# The Application of Extended Surface Filtration Bags in Gas Treatment Centres

**Stephan Broek [1] and Julie Dontigny [2]**
[1] Director, Environmental Engineering & Technology, Aluminium, Hatch, Abu Dhabi, UAE
[2] Process / Environmental Engineer, Hatch, Montreal, Canada
Corresponding author: stephan.broek@hatch.com

## 1. Abstract

The increased requirements for alumina dry scrubbers in primary aluminium smelters has put pressure on operators, engineers and technology suppliers to find new solutions to increase the capacity of dry scrubbers. A main constraint is the limited ability to increase flows due to the ever-present limitation that dry scrubbers are seldom installed with extra capacity for future requirements. One solution that has provided a cost-effective increase in dry scrubber capacity, is the use of so-called extended surface filter bags (ESB). These bags are commonly known as 'star bags'. The ESB bags are constructed with at least twice the surface area of cloth than standard bags and because of this they can operate at lower pressure drops. The gain in pressure drop can also be passed on to the fans to allow them to draw more air through the system. In this paper the authors provide an independent update on the application of ESB bags in alumina dry scrubbers in primary aluminium smelters. There are now multiple dry scrubbers equipped with these kinds of bags. The paper also goes into the principles of the working of extended surface filter bags to demonstrate where the benefits come from. Regarding the implementation, the paper highlights what preparations are required and once installed, show a successful application of a new generation of ESB bags installed in a gas treatment centre (GTC) in Europe.

**Keywords:** Gas treatment center, alumina dry scrubber, extended surface filter bags, star bags, GTC upgrade.

## 2. Introduction

Going back in time, the first patent granted that resembles a fabric type filter bag was to J. T. Jones in 1852. This was a single filter bag of 8 feet diameter and 70 feet long and it was used to filter zinc dust from process gases. It was around 1900 that the filter bag shapes transformed to the shape that we know today, which is a cylinder with a diameter of about 5 inches (127 mm). Interestingly, the first cleaning method was the shaker type since it is so simple to use. Shortly after that the reverse air principle found its way into gas filtration. Between 1910 and 1950 there were very few developments in fabric filter equipment due to the overwhelming use of electrostatic precipitators. Only after the 1950's this changed when new fabrics were derived from petroleum products whereby the new fabrics provided for properties that made filter bags resistant to higher temperatures and acidic conditions. Interestingly, it was not until 1957 when the pulse jet type cleaning was introduced in dust filtration systems [1].

Concerning alumina dry scrubbing technology, the first patent was granted to Robert T. Pring of the Wheelabrator Company in 1956. That same year Séraphin Lacroix of Pechiney was granted a patent on a similar process. However, it was Alcoa that made the most advances in the actual design of an alumina dry scrubber through their research programs. Their development commenced in 1957 and resulted in a model R173 where activated alumina was injected upstream to a baghouse. In 1962 Alcoa introduced the R252 scrubber in the Badin smelter which was the first fluid bed type scrubber. From the R252 model the R398 model was derived and this was tested first in the smelter in Warrick in 1967. Three years later a patent for the A398 technology was granted to Clayton C. Cook and Lester L. Knapp and the first industrial units were installed in the Badin plant. The R398 was now proven and became the A398 model, which is essentially the same A398 technology that is still in use today with some modern tweaks. In a similar manner, the first injection type alumina dry scrubber technology as we know it today was patented by Wolfgang Muhlrad of Air Industries (now: Fives Solios). The first industrial units were installed in INTALCO in 1973 and today are still in operation. Around the same time, Fläkt (now: GE Power Norway) installed its first alumina dry scrubbers in the smelter of Granges in Sweden [2].

Filter bag fabrics were initially made from closely woven cloths of cotton, wool, flax, or other fibrous textiles. As mentioned earlier, in the 1950's products derived from petroleum led to the creation of new, man-made fabrics that has certain advantages over natural materials. In GTCs the material of choice is almost exclusively polyester. In 1941 British scientists Whinfield and Dickson patented PET or PETE which forms the basis for production of synthetic fibers such as polyester. It was first manufactured by Imperial Chemical Industries (ICI) and in 1946 DuPont bought all legal rights from ICI. In 1950 DuPont manufactured another polyester fiber, which they named Dacron followed by Mylar in 1952. Polyester was first introduced to the American public in 1951 as the magical fabric that needed no ironing. During that period these new fabrics also started to find their way into industrial applications such as the manufacturing of filter bags [3].

For all those years, the shape of the filter bag had fundamentally not changed. If a large surface area was required for filtration, then this was created by using many rows of cylindrical bags to keep filtering velocities in range and to properly remove solids from gases. However, the need to upgrade existing filter houses was a real challenge and often required the addition of new filter compartments. This aspect drove the development of what eventually became the extended surface filter bag (ESB). The star-shaped model filter bag was certainly not the first model to increase the effective surface of a single bag, but it is proven to be one of the most reliable ones.

The first extended surface filter bag was a rigid Polyimide (P84) star-shaped needled felt bag, developed and patented in Germany by Klaus Schumann in 1993. This was a cage-less, star-shaped filter bag for hot gas applications whereby the rigid and self-supporting structure was accomplished by applying a vitrification process at 260 °C [4]. However, despite the superior filtration characteristics, the filter elements were unable to meet the 3-year life warranty because of premature flex fatigue. This meant the bag needed a cage to give it the right strength. Later in 1994 the extended surface filter bags, as we know them today, were patented in the US by Klaus Schumann and assigned to Albany International [5]. The shape of the bag looked like a star and from here onwards Albany continued to use this in the name for the bag: Star Bag™. The use of cage did allow for practically all known filter fabrics to be used, including polyester. The early applications were in the cement industry, foundries and others, mostly in shorter length up to 3.6 meter in US and Mexico, but later also e.g. in Europe and Australia in lengths up to 6 meter and more [4], [6].

At this point in time there are also pleated type filter elements in the market. The ESB technology referred to here is a so-called bag-on-cage technology as opposed to a pleated element. The pleated element design uses different media, different top and bottom construction polymers and, importantly, does not use a cage. Whilst the pleated element design has been applied to some aluminium smelter applications (ref. INTALCO), its success has been limited.

The extended surface filter bag made its introduction to the Aluminium industry in 2002 when Albany completed a conversion from conventional bags to extended surface filter bags in a fume treatment system at Metalcorp Recyclers in Gladstone, Queensland. In total 288 bags were installed, each three meters long and made of Nomex. Metalcorp operated a recyclable aluminium re-melt furnace that had a fume treatment system attached that became undersized. With the new filter bags the filtration surface was doubled which was more than what was needed, and the results were excellent. It is worth mentioning that one important improvement resulted from this work; During this project, it was recognized that the original cage design needed to change from a riveted design to a fully welded cage for better reliability and durability [6].

In 2004, Albany conducted a pilot trial with Boyne Smelters (BSL) to investigate the potential of extended surface filter bags in alumina dry scrubbing units [7]. In the pilot unit Albany tested 800 mm long bags and 1000 mm long bags to compare them with the performance of standard bags. The pilot unit had the capability to tap into the BSL GTC inlet duct and inject alumina for scrubbing to create comparable conditions with a real GTC. The results were very good and it convinced BSL to convert one cell in GTC no. 1. Albany installed 384 star bags and ran tests for a certain period after which the standard bags were inserted again for reference purposes. Running a test with different filter bags in only one cell is always difficult because it is hard to isolate this from the other cells with respect to controls and pulsing system. Albany took the cell in manual control mode to allow the process to be verified [6], [7]. Figure 1 compares the standard and extended surface filter bags.

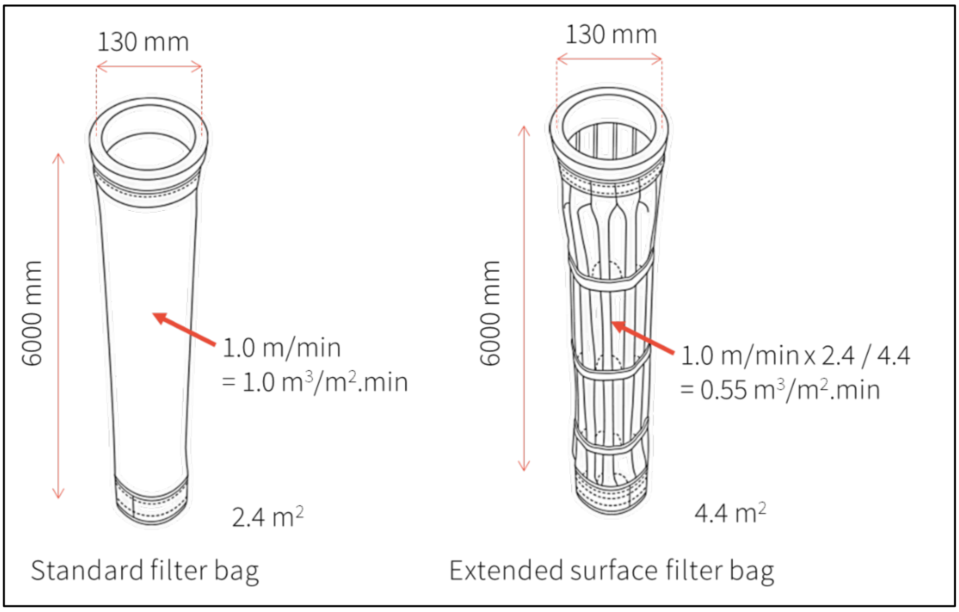


**Figure 1. Comparison between standard and extended surface filter bags.**

It is important to point out that all materials used to make extended surface filter bags are the exact same materials used to make standard bags. Only the method of constructing the bags is different to give it the star shape to extend its surface area.

Following completion of the trial in the test cell (various configurations were trialed and the test cell and control cell were swapped over to confirm results), a rapid decision was made to convert one complete GTC (2 GTC's were attached to each Potline). The results from the full GTC conversion were significant enough that the decision to convert the remaining systems was made immediately and carried out during 2005 and 2006. The original design fully welded cages are still operating today along with an improved version of the original design Star Bag™. Importantly, this application at BSL meant the extended surface filter bag is now proven to increase existing GTC capacity on industrial scale in a smelter as an alternative to building a new GTC with smelter capacity creep. It was a major step forward in the industrialization of extended surface filter bags in aluminium smelters [6].

The progress of the industrialization of the extended surface filter bags can be seen in the next table. It provides for a full overview of GTCs and FTCs operating with extended surface filter bags. Only full conversions are shown as these represent the true industrialization of the product.

**Table 1. Overview of operating GTC units 100 % equipped with extended surface filter bags [6], [8].**

| **Installation (Full GTCs only)** | **Year** |
|---|---|
| Boyne Smelters – Gladstone Australia | 2006 |
| Rio Tinto – Alma, Canada | 2010 |
| Rio Tinto – Alma (FTC), Canada | 2011 |
| Rio Tinto – ISAL, Iceland | 2012 |
| Rio Tinto – Laterierre, Canada | 2012 |
| Rio Tinto – Grand Baie, Canada | 2012 |
| Rio Tinto Arvida – Jonquière, Canada | 2012 |
| Rio Tinto – Kitimat | 2013 |
| Alcoa – Baie Comeau, Canada | 2013 |
| Century Aluminium – Nordural, Iceland | 2015 |
| Trimet – Hamburg | 2015 |
| EGA – DUBAL, UAE | 2016 |
| Rio Tinto – ISAL, Iceland | 2016 |
| EGA DUBAL, UAE | 2017 |
| Sohar Aluminium (FTC), Oman | 2017 |
| Rusal Shelekhov – Bratsk, Russia | 2017 |

The development of extended surface filter bags is ongoing. The various suppliers continue to make improvements to make the existing extended surface filter bag designs even better. Another development is the conical star bag which is a new version of the extended surface filter bag that is patented by Klaus Schumann. This is a bag with a conical bottom section called Conical Star Bag. In this design the filter bag has a frusto-conical shape that does not require the use of box pleats and cylindrical cuffs that otherwise has the potential to create dust pockets. It still must be tested on full-scale but it has the potential to further lower the pressure drop, pulse frequencies and pulsing pressures [4], [9].

## 3. Fundamentals of Gas/Solids Filtration

In this section is described what the fundamentals are behind the advantages of using extended surface filter bags. To be able to do so, we must first review the working principles such as is shown in the Figure 2. All symbols are explained at the end of the article in Section 12.

The interest is in the behavior of the flow and the pressure drop across the filter bag. Here things change when a standard bag is replaced with an extended surface filter bag. The pressure drop comprises of two parts: the pressure drop of the fabric and the pressure drop of the cake. In 1952 the scientist Sabri Ergun derived a correlation that describes the pressure loss of flow through a porous media. This correlation applies here as well.

$$f_p = \frac{\Delta P}{\delta} \frac{D_p}{\rho_f v_s^2} \left( \frac{\varepsilon^3}{1-\varepsilon} \right) \tag{1}$$

The list of symbols is at the end of the paper.

For the range of laminar and turbulent flows Ergun developed the following correlation:

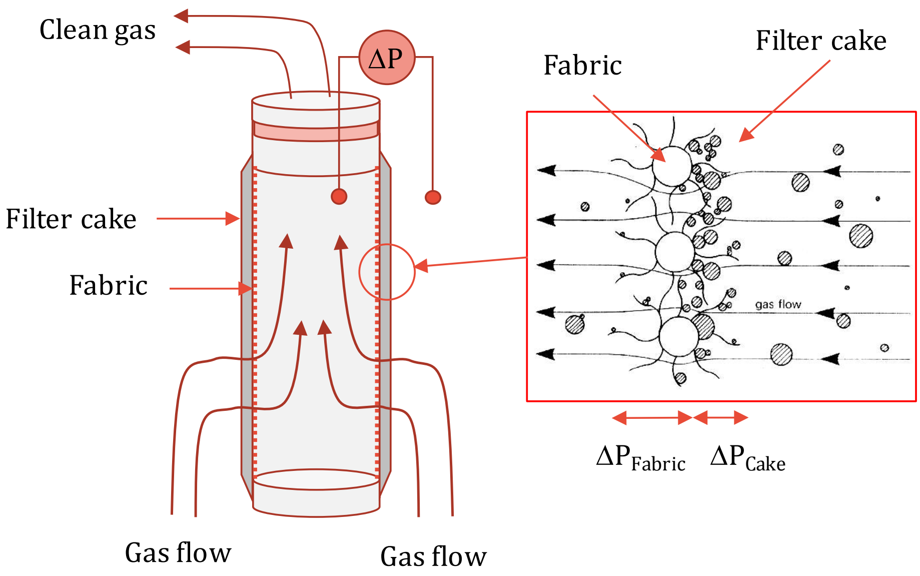


**Figure 2. The principle working of a filter bag.**

$$f_p = \frac{150}{\mathrm{Re_p}} + 1.75 \tag{2}$$

With:

$$\mathrm{Re_p} = \frac{\rho_f v_s D_p}{\mu(1-\varepsilon)} \tag{3}$$

When Equation (1) and (3) are substituted within Equation (2) then the following relationship is derived:

$$\Delta P = 150\frac{(1-\varepsilon)^2}{D_p^2\varepsilon^3}\mu\delta v_s + 1.75\frac{(1-\varepsilon)\rho_f}{D_p\varepsilon^3}\mu\delta v_s^2 \tag{4}$$

A mass balance is required to solve the thickness of the cake:

$$M = Q_m t = A\delta\rho_p(1-\varepsilon) \;\rightarrow\; \delta = \frac{Q_m t}{A\rho_p(1-\varepsilon)} = \frac{w}{\rho_p(1-\varepsilon)} \tag{5}$$

When Equation (5) is combined with Equation (4) then the next relationship is derived:

$$\Delta P = 150\frac{(1-\varepsilon)}{D_p^2\varepsilon^3\rho_p}\mu w v_s + 1.75\frac{\rho_f}{D_p\varepsilon^3\rho_p}\mu w v_s^2 \tag{6}$$

If this correlation is evaluated, then it becomes evident that the left term is governing the outcome and that the right term only has a minor contribution. For this reason, the relationship can be simplified to the first term only. By doing so, we arrive at the equation that originally was developed by Henry Darcy and is referred to as Darcy's law. In Darcy's law, the specific resistance of cake is defined as followed:

$$K_c = 150 \frac{(1-\varepsilon)}{D_p^2 \varepsilon^3 \rho_p} \tag{7}$$

This leads to the final correlation that is used to evaluate the working of extended surface filter bags:

$$\Delta P_{cake} = K_c \mu w v_s \tag{8}$$

In a similar manner, an equation from Darcy's law can be derived for the filter cloth with the difference being that the thickness of the fabric is regarded to be constant:

$$\Delta P_{fabric} = K_f \mu v_s \tag{9}$$

For the overall pressure drop is valid:

$$\Delta P = \Delta P_{fabric} + \Delta P_{cake} \quad \rightarrow \quad \Delta P = K_f \mu v_s + K_c \mu w v_s \tag{10}$$

## 4. Impact of extending the cloth area of a filter bag

The main advantage of introducing extended surface filter bags in a baghouse filter is that with the same number of filter units the total area of cloth used for filtration is increased by a factor of about 2 (depending on the number of pleats) when compared with conventional bags of the same length. Figure 3 shows a typical extended surface filter bag.

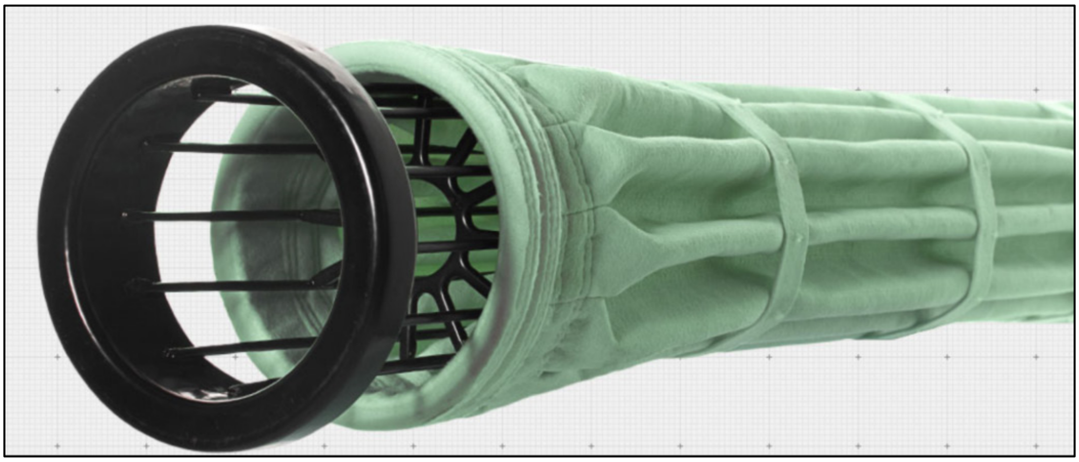

**Figure 3. An example of an extended surface filter bag.**
**(Source: Advancetex International).**

The increased filtration surface has proved to offer many benefits including the following two opposite objectives that are typically sought after by smelters proceeding with the conversion to extended surface bags:

1. **Reduce stack emissions** by maintaining constant the flow through GTC.

2. **Maximize gas flow** by reducing the differential pressure (ΔP) at filters.

These two antagonistic assets are explained in more detailed below along with other benefits that come with this.

### 4.1 Constant Flow Through the GTC

At a constant flow and a filtration surface area that is now double in size the superficial gas velocity ($v_s$) through the bags is reduced by 50 %. The correlation shows that ΔP is linear with the gas velocity and therefore, in theory, the pressure drop across the bag is also reduced by 50 % for the same thickness of cake. This would mean that if the pressure drop across the tubesheet was 2000 Pa before the conversion, that the new pressure drop setting could potentially be as low as 1000 Pa to obtain the same conditions. In practice, however, the pressure drop setting never goes below 1200 - 1300 Pa and it is more realistic to lower the setting to about 1400 - 1600 Pa. Because the flow is constant the extra pressure drop that is allowed results in a thicker cake of alumina which means that the residual scrubbing effect increases resulting is in an immediate decrease of HF emissions from the stack.

A further benefit is that the extended surface filter bags can operate with a reduced cycle time in between pulses (Figure 4, Fig. A). This means less compressed air is used but also less stress on the bags giving them a longer life. This is caused by the fact that the specific resistance of the cake is not constant (Figure 4, Fig. B). Mahmood Saleem et al [10] investigated the formation of cake on bags using different gas velocities. This research found that the specific cake resistance is not constant when the gas velocity increases by a factor of two. The research also found that when gas velocity increased that the average particle size in the cake also increased. More larger particles made it to filter bags rather than dropping out in the hopper. It was concluded that the apparent cake density is thus higher, which increases *w*. The cake builds up faster and reaches the upper limit of the control point (the point where the pulse is initiated) faster (Figure 4, Fig. A). In reverse, and this happens with the installation of extended surface filter bags, when the velocity is reduced then the cycle time is extended by a larger proportion. This explains why lower filtration velocities are normally advised for the operation with extended surface bags to reduce the frequency of cleaning pulses and optimize the life duration of the bags.

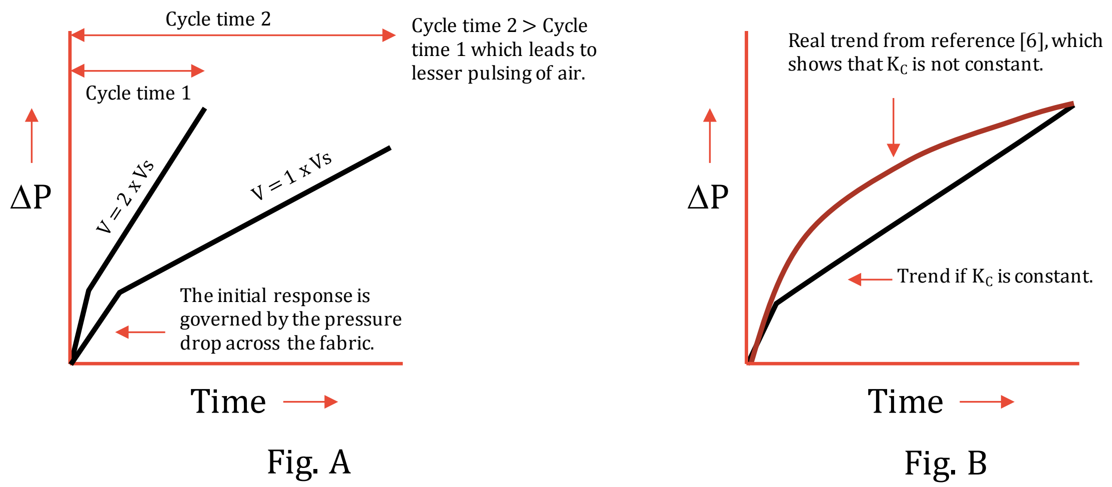


**Figure 4. Analysis of the response of pressure drop over time.**

A last benefit is also linked to the reduced cycle time. Less pulsing also means the dust emissions will be reduced. If monitored, then emissions of dust are typically spikes that coincide with a pulse. Less pulsing automatically reduces the number of spikes.

### 4.2 Increased Flow Through the GTC

The implementation of extended surface filter bags can also be used to create more flow through the GTC. Hereby there can be two options considered. The first option is to increase the pot exhaust flows to reduce the gas temperatures somewhat and to increase the gas collection of the pots to reduce roof emissions. The second option is keep the pot exhaust flow constant but to allow more dilution air to be introduced strictly for cooling purposes.

Often existing GTCs are running at their maximum capacity. This happens when a) it is operating at the maximum filtration velocities near 1.2 m/min, b) when the fans have reached their maximum capacity when the inlet damper is more than 90 percent open or c) the motor is running close to the maximum amps. By installing extended surface filter bags the pressure loss through filter bags initially drops by typically about 50 % at constant flow. It then creates the opportunity to increase the flow as the filtration is no longer the bottleneck. It is often said that the flow can 'double' too but this is not true. The flow is a function of a) the overall gas flow, b) the associated pressure drop and c) the fan curve. The overall pressure drop is the sum of all pressure drops across the individual elements that make up the complete ventilation system. The filter bags form only one element in this. Generally, the pressure drop from pot to exit of the stack is described with the following relationship:

$$\Delta P_{system} = \sum_{1}^{i} k_i \frac{1}{2} \rho v_i^2 + \left( K_f \mu v_s + K_c \mu w v_s \right) - \Delta \rho H g \quad (11)$$

Important is to recognize that the resistance from the other parts correlates with $v^2$ and the filter bags correlate with v. The chimney effect is a function of densities and therefore unrelated to v. This means that if the flow is increased that still most other elements increase in pressure drop by a factor of $\left(\frac{v_2}{v_1}\right)^2$. The net result is that the gain in pressure drop, say 1000 Pa, is quickly lost again by the increase in pressure drop as a direct result from the increase in gas velocity through the system. The net gain in flow is therefore only in range of 5 to 15 percent, which still makes this very much a viable conversion.

## 5. Project Justification

Most conversion projects occur when a changeout of standard filter bags is required after their useful life. This is the right timing and the extra costs are incremental costs that are easier to justify based on the benefits. The bags are made from more cloth so logically are more expensive. Adding the cost of cages to this, then a considerable increase in costs is incurred on top of the normal cost for a changeout. It is therefore normal that management will ask for a justification to invest in this project. This needs to be prepared ahead of time and at least one year should be reserved for the preparations and approvals before a PO can be issued. One should not wait until the existing bags start to fail.

Once the smelter engineers and lead operating staff are comfortable to consider using extended surface filter bags, a techno-economic study is the right tool to evaluate the costs and benefits. This study is meant to identify the following parameters, assuming that the number of bags and the diameter remain unchanged:

1. New filtration velocities (A/C ratio, can velocities)

2. The final bag length
3. The expected reduction in emissions
4. The expected savings in consumption of power and compressed air
5. The expected saving in aluminium fluoride additions
6. The expected increase in flow per pot
7. Implementation plan and schedule
8. The estimate of all incremental costs

It may surprise some that the length of the bags is a point of evaluation. Extended surface filter bags make this possible because there is more than enough cloth area available to take advantage of the increased surface but also to move the bottom of the bags away from the inlet zone of the filter. Bags can be shortened by up to 1000 mm. This is done in specific cases where it is common that the bottom part of the filter bags wear due to the exposure to alumina laden ventilation gases that hit the bottom of the bags. By shortening the bags the benefit of working with a lower pressure drop setting is somewhat reduced but in several cases moving away from the filter inlet outweighed this with no negative impact.

A key verification is a check on the filtration velocities before and after the conversion. Standard bags are run up to an A/C ratio of 1.3 m/min while extended surface filter bags are operated up to 1.0 m/min. The pulsing frequency is reduced and this leads to a lower consumption of compressed air. This is expensive in any smelter and the cost per unit will result in an annual saving of cost in air consumption. One can expect lower emissions of alumina and HF both from the stack as well from the potroom roof ventilators if the flow per pot is increased. This saves on alumina costs and on costs for the addition of aluminium fluoride. The new pressure drop settings will ease the operation of the fan. Using an analysis of the system resistance and the fan curve enables an engineer to determine what power is consumed under the new conditions. In most cases this leads to a saving of power. Now, this has a low unit cost in a smelter but everything adds to the bottom line.

In most cases a cash flow analysis is the best tool to compare the use of standard bags with the use of extended surface filter bags. The project is then evaluated over several years where the benefits add up. Both projects can then also be properly compared using the NPV values of each. It should be noted that it is important to manage the expectation of such an analysis. The NPV and IRR values obtained for extended surface filter bag projects are of a different kind than those of projects where, for example, a metal production increase is achieved. The purpose is to choose between both projects. One should avoid the pitfall that an accountant will purely see the project as an investment where often different company rules apply.

## 6. Product Inspections

Once the procurement process is completed and the filter bag vendor is selected for the supply of bags and cages, production will start shortly after the order is received in the plant of the vendor. It is not always considered but the experience is that it is good to include onsite inspections at the vendor production facilities. It is good to check if all materials are new and that quality control procedures are in place (and used!). Production takes place over several weeks and shipments may be in batches. Typically, bags and cages are shipped in sea containers for transportation to the smelter.

Inspections can take place during the production but should be done in the weeks prior to loading the containers and before boxes are packed. Random samples will be taken from boxes and fitted with cages. Figure 5 shows some actual inspections completed for a GTC project where Hatch dispatched qualified inspectors from its Shanghai procurement offices to the production sites.

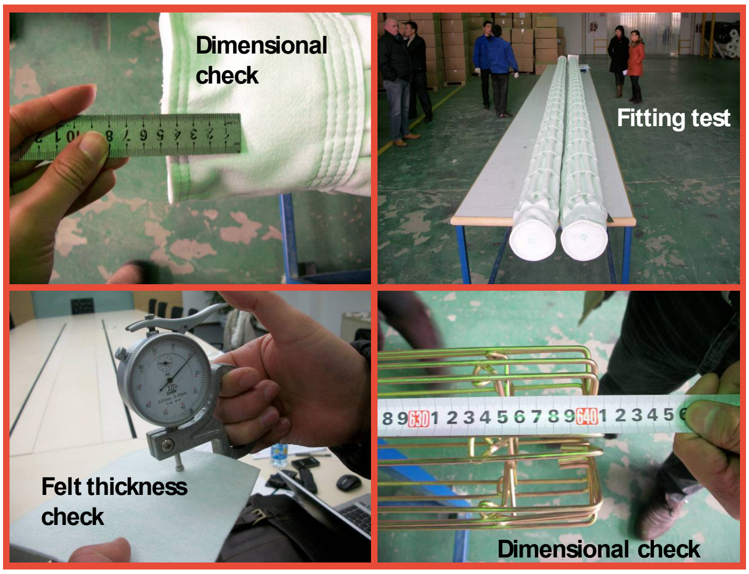


**Figure 5. Inspections at the fabrication shop prior to shipment (Source: Hatch China Procurement).**

The visual inspection is good for checking if all dimensions are within spec but also if the stitching is of good quality. The bag is fitted with a cage to check the overall fitting but also if the snap band fits snug with a steel template with the exact hole diameter. Regarding the cages a lot of attention is given to the welding of the wires and the quality of the surfaces. In most cases a coating is applied and it is very important that there are no burs or other imperfections that eventually can damage a bag and shortens its life. It is also important to check the quality/methodology of stacking of the cages. They are tightly packed in a container and often a percentage is damaged in transportation. By making sure certain good practices are applied this can be minimized.

Needless to say that after the containers have arrived on site after a journey of six weeks at sea and inspections reveal non-conformities, a lot of valuable time will be lost if any corrective actions by both the owner and the vendor are required. The inspections ahead of shipping are worth it.

## 7. Installation

In most cases, the tubesheets (or cell plates) are not changed and the exchange is one-for-one. This means an old bag and cage is removed and replaced with an extended surface filter bag and cage. As normally is the case, a good planning of the installation sequence is also required to minimize the time the filtration module must be taken off line. The vendor will provide for a custom rod that is used to push the bag and cage into place and to ensure the alignment is proper. This makes the time to install slightly longer but not by much. It is very straightforward to install the extended surface filter bags (Figure 6).

**Figure 6. Installation of an extended surface filter bag (Source: Advancetex International).**

## 8. Results

In this paper is presented some actual results from a GTC that was converted to extended surface filter bags in January of 2015. The respective smelter has made available the data for dust emissions and HF emissions from the stack for a long period of time.

### 8.1 Dust Emissions

The introduction of extended surface filter bags on the stack emissions can be seen in Figure 7:

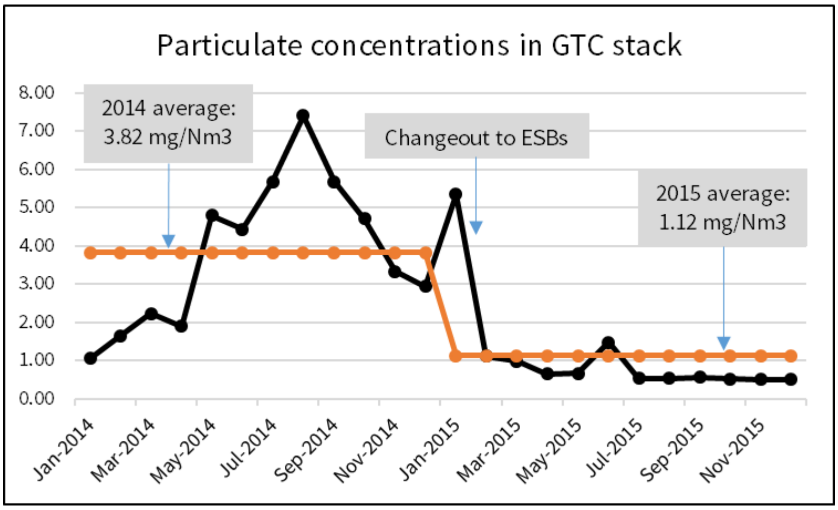


**Figure 7. Dust emissions before and after the installation of ESBs.**

The results have been very good. In fact, after the installation there was a period where there were no emissions recorded. In reaction a stack test was conducted that confirmed that the dust emission was extremely low and that dust monitors were working fine. However, it is not uncommon that after the installation of new bags the dust emissions are lower than before the changeout. That relates to the age of the bags. It is therefore of interest to see how the HF emissions behave as this normally is not correlating. This is shown in the section below.

### 8.2 HF Emissions

There has also been a distinct impact on HF emissions after the extended surface filter bags were installed (Figure 8).

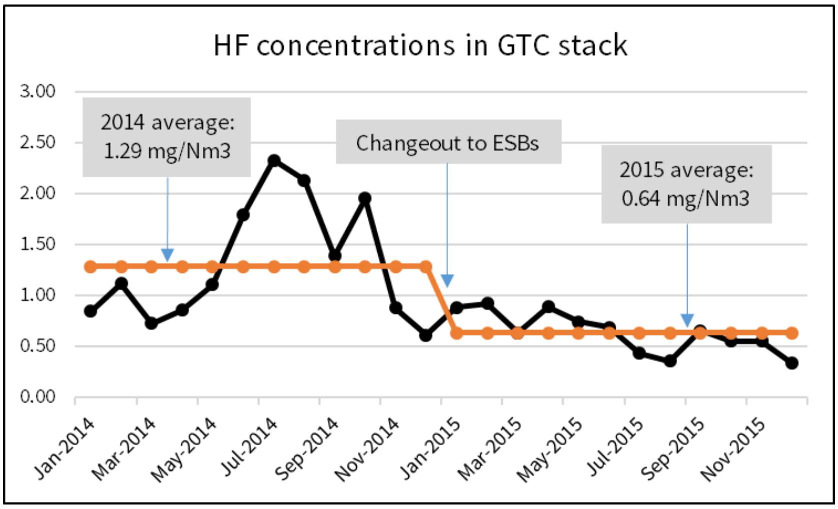


**Figure 8. HF concentrations before and after the installation of ESBs.**

The most important result is that HF emissions have dropped by almost 50 %. This is remarkable and one of the underlying reasons is that operations is maintaining a pressure drop that is close to the old settings. This means the thickness of the cake is relative large explaining the improvement. Another obervation is that the variation in emissions is also much less and that stack emissions have become more reliable.

### 8.3 Ventilation Flow

As described, the installation of the extended surface filter bags has a distinct positive impact on the capacity of the fans. It geneally allows for more flow through the system. In this specific case, the operations team is interested to maintain a specific flow through the system (Figure 9).

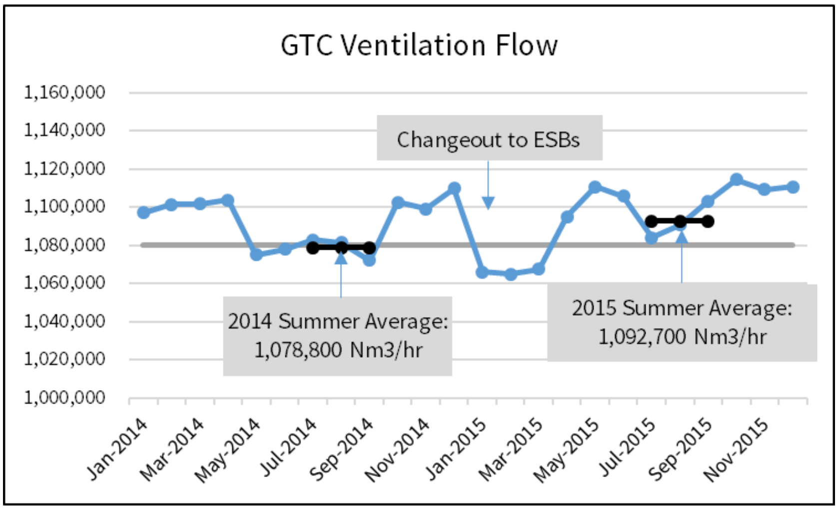


**Figure 9. GTC ventilation flows through the system.**

Figure 9 does not show the full potential of the increase in ventilation flow. This is because the operations team has a target to stay about a total value of 1 080 000 $Nm^3/h$ so there was no requirement to go beyond. However, one does observe the ability of the fans to consistently stay above target in the summer when the requirements are the highest and the fans typically suffer from the decrease in gas density as a result of higher off gas temperatures.

Irrespective, it is observed that fan capacity is increased now that the bags are replaced. Because of this, engineers are evaluating whether it is feasible to add high draft systems to the potline. This would lead to another step change in emissions reductions in the plant.

## 9. Conclusions

Filtration technology is very old and goes back to early industrialization. There have been many innovations but some make a step change and extended surface filter bags can be considered one of them. The introduction of extended surface filter bags in filter units are an example where upgrades have become much easier and more powerful than otherwise was the case. The development of extended surface filter bags shows again that a good technology takes time to find its way to industrialization, espacially in the primary aluminium industry. But adaptation is fast as the references show us and the ongoing trend teaches us that there is a general accpetance that these filter bags come with real benefits and can be justified, and importantly, deliver the envisioned results. The first introduction of extended surface filter bags in GTCs and FTCs should start in time and require the engineers to do the homework first. The steps of implementation are described in this article. This includes conducting onsite quality inspections that have been proven to make a difference and contribute to the succes of the project.

The actual results from one GTC conversion are shown as an example and this has been a good succes for this smelter. However, it is known that other smelters see the same positive impacts when they do their evaluations. This will continue to be a the driving force for future projects for further introduction of extended surface filter bags as we believe that we are only at the beginning of the use of this technology.

## 10. Acknowledgements

The authors wish to acknowledge the contributions and feedback from Mr. Klaus Schumann, Mr. Michael Neate, Mr. Brad Currell, Mrs. Petra Mühlen and Dr. Vinko Potocnik for reviewing the paper. We are grateful for the use of the actual GTC data. Lastly, we also wish to thank Hatch for the support and encouragement for our work.

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## 11. Symbols

$A$ ........................... Surface of a filter bag ($m^2$)
$\Delta P$ .................... Pressure drop (Pa)
$\Delta\rho$ .................... Difference in density between air entering the stack and ambient air ($kg/m^3$)
$\delta$ ...................... Thickness of the cake (m)
$D_p$ ..................... Diameter of a nominal particle (m)
$\varepsilon$ ...................... Porosity or void fraction (-)
$f_p$ ...................... Friction factor (-)
$g$ ....................... Acceleration of gravity ($m/s^2$)
$H$ ...................... Height of the GTC stack above the elevation of pots (m)
$K_c$ ..................... Specific resistance of cake (-)
$K_f$ .................... Specific resistance of fabric (-)
$\mu$ ..................... Viscosity of the fluid (air) (Pas)
$Q_m$ .................... Mass flow of particles (kg/s)
$\rho_f$ ..................... Density of air ($kg/m^3$)
$\rho_p$ ..................... Real density of the particles ($kg/m^3$)
$Re_p$ ................... Reynolds number related to particles (-)
$v_s$ ..................... Superficial gas velocity (m/s)
$w$ ..................... Specific weight of cake on filter bags ($kg/m^2$)