The parting line of a mold should not touch anywhere.* As long as the distance between the two halves of the parting line is kept within the design parameters of the vent for the given resin, the cavity will not flash, any more than it will flash where there are conventional vent channels of the same depth. This is not exactly a revelation—it has been used before—but often molders or toolmakers do not think of exploiting it. It is true, however, that in certain cases these vents will be progressively closed off as a cavity fills, as for example, the peripherally vented mold for an edge-gated rectangular part shown in *Fig. 6*. But there are several important points to observe: First, if the cavity were vented using several small conventional vent channels *(Fig. 7)*, they, too, would in turn be closed off. Thus, mold designers generally would not use most of the vents shown in *Fig. 7*, but only those shown in *Fig. 8*. But to see how much better it would be to use all of the vents as shown in *Fig. 7*, or better yet, vent the entire perimeter of the cavity as shown in *Fig. 6*, let us digress briefly and follow the stages of filling such a cavity.

At the start of mold fill, the entire vent area is open, which is good, for there are several reasons why maximum venting is needed during the earlier stages of mold filling. Here they are:

1. The melt front is at its hottest. As it moves along inside the cavity it will get cooler and cooler. The higher the temperature of the melt, the larger the volume of NAVs that will be given off, therefore tending to maximize the amount of gas that has to be vented.
2. The internal cavity pressure is at its lowest and the disequilibrium between the melt's semi-pressurized state in the barrel and the relatively low pressure of the unfilled cavity is at its greatest, again tending to allow the greatest volume of previously dissolved NAVs to become gaseous, thus further increasing the amount of gases that needs to be vented.
3. This is also the time when the maximum amount of air is in the cavity—before any of it is displaced by the melt.

These three conditions add up to the fact that it is in the early stages of filling that maximum volume of air and NAVs is to be vented. Now combine this with condition 4:

4. The fill rate of the mold is maximum during the early stages, and decreases as it gets closer to being full.

Therefore, in the early stages of the mold filling, the *volume* of gases to vent is maximum and the rate at which the gases should be vented must also be maximum. Thus, we need all the venting we can get—and with peripheral venting we have it.

But what if we had only used the more conventional vents as in *Fig. 8*? Would these limited-area vents allow enough gas to escape in time? Probably not. There would still be a compression buildup as the filling of the mold neared completion, perhaps enough to cause a burn.

Would peripheral venting allow enough gas to escape in time to avoid a compression great enough to cause a burn? Probably. But not definitely. But it is one more factor in our favor and we need all the help we can get. Even if it does not eliminate the problem entirely, it will at least give us more leeway in running the mold.

There is another reason why a maximum venting area is important in the early stages of mold fill. The volume of gases that must be quickly removed is largest then; and since the gases are not yet at a very high pressure (for they have not yet been compressed very much), they can nonetheless be evacuated if the vent is sufficiently large—as with peripheral venting. Moreover, with peripheral venting, the degree of compression at the end of mold fill will be much less.

The key point to be made is this: to reduce the amount of compression of gases at the end of mold fill, reduce the volume of gases in the early stages of mold fill. In other words, do not concern yourself solely with putting in small vents wherever burns occur in an attempt to let out gases that are already highly compressed, but put vents all over, to reduce that compression as it starts, by venting the maximum amount of gases from the beginning to the end of mold fill. What better way is there to do this than by venting the entire parting line?

Furthermore, by using peripheral venting there is always some place open for the gases to escape right up until the entire outside edge of a cavity is filled. In short, we have guaranteed the maximum amount of venting time. If we had only used small channel vents, even if we had put them where we expected the mold to fill last, they might be off just a little, they might just close off before the entire mold is filled. With peripheral venting that cannot happen.

Peripheral venting also provides a good solution to the unique problem associated with very thin-walled parts: since the difference between the thickness of a part wall and the thickness of the vents may be nearly nonexistent, it becomes difficult not to flash the vents, because the pressure needed to fill the part is so close to the pressure that would be needed to flash the vents. By venting the entire perimeter of a part, the total venting area can be kept the same as it was with conventional vents, or even increased, while at the same time decreasing the thickness of the vents, and therefore making it easier not to flash the mold, because now a much greater pressure would be needed to flash the vents than is required to fill the cavity.

There is one more way to minimize the volume of gases that must be vented from the mold cavity and that is to vent the runner. If the runner is not vented properly, all the air originally in the empty runner system (plus a lot of NAVs, because the plastic is quite hot at this point) will be added to the cavities. The amount can be significant and becomes a relatively greater problem when the ratio of the volume of the runner to the volume of the part increases. Failure to vent, therefore, will result in a large volume of air and already hot NAVs being pushed ahead of the melt front, compressed at the gates, further increasing their temperature and, therefore, their pressure and/or volume. (This is a situation that is similar to the compression buildup in front of inadequate vents.) Finally, these superheated gases enter the cavity, adding more pressure and heat to the air that is already there, and are quickly followed by hot melt and more hot gases.

We contend that plateout near the gate is the result of this first great influx of hot gases, and that they contain the volatiles that will eventually become the film deposit on the cavity. Whether the return of the volatiles to the solid state is chemical or merely a physical change caused by contact with the relatively cool mold is not

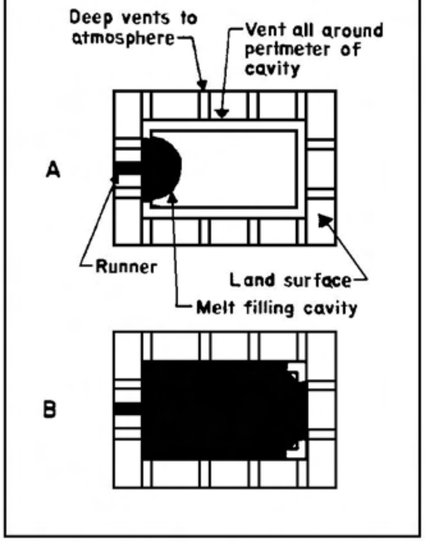

Figure 6. Filling edge-gated rectangular part with peripheral venting. A. Mold starting to fill. B. Mold almost full. Hatched area shows of vents blocked off as melt advances.

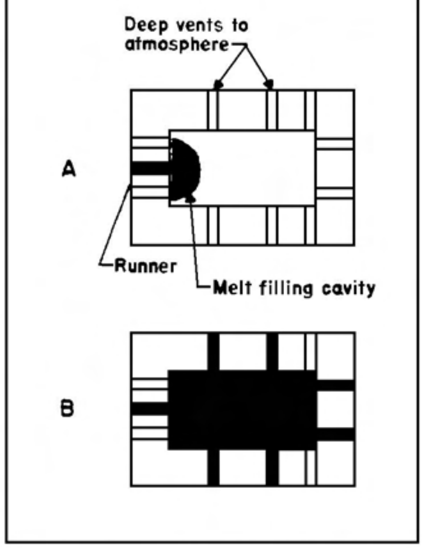

Figure 7. Filling edge-gated rectangular part with only conventional vents. A. Mold starting to fill. B. Mold almost full. Hatched areas show vents blocked as melt front advances.

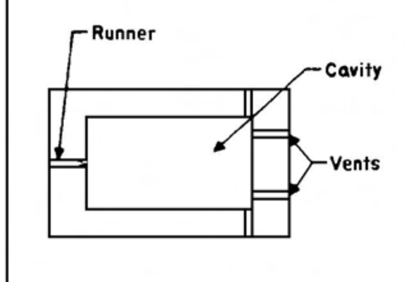

Figure 8. Typical venting: vents are placed only at far end of cavity.

certain. We hypothesize that venting these gases before they have a chance to condense on the mold will reduce plateout problems. Empirical evidence bears this out.

It would be much better to vent the runner system and allow as much of these gases as possible to escape rather than add them to the cavity. Some mold designers do vent the runner, but usually in the same limited way that they vent the cavity—with small vent channels *(Fig. 9)*. Why not vent the entire perimeter of a runner as in *Fig. 10*, or at least more than just the very ends?

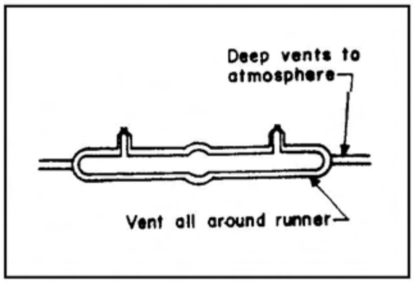

Figure 9. Runners are vented through small vent channels.

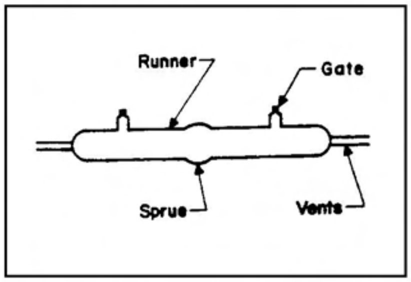

Figure 10. Entire perimeter of runner is vented.

Vent to the water line

Now that we have explored conventional mold venting methods we will investigate some of the immense potential that is opened up by the ability to vent molding gases into the water line.[a] This is made possible for the first time by the Logic Seal[b], which draws cooling water through the mold with a negative-pressure pump, therefore preventing leakage into the cavity even where the water-cooling channels are open to the cavity. Now, we can vent molds into the water line by four methods:

- Through porous metal.
- Through flats on ejector pins.
- Parting-line venting.
- Directly into the water line through tiny holes.

Each method will be discussed in some detail, along with its unique advantages. But it should first be pointed out that all of the same principles that apply to venting into the atmosphere also apply to venting into the water line. Remember that we should strive for as large a venting area as possible (of most importance in the early stages of mold fill), for as little resistance as possible (in the way of distance traveled by the gases in restricted channels), and for keeping the channels open for as long as possible. The advantage of venting into the water line is that it often allows us to do these things much better than if we had to vent the atmosphere.

Venting through porous metal: Venting through porous metal, such as pressed metal, has been attempted in the past, without much success. The trouble was that, being porous, it has very poor heat-transfer ability. It would, therefore, quickly overheat and become impregnated with melt or plugged by deposits of oil-like substances. Now, however, the back of the pressed-metal vent can be washed directly by the cooling water, which will not leak into the cavity because it is being *drawn* through by the Logic Seal rather than *pushed* through by a pressure pump.

Figure 11 shows a drawing of the test mold for a part made to demonstrate the feasibility of venting into the cooling water. It resembles a slightly oversized lipstick case. The mold is gated at the open end, on the parting line, and the flow of plastic would push all the gases up to the top, where they would become entrapped. We would expect to see bad burns there if this were a conventional mold. Such a mold would be almost impossible to vent using conventional methods, except perhaps by a pin on the stationary half of the mold. However, this would leave a mark on the top of the part.

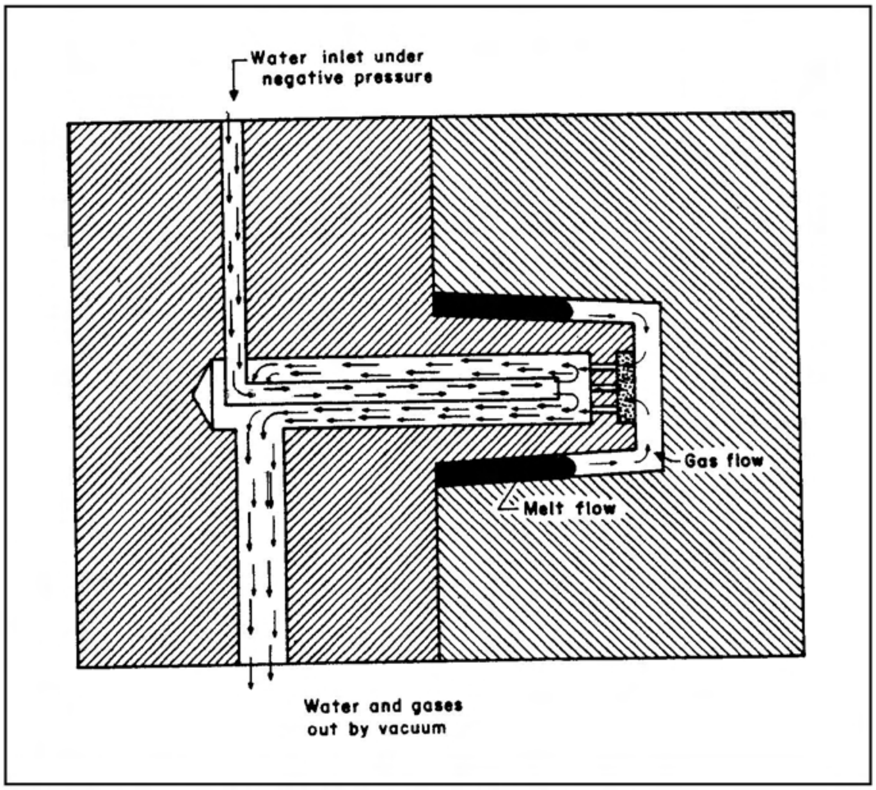

Figure 11. Test mold, with core venting into cooling water.

At the tip of the core of this mold, however, is a porous, pressed-metal disk. (In its first application the disk was 0.045 inch thick, but this has since been reduced to 0.030 inch.) The disk forms the inside of the top of the plastic part. Just under it is a metal backup plate with several 0.060-inch holes drilled in it (which have now been reduced to 0.20 inch).

The backup plate supports the pressed metal against injection pressure. (Our first test mold configuration withstood an injection pressure of 15,000 psi with no problem; this was enough pressure to fill the 1-ounce part in 0.4 second. The pressed metal disk did compress to a slight degree, but part quality or its ability to vent gases was unaffected.) Behind this disk is cooling water, brought near the tip by a long bub-

[a] Water-line venting is protected by Patent No. 4,091,069 and covers any method of venting into the water line, including all methods described herein.

[b] Logic Seal (patent pending) is a trademark of Logic Devices, Inc.

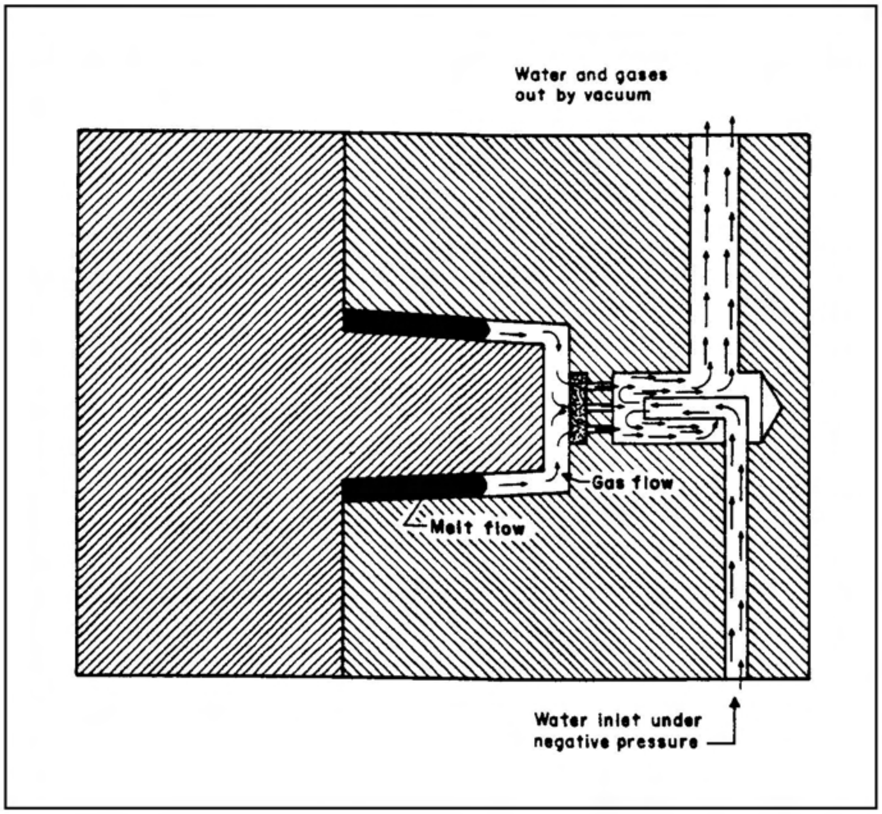

Figure 12. Test mold with cavity venting into cooling water.

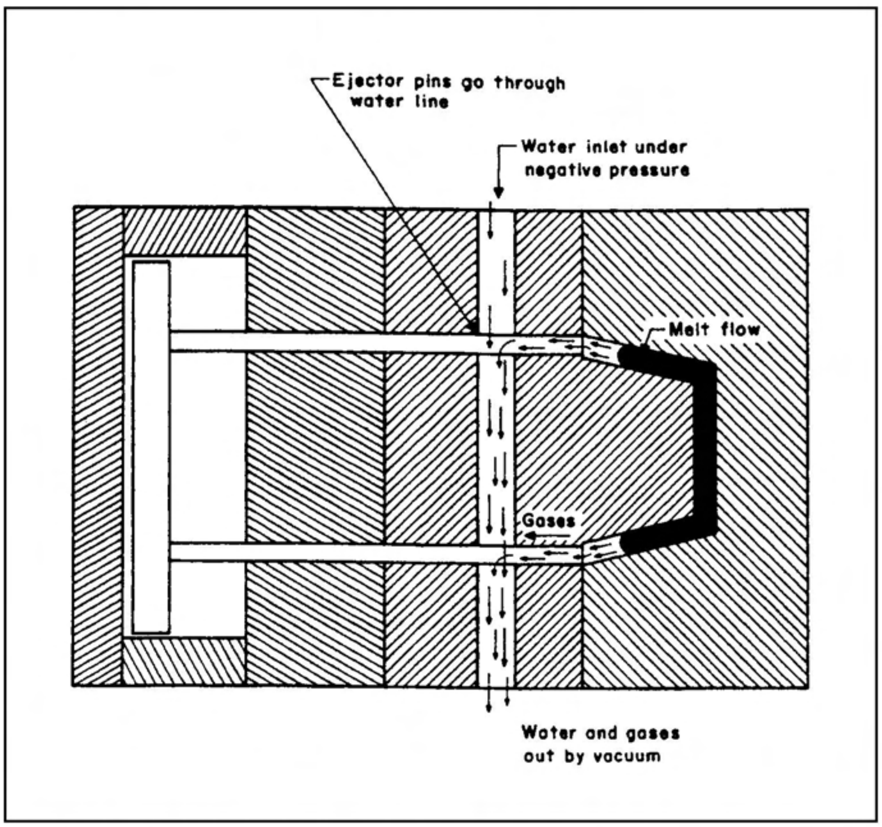

Figure 13. Test mold vented into water line through ejector pins.

bler. As the gases are pushed ahead of the plastic melt front, and up to the tip of the core, they pass through the pressed metal (its porosity of 10 micrometers does not permit the melt to enter it when it is kept cool) into the holes in the metal backup plate, and then into the cooling water.

The advantages of venting in this manner are:

- The venting area can be made quite large, therefore permitting a large volume of gases to be easily vented.
- Molds can be vented in places they never could before. New design possibilities are opened up to build more efficient and less expensive molds.
- New part designs are also made possible, since molds can be gated and vented in ways that were not possible before water-line venting.

Figure 12 is a drawing of the test mold for another part; this time, however, the venting was reversed. A new core was built without a pressed-metal vent at the bottom of it, and a new cavity was made with such a vent at the bottom of it. The venting seems to have been unaffected by the new configurations but the top of the part now, of course, reflects the coarse texture of the pressed metal.

Still another part was made with the vent also in the cavity, but this time a fine mesh screen material[c] was used instead of the pressed metal. The screen did not vent quite as well as the pressed metal, and, of course, its texture is much more coarse. Also, since its porosity is greater, we were able to plug it with melt at 18,000 psi injection pressure, even with cooling water flowing behind it, whereas we were unable to plug the pressed metal with a full 20,000 psi. In some applications its texture may not be a drawback, and it is not inconceivable that it might even become an asset. The advantage it holds over pressed metal is that should the coolant flow be inadventently interrupted, allowing the vent to overheat and, therefore, become plugged with melt, it can be cleaned with a torch, whereas the pressed metal cannot be heated without being ruined. The pressed metal, of course, can be cleaned with chemical solvents, but not all plastics can be dissolved this way.

Possible drawback

A word of caution is in order, however. When venting PVC into the water line, there is a remote possibility that hydrogen chloride gas will be given off, despite the inclusion of additives designed to prevent the occurrence. If this were to happen, hy-

[c] Dynapore, made by Michigan Dynamics.

drochloric acid would form in the water supply, and be very destructive to the cooling system. There is, however, one production mold that is running PVC and using such cooling-water venting, and no problem has yet been encountered.

Nevertheless, it would be prudent to check with materials suppliers about the possibility of volatile gases being given off, and their possible reactions with the chemicals commonly found in cooling systems (alcohol, etc), before designing a mold to use cooling-water venting. Also, if there is any question, the chemical content of the water should be checked periodically.

Venting into the water through ejector pins: With the Logic Seal providing subatmospheric pressure to the cooling water, ejector pins can be put through the cooling-water channels without danger of leaking. *Figure 13* shows a mold that is vented through flats on ejector pins. Instead of going to the atmosphere, however, the gases find their way into the water line, thereby shortening their journey. The advantages of this method are:

- The mold designer has more flexibility in the placement of ejector pins and cooling-water channels.
- With the ejector pins running through cooling water, they will not overheat and the likelihood of their becoming plugged with flash or oils is greatly diminished.
- Toolmakers, already familiar with venting through ejector pins to the atmosphere, may feel more comfortable venting into the water line this way than, say, through pressed metal.

Venting into the water line at the parting line: Two applications of venting into the water channel at the parting line offer unique advantages over venting to the atmosphere. The first *(Fig. 14)* combines venting into the water line and the Water Transfer System (patent pending), the latter designed for better cooling of the tips of long cores. While the mold is run, gases are pushed ahead of the melt front between the core and the cavity

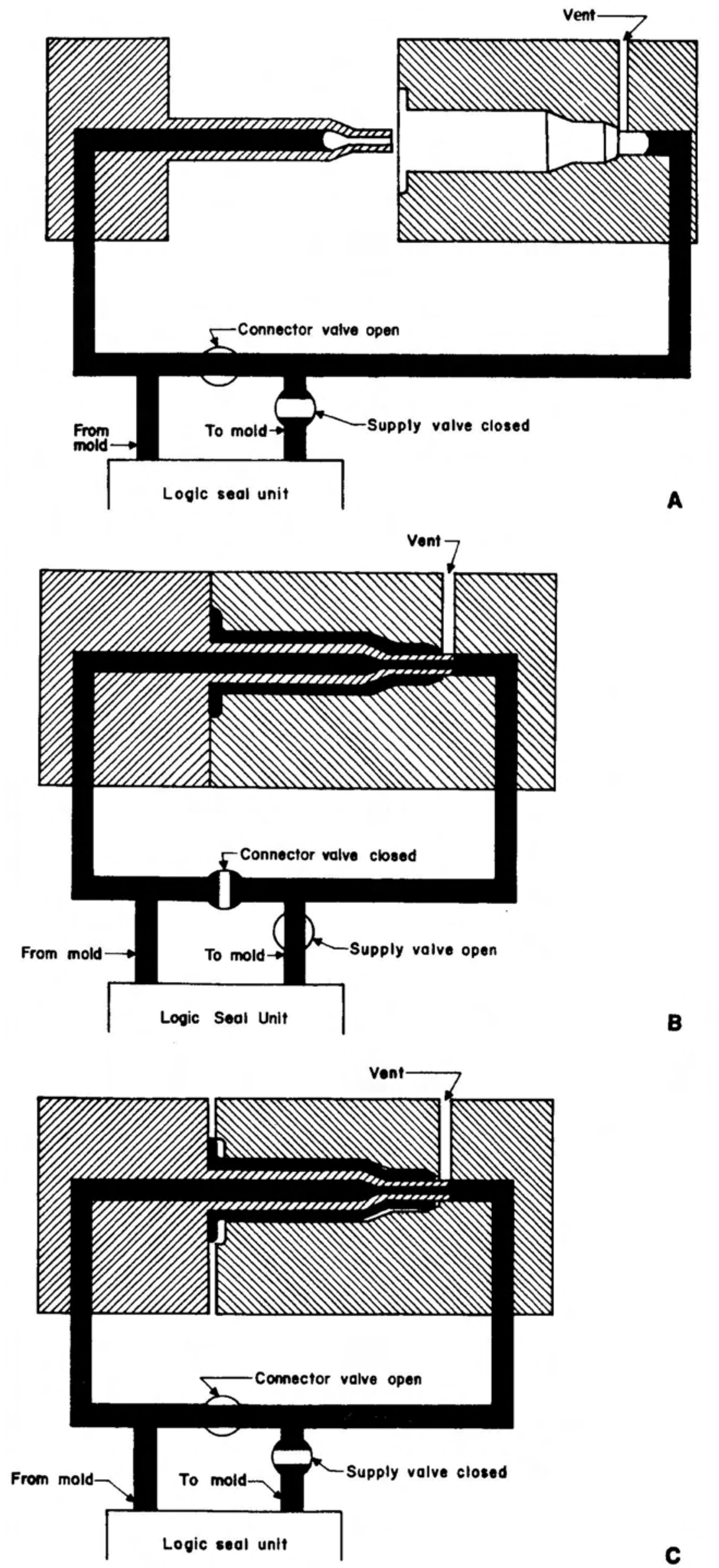

Figure 14. Mold combines parting-line venting with Water Transfer System. A. When mold is open, supply valve is closed. Return line is open in both directions. Logic Seal drains and sucks air. B. When mold is closed, supply valve is open, connector valve between supply and return is closed, allowing normal water flow through circuit. Molding gases are vented into the water line through the clearance between the core and cavity. C. Just before mold opens, connector valve is closed and supply valve is closed again, as Logic Seal drains the lines.

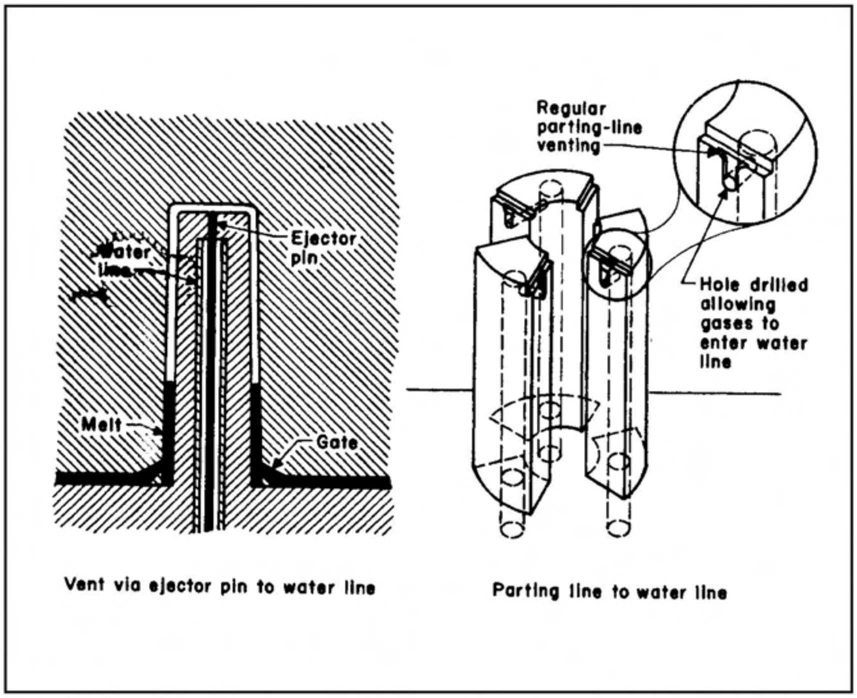

Figure 15. Core for a thread spool. Mold is edge gated and trapped gases are vented through small holes drilled at the parting line into the water line.

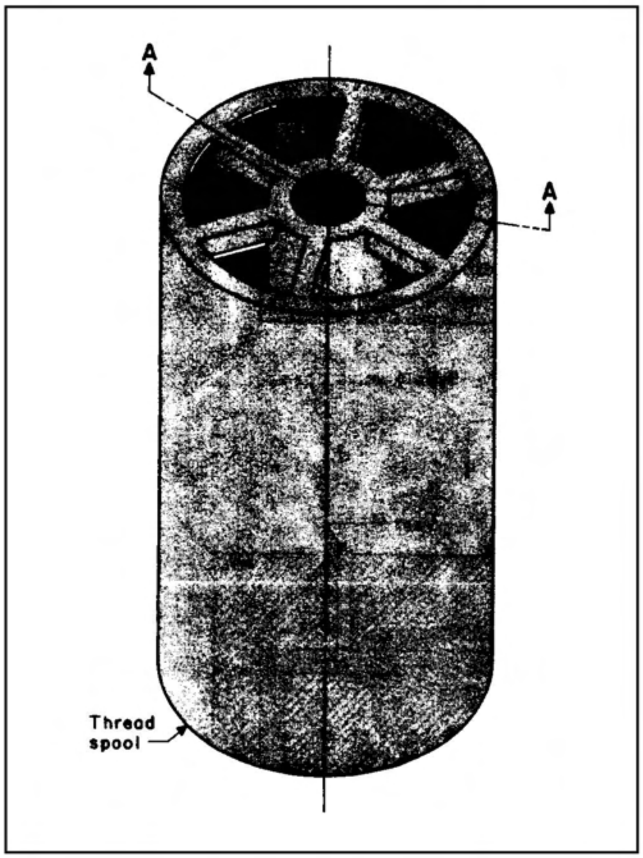

Figure 16. Thread spool.

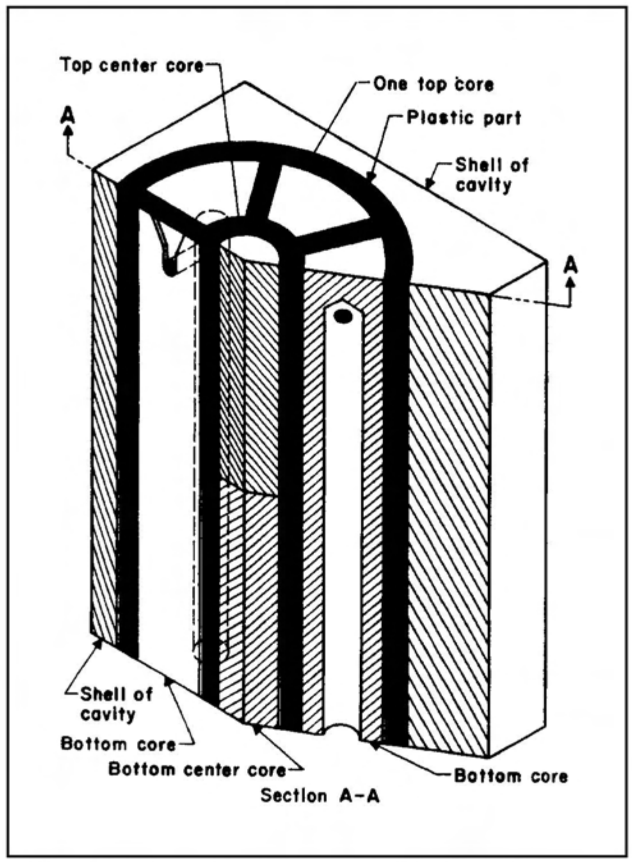

Figure 17. Cross section of cores and thread spool.

to the tip of the core. There is a slight clearance between the core and cavity that allows the gases to travel into the water line. (The vent that is shown is not for venting gases, but is designed to allow air to enter the water line as the mold opens to enable the line to be drained correctly.)

The advantage of venting this way over the more conventional way is that conventional vents would require a separate steel plate for the vents to run through, and they would also tend to plug up and need periodical cleaning. To vent into the water line does not require an additional steel plate, and the movement of the core relative to the cavity would tend to keep the vent open.

A second method

Figure 15 demonstrates the second method of venting at the parting line that would be impossible to do if it were not feasible to vent into the water channel. This shows one of the two cores that mold the thread spool shown in *Fig. 16.* The two cores mesh together, making it impossible to vent into the atmosphere. (See the cross-sectional view in *Fig. 17.*) But by providing small vent channels between the cores that lead to small holes drilled into the water line, the gases now have a way to escape.

Venting directly into the water line: Using the Logic Seal, it is possible to drill tiny holes directly through the cavity into the cooling-water channels without danger of water leaking into the cavity. This method could be used to vent a mold by tapering the holes so that the material that jets into the water line will break off upon ejection, to be trapped later by a screen. This method has not yet been tried in practice, however. □