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RECENT PROGRESS WITH DEVELOPMENT OF A MULTI STAGE FILTRATION SYSTEM EMPLOYING A CYCLONE

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Abstract

The development of a multi stage filter comprising a ceramic foam filter applied in a first chamber operating in cake mode; grain refiner added in a second chamber and a cyclone deployed in a final chamber to ensure removal of oxides and agglomerates arising from grain refiner addition was presented in TMS 2008. The first industrial prototype, installed at Trimet Aluminium at Essen in Germany, demonstrated that liquid metal could pass through the cyclone successfully without excessive turbulence or splash. Initial difficulties in achieving the desired flow rate through the cyclone were overcome by increasing the head height difference to 150 mm and a flow rate of >20t/hr was achieved in testing on a sow casting station and reported at TMS 2011. The most recent results of trials carried out on the Research Casting pit at Trimet were measurements of the metal cleanliness achieved were made are presented.

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.

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.

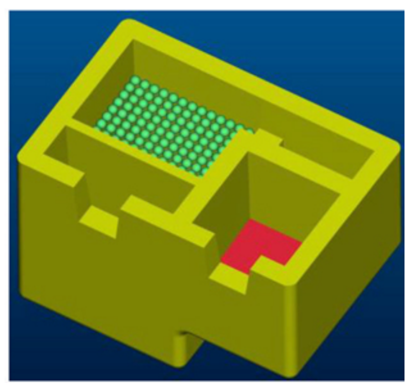

Figure 1. XC Filter design, Instone et al, [6, 7]

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 by Instone et al [6, 7]. 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 pot room 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 at Hydro Rheinwerk ,Neuss.

A typical result for inclusion removal efficiency measured by LiMCA is shown below in Figure 3,

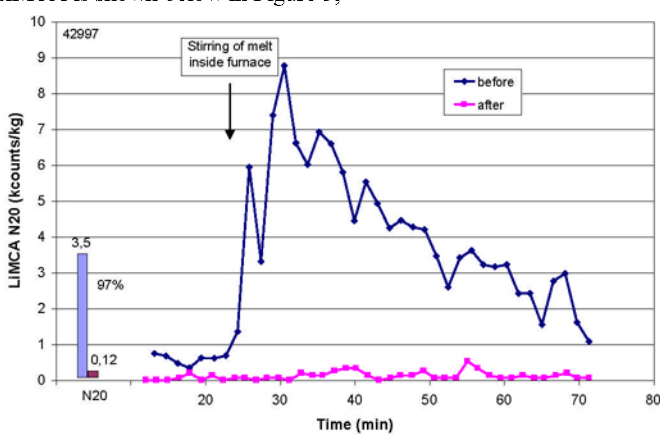

Figure 3. LiMCA N20 run chart and average N20 counts for charge 42997

This clearly shows the potential of the XC Filter to provide bed filter performance, i.e., < 700 counts LiMCA N20 post filter from a compact unit with low hold up volume and a small footprint.

However in a further development, again based on a three stage configuration applying the principles learned from the earlier work with VAW [2] a cyclone was introduced as the third stage replacing the min bed filter used in the XC design. The object of using a cyclone was to further minimize footprint and importantly to provide a low maintenance solution for the operation of the third chamber that would make it suitable for application involving short runs and frequent alloy changes.

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 in Figure 5 which depicts the % particle removal efficiency for different flow velocities for 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 which are shown below in Figure 4.
The results of the flow modeling and design of the cyclone have been presented in detail separately by Turchin et al [9]

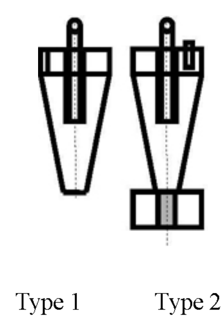

Figure 4. Cyclone designs

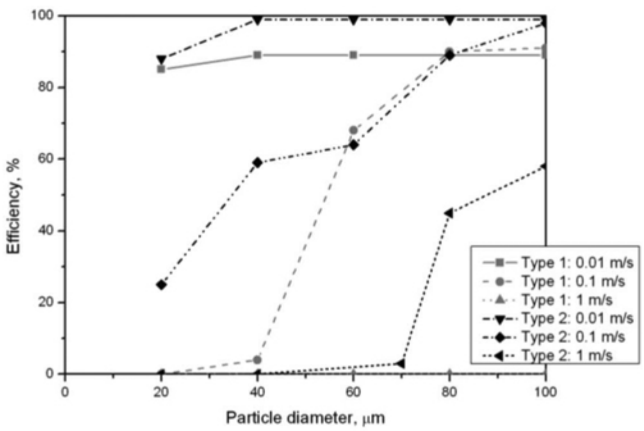

Figure 5. Predicted efficiency for particle removal by cyclone

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.

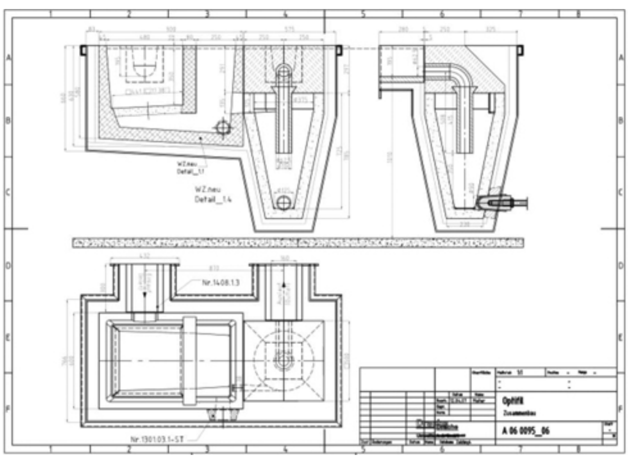

Figure 6. Final design of three stage "OptiFilter" filtration unit.

First casting trials

Casting trials were carried out at Trimet Aluminium with the three stage " Optifilter design" shown in figure 6. The casting with conditions were as follows:

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.

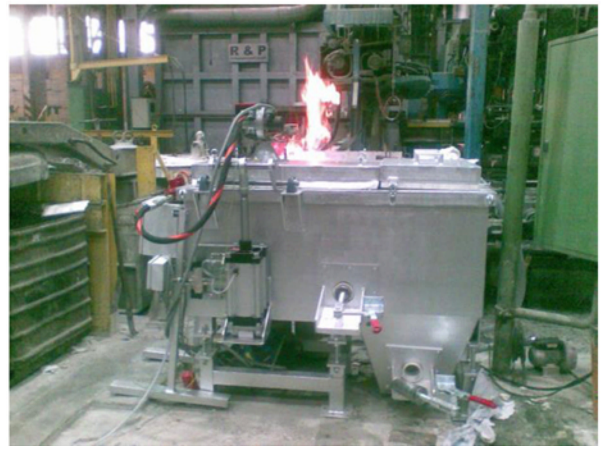

Figure 7. The prototype "Optifilter" filtration unit under pre heat at Trimet Aluminium.

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 as shown in figure 8 below; 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 8. 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 shown below in figure 9. 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, equivalent to a casting rate of >20t/hr.

Figure 9. Casting trial at sow casting pit

Testing at the R&D casting pit of Trimet

The next stage involved setting the system up on the Research and Development casting pit at Trimet Aluminium (figure 11), with a 150mm available head height difference and casting a large diameter single billet over the period of one hour. PoDFA and Prefil samples together with billet slices will be taken to enable an assessment of the effect on cleanliness of the Optifilter to be undertaken.

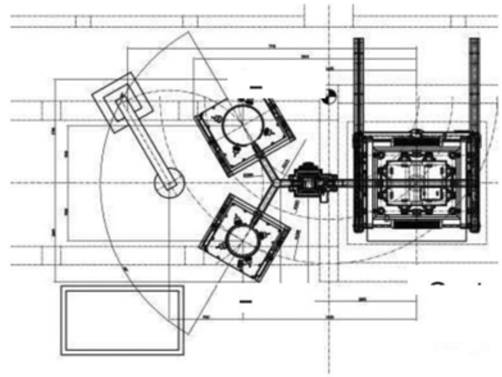

Figure 10. Layout of R&D casting pit.

Figure 11. Photograph of R &D casting pit taken from the casting table side.

The results will be presented at the conference in Orlando in March 2015.

Discussion

The two technologies discussed 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 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. Should it be successful the cyclone will 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.

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 will potentially provide a high efficiency filtration solution for casthouses where frequent alloy changes or low volume operations necessitate fully draining the filtration unit between casts.
4. Results of the measurement of filtration efficiency will be presented at the TMS meeting in Orlando in 2015.

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