

Low Resistance, High Flow PrimaFlow® Filters - Latest Results in Carbon Bake Fume

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Abstract

Extended surface filter bags (ESB), also known as StarBags™, have been used for nearly twenty years in primary aluminium smelter gas treatment centres (GTC). They have repeatedly been used as a cost-effective way to increase the capacity of an existing GTC when potlines increase metal production with line amperage increase, thereby debottlenecking production increases without the need for capital upgrade in the GTC.

With the ever-increasing loads in GTCs with each incremental smelter amperage increase, the original and subsequently modified designs of ESB filters reached the limit of their capability in several primary aluminium smelters towards the end of the last decade. Low resistance, high flow PrimaFlow® ESB filters were developed to address this design limitation and continue to push through performance barriers in several aluminium smelter GTC applications.

Carbon bake fume gas treatment centres (FTC) sometimes also undergo increasing load with primary aluminium smelter amperage increases. FTC filter baghouses have their own technical challenges, meaning gas flow rate and filter differential pressure becomes increasingly difficult to maintain over the life of the FTC baghouse filters. Low resistance, high flow PrimaFlow® ESB filters have now also proven to be a cost-effective solution in aluminium smelter FTC baghouses, with long-term operational performance able to be maintained.

This paper will discuss the latest comparisons in computation fluid dynamics (CFD) modelling of ESB filter designs, which help explain the extended application capacity of the PrimaFlow® filters. This extended application capacity will be shown in the long-term operational performance of PrimaFlow® ESB filters in an aluminium smelter prebaked anode FTC application.

Keywords: Fume treatment centre, Alumina dry scrubber, ESB filters, StarBag™, PrimaFlow®.

1. Introduction

In the mid-1990s the first ESB filter (the StarBag™ [1]) was invented [2] but the initial commercialization was slow until Albany International (currently known as Solaft Filtration Solutions, Micronics Engineered Filtration Group) undertook the first pilot trial of StarBags™ and subsequent full GTC retrofit at Boyne Smelters in 2005-2006 [3].

As is common with many new developments, there were many design changes between the original patented concept and the fully commercialized product. These design modifications focused on maximising the available filter cloth area, enabling a product capable of mass production and providing sufficient structural integrity to the filter support cage.

Subsequent aluminium smelter GTC StarBag™ retrofit projects [4] proved StarBags™ to be a genuine and repeatable viable alternative to GTC capital equipment upgrade when the smelter increased metal production through amperage increase. However, in other later installations where total gas flow through the GTC was increased more significantly, application limitations of the current design ESB filters meant that some of the previously achieved process improvements were no longer achievable.

2. Design and Limitations of Established ESB Filters

The original filter cages of the ESB concept [5] incorporated pleated filter bag on a twin wire cage to support an eight pleat ESB filter. Subsequent ESB filter cages of the concept incorporated a pleated filter bag on a cage to support 10 or 12 pleat ESB filters [6]. The increase in number of pleats was to enable a further increase in available filtration surface area over prior art. Pressed metal horizontal support members were cut and pressed automatically with consistent quality, with a more robust cross-sectional shape to support the wire cage and this significantly reduced the difficulties in welding to the longitudinal components, Figure 1. These subsequent cages thus focused the design on maximizing filtration area and increasing the structural integrity and quality of the filter support cage.

Full conversion of GTCs to the pressed metal support cage design of the ESB technology in aluminium smelters were successful in several application cases. However, in some other full GTC conversions where more significant increases in gas flow to the GTC were implemented, or where subsequent embodiments of ESB filters were greater than 5 m in length, the ESB filters were unable to provide the same reduction in DP (Delta Pressure or pressure difference), emissions and pulse frequency and in some cases, actually added total gas flow resistance (increased DP).

3. Literature Review – ESB Filters

There have been several publications discussing the theory of each component of pressure drop across fabric filters. One study on ESB filters [7] stated that the pressure loss across the filter bag is attributable to just two causes: namely gas flow through the dust cake and filter media, and pressure loss caused by gas flow on the clean side of the filter.

Another study [8] more critically analysed with CFD modelling the non-uniform flow along the length of long filter bags. The results indicated that gas flow does not readily enter the filter at the bottom of long filters, and that it is possible that 70 % of the flow is filtered in just the top 30 % of a long bag filter. This study concluded that when designing a system to extend the operating life of a filter bag, an important design consideration that is often overlooked is the uniformity of gas flow when long filter bags are installed.

A further study [9] used CFD modelling to demonstrate the flow and subsequent pressure drop induced by multiple restriction orifices in a cylinder. This study concluded that double orifices produced a pressure drop largely from the abrupt change in the flow passage cross-sectional area causing high level of turbulence and thus creating a double peak in velocity and pressure coefficient, and that these peaks were higher than the case of a single orifice. When the spacing of these orifices was at a distance of two times the pipe diameter, the peak velocity was higher than when the orifices were closer together.

A more recent study [10] stated that the filter cage within the pressed metal component ESB filter contains multiple flow restricting orifices and the spacing between these orifices is approximately two times the nominal external filter diameter. Logically, this study implies that in the clean side

of the ESB filter, the flow through the multiple pressed components would impart turbulence, increased gas velocity and pressure drop that increase with filter length.

This study [10] went on to outline a new ESB design methodology which optimised the available filter bag available filtration area and also considered the gas flow restrictions on the clean side of the filter caused by gas flow through the filter cage. The resultant new ESB design, the PrimaFlow® filter [11] Figure 2, was applied in several aluminium smelter applications and the results demonstrated that previous ESB performance barriers were far exceeded with the new design.

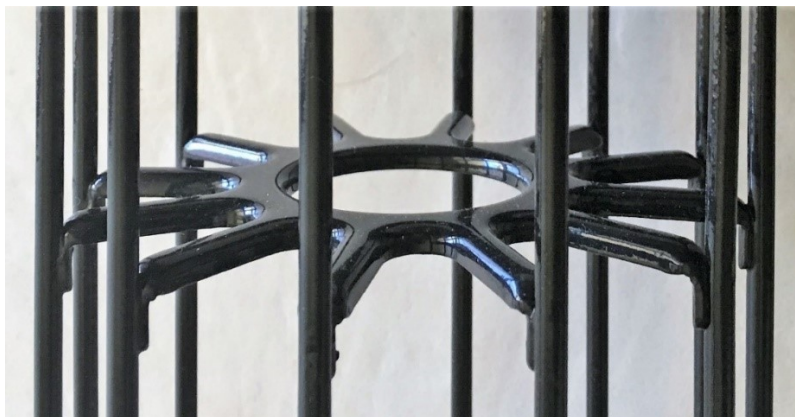


Figure 1. Previous 12-pleat ESB design [6] with pressed metal component cage.

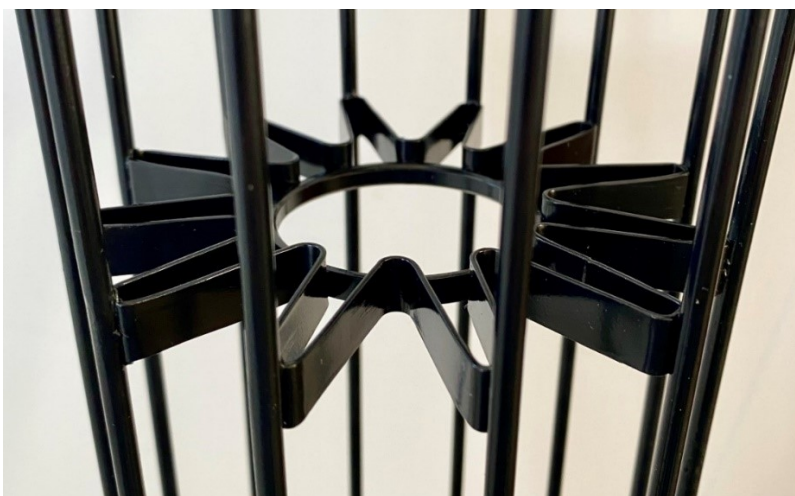


Figure 2. Patented [11] High gas flow PrimaFlow® design.

4. ESB Filters in Aluminium Smelter Carbon Bake Fume

While the vast majority of ESB industrial applications have been in aluminium smelter potline fume, ESB filters do have great potential for successful implementation in other industrial applications. Likewise, the vast majority of ESB design and application studies have also focused on their application and merits in aluminium smelter potline fume treatment.

In the more recent ESB study [10] where the design philosophy for PrimaFlow® filters was outlined, the first stage of application results over a six-month period for these filters installed into a smelter carbon bake fume treatment plant was outlined.

The fume treatment in the carbon bake process FTC is different from the fume treatment for the reduction potline GTC. The differences come mainly from the different chemical components in the gas stream and well as the added process variables in carbon bake fume treatment creating complex process control issues [12]. Whilst the GTC process is maintained in a fairly constant state of control, the FTC process is more subject to variables such as where the fire cycle is operating within the carbon bake ovens.

However, just as amperage increase projects increase the duty on the GTC, such amperage increases can also increase the duty within the carbon bake FTC. The extent as to whether the FTC load increase becomes a bottle neck to anode production depends on many variables and whether the FTC was previously at a critical operating limit. For example [13], if the FTC is operating with all control valves fully open this may limit part of the control in the bake furnaces and could result in operating periods where full pitch burn is not possibly causing excessive tar formation. Furthermore, insufficient gas flow in the furnace ring main will lead to longer fire cycles to achieve the desired anode quality, resulting in an anode production capacity constraint.

For the smelter potline GTC, the use of ESBs may allow increased production through increased amperage without compromising on environmental emissions. For the smelter carbon bake FTC, the use of ESBs can potentially widen the feasible control valve adjustment range maintaining full pitch burn, even where an increase in anode oven dimension is necessary. Through greater gas flow from lower FTC filter differential pressure, ESBs can also maintain anode production by preventing increases in fire cycle times and reduce the risk of start-up explosions. While these are different process objectives, they both come with the possibility of using ESBs as a means of debottlenecking the fume treatment process during amperage increase expansions. ESBs also offer other operating benefits to both applications in that overall plant operating expenses (OPEX) may be reduced with recued energy and compressed air consumption. Such carbon bake FTC potential bottlenecks and OPEX considerations extend to many parts of the gas treatment process [13] and the justification and benefits of a change to ESB filters in the FTC need to be considered alongside other areas within the process that could be operating at their capacity limit.

5. New Computational Fluid Dynamic (CFD) Modelling Study

For new equipment design optimisation, gas flow turbulence studies, older equipment retrofit optimisation and pulse jet cleaning studies, Computational Fluid Dynamics (CFD) modelling has been a widely used and valuable tool. To understand the greater than expected results achieved in previous PrimaFlow[®] filter studies, CFD modelling of the new product design gas flow chamber was undertaken. The CFD modelling used the well-established Unsteady Reynolds-Averaged Navier Stokes (URANS) simulations [14], initially for gas flow through various filter product designs, after which particulate dust flow and deposition was also modelled.

Previous ESB study DP calculations [7] considered DP of the filter cake and filter media only. Later studies included the DP from gas flow though the internal structure [10] and demonstrated the increasing and exponential importance of this as gas flow increases. This study utilized URANS CFD modelling of the external and internal structure of the filter bag and cage to visualize the effect of these DP contributors.

The gas flow chamber test facility previously used in the design optimization for PrimaFlow[®] filters [10] was modelled for gas flow and pressure drop in absence of particulate material. Three models were constructed: A non-ESB conventional cylindrical filter (Figures 3-4); a Star Bag ESB with pressed metal component cage (Figures 5-6); and a PrimaFlow[®] ESB filter with optimised bag and cage design (Figures 7-8). These CFD models demonstrated preferential gas flow to the bottom end of conventional cylindrical bags, a preferential flow of gas to the top end

of the pressed metal component filters, and a more even gas flow distribution over the length of the PrimaFlow® filters. Corresponding profiles in gas pressure within the filter internals were also observed.

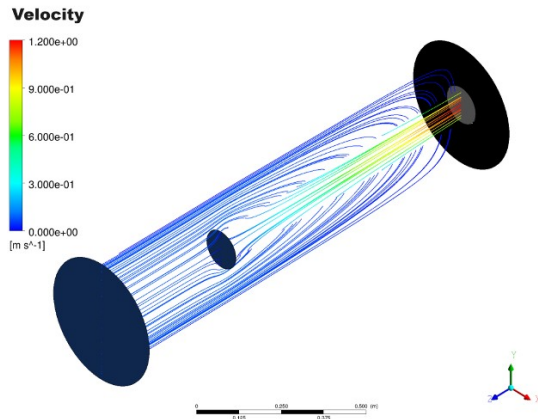


Figure 3. Conventional bag velocity profile.

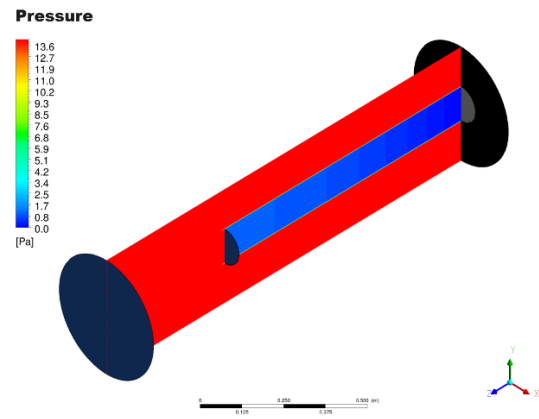


Figure 4. Conventional bag pressure profile.

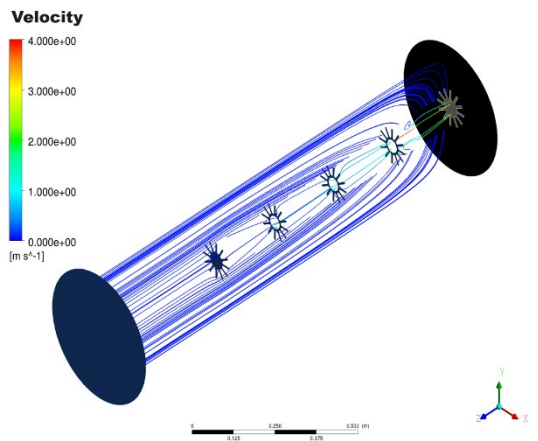


Figure 5. Star Bag velocity profile.

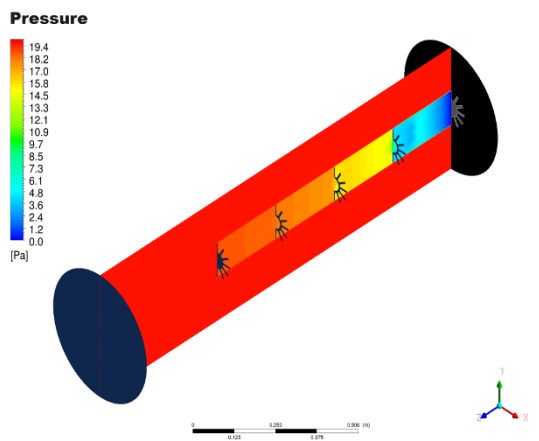


Figure 6. Star Bag pressure profile.

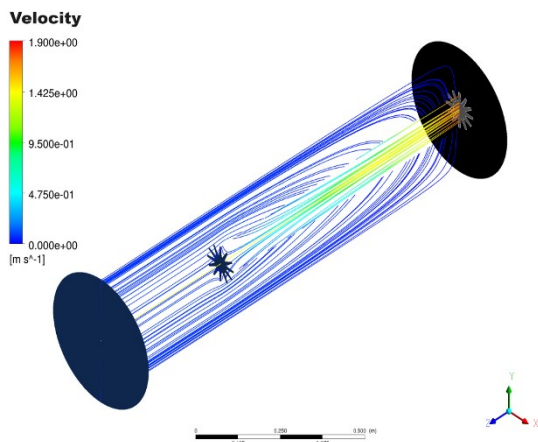


Figure 7. PrimaFlow® bag velocity profile.

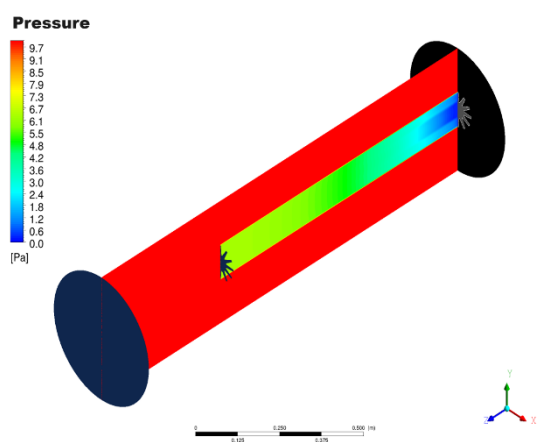


Figure 8. PrimaFlow® bag pressure profile.

The previously suggested turbulent gas flow [10] at the smaller orifice of the pressed metal Star Bag cage was also confirmed by the CFD model. The high turbulence and high shear layer regions caused by the jet-like flow can be visualized in the CFD model.

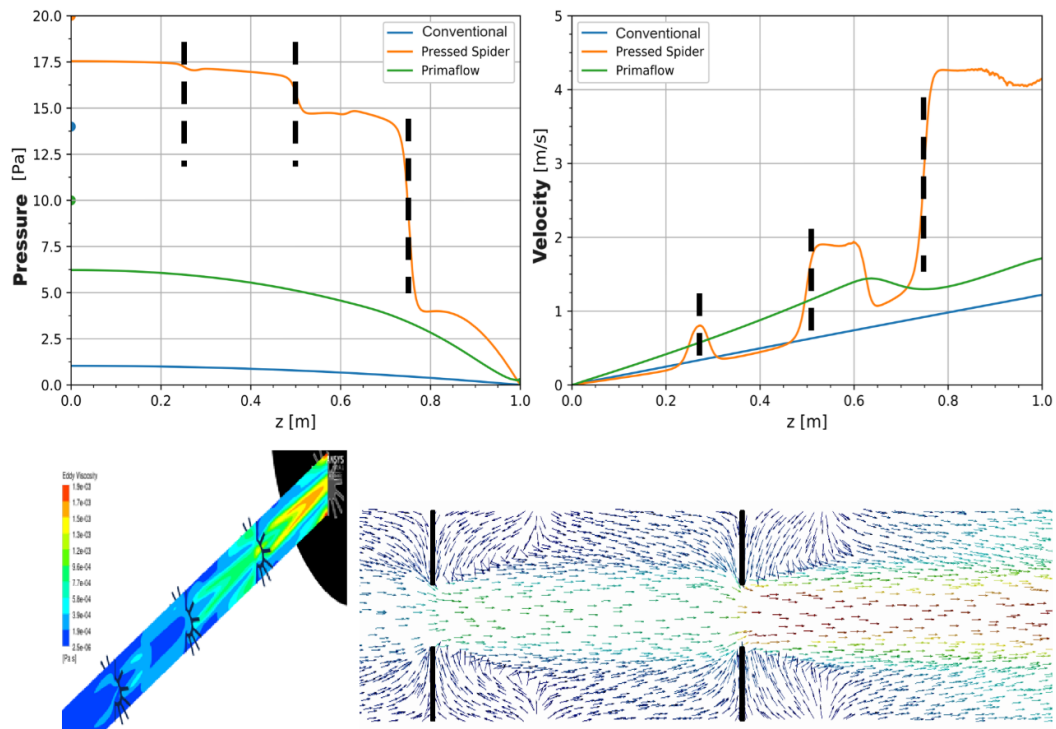


Figure 9. Pressed metal Star Bag cage, high turbulence and high shear layer regions.

The pressure drop was then calculated of the same given gas flow as the actual gas chamber test results and good correlation was found between the CFD model and the actual gas flow chamber test results.

Table 1. Single phase gas flow, experimental vs CFD results.

Geometry	Experimental Gas Flow Chamber ΔP (Pa)	CFD model calculated ΔP (Pa)
Conventional cylindrical bag	88	93
Star Bag (with pressed metal cage)	165	152
PrimaFlow® (with optimised bag and cage design)	70	76

The CFD model was then extended for multiphase gas and particulate flow to examine how the projected gas flow would distribute particulate matter over the full surface of the filter bag geometries. To describe the particle size distribution with an interval of $1 \mu m \leq dp \leq 100 \mu m$ the Rosin-Rammler-Bennet distribution was used, with mean diameter $dp' = 18.2 \mu m$ and coefficient of uniformity $n = 0.8856$ as a typical dust collector particle size distribution.

In correlation with the gas flow models, the multiphase model demonstrated a high particulate concentration at the bottom end of conventional cylindrical filters (Figure 10), a high concentration of particulate at the top end of pressed metal component ESG filters (Figure 11), and an even particulate distribution over the full length of the PrimaFlow® filters (Figure 12).

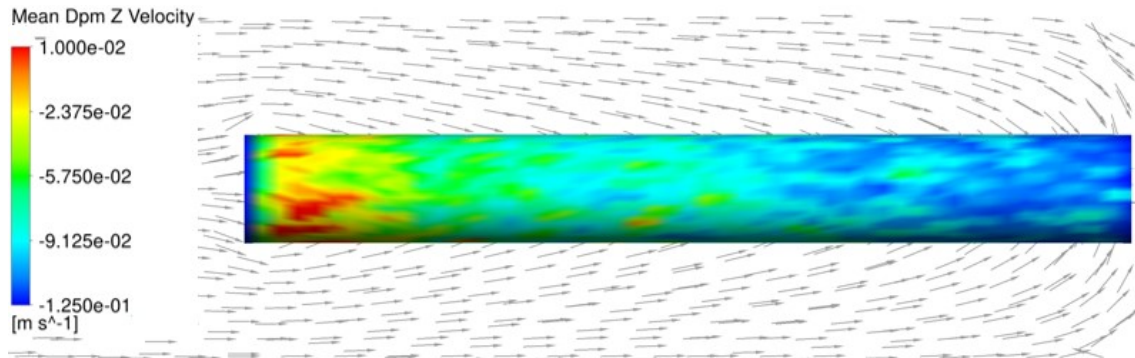


Figure 10. Conventional filter bag, high dust concentration at the bottom end of the bag.

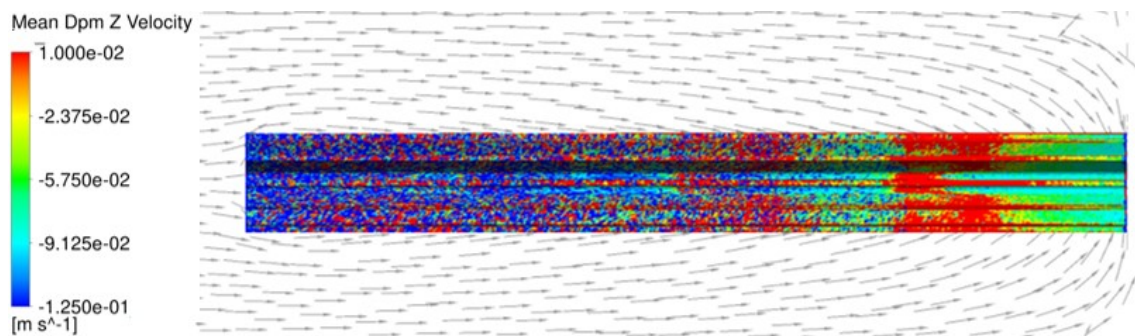


Figure 11. Star Bag with pressed metal cage, high dust concentration at the top end of the bag.

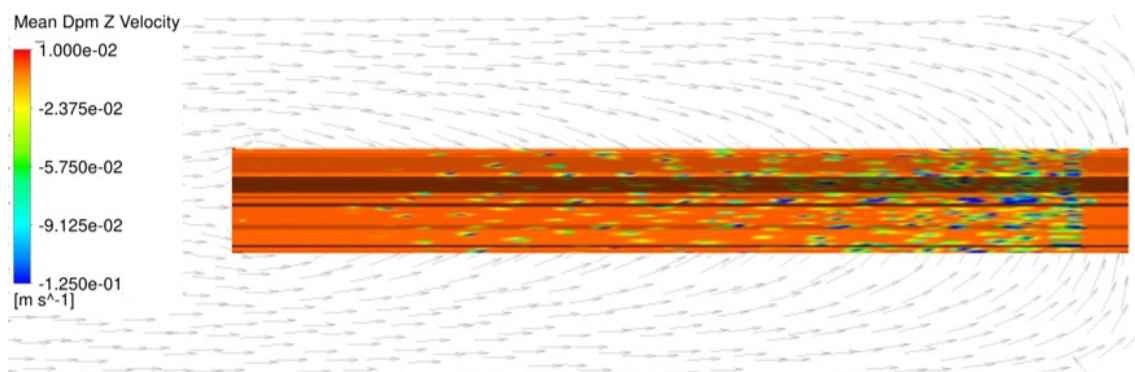


Figure 12. PrimaFlow® filter bag, even dust concentration over the full length of the bag.

6. Case Study – Rio Tinto Aluminium Alma Smelter, Canada

In the preceding ICSOBA technical paper [10], several case studies were presented. Outlined below is updated performance information for the case study where PrimaFlow® filters were applied in carbon bake fume treatment.

Rio Tinto Aluminium's Alma Smelter in Canada were using 8-ray ESB filters and cages for ten years since 2010 in both GTC and FTC applications. While the conversion to ESB filters brought many operational benefits [4], the filter installation crew have always reported difficulties and excess time required with filter cage insertion and removal in their FTC.

In order to test the PrimaFlow® concept and assess the merits concerning ease of installation, two filter cells within the carbon-bake fume treatment baghouse were fitted with PrimaFlow® filters

[11]. The customer reported satisfaction with the ease of installation, and they observed three measurable performance benefits of the PrimaFlow® filter over the 8-ray ESB filters over the first 12 months of operation [10], Figures 13, 15 and 17.

Now after 36 months of operation, the PrimaFlow® filters are still able to maintain the trends of lower DP, lower pulse cleaning frequency and higher gas flow, Figures 14, 16 and 18. The customer now has installed PrimaFlow® filters in all four filter cells. The operational results for the original 8-ray ESB filters in indicated with the blue line, and the operational results for the PrimaFlow filters are indicated with the yellow lines in Figures 13-18 below.

It should also be noted that during this time the smelter upgraded the furnace burners and they have increased potline amperage. They have maintained FTC process control, maintained adequate bake furnace fire cycle times and not had any increase with FTC particulate emissions from the fabric filter baghouse.

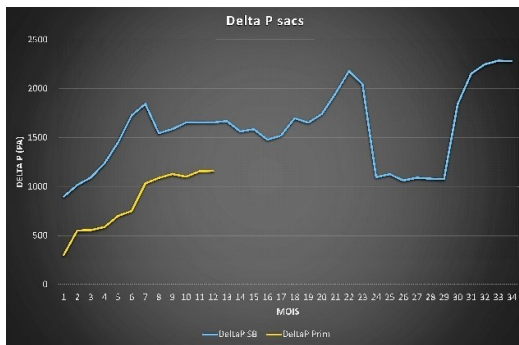


Figure 13. FTC filter DP rate after 6 months.

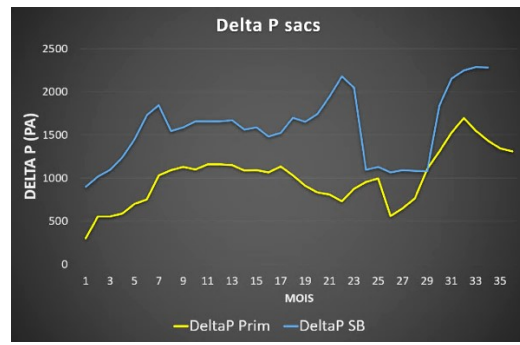


Figure 14. FTC filter DP rate after 36 months.

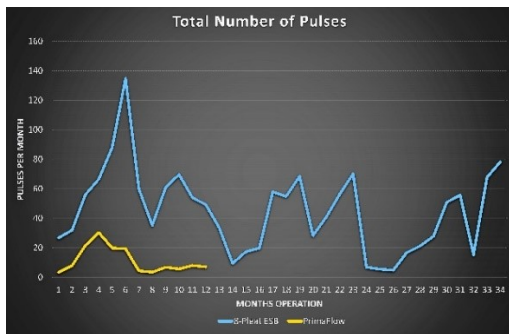


Figure 15. FTC filter pulse rate after 6 months.

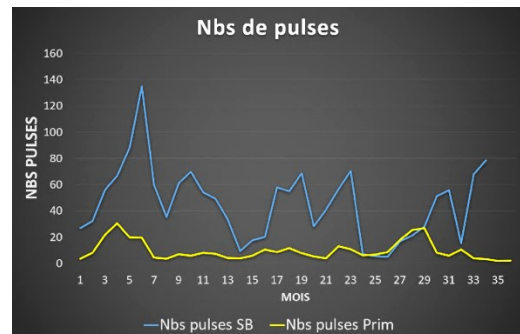


Figure 16. FTC pulse rate after 36 months.

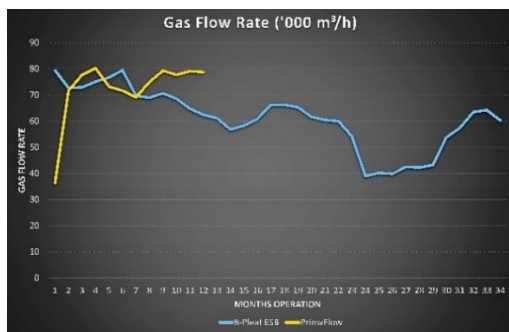


Figure 17. FTC filter flow rate after 6 months.

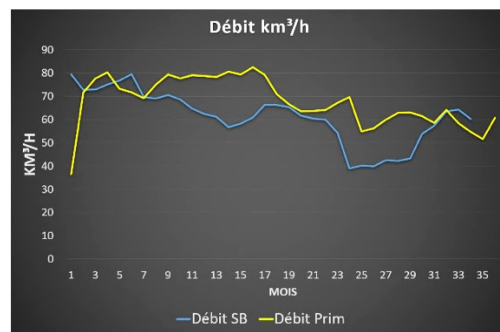


Figure 18. FTC filter flow rate after 36 months.

7. Conclusions

When application limitations with the implementation of older design ESB filters were identified with respect to long length filters and high gas flow, a new system of ESB filter design was undertaken. Rather than single mindedly focusing on maximizing filter area, the new and more balanced design methodology optimized the filtration area of the ESB filter, managed the filter internal gas flow resistance and a combined this with a new generation of high capture low resistance filter media.

A recent CFD modelling study has demonstrated that this new design philosophy resulted in a more even gas flow and particulate distribution over the full length of the filter. The CFD calculated results correlated well with both the measured results from the horizontal gas flow chamber test rig used in product design, as well as the results achieved in more challenging applications where previous ESB embodiments had failed.

The PrimaFlow[®] system has continued to demonstrate long term results in full filter baghouse conversions, with the capability to provide significantly higher gas flow and lower differential pressure than any previous embodiment of the ESB filter concept. Successful long-term results have been achieved in both aluminium smelter potline gas treatment centres and anode bake carbon fume treatment centres.

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