Light Metals 2011 *Edited by: Stephen J. Lindsay*
TMS (The Minerals, Metals & Materials Society), 2011

A REVIEW OF THE DEVELOPMENT OF NEW FILTER TECHNOLOGIES BASED ON THE PRINCIPLE OF MULTI STAGE FILTRATION WITH GRAIN REFINER ADDED IN THE INTERMEDIATE STAGE

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Keywords: Filtration, Cyclone

Abstract

Recent developments in filtration technology based on the principle of using a three stage process where a ceramic foam filter is operated in cake mode in the first stage; grain refiner is added in a second chamber and a further filtration means is used in the third stage to remove oxide inclusions or agglomerates originating from the grain refiner addition are reviewed. The first development – the XC Filter, was presented by Instone et al in 2005 and described a system where a small deep bed filter (DBF) was successfully applied in the third chamber.
A second prototype multi stage filter was described at TMS 2008 based on the same principle but with a cyclone deployed in the final chamber. An industrial prototype was constructed based on water modeling work and plant trials were undertaken.
The current stage of development of each system and their relative merits are evaluated.

Introduction

Peter Waite (1) stated that there was a definite need to develop an efficient, low hold up volume, filtration process capable of treating high flow metal rates. The object of the work reviewed is in each case to develop a filter that could deliver the high efficiency performance of a deep bed filter but with low hold up volume, low floor space requirement and the ability to be used economically in conjunction with frequent alloy changes.

The phenomena of enhanced filtration efficiency in ceramic foam filters that could be achieved by adding the grain post filter reported by Towsey et al (2) provided the starting point.
This phenomenon was first reported by Kakimoto et al (3) in 1996 in relation to the operation of porous tube filters. Kakimoto concluded that bridges of CaO particles that tended to form at the pores at the surface of a tube filter were "suppressed" by the addition of boron containing grain refiners. That is the addition of titanium diboride particles prevented the formation of a stable filter cake which is initiated by the formation of bridges as a first stage to support the subsequent cake formation. This conclusion was reached on the basis of metallographic examination of spent tube filters.

In 2002 Towsey et al (4) reported the results of an extensive study on the effect of addition of various grain refiner compositions on the performance of ceramic foam filters with the conclusion that grain refiner addition, via a suspected agglomeration behavior and alteration of filtration mechanism, prevented bridge formation in finer pore ceramic foam filters thus reducing the hitherto observed very high filtration efficiencies reported in earlier work (5).

A more recent study by Lae et al (5) using a filtration pilot showed that from the point when standard AT5B grain refiner was added to alloy 5182 at a casting speed of 1.8cms/s the post filter Limca count increased from 9k/kg up to 20k/kg and the filtration efficiency decreased from 71% to 31%. It was concluded that this was due to the interaction of grain refiner particles with the bridge formation mechanism observed in non grain refined melts.

The XC Filter – three stage filter with mini bed

In 2005 Instone et al (6, 7) described a new design of filter unit named the XC filter which gave superior filtration efficiency achieved by the combination of ceramic foam filtration and deep bed filtration. Importantly this design comprised a three chamber unit with a ceramic foam filter in the first chamber, grain refiner addition in the second chamber and a small bed filter in the third chamber.

The design concept is shown schematically in Figure 1.

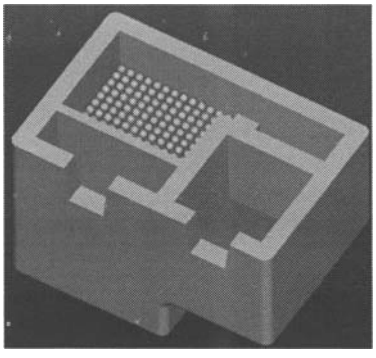


Figure 1. XC Filter design, Instone et al, (6, 7)

Several prototypes of this filter were built and tested over the period 2000-2005 at the pilot DC casting center at the Rheinwerk smelter in Neuss Germany. More than 80 evaluation casts using this technology were conducted in this period. This evaluation program extended through to a three week pre-production trial. The results of the pilot testing compiled using LiMCA and PoDFA measurement techniques showed that excellent filtration efficiency could be achieved. These results have been reported previously by Instone et al (6, 7). In this paper the results achieved during the pre-production trials will be discussed.

This extended casting campaign was performed with the XC-Filter prototype shown in Figure 2 to demonstrate the long-term stability of the technology under production conditions. This work also helped to finalise the various scale-up parameters for a production unit. Unlike previous trials which were conducted using potroom metal, these trials were performed using metal prepared from recycled foil scrap or processed dross and delivered to the furnace as molten pre-alloyed metal.

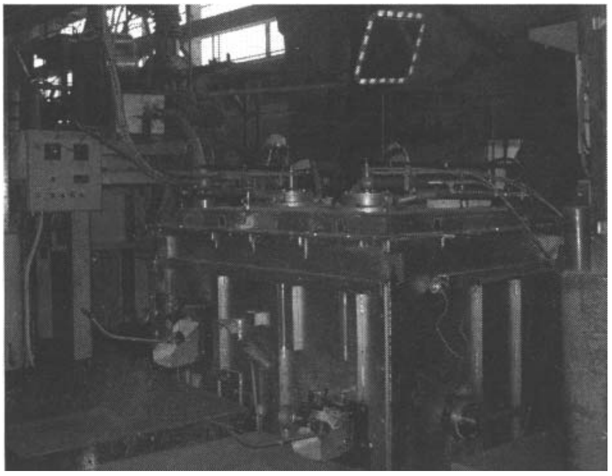


Figure 2. Industrial prototype XC filter used for these trials

An overview of the casting program and a summary of several important parameters is presented here:

- Total of 37 casting trials performed in this campaign
- Changed bed filter filling after 13 casts due to small leak at tap hole.
- 7 CFFs used – changed out after on average 5 casts

The following parameters were used for all casts:

- 1 mould of 1750mm x 600mm size
- Flow rate of ≅10t/h
- Casting speed of 62 mm/min
- 30ppi CFF – 3 suppliers
- 5-layer DBF- bed filter construction as used in the previous work
- Grain refinement after CFF and before DBF (3:1 TiB rod from LSM at 0.6kg/t)
- Layout of casting and measurement equipment shown schematically in Figure 3.

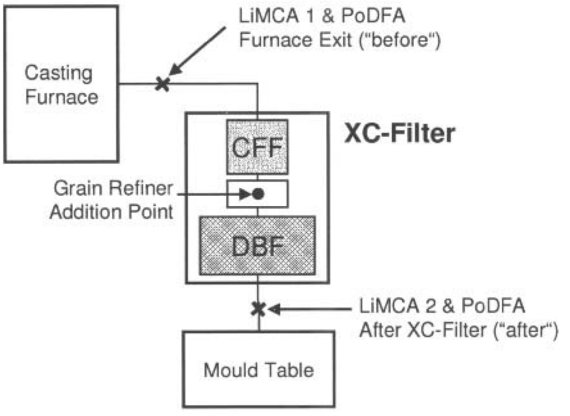


Figure 3. Plan view schematic of centre 40 at NESIC, showing positions for melt quality measurement by LiMCA and PoDFA and the position for the addition of the grain refiner

Melt treatment: The furnace was de-drossed after filling with the liquid metal. No alloying or gas injection was performed. On occasion, in order to increase the inclusion loading during casting, the melt in the furnace was stirred manually with a paddle. A typical LiMCA curve showing the effects of this stirring operation is shown in Figure 4.

Inclusion removal efficiency was found to be higher for the stirred melt with higher inclusion levels. This effect is shown for several casts in Figure 5. Figure 6 shows the increased filtration efficiency for different particle sizes. This figure also shows that the level of inclusions at the filter exit did not increase as a result of the stirring operation, which demonstrates the robustness of the XC filter.

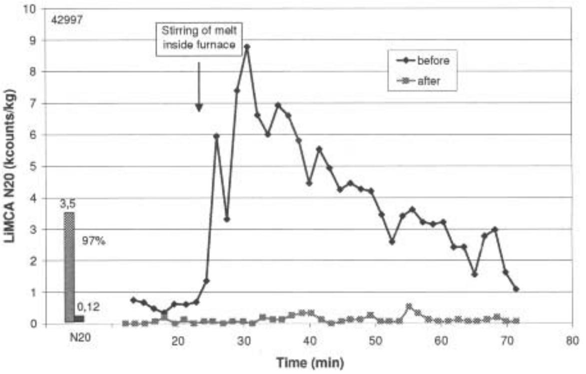


Figure 4. LiMCA N20 run chart and average N20 counts for charge 42997

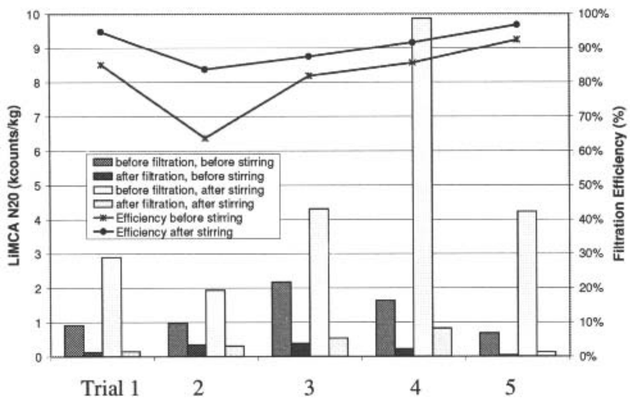


Figure 5. N20 values measured at the two LiMCA positions before and after stirring of the melt in the furnace

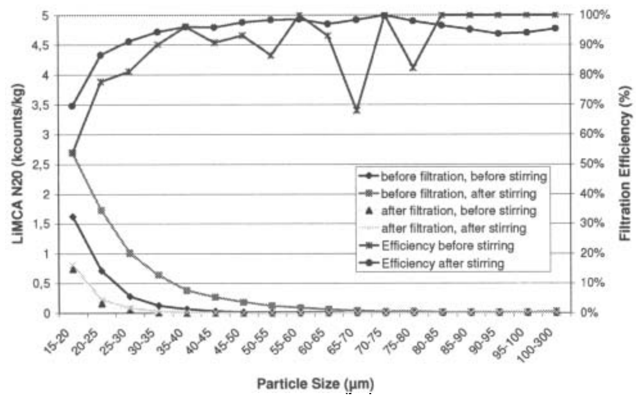


Figure 6. Inclusion size distribution for stirred and settled melts measured at the two LiMCA positions.

Performance of XC-filter at different levels of inclusion loading

Figure 7 shows the average LiMCA N20 values for all charges before and after filtration. The filtration efficiency is sorted by the inclusion loading in the metal coming from the furnace. As seen in the previous examples, the filtration efficiency results show a correlation between filtration efficiency and inclusion loading. Four ranges of inclusion loading were defined:

- ultra low loading below 1.0k/kg,
- low loading between 1.0k/kg and 2.0k/kg,
- medium loading between 2.0k/kg and 5.0k/kg,
- high loading above 5.0k/kg.

For these four ranges the average inclusion loading before and after filtration and filtration efficiency were calculated. For inclusion loading >1kcounts/kg (N20) filtration efficiency was greater than 85%.

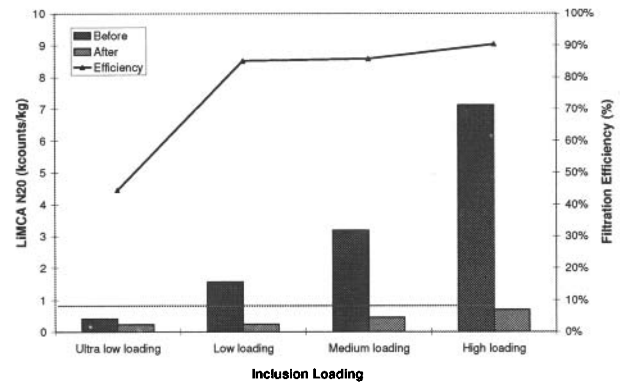


Figure 7. Effect of inclusion loading on filtration performance Capacity of CFF and bed filter in the XC-Filter

An important factor of the performance of the CFF in the XC-Filter is the capacity of the filter, that is, the amount of metal that can be passed through the filter before it has to be replaced. None of the CFFs was replaced due to blockage of the filter or deteriorations in the filtration efficiency. Never the less, the filter capacities achieved in these trials were significantly higher compared to the results gained in previous casting campaigns. The main difference between these two campaigns is the metal source. In the past only pot room metal was used for the trials while re-melted foil scrap or metal won from processed dross was used in the current campaign. This recycled metal had of course already been inoculated with TiB grain refiner.

Metallographic inspections of the used filters supported this argument. Al-Oxides, predominantly present as oxide-skins were mainly observed in the samples. No bridging in the uppermost cells of the CFFs, such as previously documented, was observed in any of the used filters examined. As has been previously suggested, Titanium Boride particles present in the recycled metal may have prevented the formation of bridges in these filters.

A reduced efficiency of the CFF may have resulted due to the presence of these grain refiner particles in the melt. This in turn would have increased the number of inclusions entering the bed filter. A higher total filtration efficiency and bed filter capacity under production conditions could be expected to when using exclusively potroom metal.

The overall filtration efficiency when using recycled metal was also considerably higher than that of a standard CFF when used in conjunction with TiB grain refiners.

PoDFA samples, before and after filtration, were taken at a casting length of about 2m for each cast. Selected samples were chosen for further metallographic investigation. The same methodology as used for the evaluation of the LiMCA data, was applied to the PoDFA data and confirmed at least semi-quantitatively the good filtration performance of the XC filter. The metal exiting the furnace contained a variety of particles such as Al-oxides, Mg-oxides and Al-nitrides. After passing through the filter the amount of inclusions present in the melt was significantly reduced with the predominant inclusion type being Al-oxides.

Optifilter – three stage filter with Cyclone

In 2005 Katgerman (8) described work on water modeling and computer modeling of flow control devices. It is well known that dams and weirs placed in a launder section or a chamber, such as that forming part of a degassing apparatus, contribute to the removal of inclusions. However, Katgerman concluded that, although this could be effective for small concentrations of particles, this technique suffered from the drawback that small fluctuations in the flow behavior may reintroduce the sunken particles (collected at the base of the dams due to settling out by virtue of their higher density relative to liquid aluminium) into the metal flow.

Instead, based on flow calculations, the concept of a cyclone was developed and subsequently proven in terms of effectiveness by further numerical and water modeling experiments.

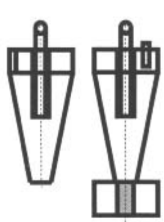
Design of the prototype

A design concept was determined based on the above considerations and comprised three chambers:

- A first chamber containing a ceramic foam filter
- A second chamber for the addition of grain refiner
- A third chamber containing a cyclone.

A key requirement of the design was that it should be able to work effectively with a maximum available head height at the casting pit of 1000 mm. The cyclone itself was required to fit into maximum external space of 1000mm x 1000mm x 1000mm which meant in practice, after allowing for the metalwork and refractories, that the maximum internal height for the cyclone would be 740 mm.

The efficiency predicted is shown below. The figure depicts the % particle removal efficiency for different flow velocities and two types of cyclone design, type 1 without a container for inclusion capture at its base and type 2 with a container for inclusion capture.
The results of the flow modeling and design of the cyclone have been presented in detail separately by Turchin et al (9)



Type 1 Type 2

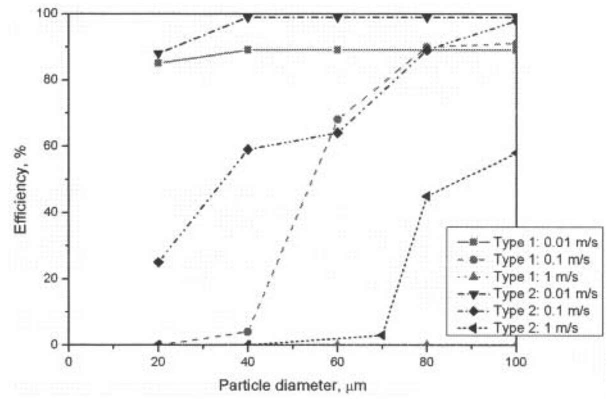


Figure 8. Predicted efficiency for particle removal by cyclone

The model shows an expected removal efficiency of approximately 50% for particles >60micron with a flow velocity of 0.5 m/s rising to 80% for particles > 100 microns. However, the true removal efficiency can only be determined by actual operation of the unit in practice.

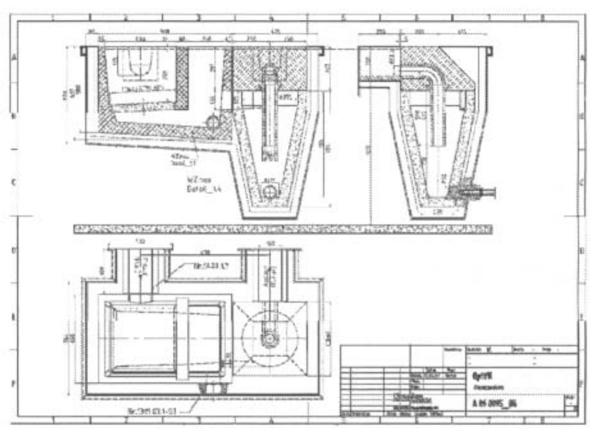


Figure 9. Final design of three stage "OptiFilter" filtration unit.

First casting trials

Casting trials were carried out at Trimet Aluminium under the following conditions:

- Alloy: 1000 series 790
- Number of billets: 32
- Billet length: 2000 mm
- Cast size: 13,000kg
- Casting speed: 200kg/min
- Casting temperature: 790° C

Some difficulties were experienced with preheating the first chamber containing the ceramic foam filter and the cyclone chamber

Despite these initial problems a heat was successfully started at the second attempt and metal flowed through the filter for some 20 minutes before freezing off on the casting table.

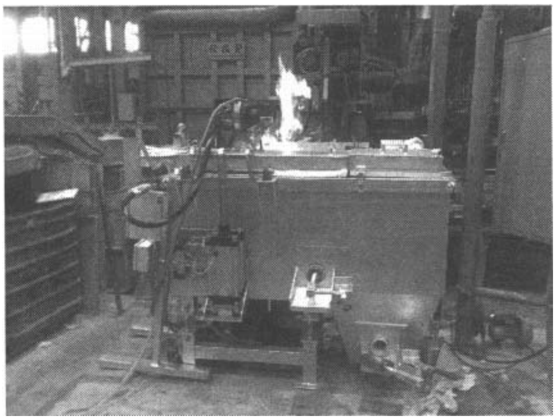


Figure 10. The prototype "Optifilter" filtration unit under pre heat at Trimet Aluminium.

Second casting trial

Following modifications to the prototype to improve insulation and pre heating a second casting trial was attempted using the same conditions as in the previous test. However, although liquid metal passed successfully through the cyclone it was observed that the flow rate was very low – the exit tube only filled to approximately 10% of the exit cross section and it was estimated that the flow rate being achieved was of the order of 3t/h instead of the 15 t/h target.

Figure 11. View of the exit flow from the cyclone showing that the exit flow tube is only partially filled.

From these second series of trials it was concluded that:

The measures to improve insulation and increase preheat temperature had been successful.
Nonetheless despite this the unit still froze off and this was due to the outlet flow rate having been restricted to only 3t/h.

It was considered that restriction to the outlet flow must be due to either insufficient head height to overcome the resistance to flow of the cyclone and or an insufficient cross sectional area at the cyclone inlet slot to allow adequate flow through the cyclone.

Further water modeling

It was decided to re validate the flow modeling and conduct further water model tests at Delft University to verify the model. The water model was set up with a facility to use a variable inlet and head height. After extensive testing it was concluded that both an enlarged inlet slot cross sectional area and additional head height of +150mm would be required to ensure that the outlet pipe was completely filled.

Modifications were subsequently made to the prototype to provide an additional 150mm of head height and further liquid metal trials were undertaken on a sow caster at Trimet. The result was very satisfactory with the outlet pipe being completely filled with a 2.4 tonne crucible being cast through the Optifilter in less than 5 minutes.

The next stage will involve setting the system up on the research casting pit with a 150mm available head height difference and casting two billets over the period of one hour. Podfa samples and billet slices will be taken to enable an assessment of the effect on cleanliness of the Optifilter to be undertaken.

Discussion

The two technologies reviewed stem from a common starting point: the observation that addition of grain refiner in front of a CFF reduces filtration efficiency by preventing the formation of bridges at the top surface of the filter which act to form a filter cake which changes the filtration mode from being substantially depth filtration to cake mode filtration.

To use this phenomena in a practical way it is necessary to employ a third chamber to ensure that no oxide stringers or boride agglomerates from the grain refiner can pass from the filter to the casting table.

Two approaches have been developed to the prototype stage, in one case using a mini bed in the third chamber, in the other applying a cyclone.

The XC filter on the one hand has progressed successfully to a pre production stage trial were 37 heats were cast over a period of three weeks indicating the robustness of the technology and its suitability for casthouse operation. The results in terms of filtration efficiency were excellent with efficiencies of 97% for inclusion sizes over 50 microns together with average post filter N-20 Limca counts of 400/kg.

The Optifilter initially suffered from difficulties in achieving the desired flow rate through the cyclone. At first this was thought to be due to problems with pre heat or insufficient inlet slot cross sectional area. Both of these were corrected but the flow rate was still inadequate and subsequent further water modeling pinpointed insufficient head height. When the head height difference was increased to 150 mm the outlet pipe was completely filled and a flow rate of >20t/hr was achieved on a sow casting station.

Ultimately it is anticipated that with sufficient head height that the cyclone will function satisfactorily however the requirement for additional head height of the order of 150mm may make it difficult to retro fit the Optifilter into existing casting lines without significant modification. Nonetheless should it be successful the cyclone would provide a low maintenance third chamber which would make it possible to use the system for frequent alloy change or low volume operations were it is necessary to drain the box completely between charges.

On balance the ability of the XC filter to deliver ultra high efficiency is already proven under production conditions and the system will be suitable for application were either long runs of the same alloy are made or were it is possible to flush through the relatively small hold up volume to allow a number of alloy changes to be made in sequence without the need to drain the bed. On the other hand if successful the Optifilter will provide a similar high efficiency filtration solution for frequent alloy change or low volume operations where it is necessary to fully drain the filtration unit.

Conclusions

In summary the following conclusions can be drawn regarding the stage of development and relative merit of each of the two technologies:

XC Filter – three stage filter with a mini bed

1.During a production trial campaign involving casting 37 heats in sequence over a three week period a consistently high metal quality for the filtered metal was achieved through out and the prototype system functioned satisfactorily. The metal quality (LiMCA N20) after filtration averaged 0.4k counts/kg and consistently bettered the target value of <1k counts/kg,
2. The trials proved the operational robustness and the usability of the XC-Filter concept. No major change in concept is considered necessary for the industrial version. Over 80 casts have now been performed with this prototype,
3. Stirring of the melt in the furnace increased the total number of inclusions as well as the number of larger inclusions reaching the filter from the furnace. The metal quality of the filtered metal leaving the XC-Filter was independent of variations in the level of incoming inclusions. Consequently higher filtration efficiencies were realised for high inclusion loading situations
4. The capacity of the CFFs increased compared to the results of 2003. The different metal source: recycled metal instead of potroom metal, is believed to be the main contributing factor here,
5.The filtration efficiency for metal entering the filter with 1k – 10k counts per kg was 85%-90% but decreased significantly to approximately 45% for very clean metal entering the filter with less than 1k counts per kg,
6. XC filter is suitable for application in casthouses where either long runs of the same alloy are made or were it is possible to flush through the relatively small hold up volume to allow a number of alloy changes to be made in sequence without the need to drain the bed.

Optifilter – three stage filter with cyclone

1. The system has been developed to the stage of providing a prototype for production trials but practical difficulties have been encountered with priming the cyclone chamber. It has been demonstrated in casting trials that a head height difference of approximately 150mm will be required between the inlet and outlet levels to drive metal through the cyclone at a sufficient rate to achieve the required flow rate for casting.
2. Further trials are planned with a modified prototype with a 150mm head height difference during which filtration efficiency measurements will be conducted.
3. Providing the above are successful the system would potentially provide high efficiency filtration solution for casthouses where frequent alloy changes or low volume operations necessitate fully draining the filtration unit between casts.

Acknowledgments

The Authors would like to express their sincere thanks to the management teams and casting personnel of: Hydro Aluminium Deutschland GmbH Research and development centre Bonn; and Trimet Aluminium AG casthouse at Essen.

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