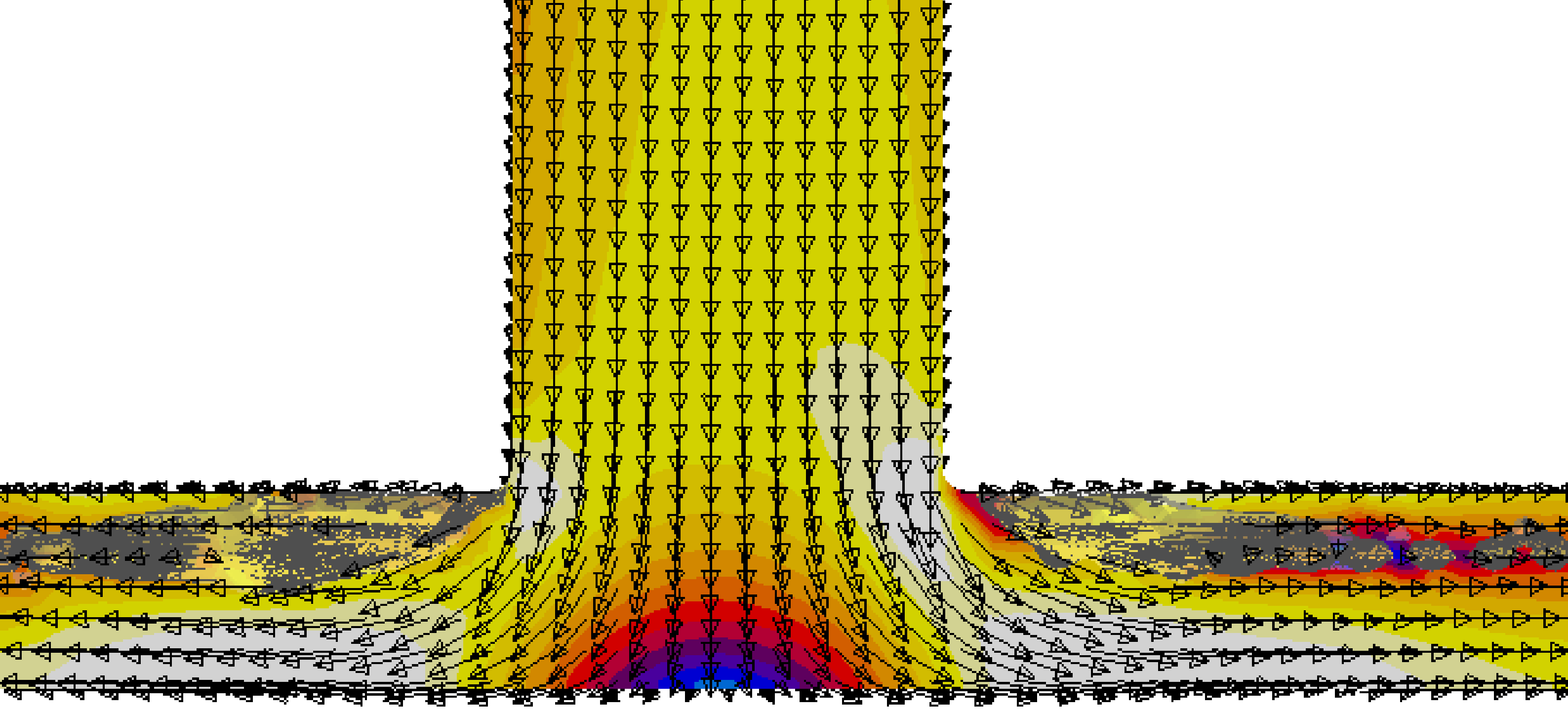

BEST PRACTICE FILTER APPLICATION TECHNIQUES FOR VERTICALLY PARTED MOLDING MACHINES

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Vertically parted molding machines were introduced to the foundry industry in the 1960's, and have since grown to become the highest grossing method of producing iron casting tonnage. Ceramic foam filters were introduced in the 1970's and have matured to become a consistently performing device that is able to meet the production demands of high speed, vertically parted molding machines, even those with the capability to produce up to 550 molds per hour. Countless filter application methods and techniques have been investigated by foundries, equipment manufacturers and suppliers alike to develop optimum foam filter applications to meet the high speed and precision placement requirements of the equipment. Some approaches have proven to be more successful than others. This initial work focuses on the effect of filter placement in the gating system and the print design itself on metal flow characteristics and casting quality.

INTRODUCTION

A standard 60x60x22mm (2.36x2.36x0.866inch) square horizontal filter print was chosen as the baseline configuration to begin the analysis.

Several modifications were made to this filter print and runner system such that the effect of these design modifications on fluid flow characteristics could be evaluated. In addition, a non-filtered system was evaluated as well as a system with the filter location high in the mold to represent multiple casting cavity molding situations.

All fluid flow analyses were conducted using commercially available, first principles computational fluid dynamics software. Each of the two iron plate castings is 203x355x19mm (8x14x0.75in) in dimension and approximately 9.75kg (21.45lb) in weight. Total pour weight was approximately 25-26kg (55-57lb), depending on the configuration. For the unfiltered system, the gating system weighed 5.82kg (12.8lb). The filter flow was represented using 10ppi foam filtration pressure drop data for a 22mm (0.866in) thick filter. Fill time was approximately 11 seconds for all configurations, representing a flow rate of approximately 2.3kg/s (5lb/s).

The first comparison is between a configuration without a filter and a configuration with a standard filter print with sprue designed such that the flow directly impinges on the filter itself, as shown in **Figure 1**. The standard filter print is created in the ram side of the mold, and adds about 9% to the gating system weight. The gating system weighs 6.36kg (14lbs).

At 0.3 seconds (**Figure 2**), the flow is just beginning to exit the filter, and the filter print is not yet filled. The filter, acting as a flow discontinuity, removes a significant amount of inertia from the flow, and reduces the velocity of the metal to approximately 0.3 to 0.4m/s (11.8 to 15.7in/s). The non-filtered flow shows considerable air entrapment where the sprue meets the runner bar, which increases the potential for mold erosion.

Fig. 1. Casting Configurations with No Filter (Left) and Standard Filter Print (Right)

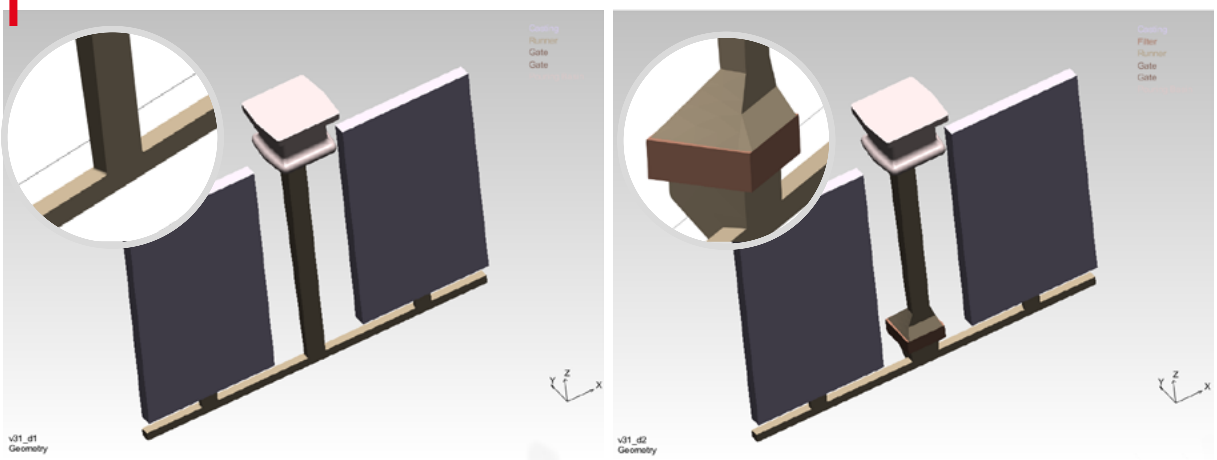
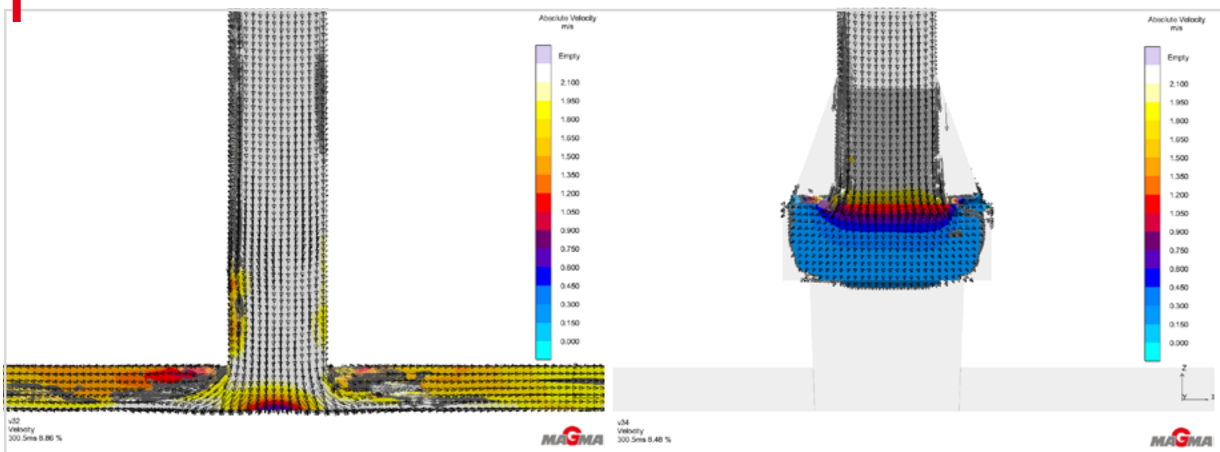


Fig. 2. Flow Comparison for No Filter and Standard Filter Print Gating at 0.3 Seconds



Air entrapment continues at 0.5 seconds **(Figure 3)** for the non-filtered configuration, while a small bubble of air also appears just below the filter for the standard filter print design. Note the significant difference in flow velocities between these two systems.

The runner bar is fully flooded at 0.9 seconds **(Figure 4)**, and the velocity profiles shows that there are significant differences in runner bar metal velocity.

The flow velocity is consistently higher for the unfiltered gating system, as compared to the gating system with the standard filter print located near the bottom of the mold. The next comparison is between the standard filter print configuration and a configuration with the same filter print, but with the sprue moved to the swing side of the pattern plate, as shown in **Figure 5.** This change adds about 4% to the gating system weight, as compared to the standard filter print design. The gating system weighs 6.62kg (14.6lb).

Fig. 3. Flow Comparison for No Filter and Standard Filter Print Gating at 0.5 Seconds

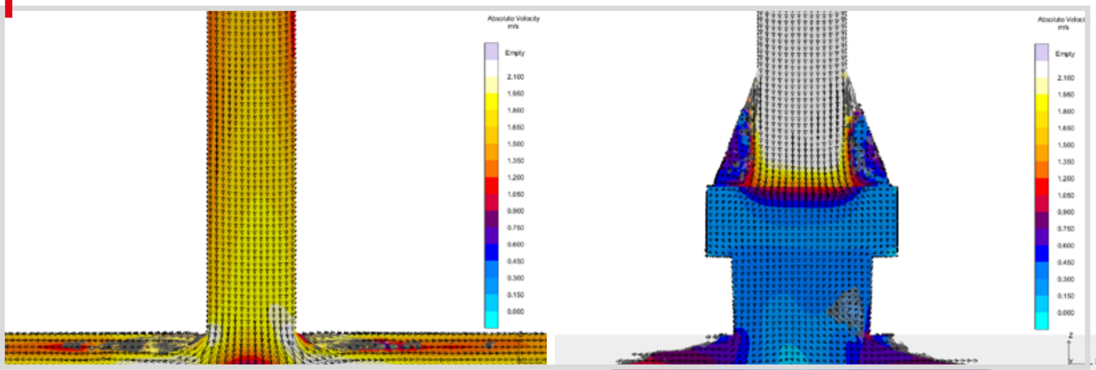


Fig. 4. Runner Bar Side Centerline Flow Comparison for No Filter and Standard Filter Print Gating at 0.9 Seconds

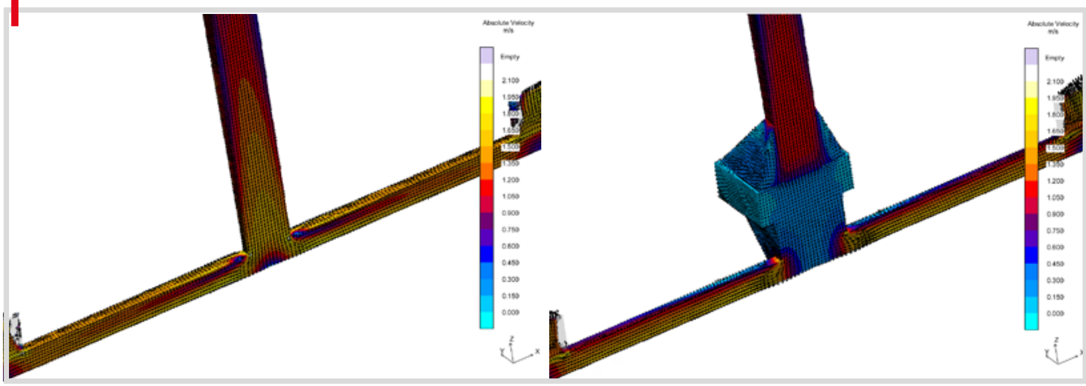
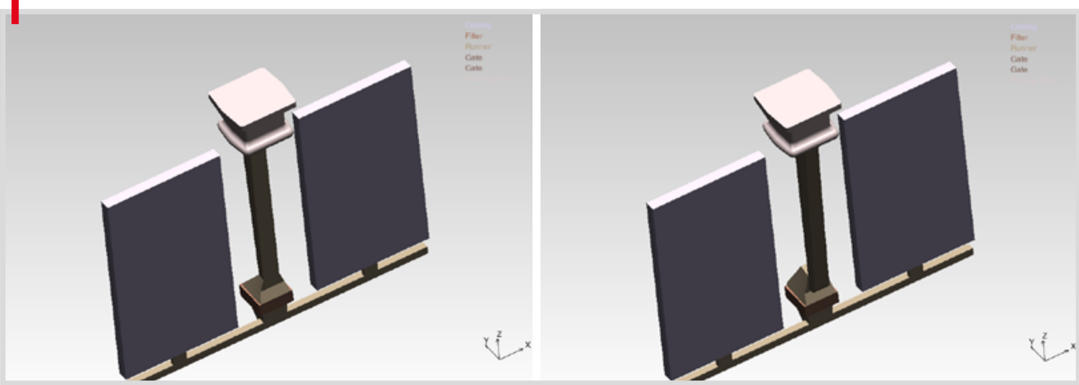


Fig. 5. Casting Configurations with Standard Filter Print (Left) and with Cross-Over Sprue (Right)

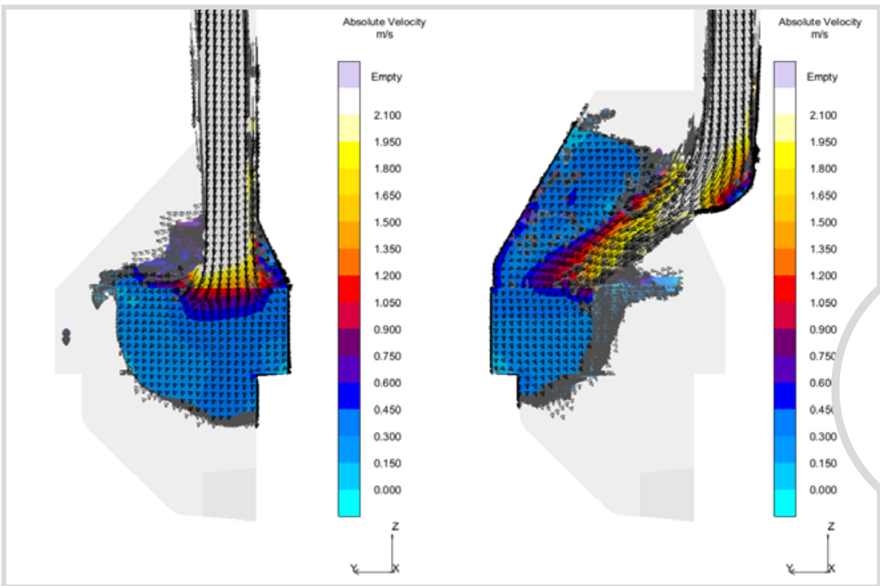


With the standard sprue, the metal enters the filter print in a vertical fashion, while for the cross-over sprue, the metal is directed horizontally. This difference results in significantly altered flow characteristics within the filter print, clearly apparent in **Figure 6** at 0.35 seconds into the fill.

For the standard gating, the flow directly impinges onto the filter and begins to prime and flow into the filter. For the cross-over gating, the flow impinges on the filter print back wall and does two things. First, the flow begins to prime and enter the filter at the back of the filter print. Second, and most importantly, the flow begins to wash the filter horizontally, and begins forming a strong eddy current at the back of the filter print which could help to mechanically move inclusions into the slag trap.

Until finally, at 0.65 seconds **(Figure 7)**, both filter prints are fully flooded and both slag traps exhibit eddy current flow.

The comparative flow profiles within each filter print remain the same for the rest of the filling process. The main point to take away from these images is the fact that the cross-over design creates a strong eddy current immediately, and has the possibility to move inclusions into the slag trap during the entire filling cycle. The standard filter print takes about 0.5 seconds to create an eddy current, and the current is smaller in size and weaker in strength than for the cross-over design. Overall fill time between these designs is similar, and not affected by the flow differences within the filter print.



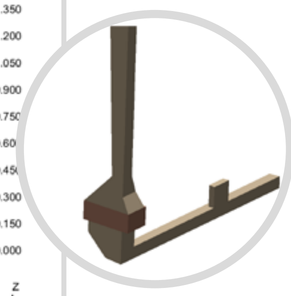


Fig. 6.
Flow Comparison for Standard Filter Print Gating and Cross-Over at 0.35 Seconds

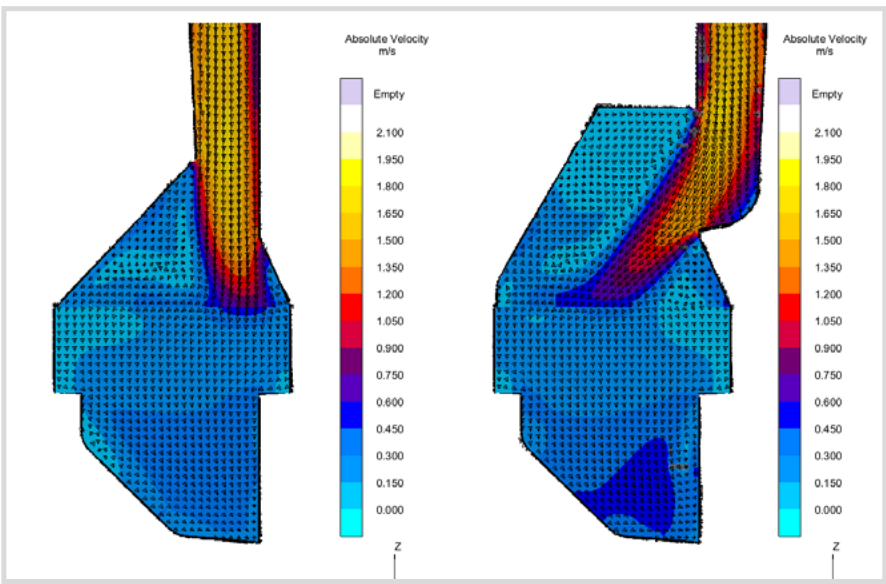


Fig. 7.
Flow Comparison for Standard Filter Print Gating and Cross-Over at 0.65 Seconds

Reviewing the flow at the vertically sectioned side centerline for the whole runner bar, the flow profiles are very similar for the two configurations (**Figure 8**).

Figure 9 shows two other designs that were also evaluated for this study, but the results will not be shown explicitly here. Please reference the full 2018 Ductile Iron Society paper of the same title as this article for the detailed examination.

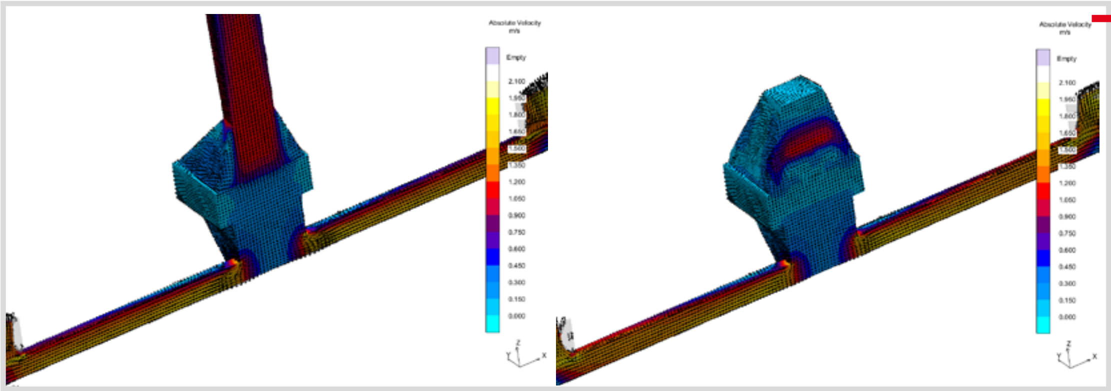


Fig. 8.
Runner Bar Side Centerline Flow Comparison for Standard Filter Print Gating and Cross-Over at 0.9 Seconds

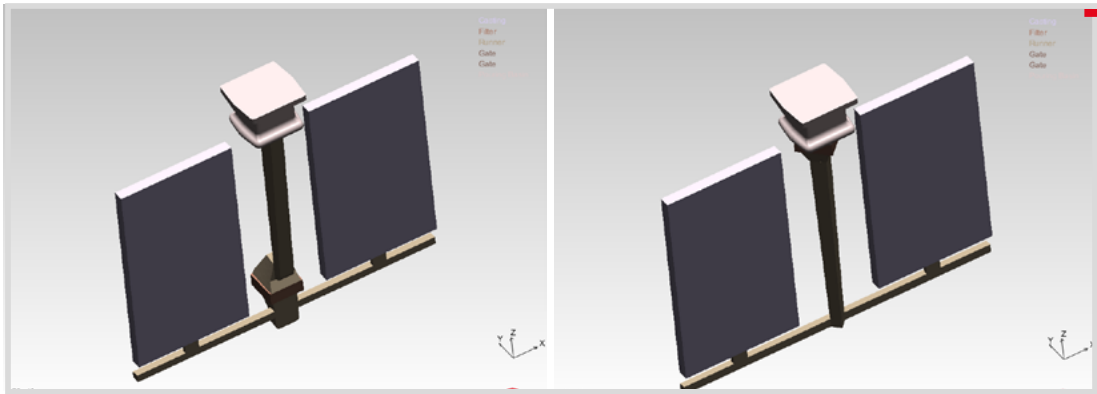


Fig. 9.
Casting Configuration with Cross-Over Sprue and with Well and Configuration with Filter at Top of Sprue Gating at 0.9 Seconds

Qualitative, comparative analyses, like the ones shown thus far in this paper, can provide powerful, convincing imagery of gating system changes that positively or negatively affect metal flow characteristics.

Historically, comparative analyses between gating systems have provided sufficient evidence to trial and implement concepts and designs that improve metal flow and casting quality. However, an engineer is inclined to evaluate design concepts analytically, and to assign absolute values with visuals. In effect, an engineer desires to combine a quantitative analysis with a qualitative analysis.

This next section details how practical gating knowledge was combined with the software program's optimization and design of experiments (DOE) features such that all five configurations could be simulated and quantitatively evaluated simultaneously.

The quantitative evaluation is based upon these three main calculated objectives:

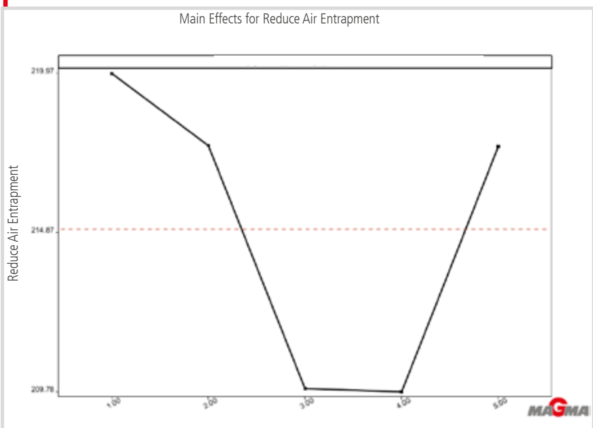
1) The air entrapment objective criterion calculates the concentration of gas that has been trapped in the molten metal due to the collapse of air cavities. Higher values indicate unfavorable flow conditions resulting in the formation of small blowholes as well as defects due to chemical reactions. The results are shown as the percentage of gasses that has been dissolved in the molten metal.

2) The smooth filling objective criterion calculates the average amount of metal front free surface area during filling, and is another measure of the potential for gas related inclusions. It is calculated as an area, in millimeters.

3) The mold erosion criterion is calculated and recorded when the metal flow impinging on a mold mesh cell exceeds a certain velocity for a certain amount of time. This calculation is complicated, and is properly explained in the full paper.

An initial, straight forward approach to evaluating the various designs is to review how significantly the configuration affects the individual criterion being calculated. As an example, **Figure 10** shows how each configuration, or design, affected the calculation of the air entrapment filling objective equation. (The red dashed line represents the average criterion result.)

Fig. 10. Main Effect for Air Entrapment Criterion



For this objective, Designs 3 and 4 performed the best, followed by Designs 2, 5 and 1.

Design	Description
1.	Configuration with no filter
2.	Configuration with standard filter print
3.	Configuration with standard filter print, cross-over sprue
4.	Configuration with standard filter print, cross-over sprue and well at the base
5.	Configuration with filter near the top of the mold

The most powerful part of the evaluation allows the engineer to review the effects of a design on multiple criteria at the same time **(Figure 11)**. The designs are listed on the far right, and the calculated criteria are located on the y-axis. Each calculated criterion is given a unique y-axis, and the values are shown with the criterion labeled at the top of the graph. The colored lines are used to connect the criterion scores for each design.

Each design has a uniquely colored line. (Design 1 is aqua, Design 2 is blue, Design 3 is red, Design 4 is orange and Design 5 is yellow.)

For this analysis, there are three objectives, as discussed before, but now they can be evaluated simultaneously. The ideal design would have the lowest calculated value for each criterion. However, even if this is not the case, the individual results from each design can easily be compared using this tool.

To find the best designs, the top red arrows can be manipulated to remove the worst designs with the highest calculated values. This is best demonstrated one objective at a time. To begin, Figure 12 shows the evaluation tool with the "reduce air entrapment" arrow moved down slightly to eliminate Design 1.

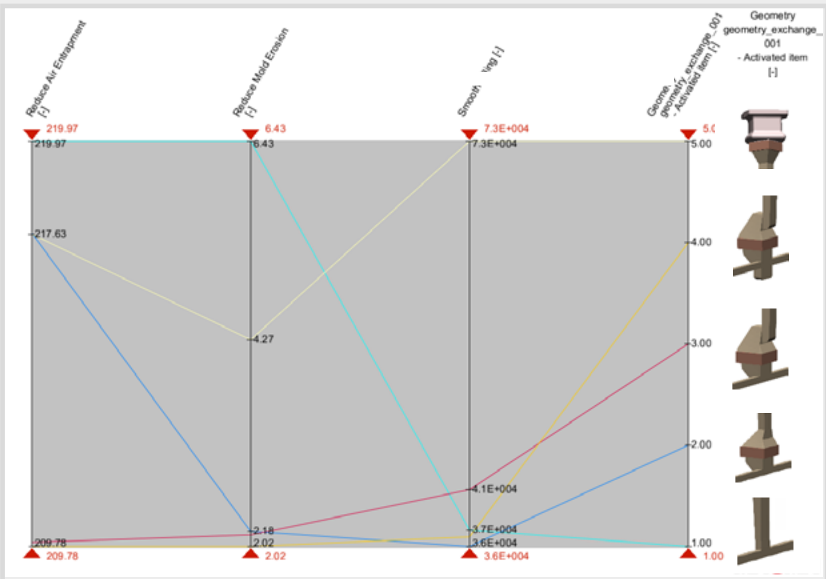


Fig. 11.
Parallel Coordinates Criteria Evaluation

Fig. 12. Parallel Coordinates Criteria Evaluation

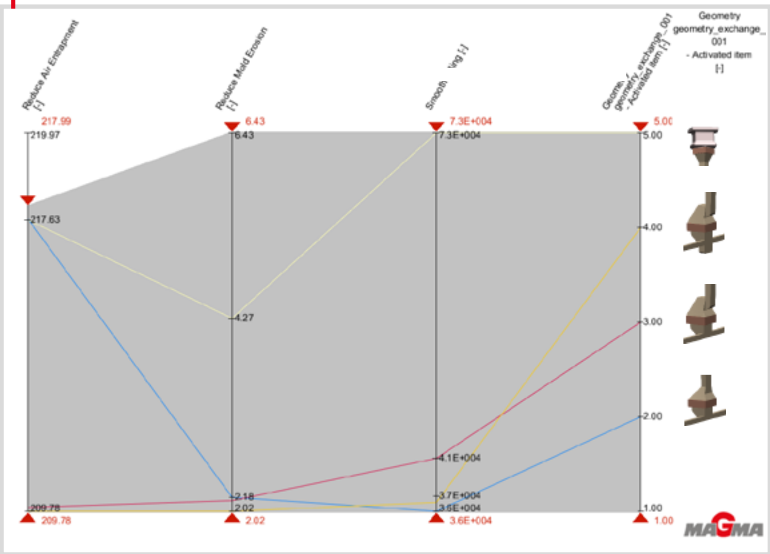


Fig. 13. Parallel Coordinates Criteria Evaluation

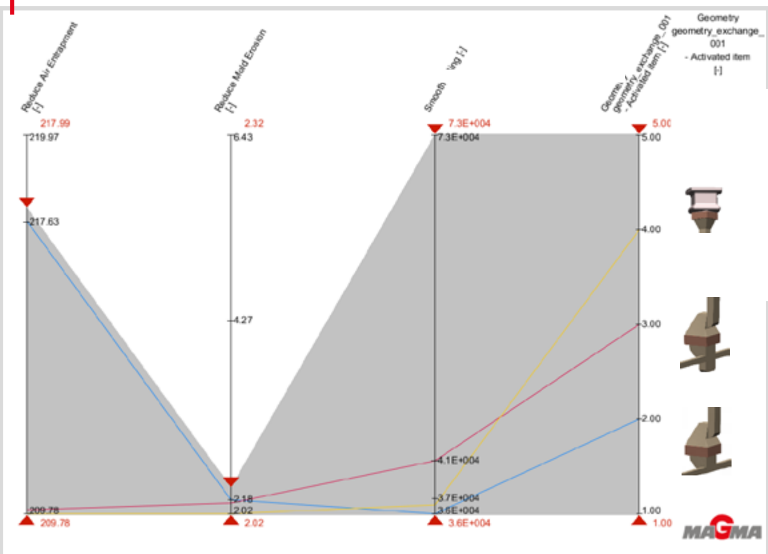
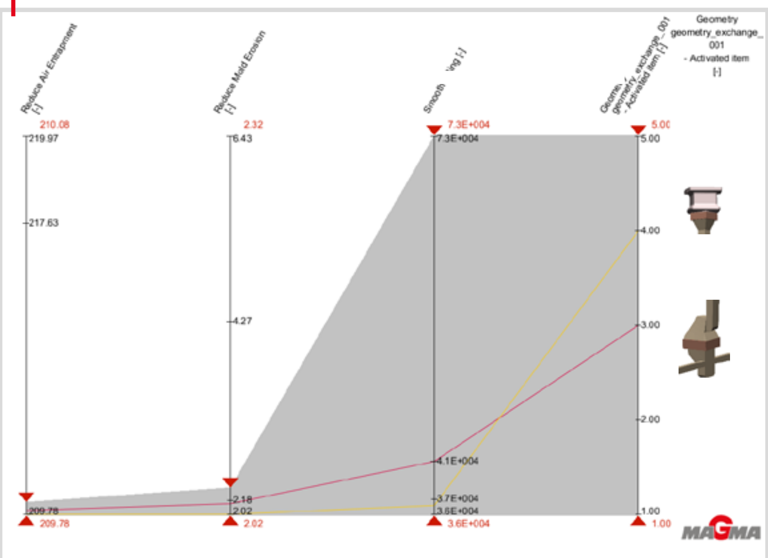


Fig. 14. Parallel Coordinates Criteria Evaluation



Note, the line for Design 1 is eliminated, and disappears from the chart. If the "reduce mold erosion" arrow is pulled down below the value of 4.27, the line for Design 5 is eliminated, as shown in **Figure 13.**

Based on these settings and criteria, Design 2, Design 3 and Design 4 are the best gating systems. A review of the remaining criteria shows that there is still a large, relative separation in values for the "reduce air entrapment" criterion, so the "reduce air entrapment" arrow is further lowered, thus eliminating the line for Design 2, as shown in **Figure 14**.

Designs 3 and 4 are the best designs based on this evaluation, and have similar criteria values for all three objectives. However, there are some small differences that separate the designs. By moving the "smooth filling" arrow below the calculated value of 41,000, as shown in Figure 14, the line for Design 3 is eliminated and Design 4 is revealed as the best design of the five evaluated (**Figure 15**) on the next page.

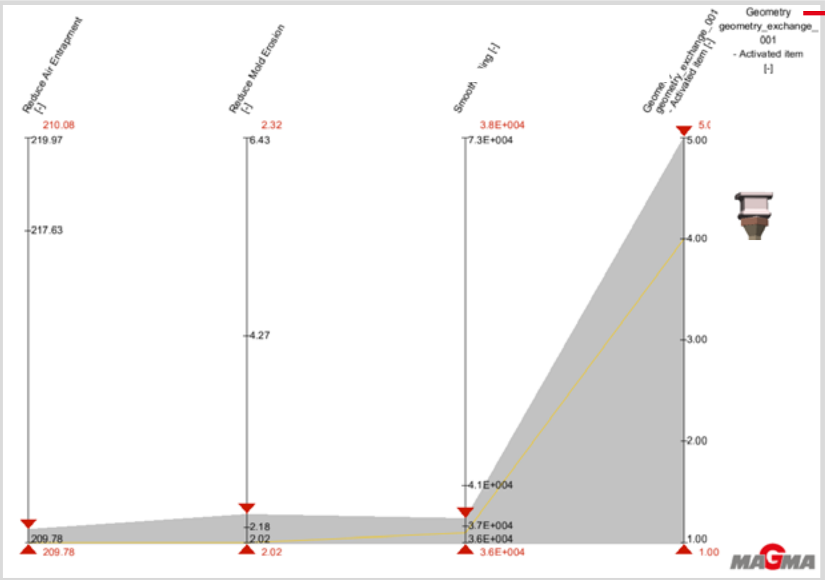


Fig. 15.
Parallel Coordinates Criteria Evaluation

When considering all three criteria, Design 4, the cross-over filter print with a well, is clearly the best gating system. Design 3 is the second-best gating system, followed by Designs 2, 5 and 1. These results are consistent with the conclusions from the qualitative evaluation.

In general, the conclusions are as follows, starting with the best design based on this analysis.

Standard filter print with sprue on the swing side and well at the bottom of the sprue

- Washes filter and quickly creates strong eddy current to move inclusions to the slag trap
- Less risk of pushing inclusions directly through the filter
- Minimal 2.5% increase in gating system weight, as compared to same system without a well
- Recommended, preferred design

Standard filter print with sprue on the swing side but without the well

- Washes filter and quickly creates strong eddy current to move inclusions to the slag trap
- Less risk of pushing inclusions directly through the filter
- Minimal 4% increase in gating system weight, as compared to standard filter print with sprue on the ram side
- Recommended design if including a well is not possible due to pattern plate real estate issues

Standard filter print with sprue on the ram side

- Filter, acting as a flow discontinuity, removes significant inertia from the system (reduces velocity)
- Creates small eddy current to move inclusions to the slag trap
- 9% increase in gating system weight as compared to unfiltered system
- Recommended design if sprue must remain on ram side

*Reference: "Best Practice Filter Application Techniques for Vertically Parted Molding Machines", presented at the Ductile Iron Society Keith Millis Symposium, 26 October, 2018, Hilton Head, SC.

Check out our filtration video.

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