FILTERCALC* for steel – a Windows™ based programme for sizing foam filters for steel

Abstract

The widely accepted benefits of ceramic foam filters for steel casting include removal of non-metallic inclusions, reduction of turbulence to minimize reoxidation and simplified gating (1,2). However, the filter must be properly sized and applied for maximum effectiveness and cost efficiency.

Filter selection historically has been based on tables of flow rate and filtration capacity ranges derived from foundry experience under general melting, pouring and moulding conditions. This has often required interpolation and extended foundry trials to determine proper selections for specific applications. Elaborate methods already exist to design successful filter gating systems, but they are not widely used due to economic and/or time constraints.

A new computer programme simplifies and increases the accuracy of filter selection. It uses physical principles herein described governing fluid flow and empirical data from extensive water modelling studies to determine the pressure drop effects of introducing ceramic foam filters into the molten metal stream.

Introduction

A properly sized filter for a casting meets a maximum mould pouring time requirement while adhering to a filter capacity limitation, which is defined as the amount of metal that will pass through prior to blockage.

The pouring time is influenced by the geometry of the casting and mould, alloy type, mould and core materials, pouring temperature, and pressure drop as flow passes through the filter. Filtration capacity is influenced by alloy composition, deoxidation practice, metallostatic pressure, pouring temperature and the filter porosity and frontal area.

Besides removing inclusions from steel through filtration, filters modify metal flow and reduce turbulence. The flow modification produced is a function of the filter material, thickness, pore size and inlet flow velocity.

The maximum flow rate of the system is determined by the system choke. For direct pouring systems, the choke is always the exit area of the direct pour unit (KALPUR" unit). For in-line gating, determining the location of the choke is more complex, and could be affected by the exit area of the sprue, the filter print, the filter flow characteristics and the foundry process conditions. Depending on the above constraints, the in-line system choke will either be located at the sprue exit or at the filter print exit.

Ideally, choking before the filter should be avoided due to the increased potential for turbulence and mould erosion.

Current Filter Selection Methods

Existing filter sizing methods utilize tabular data from general foundry experience. Ranges, rather than specific flow rates and filtration capacities, are normally given for each filter size. It is difficult to adjust these values to account for variations in alloy type, metal cleanliness, moulding conditions and pouring practices found at an individual foundry.

Using current methods, once a filter size is selected, the sprue is simply sized by using a recommended sprue-to-filter-area ratio. However, this technique is approximate because clogging of the filter is proportional to the quantity of metal passed through the filter, not the sprue-to-filter-area ratio.

Filtration capacity is based on several considerations. Major limiting factors include clogging at which filter flow rate is significantly affected, or failure of the filter structure due to exceeding the filter capacity.

Current filter selection methods are severely limited and generally result in over sizing and higher filtration costs. This could conceivably prohibit the use of filtration on a particular casting.

To simplify and improve ceramic foam filter sizing accuracy, a unique computer programme has been developed. It is an advanced application tool that considers filter behaviour within, and as part of, the specific gating system to be used.

Physics of Flow

Applied physics can significantly improve filter sizing accuracy. Several methods exist to physically model the flow through a filter. The most accurate and complex require iterative solution of the Navier-Stokes equations. They employ sophisticated software, are computationally intensive, and generally require user expertise. They are not simple application tools.

A less rigorous method is to apply the Conservation of Energy (Bernoulli) (3) equation to solve for fluid flow characteristics. Simply stated, Bernoulli's equation defines the relationship between pressure, head height and velocity of a fluid in a system. For simple gating systems, this method is adequate and significantly better than previous filter sizing methods. Complex gating systems require more complete flow analyses.

In all cases, physics-based models of filter flow require empirical data describing pressure drop characteristics of the filter as a function of filter inlet velocity. Pressure drop data describes the restrictiveness of the filter and can be measured using water modelling. A detailed report on the development and validation of water modelling data for steel filtration devices can be found in the literature (4,5).

The head height, system losses, pouring temperature, alloy density and viscosity, filter type, exit area and thickness all play a role in determining the velocity at the exit of the filter. System losses include not only pressure drop, but also flow losses from turning and contraction/expansion of the gating system.

By balancing head height and system losses against one another, the velocity at the exit of the filter can be determined. The flow rate of the system can then be calculated using the filter exit velocity, metal density and filter exit area.

While filtration capacity for a given filter is still determined from empirical tables based on alloy type, metal cleanliness and pouring conditions, this more precise calculation of flow rate significantly improves filter selection accuracy.

The FILTERCALC™ for Steel Programme

Inputs

To use the programme, the user simply inputs already known or easily calculated information in the windows provided on the Filter Design screen (figure 1).

Filtration Method can be chosen as In-line or Direct pour.

If the ***In-line*** method is chosen, there are several filter print types to choose from, as shown in Figure 2.

Figure 1: Filter design screen

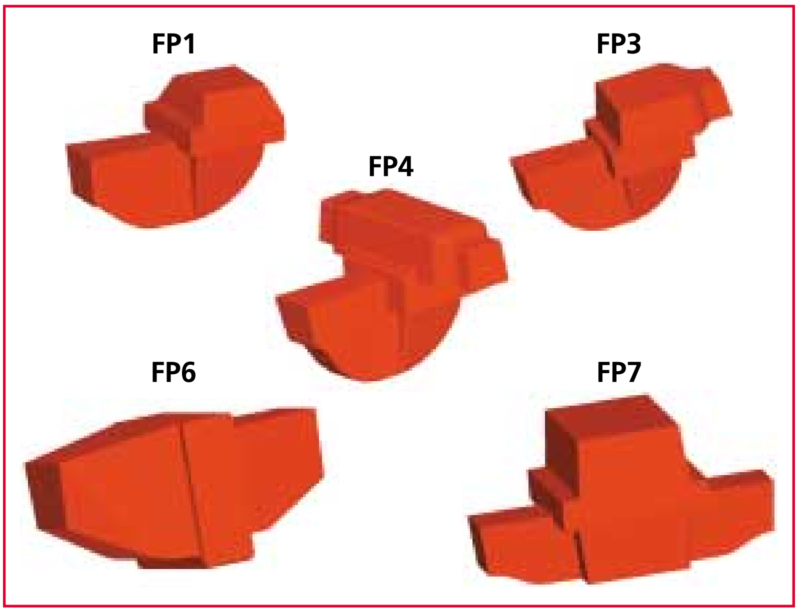

Figure 2: Steel filter print designs

For the Direct pour method, there are several sleeve component shapes to choose from in the drop down menu, including ***Tube, Insert and Round Neckdown (RND)***.

The entire mould cavity **Pour Weight** is input, even if there is more than one casting per mould. The number of filters is asked for later, thus allowing the programme to establish the requirements for capacity and flow rate per filter. **Note:** The programme will assume that the same amount of metal is required to go through each filter.

The **Maximum Pour Time** can be input, or by using the **Calculate** button, can be determined using the equations from the 1958 US Naval Research Report, "Pouring Times for Steel Castings" (6).

The **Delay Time** input accounts for foundry-specific pouring behaviour. At the start of pouring, the initial flow rate is generally low and increases to steady state flow until the end of pouring. Using an average flow rate to calculate pour time could undersize the filter. Therefore, proper filter sizing requires that the maximum flow requirement be considered.

The **Delay Time** is the variable time occurring before and after the steady state flow, resulting from filter priming and human variations in pouring. If a foundry pours hard, or uses automated pouring, this input can be ignored or set to zero. This is the default setting. The **Delay Time** input is subjective, and is most critical for small castings.

The pouring time for sizing is the input **Maximum Pouring Time** minus the **Delay Time**. Then, the required mass flow rate is calculated as the metal weight per filter divided by the pouring time for sizing.

The **Pour Temperature** is input, or can be calculated from metal chemistry inputs (using the **Calculate** button).

For the **Effective Head Height** of the system, a known value can be input or the user can select **Calculate** to determine it, as shown in Figure 3.

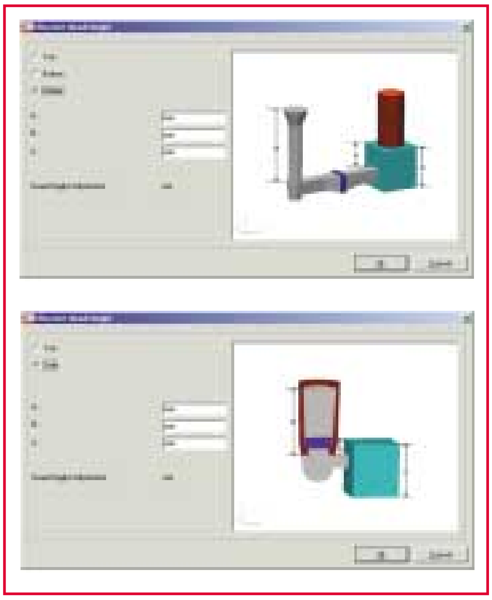

Figure 3: Calculating effective head height

This input is very important to determining the metal flow rate, so care should be taken to input correct values. Increasing the head height will result in higher flow rates, and potentially smaller filter size recommendations. See the Direct Pour discussion below.

The optional **Sprue Diameter** and **Sprue Exit Area** inputs only apply to in-line systems. The user may choose to allow the programme to calculate these dimensions as described in the Filter Sizing Logic section below.

The **Capacity Factor** input is applied to the **Maximum Capacity** shown for the Standard Filter Recommendation. It enables the user to adjust the capacity based upon metal cleanliness and foundry experience.

The **Alloy Type** can be chosen from several alloys. Within the programme, each alloy has its own thermophysical data as a function of temperature, and this information is used to calculate the flow rate.

Finally, the **Ladle Type** (Lip or Bottom pour) and the metal **Deoxidation Practice** (CaSi/Al or Zr/Ti) are input. These values affect the **Maximum Capacity** of the Standard Filter Recommendation.

Filter Recommendations

Once the inputs are entered, the recommended filter appears in the Standard Filter Recommendation panel of the screen.

The default filter recommendation is 10ppi STELEX, ZR. Alternate filter types can be chosen from the drop-down menu, and the resulting size recommendation is given. (Note: The filter size is given for in-line applications, and the KALPUR unit size is given for direct pour applications). The **Maximum Capacity** and **Maximum Flow Rate** of the filter are shown, and the programme identifies whether the filter (or unit) was **Sized By** filter flow rate, filter capacity constraints, or sprue exit area (in-line applications only).

The **Predicted Pour Time** is calculated using the maximum flow rate for the recommended filter and the delay time. This value will always be lower than **Maximum Pour Time** plus the **Delay Time**.

The **Critical Choke Area** and **Diameter** dimensions identify the minimum **Sprue Exit Area** that can be used before the sprue becomes the choke of the system and reduces the flow rate (in-line applications).

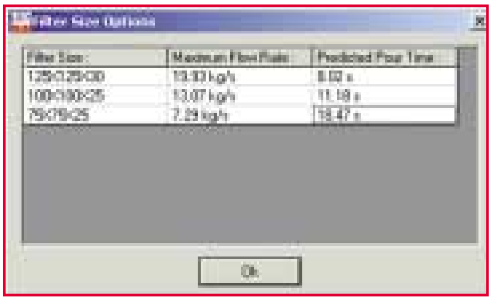

Figure 4: Filter size options

If the recommended in-line filter or direct pour unit was **Sized By** filter flow rate, it may be possible to evaluate smaller filter/unit options that still satisfy the filtration capacity requirements. However, these options will result in lower **Maximum Flow Rates** and higher **Predicted Pour Times**. Options (figure 4) can be evaluated by selecting the **Size Options** button, next to the **Filter** recommendation.

In this figure, two additional filters are shown that can also satisfy the filtration capacity requirements if the **Max. Pour Time** constraints can be relaxed.

The Standard Filter Recommendation is for a STELEX ZR 125 x 125 x 30 mm filter, which would result in a predicted pour time of 8.02 seconds (6.02 actual + 2.0 delay).

However, if a slightly longer pour time is acceptable, a 100 x 100 x 25 mm filter could be used, with a total pour time of 11.18 seconds (9.18 + 2).

A 75 x 75 x 25 mm filter could be used as well, but the predicted pour time would increase to 18.47 seconds (16.47 + 2).

Filter Sizing Logic

First, the programme sizes the filter to satisfy the **Max. Pour Time** requirements (maximum flow rate); then it considers filtration capacity.

Direct Pour

For direct pour configurations, the exit area of the KALPUR unit is the choke. First, the smallest KALPUR unit in the database is chosen. The programme calculates the exit velocity as described above; then it calculates the required flow rate, using the KALPUR unit exit area. If the calculated flow rate does not meet or exceed the required flow rate, the programme chooses the next largest size KALPUR unit and recalculates. This continues until a KALPUR unit that meets the flow rate (**Max. Pour Time**) constraint is found.

Care must be exercised in determining the effective head height for a KALPUR unit. When pouring rapidly from a lip pour or tea pot ladle with a large diameter metal stream, the effective head height may be closer to the pouring height of the ladle than any liquid level in the direct pouring unit. In pouring where a smaller metal stream is dissipated into a built-up reservoir of metal above the filter, the metal height in the KALPUR unit would be the effective head height.

If the KALPUR unit also meets the filtration capacity requirements, then the programme is done. If not, the programme recalculates, using the next largest KALPUR unit, until the filtration capacity requirement is met.

In-Line

The in-line case is more difficult because it requires determination of whether the system choke is the filter or the sprue.

If the filter is the choke, the calculations are identical to the direct pour situation. However, if the sprue exit area is the choke, the system is constrained by the sprue, and not the filter. Here, the recommended filter is sized according to the flow rate constraint determined by the sprue exit area.

The filtration capacity calculations are then done, as described above. The programme will tell the user when the sprue has become the system choke (**Sized By**). Caution should be exercised whenever the **Sprue Exit** input constrains the flow rate. A better approach is to leave the **Sprue Exit** input blank, and allow the programme to output the sprue exit dimensions. If **Sprue Exit Area** or **Sprue Diameter** inputs have been entered, check to ensure that the **Predicted Pour Time** does not exceed the **Max. Pour Time**.

It should also be noted that actual pouring times could be longer than predicted pour times when an adequate pouring rate cannot be maintained. For example, pour rates in excess of 16 kg/s (35 lb/s) are generally difficult to achieve with a lip or teapot ladle, and thus would be difficult to model using this programme.

Filter Prints

The programme allows the user to view the various filter print designs. Examples are shown in Figure 2.

Once a filter has been recommended, the user can view the filter print drawing and print out its dimensions (figure 5).

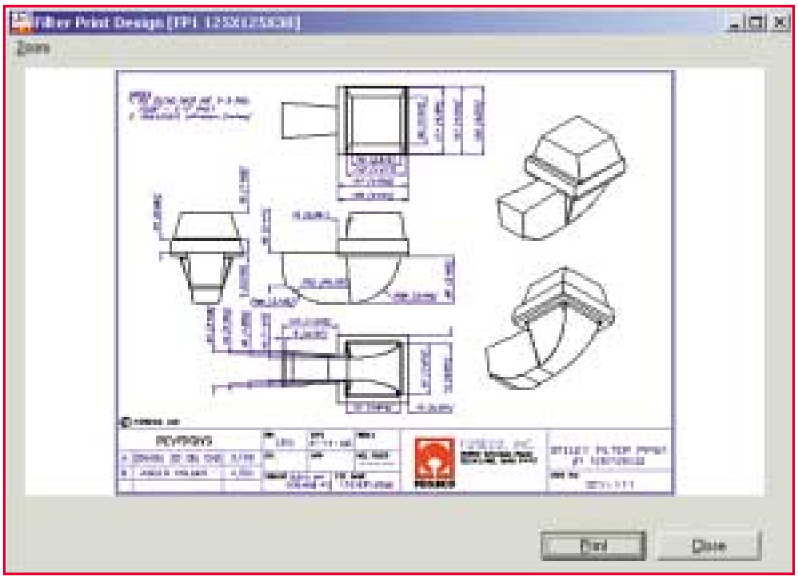

Figure 5: Filter print design drawing

Validation

The FILTERCALC for Steel programme results compare very well with those obtained using published datasheet information. However, because the programme allows for significant adjustment of input variables, recommendations are more accurate than would have been possible using datasheet information.

Two production casting examples were analyzed to see if the programme could accurately predict filter sizes and pouring times recorded during actual production. For in-line filtration, a 2-up oil tool casting was selected. For direct pour, a 2-up valve body was selected.

In-line

Figure 6 shows the cope and drag patterns for the 2-up oil tool casting. Note that the FP1 filter print design is used.

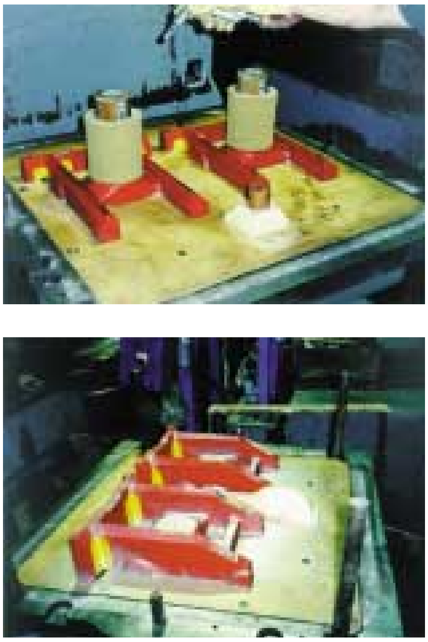

Figure 6: Cope and Drag patterns for 2-up oil tool casting

The actual poured weight of the mould is 141.5 kg and the net weight of each casting is 45 kg, for a net yield of 64%. The pouring temperature of the carbon steel is 1602°C. The chemistry is: (0.16% C, 0.56% Si, 0.96% Mn, 0.038% Al, 0.07% Cr, 0.08% Ni, 0.02% Mo, 0.019% P and 0.014% S). Electric arc melting is employed.

A teapot ladle is used; the desired maximum fill time for this unpressurized runner system is 14 seconds.

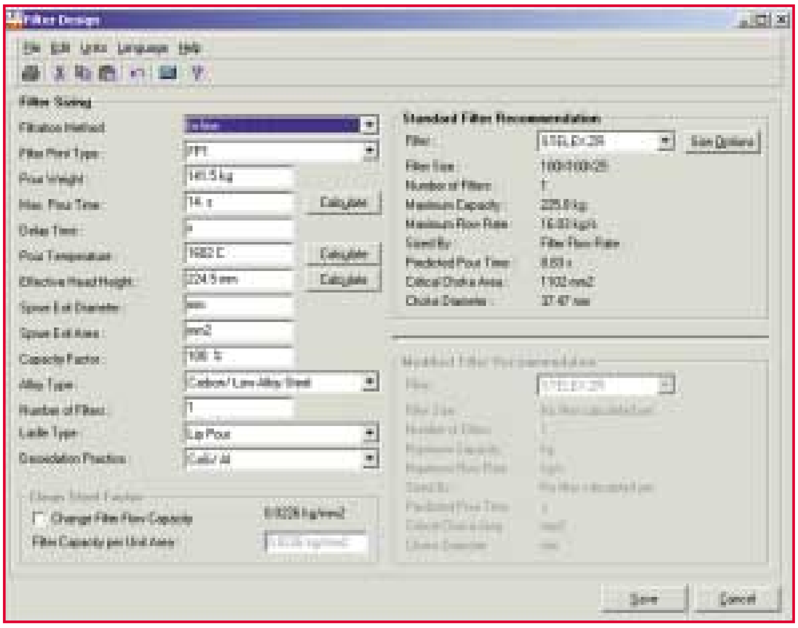

Figure 7: Filtercalc for Steel inputs and recommendation for oil tool casting

Figure 7 shows the inputs and recommendation.

The programme recommends a 100 x 100 x 25mm filter for the FP1 filter print. The filter has a **Maximum Capacity** of 225.8 kg and **Maximum Flow Rate** of 16.03 kg/s. (A 224.5 mm head height is input, calculated from the gating system dimensions.) This configuration is **Sized By** filter flow rate, thus the filter print exit area is the choke of the system.

In actual practice, a 100 x 100 x 25 mm filter is used with an FP1 filter print. The actual casting configuration is poured in an average of 8.85 seconds, with a standard deviation of 1 second. This agrees well with the **Predicted Pour Time** of 8.83 seconds, well within the standard deviation of 1 second.

In addition, the measured flow rate of 16.25 kg/s agrees well with the predicted **Maximum Flow Rate** of 16.03 kg/s, well within the standard deviation of 2 kg/s.

Direct-pour

Figure 8 shows the cope and drag patterns for the 2-up valve body casting.

Figure 8: Cope and Drag patterns for 2-up valve body casting

The actual poured weight of the mould is 169 kg. The net weight of each casting is 40 kg, for a net yield of 48%. The pouring temperature of the carbon steel is 1606°C. The chemistry is: (0.26% C, 0.38% Si, 0.79% Mn, 0.058% Al, 0.16% Cr, 0.06% Ni, 0.05% Mo, 0.015% P and 0.008% S). Electric arc melting is employed.

A tea pot ladle is used; the maximum pour time for this unpressurized runner system is 20 seconds.

Figure 9: FILTERCALC for Steel inputs and recommendation for valve body castings

Figure 9 shows the inputs and recommendation.

The programme recommends a 4 x 6 direct pour unit (with 100mm STELEX ZR filter). The filter has a **Maximum Filtration Capacity** of 177.3 kg and **Maximum Flow Rate** capability of 12.74 kg/s. (This is based on a 117.8 mm head height, assuming the KALPUR unit is $^{3}/_{4}$ full, standard practice at this foundry.) This configuration is **Sized By** filter flow capacity.

In actual practice, a 4 x 6, 100 mm direct pour unit is used. The actual casting pouring time averages 14.5 seconds. This agrees well with the predicted fill time of 13.28 seconds. In addition, the actual measured flow rate of 11.65 kg/s agrees well with the predicted **Maximum Flow Rate** of 12.74 kg/s.

The predicted flow rate results are within 8% of actual practice for this direct pour configuration.

These results are consistent with other in-line and direct pour configurations that have been evaluated.

Summary and Conclusions

To reduce the complexity of sizing filters for steel castings, a unique, advanced filter application tool has been developed. This computer programme generates more-accurate recommendations because filter behaviour is considered within, and as part of, the gating system; because it is based on physical principles governing fluid flow; and because it utilizes foundry-specific inputs.

The result is less-conservative recommendations than those derived from flow and capacity ranges traditionally found in datasheets. This offers the potential for more-cost-effective filtration solutions.

References

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