The application of foam filters to optimize aluminum casting production

Background

It has been known since aluminum was first used for commercial casting purposes that a melt can contain many non-metallic particles, films, or clusters in sizes from a few microns to several millimeters. Whatever the size and chemical composition of these inclusions, they have been shown to be detrimental to the finished casting in some way, often by decreasing the mechanical properties and increasing the propensity to leak under pressure. Castings can also be more difficult to machine and be cosmetically unacceptable.

Furthermore, these inclusions add to the difficulty in making the casting by reducing the fluidity of the metal.

It has also been recognized that, as aluminum oxidizes very readily, turbulence of the melt is to be avoided. Turbulence leads to 'folding in' of oxides and creation of new oxides from exposure of clean aluminum to the atmosphere. To counter this in gating arrangements, it is usual in aluminum foundries to use non-pressurized systems for example 1:2:4 so that metal front velocities are minimized.

The introduction of foam filters to the aluminum industry approximately 20 years ago was a major advance, and much work was done to characterize the effect of foam filters both from the point of view of what was removed, in terms of particles and their size, and what effect this had on the quality and mechanical properties of the casting.

The foam filter was recognized to have a unique, tortuous, path through its body which trapped inclusions and allowed clean, smooth-flowing metal to exit into the mold cavity, see figure 1. By the 1980's high-integrity aluminum foundries, as well as iron, steel, and non-ferrous casters saw the benefits of such a system. The foam filter for 'in-mold' use went from invention to industrial use in a short space of time. On the aluminum side there was hardly an aerospace part that was not filtered. As often happens with major advances however, the

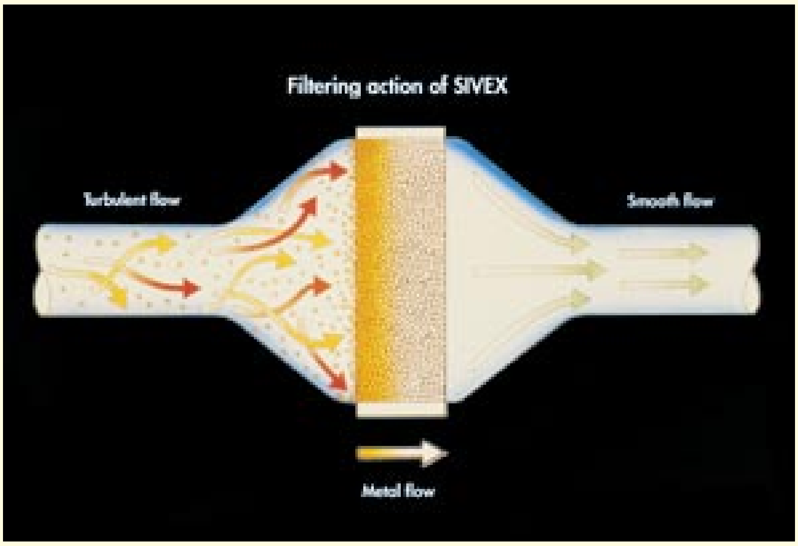

Figure 1: A schematic view of the cleaning effect and flow smoothing of foam filters.

product/process had not been fully optimized. The leap upward in quality was so large that there seemed to be little requirement for further and deeper investigations.

It was not until the flow-smoothing properties of foam filters were investigated that the realization was made that not only could the value of inclusion removal be obtained from foam filters, but also the smoothing of turbulence in the metal stream could lead to benefits in the area of yield and productivity. This breakthrough lead to the development of the KALPUR direct pouring system, whereby the gating system is replaced by a foam filter contained in an insulating sleeve. Metal is poured directly into the mold cavity through this unit, which also gives benefits in directional solidification, as now the thermal gradient in the solidifying casting is optimized for best feeding efficiency, see figure 2.

Since this development, many foundries around the world making all types of castings have adapted their production to this technique which, given the right casting configuration, can lead to maximized productivity, as well as quality considerations (1) both in permanent mold and sand molding applications (2).

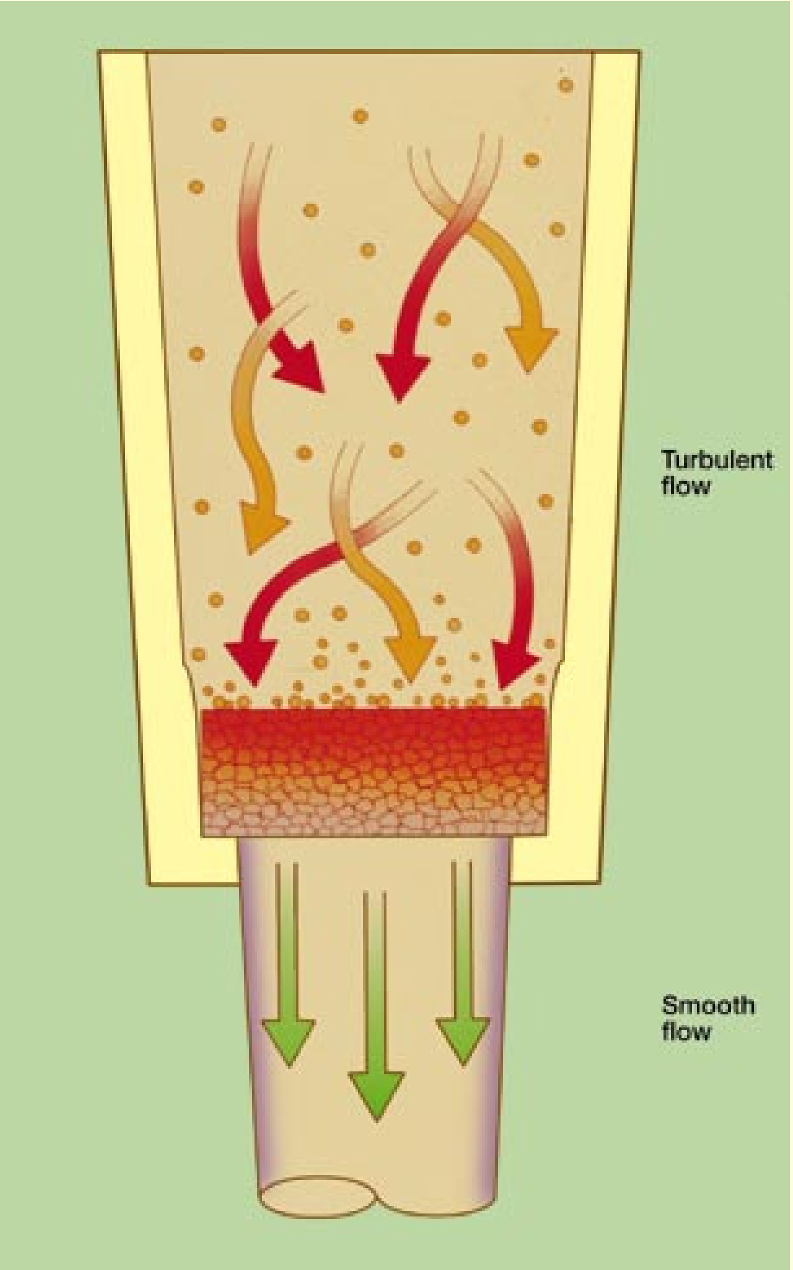

Figure 2: A schematic view of the cleaning and flow-smoothing effect of pouring directly into the mold cavity through a direct-pouring unit.

This brings us close to the present day. Foam filters are used in conventional gating and direct-pour systems for the removal of inclusions and the smoothing of turbulent flow. The importance of each is fully recognized if not fully quantified by the industry. However, if the benefits of filters are to be optimized, then the following points need to be addressed.

- Direct-pour systems need to be developed so that permanent mold foundries can produce castings without excessive trial and error and without increasing cycle times due to longer riser solidification.
- It is important to be able to remelt returns containing filters and to be able to ensure that no filters or filter particles remain in the melt.
- Foam filters are made from impregnating polyurethane foam during the manufacturing process. This leads to dimensional variations which, although controlled to within limits, could be reduced by further development efforts.
- The industry is changing. More castings in the automotive sector are switching from ferrous metals to aluminum. Therefore, castings are having different demands placed on them. Commercial as well as technical factors are an increasing part of the picture, and foam filter technology and application must recognize this.

Introduction

There is increasing pressure from the automotive and other large end-users of aluminum castings for quality products at less cost. The focus of the industry has moved to improved productivity, thinner walls, and tighter dimensional tolerances without compromising quality. Value is added to the finished casting, but selling price is often not permitted to rise.

Foam filters fit naturally into this scenario as they add value in terms of quality, yield and productivity. However, foam filters themselves needed to be investigated more closely.

It is known that foam filters smooth flow, but to what extent? Research (3) has shown that melt front velocities of less than 0.5 m/s are required for non-turbulent flow. Exit velocities of metal streams from foam filters were measured and found to fall within these limits (4).

Modelling of gating arrangements, now that these parameters could be measured, was an important step in allowing a lot of the art of rigging to be replaced by flow simulation techniques. This was an important criterion for the next step forward, which could only be taken with the advances in computer power that occurred in the 1990s. The reasons for its importance is the 'getting it right, first time, every time' is a major drive in the quality movement. This technology would be a vital tool in accomplishing that goal. The application engineering of optimized gating systems becomes scientifically founded.

Of equal importance, but different in nature, is the foam filter itself. The technology behind the filter composition was examined in terms of dimensional accuracy, remelt characteristics, and mass production to meet the needs of the industry. These areas have been subject to intense study and are outlined below.

Novel filter technology

For aluminum foundries, a new graphite-based non-ceramic foam filter, designated SIVEX FC, is now available from Foseco. The filter's novel formulation provides significant advances in performance and remelting characteristics when compared with conventional alumina-based or silicon carbide-based ceramic foam filters.

Historically, the most widely used foam filter for aluminum has been a phosphate-bonded alumina ceramic. It is typically white in color, very hard, abrasive and brittle. This brittleness requires care to ensure that fine particles do not break off and enter the mold cavity with the metal stream, becoming deleterious inclusions in the casting.

Ceramic alumina or silicon carbide inclusions will reduce mechanical properties of the casting, and both will be very damaging to machine tools, reducing their useful life.

Additionally, to avoid contamination of the melt with filter particles during the recycling of sprues, runners and risers, it is often necessary to cut out the portion of the runner containing the filter. This runner section will then require a special remelting practice in-house, or must be sold to an outside scrap recycler at a significantly discounted price versus the cost of purchased ingot.

Another concern in remelt is that, if large quantities of phosphate-bonded alumina filters are recycled in a manner where there is a long contact time with the melt – in excess of three or four hours – some phosphorus could possibly dissolve. This could contaminate the melt, potentially interfering with ('poisoning') any modification treatment.

Silicon carbide filters are also subject to some limitations in their remelt capability, since low-silicon alloys can pick up silicon from remelted returns containing filters.

SIVEX FC filters exhibit all of the advantageous characteristics of standard reticulated foam filters, cleaning the metal by removing dross and non-metallic inclusions. Because of the filter's high surface area, even particles much smaller than the size of its pores can be captured and retained in the depth of the filter.

The foam structure also provides smooth, non-turbulent metal flow, so that oxide formation during mold filling is avoided. This generally allows for simplification and reduction of gating systems, providing significant cost savings through yield improvement.

Dimensional control is excellent – with typical tolerances of +0.0, –0.06 inches. Metal flow rates and flow capacity before blockage are comparable to those of similar ceramic foam filters.

Specific advantages of the novel formulation of SIVEX FC filters include:

- The absence of abrasive ceramic components allows significant new freedom in filter location, even very close to the casting surface, since the filter can be removed by machining without damaging the cutting or machining tools.

- The filter's low density – only about 60% the density of comparable ceramic filters – means that filters readily float to the surface of the melt during recycling of gates. They are then easily skimmed off with the dross, eliminating concerns about particles remaining in the melt.

- The phosphate-free binder further eliminates concerns about melt contamination during recycling.

- Because the graphite composition is more easily wetted by molten aluminum than are typical filter ceramics, the metal head height required to effectively prime the filter in the early stages of pouring is reduced. With ceramic filters, a priming head of about four inches is typically needed. With SIVEX FC filters, this is typically reduced to 2.5 inches.

- The low density and low thermal capacity to the filters result in reduced heat loss from the metal to the filter, preventing premature freezing and allowing feeding through the filter to take place more easily when used in a direct pouring application.

Use of computational fluid flow techniques

As has been said earlier, a lot of foundry methoding has taken place on a trial and error basis. The industry for years has been trying to interpret precisely what happens as metal flows inside the mold cavity, and many thoughts and theories have been postulated. A great deal of work has been performed on optimizing metal velocity (3), thereby preventing turbulent flow and oxide formation. It is with this background that the use of computational techniques started increasing.

The design of the perfect running system can ensure that metal reaches the cavity under the correct conditions, but what it doesn't do is ensure that it comes in at the correct point of the cavity. There is still the possibility in complex geometries of turbulent flow after the point of entry into the mold cavity. It is for this reason that fluid flow analysis is coming more to the fore to give an understanding

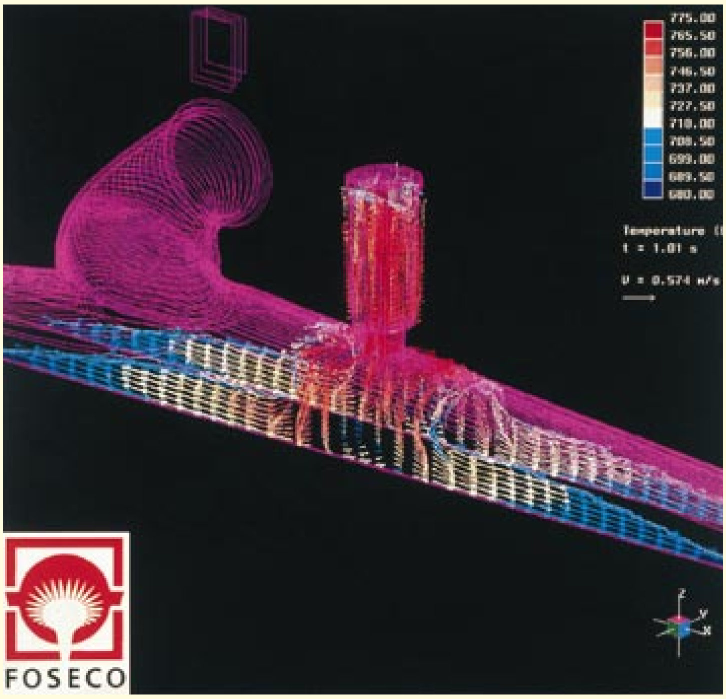

Figure 3: Air inlet manifold showing flow simulation study.

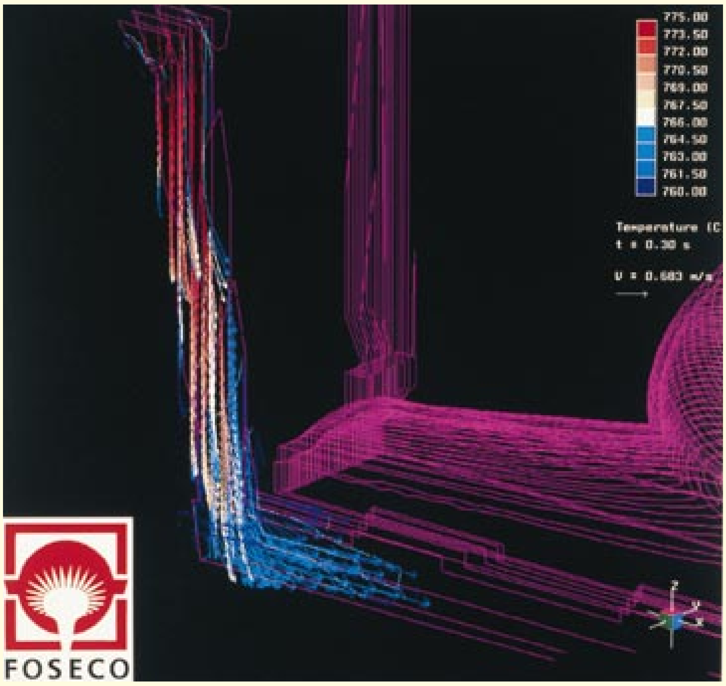

Figure 4: Runner bar simulation showing turbulent flow.

of where best to position gates and running systems and also to determine how the casting will solidify, thereby locating the areas required for additional feed. Many commercial packages for computational fluid flow analysis are now available on the market, and the Foseco group has been using one of these packages for in excess of three years in order to help foundries determine optimum positions for running and riser systems, see figure 3, and for the location and use of KALPUR direct-pouring units. These flow simulation systems are not entirely foolproof, but they do allow more detail on how the metal flows as it fills the mold cavity, see figure 4, and where areas of turbulence are likely to be. A temperature distribution within the mold cavity as filling progresses (5 and 6) is also available to the user. This gives a more detailed understanding of how the casting is likely to solidify as there is a closer knowledge of the temperature distribution at the point when the casting cavity becomes full.

Using this type of analysis, simulation of filling can take place before the permanent mold is produced or fabrication of patterns for sand molds is done to see where the problem areas are likely to be for a particular casting, and to optimize the running system, see figure 5. Further, it can enable foundries to discuss with the casting designers modifications or refinements to the casting that would improve the flow characteristics without necessarily changing the engineering application of the component itself. It takes away the ‘hit and miss’ aspect that is currently employed and moves the foundry closer to the ‘get it right first time’ principle, which reduces the time to produce prototype castings and optimizes the amount of metal required to produce the casting, thereby leading to improved productivity.

Figure 6 shows flow through and around a filter during flow simulation. Much work has been performed in terms of defining the boundary conditions for a filter to be used in computational fluid flow analysis such that the effect on the flow and temperature distribution of the metal through the filter can be observed. Different porosities of filters obviously have different effects in terms of the flow characteristics of the metal and on the temperature distribution. Importantly, this technique has been able to scientifically support the positioning of direct-pour systems – see figure 7 – which are subsequently put into commercial production – figure 5. The combination of this technique with SIVEX FC filter technology is now a powerful tool available to foundries. Combined with costing considerations, casting cycle times, and productivity requirements, a true cost/benefit analysis can be carried out.

Cost/benefit analysis

Filters have historically been viewed as an additional cost to the casting, with justification for their use occurring only when cost of scrap is greater than filter cost. This is a common perception, but the reality is somewhat different as highlighted by this example.

A detailed study was made at an automotive foundry in Europe producing intake manifolds for automobiles. Yields were typically around 55%. The costs associated with the production of parts at this plant were obtained, including fixed overhead, wage rates, average overtime, permanent mold maintenance, scrap rates for cores as well as castings, metal costs, melting costs, and treatment costs to give a full picture of the total production cost.

A model was then created showing the effect that scrap and yield had on productivity and how productivity could be measured in cash terms. The single largest financial component was metal and the model showed that the improvement on the profit line in reducing scrap from 5% to 1% was an overall 3% extra profit. As is well known, the cost to achieve this kind of reduction in scrap is often high, even if it can be achieved at all. However, improving yield from 55% to 72% doubled the profit per casting, and also reduced production time and therefore overtime. The amount of time in the trimming room was reduced by 30% allowing labor redeployment and removal of a potential bottleneck.

The impact on the cash flow of the business was a staggering $4.5 million. Although the cost of their direct-pour units used was around $1.45 each, the gross margin achieved on the part improved by 5%. Factors which showed as significant contributors to the overall improvement are:

- labor
- trimming
- treatment
- power
- compressed air
- furnace maintenance
- reduction in metal inventory

This analysis leads to a change in focus. Instead of concentrating only on small scrap reductions, yield improvement should be given a much higher priority.

A table of case studies – table 1 – was compiled from foundries who have begun to take some or all of these factors into account when making decisions on how to increase profitability. Although all of these foundries have different cost structures, the one thing that they have in common is that metal is their most significant single item of expenditure.

One recent study has been expanded to give more practical detail on the procedures involved in converting to the optimized gating arrangements.

Case study

This UK semi-permanent mold foundry is producing a Volvo truck manifold casting with a section thickness of ⅛ inch and an overall length of 39 inches. The problems associated with this casting were mainly lack of pressure tightness. Despite trialling numerous rigging systems, the high leak rate resulted in the need for 100% impregnation. Direct-Pouring was recommended as an alternative. The before and after gating arrangements are shown in figure 7 and figure 5.

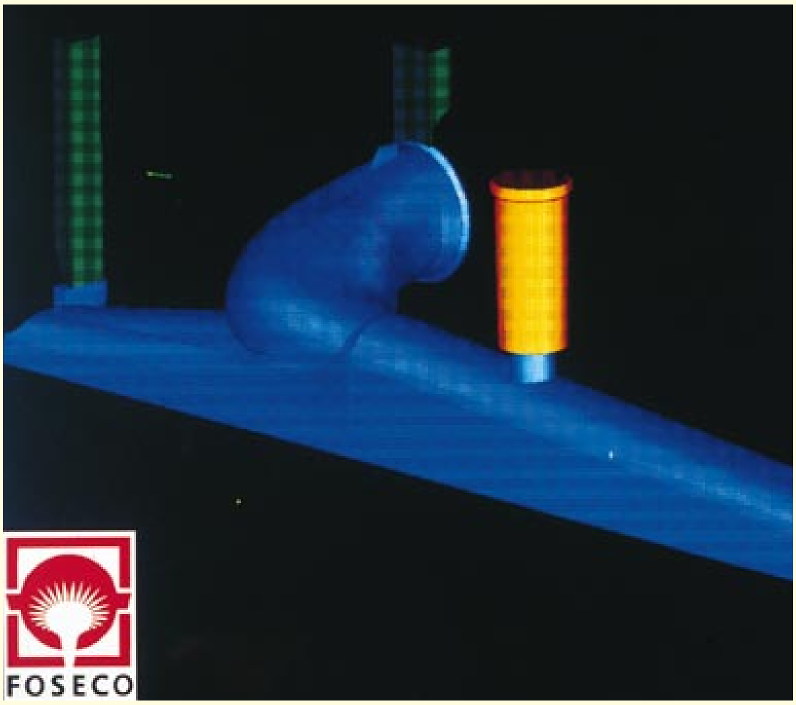

Figure 5: Air inlet manifold showing optimized gating arrangement with direct-pour.

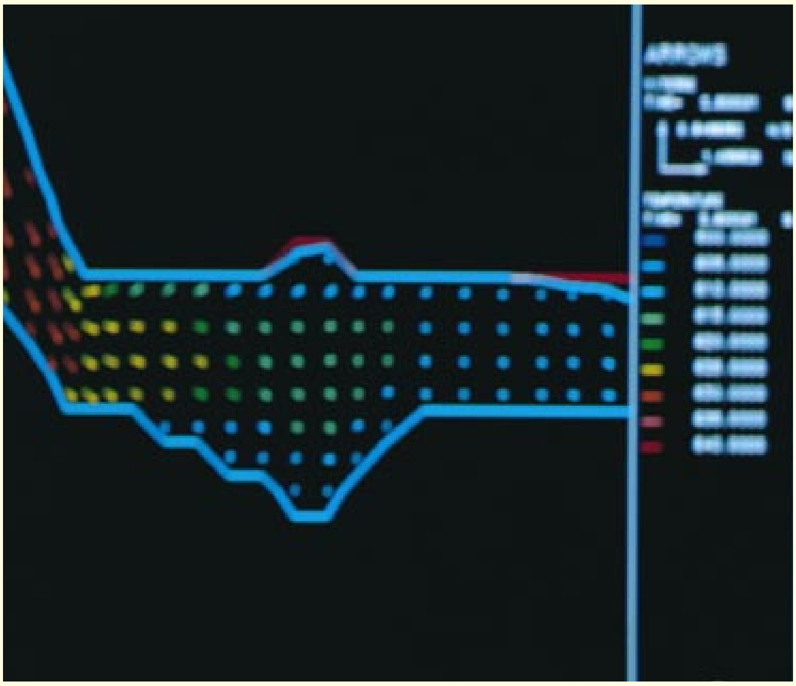

Figure 6: Flow simulation through a foam filter.

Country	Casting	Production per month	Weight (lb)	Direct-pour	Justification criteria for acceptance		
					Quality	Productivity	Yield
UK	Manifold	500	10	Yes	Yes	Yes	Yes
Germany	Frame	900	7	Yes	Yes	Yes	Yes
Switzerland	Wheel	40	170	Yes	Yes	Yes	Yes
Germany	Housing	10,000	22	Yes	No	No	Yes
France	Wheel	40,000	24	No	Yes	Yes	No
Spain	Manifold	10,000	5	No	Yes	Yes	No
France	Cyl Head	55,000	29	No	Yes	No	No
USA	Manifold	1,000	26	Yes	Yes	Yes	Yes
USA	Cyl Head	12,000	23	Yes	Yes	Yes	Yes
Germany	Wheel	50,000	21	No	Yes	No	No
UK	Pump	2,000	5	Yes	No	No	Yes
France	Turbo	7,500	2	Yes	Yes	Yes	Yes
Spain	Fan	50	68	Yes	Yes	Yes	Yes
UK	Converter	1,500	2	Yes	Yes	No	No

Case studies of production castings showing reasons for conversion from conventional to optimized gating arrangements.

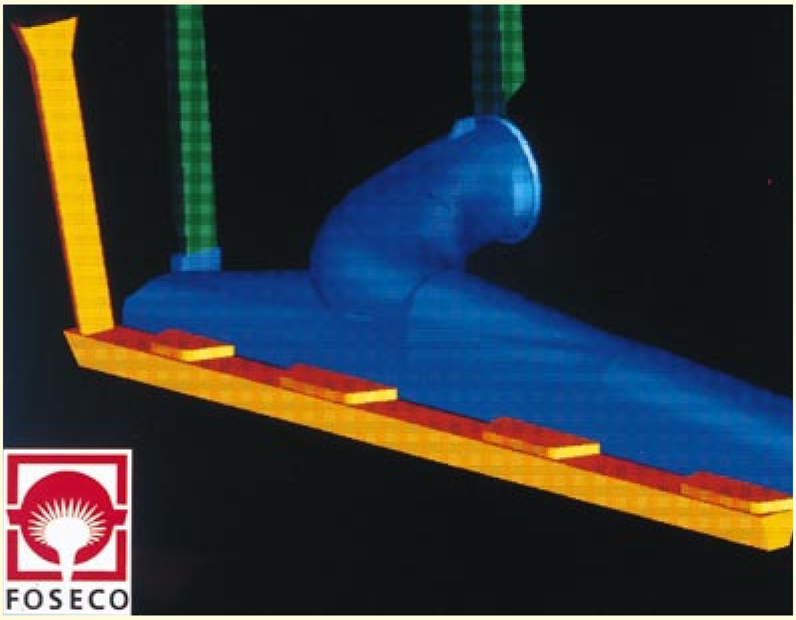
Figure 7: Standard pouring system for an inlet manifold.

The casting yield data is presented below:

	Before	After
Gross wt	15 lb	10 lb
Net wt	7 lb	7 lb
Yield	45%	70%

The immediate value recognized was the complete elimination of impregnation from the manufacturing process.

An additional benefit was the yield and the associated productivity improvements. The simplification of this gating dramatically reduced the mold costs and lead time at the toolmaker.

Summary and conclusion

The value of foam filtration technology both in terms of the physical characteristics of the filter itself and its applications has been significantly increased by recent developments. These include:

- New filters with significant advantages in performance and remelt.
- Advanced application engineering techniques simulating mold cavity filling.

Armed with this understanding, work can be focused not on general parameters, but on the specific aspects of the casting process which will add most value to that particular casting. Many large foundries are now using ‘optimized filter technology’ to help achieve the financial goals as well as the technical goals. Continuous improvement is still a must, but a milestone has been reached. Foundries are not only asking:

- How much does it cost?

but are also asking themselves:

- How much value can it add to my casting?

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