SUMMARY
Gating techniques for high density, vertically parted green sand molds have been shown to require no different knowledge of gating principles than required for horizontally parted molds. Basic fundamentals of sprue design, flow characteristics of the metal, and venting requirements were briefly reviewed and related to some of the practical aspects of casting production.

The necessity of obtaining adequate feed metal transfer from risers was also discussed and related to typical mold configurations.
INTRODUCTION

If metals were perfectly inert chemically, if they absorbed no gases, if they exhibited no shrinkage on cooling, if they were not erosive to the mold, and if they all exhibited the same thermal properties and surface effects, one would not have to consider the subject of gating design and the manufacture of a casting would be greatly simplified. Unfortunately, these conditions are not found in commercial alloys. As a result gating systems must be designed to accomplish the following objectives:

1. Fill the mold rapidly, without developing cold shut or requiring excessively high pouring temperatures.

2. Reduce or prevent agitation or turbulence and the formation of dross in the mold.

3. Prevent slag, scum, dross, and eroded sand from entering the casting via the gating system.

4. Prevent aspiration of air or mold gases into the metal stream.

5. Avoid erosion of molds and cores.

6. Aid in obtaining suitable thermal gradients to assist directional solidification and minimize casting distortion.

7. Obtain maximum, or an adequate, casting yield.

Since it is readily evident that not all of these requirements are composable, it will be necessary to enter into intelligent compromises to achieve the desired goal. The factors influencing gating design may then represent several considerations. First, the theoretical conditions governing the flow of metals must be evaluated to minimize aspiration of gases and to control metal flow. Various material characteristics must be considered, particularly with respect to their response to flow variations (e.g., materials which oxidize readily and form slag and/or dross). Economic considerations always are significant and generally involve items such as the space available within the mold cavity and the yield requirements or desires. Finally, various engineering factors must be properly accounted for. These include certain specific details peculiar to a given casting—the casting geometry and its location in the mold, the presence of cores, the need for risers, the required cleanliness of castings, etc.

It will not be possible, nor should it be necessary, to consider all of these factors at this time. On the other hand, it may be of interest to review certain considerations which should be realized when designing gating systems for vertical parting line molds.

Fundamental Principles

Metal flow in a gating system may be considered on the basis of elementary hydraulic principles since many of the problems indicated previously are problems in fluid flow and the laws governing fluids can be studied profitably to improve any design.

While most textbooks refer to the control of metal flow to avoid turbulent flow and to maintain streamline laminar flow, it must be noted that most cases the pouring of commercial alloys results in turbulent flow. The boundary between laminar and turbulent flow is indicated by a Reynolds number (R) of 2000-3500.

$$R = \frac{\nu D \rho}{\nu}$$

where,

- $v$ = mean velocity of fluid
- $D$ = diameter of pipe through which fluid flows
- $\rho$ = density of fluid
- $\nu$ = kinematic viscosity of fluid

Because of the high density of metals, particularly the iron and copper base alloys, fluid flow is nearly always turbulent, unless the flow velocity is extremely slow. In that case most metals would solidify prior to the completion of pouring.

Ignoring factors relating to turbulence and frictional losses, the design of a gating system is controlled by Bernoulli's equation (1) and the law of continuity (2), Fig. 1.

$$h + \frac{p}{\rho} + \frac{v^2}{2g} = \text{konst.} \quad (1)$$

$$Q = v_1 A_1 = v_2 A_2 \quad (2)$$
Figure 2

where:

\[ h = \text{potential head, or height above a given reference plane} \]
\[ p = \text{pressure} \]
\[ \rho = \text{density} \]
\[ v = \text{velocity of metal flow (} v_1 \text{ and } v_2 \text{ refer to the velocities at certain points)} \]
\[ g = \text{acceleration due to gravity} \]
\[ Q = \text{volume flow rate of metal} \]
\[ A = \text{area of the point of velocity measurement} \]

Sprue Design

These relationships can now be used to discuss the design of the sprue. Consider for example an impermeable mold, one which will not permit any gases to be drawn into it or the passage of any gas or liquid through its surface, Fig. 1. The metal being poured into this sprue and pouring cup is maintained at the level 1 and is exposed to atmospheric pressure at levels 1 and 3. In this case:

\[ h_1 + \frac{p_1 + \frac{v_1^2}{2g}}{\rho} = h_3 + \frac{p_3 + \frac{v_3^2}{2g}}{\rho} \]

since,

\[ \frac{p_1}{\rho} = v_1 \]
\[ \frac{p_3}{\rho} = v_3 \]

and,

\[ h_3 = 0 \]
\[ h_1 = \frac{v_3^2}{2g} \]

or,

\[ v_3 = \sqrt{2gh_1} \]  
(3)

In other words, the velocity of the metal flow at level 3 is a function of the total pressure head, \( h_1 \), in this impermeable mold.

But, applying Equation 2:

\[ Q = v_1 A_1 = v_2 A_2 \]

since the volume flow rate must be the same at level 1 and level 2, and because the cross sectional areas are constant,

\[ v_1 = v_2 \]

then, from Equation 1:

\[ h_2 + \frac{p_2}{\rho} = h_3 + \frac{p_2}{\rho} \]

\[ p_2 = p_3 - h_2 \rho \]  
(4)

The pressure on the liquid level 2 is less than that at level 3 (or level 1) meaning that aspiration of gases will tend to occur if the mold permits it. If the shape of a freely falling stream of metal is considered, Fig. 2, the stream will be exposed to atmospheric pressure along its entire length. From Equation 3:

\[ v_2 = \sqrt{2gh_{c2}} \]

and from Equation 2:

\[ A_2 v_2 = A_1 v_3 \]

or:

\[ \frac{A_2}{A_1} = \sqrt{\frac{h_1}{h_2}} \]  
(5)

which describes the ratio of the areas of a metal stream flowing from the sprue cup. The result is a sprue having a
taper determined by the height of the pouring cup and the total height of the sprue and cup. Since this relationship does not indicate a simple sprue shape, $A_2$ and $A_3$ may be connected by straight lines. If $A_3$ is slightly smaller than the relationship of Equation 5, metal flow rates will be controlled at the sprue base, and will cause the sprue to be filled readily. The increased area of the sprue between $A_2$ and $A_3$ will result in a slower metal velocity, and decreased turbulence. Non-tapered sprues, or sprues with insufficient taper, must also be considered, however. The flow rate in the system is controlled by the area of the sprue at the top of the sprue, however, the use of a choke of an area equal to $A_3$ will cause the flow rate to be determined by the choke area and will then result in a filling of the sprue with similar results to that of a tapered sprue. To insure this condition early in the pouring process, it is desired that the choke be placed as near the sprue as possible.

**Pressure Head Effects**

A very important factor in vertical parting line molds is the effect of the pressure head in pouring and its relationship to the height of the metal in the mold cavity. As the metal rises in the mold cavity, the pressure at the base of the sprue increases thus decreasing the flow velocity of the metal:

$$v_a = \sqrt{\frac{2g}{\rho} \left[ h_1 + \frac{p_1 - p_2}{\rho} \right]}$$

and therefore the flow rate decreases as the mold cavity is filled.

**Pouring Basin**

The design of the pouring basin has also been considered in detail in the literature. Basically, the pouring basin should permit the entry of metal from a ladle at a rate sufficient to fill the gating system. The pouring basin should also be designed so that a minimum amount of aspiration occurs in flow through the basin.

**Sprue Basin**

Since the base of the sprue represents the highest velocities of flow, the mold is subject to erosion at this point. A basin, or enlargement, at the base of the sprue is necessary to prevent erosion of metal at the sprue base. The basin then results in metal flowing on metal reducing the erosion tendency by absorbing the impact and kinetic energy of the falling stream. In addition, the enlargement of this area reduces the metal flow velocity resulting in decreased turbulence in the metal stream.

After considerable testing of sprue basin designs, it was determined that the extension of the sprue beneath the runner should be greater than the runner depth, and that the horizontal cross-sectional area of the well should be more than five times the sprue area at the base.

**AFS Research Results**

As a result of several years of research regarding vertical gating systems sponsored by the American Foundrymen's Society, a gating system capable of filling a plate shaped casting with minimum turbulence was developed, Fig. 3. This system employs:

1. Tapered sprue, to minimize aspiration and turbulent flow.
2. Enlarged sprue base, to effect reduced erosion of the mold and to decrease metal velocity.
3. Runner extension, to provide a reservoir for the first metal entering the gating system which "cleans" the system.
4. Bottom gate, to obtain low turbulence in the metal as the mold cavity is filled.
5. Up sprue, to provide a device whereby the metal can flow upward uniformly.
6. A web gate, to enable the smooth, uninterrupted flow of metal to the casting.
7. A riser incorporated in the up sprue.
From a practical point of view, however, the design suggested could be applied to only a limited number of casting geometries. Furthermore, the amount of metal involved in the system and the space it occupies may be excessive for most applications.

Practical Aspects of Vertical Gating Systems Design
As mentioned earlier, certain modifications of gating system design theory are advisable depending upon the specific details of a given casting or set of castings within a mold. Several of these more important aspects, as they relate particularly to vertical gating systems will be discussed here.

Pouring Rate
The specific rate at which a mold should be poured is a function of the pouring rate obtainable from the ladle or pouring device, the characteristics of the metal, and the arrangement of the cavities within the mold. In general, it is desirable to fill the mold cavity as rapidly as possible considering the turbulence which may be created in filling the cavity, the stresses imposed on the mold, and the effect of the metal on the mold itself. For example, if conditions result in hot metal at the pouring spout, a rapid fill rate will not permit the metal to cool prior to its entry into the mold cavity resulting in possible metal penetration, etc. As a rule, however, many molds could be filled more rapidly than they are.

The filling rate of the mold is determined by the choke area in the gating system. As a first approximation 100 lb. (45.4 kg) of cast iron will flow through an area of one sq. in. (6.45 cm²) in 6.3 seconds (or, 10 kg of cast iron will flow through an area of 1 cm² in 7 seconds). This figure will vary with the pressure head of the system, frictional forces involved, fluidity and flow characteristics of the iron, etc.

The choke area selected must be such that the flow rate is less than that capable of delivery to the system if the system is to be filled and the flow of metal controlled. It should also be noted that placement of the choke at the base of the spout or near the spout base, will enable the system to be rapidly filled up to the choke thus gaining control of metal flow early during the pouring operation. When the spout is not maintained full of metal, the control of metal flow into the mold cavity is generally lost.

Sprue Design
Since a properly tapered sprue often results in a sprue of excessive area in a deep vertical mold, it is thought that a straight sprue of smaller area will suffice if a choke is placed at or near the sprue base. However, it must be recalled that the choke at or near the sprue base is only effective in controlling the metal rate when the area at the top of the spout is at least equal to the value expressed in Equation 5. Use of a smaller area will then negate the rate control effect of the choke and the top of the sprue will control the flow rate.

A pouring basin at the top of the spout is of considerable value since it provides a method whereby the rate of flow can be controlled. When metal is poured directly down the sprue, the pressure of the metal in the spout is increased by the metal issuing from the pouring ladle. Furthermore, lack of an adequate pouring basin does not permit the pourer to react rapidly to varying flow conditions experienced in the filling of the mold. The pouring basin should be large enough for the operator to pour as rapidly as the system will permit, yet permit the operator to adjust the flow rate from the ladle during the pour.

Runner Design
Perhaps the greatest compromise of theory with practical acceptability enters into the design and location of runners in a gating system. In most cases, runner location is determined by the space remaining in a mold after the patterns have been positioned. To use the runners to fully permit slag or dross to be separated from the metal during flow requires excessively large and long runner systems. As a result, each runner system must be designed for the specific casting to deliver clean metal to the mold with a minimum of turbulent flow. The usual manner of expressing runner dimensions is in terms of the gating ratio S.R.G.; or the ratio of the total cross-sectional areas of the sprue, runners and gates. Several systems of gating, employing different gating ratios, have been suggested for different metals. Basically, these systems are of two types -- pressurized and non-pressurized -- and differ principally in the location of the choke within the system.

In pressurized systems the choke is located at, or near, the casting ingate. The purpose of this system is to cause the metal to back up in the gating system (sprue and runners) and permit slag, dross, dirt, etc. to be separated from the metal.
stream prior to entry of the metal into the casting. However, since most gating systems do not allow sufficient runner length or area for the metal flow to slow down and permit the non-metallic to separate, the system usually is only partially successful. Furthermore, these systems impose high flow velocities at the ingate resulting in possible turbulence within the mold cavity, and erosion of the mold cavity where the metal stream impinges. Typical systems of this type include the 4:4:4 and the 100 reduction systems. In the latter case the gate areas control metal flow and each previous section of the gating system is increased in area by 10%.

Truly non-pressurized systems contain the choke at, or near, the sprue. Gating system research has shown the most satisfactory ratio of sprue area to runner area to gate area to be 1:4:4.

Frictional losses in the system cause the runners to be pressurized, in a sense, with respect to the gates.

It is significant to note that in this system, metal flow control is obtained when the sprue is filled. On the other hand, the pressurized system is not in control of metal flow until the entire gating system is filled. In many cases, about 25 to 30% of the casting is filled by this time.

A compromise system which has worked very well in many vertical gating system employs the choke, at, or near, the base of the sprue with runner cross-sectional areas two to four times the choke area. This permits primary control of metal flow at the sprue, and reduced velocity of metal flow in the runner. By establishing the gate area equal to the choke area, there is a tendency to fill the runners to permit slag and dirt separation. To permit ready removal of the casting from the gating system the gates may be flared and reduced in thickness at the casting. The literature discusses in detail these factors which must be considered to obtain uniform flow through runners and gates.

Runner location is also a compromise since bottom gating in a vertical parting line mold provides quiescent entry of metal into the mold cavity, but also places the hottest metal at the bottom of the casting, where the mold has already been heated by the metal passing through it. Usually, this results in thermal gradients in opposition to those desired for proper directional solidification. On the other hand, entry of metal into the top of the mold results in turbulence during metal flow, particularly if the mold cavity is not filled rapidly.

Venting
Perhaps the least understood aspect of gating involves the use of vents to relieve the pressure of gases generated by the contact of hot metal with the mold or cores during the filling of the mold. This is particularly significant in high pressure molding operations where the mold is of sufficient density to virtually negate its ability to permit gases to pass through the mold.

As the mold is filled with metal, the heat wave preceding the metal, and the heat penetrating the surface of the mold and core, causes gases to be driven from the mold and core. In general, these gases are generated at low temperatures and, because of their substantial volume, are not the mold cavity since this offers the least immediate resistance to their flow. The gas pressures within the mold cavity are therefore increased and must be offset by the entering metal. It therefore becomes more difficult to fill the mold cavity, particularly during the last stages of filling, where the gas pressures may be quite substantial. Because of the low permeability of the mold, the gases, must, for the most part, be forced back into the core.

Venting of the cores allows some of these gases to be released through the vents, however, the mold cavity also appears as a vent to the generated gases. Most of the gases seen issuing from core vents are released after the casting has been poured and are of little or no concern to the filling of the mold cavity. Only when these gases are allowed to develop substantial pressures will they enter the metal after the mold cavity is filled.

On the other hand, the mold itself may be vented to permit the ready escape of gas. It should be recalled, though, that when these vents are filled with metal they are no longer effective as mold vents. Usually these vents are placed at the upper most parts of the mold cavity where they also serve to indicate when the mold cavity has been filled with metal. If a substantial amount of gas is released during the filling of the mold, such as when a core is surrounded by metal, precautions must be taken against erosion of the core or mold at the
vent by the escaping gases, and against distortion of the mold cavity due to the pressures involved.

The generation of gases within the mold cavity can develop back pressures which control the rate of filling of the mold and negate the effect of the choke. This fact, coupled with the decreased flow rate experienced during the latter stages of filling a mold, necessitates that the sprue be maintained full at all times to effect the greatest possible pressure on the metal during the last stages of pouring.

This is particularly significant where a vertical parting line is present since the volume flow rate varies widely with changes in the hydraulic head, and the hydraulic head is usually quite small near the end of the pour. Incomplete filling of the mold, surging of metal flow making it appear the mold cavity is filled and entrapped gas pockets in the mold cavity may result if these precautions are not considered.

Unfortunately, there do not appear to be any specific rules to apply to the design of mold vents. This is probably due to the fact that the requirements for vents depend on the individual casting as well as the gating system used.

Risers in Vertically Parted Green Sand Molds

The purpose of a riser is to provide feed metal to a casting, and to do this, a riser must contain liquid metal in it until the casting, or casting section to which the riser is attached, is completely solidified. To enable the riser to solidify after the casting it is common practice to gate into the riser thus heating the riser by the metal passing through it and into the casting, and thereby establishing initial thermal gradients such that the metal in the riser will be hotter than the metal in the casting. It is not always possible, however, to gate into a riser. In that case, metal flows into the riser from the casting and is thus colder than the metal in the casting. To insure that the riser will solidify after the casting then requires the use of effectively larger size risers.

Another fact governing riser design is that the transfer of feed metal from a riser (particularly where the riser diameter exceeds 2 in. (5 cm.)) is accompanied by the formation of a pipe within the riser. This pipe permits atmospheric pressure to act on the liquid metal forcing it into the section to be fed. It is necessary, however, to recognize that the liquid metal in the casting acts much like a manometer. Therefore, the riser must be designed to be fed if the riser feed metal is to be transferred to the casting.

Another consideration is the transfer of feed metal from a riser to a casting is accompanied by the formation of a pipe in the riser, particularly where the riser diameter exceeds 2 in. (5 cm.). This pipe permits atmospheric pressure to act on the liquid metal in the riser, since the liquid metal in the casting acts much like a manometer. Accordingly, the riser should be positioned above the section of the casting being fed if the riser feed metal is to be transferred to the casting.

In vertically parted green sand molds it is often necessary to compromise on the gating system design to enable an effective riser to be incorporated into the system. Wherever possible, runners should lead to risers rather than to castings, although when this is done, the metal flow within the mold cavity may be more turbulent than otherwise.

For example, consider the ring casting shown in Fig. 4. Three bosses are present on this casting which must be fed by risers. Because of its size, the ring can be gated only along one side of the pattern and, therefore, only one riser (either 1 or 2) can be made a hot riser while the other two will be cold risers. If the riser gate is the only gate into the casting, as the metal enters the hot riser, it falls down through the mold cavity filling the mold cavity and the risers. The cold risers must be made larger than otherwise necessary in order to overcome the effect of the colder metal.

The transfer of feed metal from the risers to the casting must then be examined. Riser 3 which is positioned well below the highest part of the casting, and below risers 1 and 2, will be able to pipe only if the casting sections, a solidly completely preventing liquid metal from draining through them into the boss below riser 3. When this occurs, feed metal from the boss will be only available from riser 3 and the riser must then be capable of generating a pipe to effect the metal transfer.

Risers 1 and 2 must be sufficiently high to prevent the draining of metal from section b into the adjacent bosses.
Figure 5