ADVANCED COMPACT FILTRATION (ACF): AN EFFICIENT AND FLEXIBLE FILTRATION PROCESS

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Abstract

Deep bed filters are well known not only for providing efficient inclusion removal that is required for critical products, but also for their relatively high metal hold-up. In multi-alloy casthouses, filtration costs associated with deep bed filters can be considerable due to filter media replacement and scrap metal generation at alloy changes. This paper describes the key components of a new metal filtration technology, the Advanced Compact Filter (ACF) developed and industrialized by Rio Tinto Alcan (RTA). The ACF provides flexible, efficient and robust filtration suited for large product mix environments. This technology was successfully demonstrated on critical products, and is now fully implemented and operated in one Rio Tinto Alcan casthouse. This paper also presents the main benefits for cost reduction provided by this technology.

Introduction

In-line filtration to remove inclusions from the melt is mandatory for the production of various aluminum alloys and products. Different technologies such as ceramic foam filtration, porous tube filters and deep bed filters are available depending on the metal cleanliness requirements of the products. The choice of equipment is driven by the product requirements according to filtration efficiency, cost and flexibility. Typical filtration efficiency by technology type is presented in Figure 1.

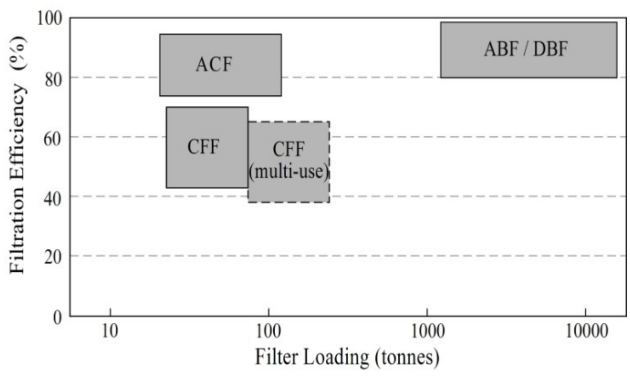

Figure 1. Efficiencies of different filtration technologies (ABF, CFF and ACF)

Owing to its high efficiency of typically greater than 90%, the Deep Bed Filter or the Alcan Bed Filter (DBF or ABF) is commonly used for critical product applications such as can end stock (CES) and lithographic sheet. However, over thirty years of operating experience within Rio Tinto Alcan casthouses has demonstrated that deep bed filtration costs are high and can vary from 2 to 14$/mt, depending on the volume of metal that is filtered through each bed. The tonnage filtered through a DBF varies depending on alloy specification, molten metal origin, and the number of different alloys that are produced by the casthouse. Moreover, deep bed filtration technology reduces the casthouse operational flexibility. Due to the significant metal hold-up volume that is maintained between casts, the frequency of alloy changes is kept to a minimum, and rigorous planning of product orders is required. In addition, when producing high magnesium alloys, the tabular alumina beds must be "conditioned" with a more tolerant alloy to eliminate sodium pick-up from the new filter material. This is required more specifically on can end stock to avoid the formation of downstream fabrication defects such as edge cracks.

On the other hand, ceramic foam filters (CFF) are widely used for the production of a vast number of alloys and products such as foundry remelt ingots and general purpose sheet ingots. With filtration efficiencies varying from 30 to 90%[1,2], the CFF is limited to applications requiring moderate metal cleanliness. In addition, CFF filtration costs are relatively low and consistently fall between typically 2 and 4$/mt. This type of equipment does not require metal hold-up between casts nor bed conditioning, for high magnesium alloys, and therefore allows greater flexibility for alloy changes.

In order to meet the market demands of on-time delivery over a wide range of products and alloys, without compromising the stringent metal cleanliness requirements of different customers, there is a need for a flexible, efficient and low cost filtration technology that combines the best aspects of deep bed and CFF filtration technologies, while eliminating the inconveniences of both.

Consequently, a new technology, the Advanced Compact Filter technology (ACF), was developed at the Arvida Research and Development Centre of Rio Tinto Alcan to obtain inclusion removal efficiencies comparable to deep bed filtration, while offering a low cost and high flexibility similar to the ceramic foam filter.

Filtration Mechanisms

The filtration mechanism of a given filter will greatly influence its global inclusion removal efficiency. Two distinct filtration mechanisms exist: cake and depth filtration. Cake filtration occurs when particles are separated from the molten metal at the top (inlet) of the filter medium, as seen in Figure 2. Initially, the intrinsic filtration efficiency of the base filter may be relatively low. During filtration, the accumulation of these particles dynamically creates a second filter medium layer on top of the base filter. As such, the ability to separate even smaller particles is achieved, and the filtration efficiency increases as the cast progresses. However, the increase in efficiency is obtained at the detriment of metal head loss, as seen in Figure 3. This exponentially increasing head loss quickly limits the total amount of metal that can be cast by diminishing the available metal level at the filter outlet or casting table. Moreover, cake filtration is more susceptible to inclusion releases due to the formation of unstable agglomerates. Cake mode is more likely to occur when using standard high ppi CFF filters. The high resistivity produced by a combination of small pores and a more closed morphology is less robust to metal cleanliness variation at the furnace outlet.

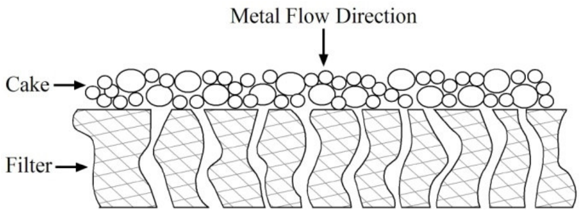

Figure 2. Schematic of cake mode filtration

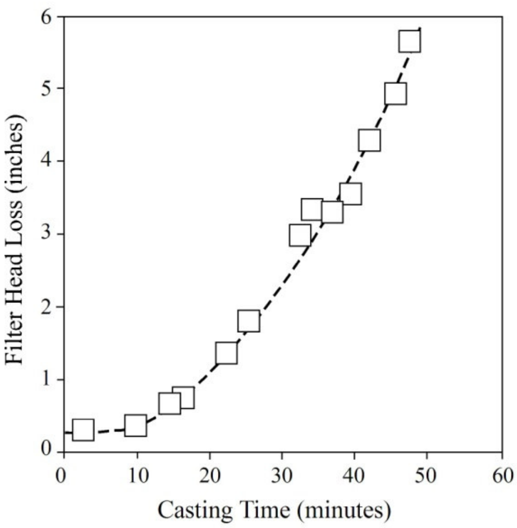

Figure 3. Head loss generation during cake filtration[3]

To obtain efficient and consistent metal filtration performance, while generating only moderate head loss, depth-mode filtration is preferred. This is the principal mechanism active in the DBF and is also present in the CFF. Inclusion particles are separated from the molten metal by adhering to the surface of the filter medium throughout its entire depth, as illustrated in Figure 4. In this manner, the entire filter is used. In the absence of a filter cake, the head loss tends generally to increase linearly as inclusions deposit within the depth of the filter over its life. In order to operate a standard CFF in depth filtration mode, the metal velocity must not exceed 15 mm per second[1,3].

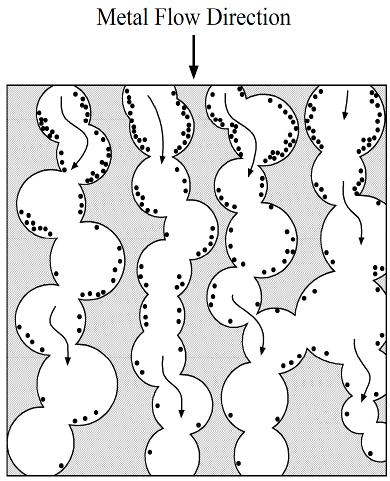

Figure 4. Illustration of depth-mode filtration through a CFF[3]

The morphology of the ceramic filter medium greatly affects the inclusion removal efficiency obtained by way of depth-mode filtration. Inclusions are separated from the molten metal by the action of gravity, by direct interception on the filter surface and by fluid dynamic effects acting between the filter medium and the inclusion particles. To favour these mechanisms, metal must flow in a convoluted pattern within the filter. A maximum number of capture sites must also be available on the filter medium surface that is in contact with the molten metal. For a ceramic filter, three principal morphological considerations affect the metal flow pattern and the filtration efficiency, specifically: pore size, apparent density and window openness. Pore size is defined as the number of openings (or pores) in a ceramic filter medium per linear inch. Filter apparent density is the ratio of the total weight and volume of the filter compared to the same volume of a 100% dense ceramic material. The density of a standard CFF is typically 10%. Window openness measurements are taken using a scanning electron microscope (SEM) on a cut surface of a CFF. Typically, an image analysis program evaluates the amount of voids in the structure.

Past studies have shown the benefits of finer pores[4,5,6,8] on standard CFF filtration efficiencies for 30 to 60 ppi filters (see Figure 5). Smaller pores increase the number of channels through the filter and therefore increase the filtration efficiency. In the same way, lower density and higher window openness also increase filtration efficiency[7].

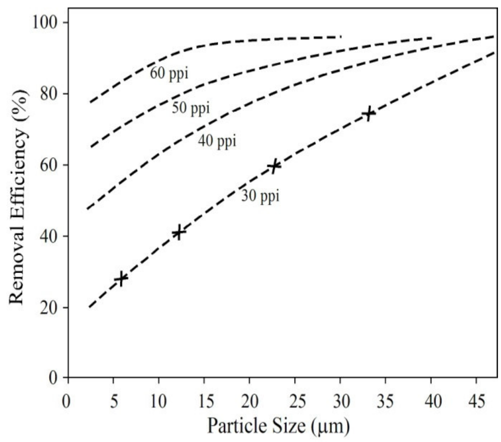

Figure 5. Filtration efficiency of standard CFF filter sizes (ppi)[8]

The morphology of the CFF is a compromise between permeability (resistivity to metal flow), filtration efficiency, mechanical strength and priming resistance. A morphology combining finer pores, lower densities and high window openness will increase the filtration efficiency. However, both the resistance to the metal flow and the pressure needed to initially prime the filter with molten metal will also increase. In typical casthouses, these two parameters are limited by the plant layout and more specifically, by the elevation difference between the furnace and the casting machine. Moreover, a priming pressure higher than 500 mm of aluminum is unpractical and not industrially viable. The ACF technology was developed to solve this problem and allows the use of higher efficiency ceramic filter morphologies.

ACF Equipment

Fundamental research was carried out at the Arvida Research and Development Centre (ARDC) in an effort to increase the filtration performance of a compact, single-use filter. Different filter morphologies were tested to obtain the filtration performance required for producing critical products such as can end stock. In partnership with Selee Corporation, a well established ceramic foam filter manufacturer, a ceramic filter corresponding to the desired morphology and mechanical strength requirements was fabricated. This ceramic filter has a reticulated cell structure with fine pores, low density and high window openness providing excellent performance and an overall filtration cost similar to the standard CFF. However, the required priming pressure is too high for available industrial equipment.

The patented Advanced Compact Filter (ACF) was development and industrialized by Rio Tinto Alcan to allow the use of such filter morphology. It provides an innovative means of reducing the required priming pressure on the filter. A vacuum is formed under the filter to increase the pressure differential between the upstream and downstream sides of the filter. This quick and instant vacuum provides ideal conditions for consistent and uniform priming, and reduces the metal priming depth requirement upstream of the filter. The ACF technology is adapted to the use of one or multiple filter cartridges. A schematic of the process showing an example of a multi-filter ACF is presented in Figure 6.

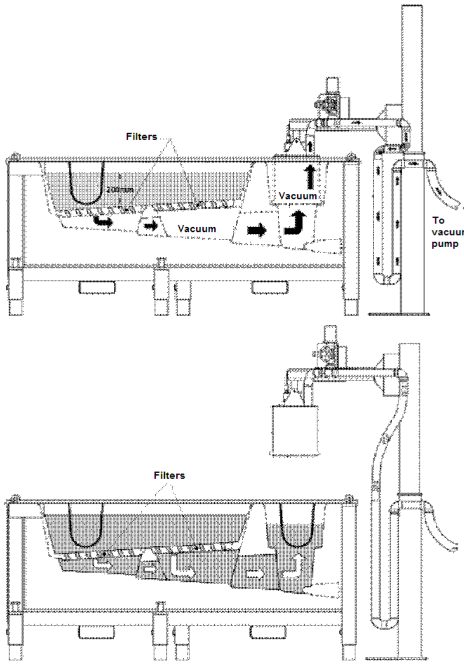

Figure 6. Priming mechanism of the ACF

At cast start, incoming molten aluminum covers the preheated filters in an adapted CFF bowl. The static pressure is insufficient to prime the filters. When a given upstream metal height is obtained, a vacuum reduces the downstream pressure under the filters. The resulting pressure gradient will prime both filters simultaneously. Once the priming is completed, filtration can take place in a fashion similar to that of a standard CFF, but with greatly improved performance.

An example of an industrial ACF unit is shown in Figure 7. This unit consists of an adapted CFF bowl that accepts two 23-inch ceramic filter cartridges, an hermetic outlet well that is designed to allow creation of the initial priming vacuum, a vacuum pump, a tap hole for metal drainage, an integrated preheating lid as well as process measurement and control equipment.

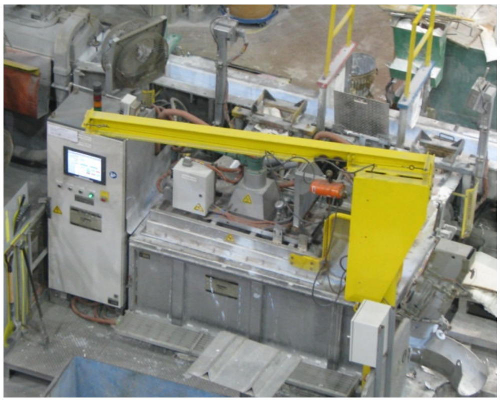

Figure 7. The ACF filter in an industrial environment

The type of ACF ceramic filter that is used depends on the product cleanliness requirements as well as on other process parameters. It can be selected from a wide variety of morphologies ranging from coarse (20 ppi equivalent) to fine (80 ppi equivalent). For traceability and process control, the barcode of each filter is scanned by the casting operators. Once installed, a programmed preheating cycle is applied by means of a high excess air burner in order to obtain a uniform filter temperature, while avoiding hot spots and physical degradation of the filter. A cast can be started through the ACF only after PLC supervision determines that sufficient preheating has been obtained. At cast start, if required for the particular filter medium being used, the vacuum unit is lowered to seal the outlet well of the filter bowl. When a sufficient metal height is detected above the filters, a vacuum ramp between -0.1 and -10 kPa per second is applied to obtain consistent and uniform priming. Different vacuum ramps are used to optimize priming while avoiding any filter damage. When metal is detected in the outlet well, the vacuum unit retracts and filtration begins.

Filtration Performance

The industrial scale production of quality-critical products (such as AA5182 can end stock) using the ACF began, in 2010, at one Rio Tinto Alcan casthouse. This alloy was previously filtered using a DBF, which is the standard technology for the American canning industry. A complete characterisation of the filtration and ingot performance was carried out.

Can end stock is now filtered using the improved ACF filter morphology for cast weights of typically 100 tonnes. Vacuum priming is obligatory to initiate the casts. Filtration performance was characterised by taking LiMCA and PoDFA measurements upstream and downstream of the ACF. Inlet sampling was taken directly at the furnace outlet prior to any grain refiner addition and before degassing through the Alcan Compact Degasser (ACD). The outlet sampling position was approximately two meters downstream of the ACF. Spectrographic samples were also taken downstream of the ACF to detect potential sodium release from the filter material. Metal head loss across the filter was recorded continuously using laser measurement of the metal level in the trough at the furnace exit and downstream of the ACF.

During this work, it was found that the LiMCA measurements taken downstream of the ACF were influenced by the presence of microscopic gas bubbles of typically 20 to 40 µm in diameter that were entrained in the molten aluminum downstream of the in-line degasser. These bubbles pass through the ACF filters and artificially increase the downstream N20 value, thus wise reducing the calculated filtration performance of the ACF. To quantify this effect, a series of casts were carried out during which time the ACD degasser was removed from the trough at mid-cast. LiMCA readings taken after the ACF were analysed and corrected, if needed. Uncorrected values are presented in this paper, except if stated otherwise.

Typical LiMCA measurements for one cast of can end stock are presented in Figure 8. The filtration efficiency is stable during the entire duration of the cast. No inclusion releases were detected. The filtration efficiency of the ACF was calculated as follows:

$$\text{Filtration efficiency} = \frac{\left(N20_{Furnace} - N20_{ACF}\right)}{N20_{Furnace}} * 100 \qquad (1)$$

LiMCA metal cleanliness results for 32 casts of can end stock alloy AA5182 are summarised in Figure 9. A filtration efficiency of 96.4% was obtained with an average corrected N20 count of 1.6 k/kg. Additional results comprising over two hundred PoDFA measurements taken during twenty casts of the same alloy are summarized in Figure 10. In this case, an additional sampling position was considered between the degasser (ACD) and the ACF.

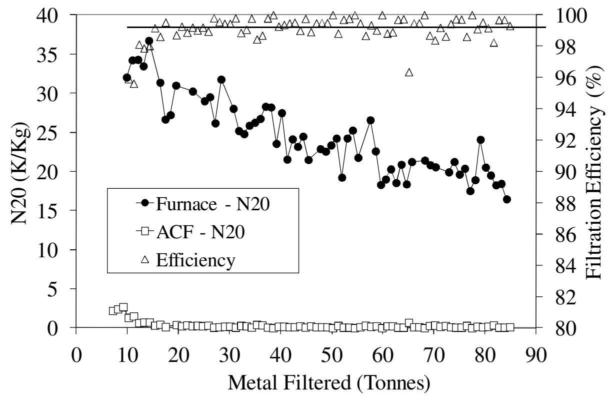

Figure 8. LiMCA data for a typical cast of CES

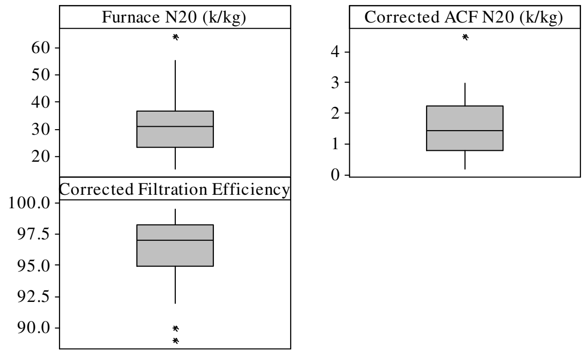

Figure 9. Metal cleanliness: LiMCA N20 count across the ACF

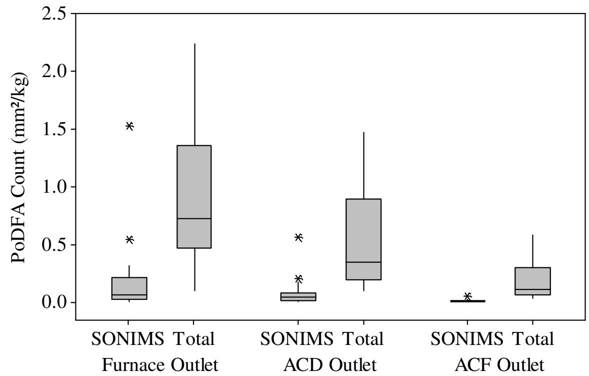

Figure 10. PoDFA count across the process

PoDFA SONIMS (hard particles) results reveal an efficiency of 92% with an average inclusion count of 0.006 ± 0.014 mm²/kg after the ACF, which is in agreement with the efficiency measured using LiMCA. This filtration performance as well as the absolute LiMCA and PoDFA values allows a transparent process change from deep bed to ACF filtration technologies with respect to downstream product performance at the rolling mill and at the can maker. In addition, for high magnesium alloys, the sodium release from the ACF was maintained below the North American specification without change to either the furnace or in-line alkali removal processes. From January 1st 2010 to August 31st 2012, over 144,000 tonnes of aluminum were produced using the ACF technology including 36,000 tonnes of can end stock AA5182. Figure 11 shows the normalized ingot rolling performance of metal filtered using the ACF compared to the DBF. No difference is noted with respect to several quality issues that lead to rejected metal, either in the casting pit, or at the rolling mill.

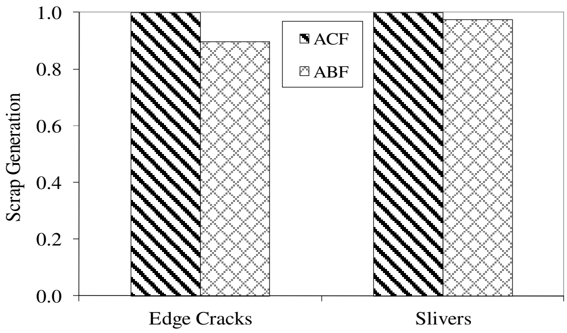

Figure 11. Rolling performance of ACF filtered CES (350 ingots)

The ACF also shows excellent resilience to process fluctuations. Average furnace N20 cleanliness levels varied from 15 to 64 k/kg. Nonetheless, stable metal cleanliness is maintained downstream of the ACF. The metal head across the filter remains stable during the casts, as shown in Figure 12. A linear increase in metal head is to be noted, which is typical of the depth-mode filtration mechanism as opposed to cake-mode filtration.

As shown in Figure 13, the metallostatic head loss across the ACF is stable cast after cast and stays within the limits dictated by the physical layout of the casthouse.

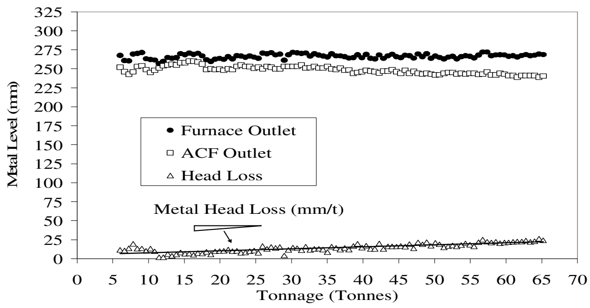

Figure 12. Typical metal head loss across the filter

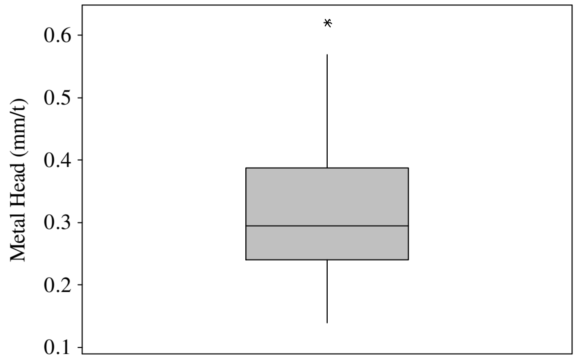

Figure 13. Historical range of the metal head loss across the ACF (124 casts)

Conclusion

A new patented technology, the Advanced Compact Filter (ACF), was developed and industrialized by Rio Tinto Alcan. This new technology provides filtration performance similar to deep bed filters and has proven its efficiency and robustness by producing over 36,000 tonnes of can end stock material. The ACF distinguishes itself by an innovative priming system that uses a vacuum unit and allows the use of finer filter morphology with lower densities and a more open internal structure. Owing to the fact that there is no metal hold-up between casts, the ACF has a positive impact on the casthouse flexibility by allowing quick and frequent alloy changes without scrap generation. Production lots are adapted to the clients' needs, hence reducing inventory and contributing to on-time deliveries. Finally, the operation costs of the ACF are of the same magnitude as that of a standard CFF.

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