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# COMPACT FILTER DESIGN FOR GAS TREATMENT CENTERS

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## Abstract

The footprint occupied by the GTC is an increasing concern since roadways, alumina handling and storage fill the courtyard, the area between pot rooms. This area is further congested by high draft systems and collector ducting. The application of new heat exchangers has been recently discussed because it has the potential to reduce the footprint in two ways 1) by causing a reduction of the actual flow through the filters by eliminating the controlled ingress of dilution air and 2) the reduction in gas temperature reduces the "actual" volumetric flow rate to the baghouse [1].
This paper describes a different approach taken by Danieli Corus to develop a compact filter module design that is aimed to reduce the overall footprint and capital costs of a GTC. Dubbed as the "Chinook" module, the design comprises of two low pressure rotating pulse systems combined into a single filter module thereby reducing the total number of modules and required associated equipment. Computational Fluid Dynamic (CFD) modeling was applied and confirms that while maintaining industrial standards on air/cloth ratio and can velocity, the footprint potentially is reduced by 25-30%. Placing the circular bag array of the low pressure pulse system into a square filter housing eliminates any concerns regarding the can velocity since the majority of gas flow migrates to the open areas around the filters. Modules can be upgraded to longer filter bags and/or to filter bags with extended surface without the need to increase the cross sectional area of the module itself. Future developments also include a positive pressure concept to the Chinook module with an exhaust fan upstream of the module and one independent stack on top of each module. Combined with the design aspects discussed, the positive pressure concept has the potential to further reduce the GTC footprint to about 60% in total.

## Introduction

In the selection of a new Gas Treatment Center (GTC) a great number of factors are considered such as economics, performance, maintainability, bag life and power consumption. One other essential factor is the physical space occupied by the GTC. The GTC footprint is important when one considers that potroom courtyards are typically crowded with alumina handling systems, roadways, overhead ductwork and mechanical /electrical buildings. In some instances, the parallel potrooms are located so close together it leaves little space for a conventional GTC. It is advantageous if the GTC could be more compact and occupy a smaller area. Additionally, such smaller footprint also presents a direct savings in capital investment, which makes a compact design even more attractive.

## Gas Cooling

The simplest and most direct means of reducing the GTC footprint is to reduce the actual volume of gas being treated. Typical potroom gas temperatures range from 130 – 180°C and must be cooled before being treated at the GTC. The cooler the gas, the less actual volume has to be filtered. Mixing the hot gas with dilution air is a traditional means of cooling but this directly adds to the total gas volume being treated due to the low heat capacity of air. It isn't unusual to have 1 or 2 filter modules directly associated with handling of the dilution air flow. Other direct cooling techniques such as water injection are possible but this increases the humidity of the gas and may pose process risks such as scaling or corrosion. Perhaps the most technically feasible means of cooling the gas temperature without injection is the use of a heat exchanger. The intriguing aspect of the heat exchanger is that the process gas is cooled but the other characteristics of the gas do not change. However, the heat exchanger adds significant commercial concerns such as added pumps and equipment, risk for scaling and management thereof. A reliable and continuous cooling medium source, low grade heat dissipation and arguably an increase in energy consumption could make the heat exchanger impractical. On account of this, the injection/evaporation of water and the use of a heat exchanger are further ignored for the purpose of this article. The GTC footprint could still be drastically reduced by more conventional means while achieving the cooling requirement with dilution air.

To come to a new concept with reduced GTC footprint, the following key aspects were evaluated:

- Filter Module Type;
- Module Configuration;
- Fan and Stack position.

## Filter Module Type

There are primarily two (2) main filter module types used in Gas Treatment Centers and they are often categorized by their bag cleaning technology. The first is the High Pressure (HP) / Medium Pressure (MP) pulse system that uses conventional circular filter bags and operates between 3 – 5 bar. The second type is the Low Pressure (LP) rotating pulse system that uses oval shaped filter bags and operates at just 0.7 – 1.0 bar.

There are several mechanical differences between the two types:

- MP requires an air compressor station and dryer to provide the pulse cleaning air compared to a set of Positive Displacement Blowers for the LP.
- The MP system requires multiple (20-30) small pulse valves and blow pipes per module compared to a single large pulse valve and 3 rotating blow pipes for the LP.
- The height of the clean air plenum above the tubesheet is relatively low for the MP system whereas the LP system may require three (3) meters height or more.

Both systems have pros and cons and therefore the GTC suppliers typically opt for systems for which they have the most experience.

Pulse Cleaning Technology vs. Filter Bag Surface Area

Next, the pulse cleaning systems were evaluated by their physical characteristics in association with their filter bags. The preferred pulse cleaning system should provide potential for the maximum filter surface area available for particulate removal thereby creating a module that handles the largest volumetric flow.

To do this, the bag cleaning principle had to be re-visited since the systems are different albeit proven effective. The MP works with a shock wave that ripples down the bag to release the filter cake while the LP uses a high volume of air to rapidly but gently inflate the bag. Filter bags with lengths of 8-10m are in use for both pulse cleaning systems and both are competitively used in the market. The question is if there is a way to distinguish between effectiveness for varying bag lengths? In 1988, the Electric Power Research Institute (EPRI) sponsored a series of pilot tests on pulse jet fabric filters [1]. This work was summarized in a table that quantified the energy available in a pulse at different locations along the bag length. A selection from the EPRI study is presented in Chart I below:

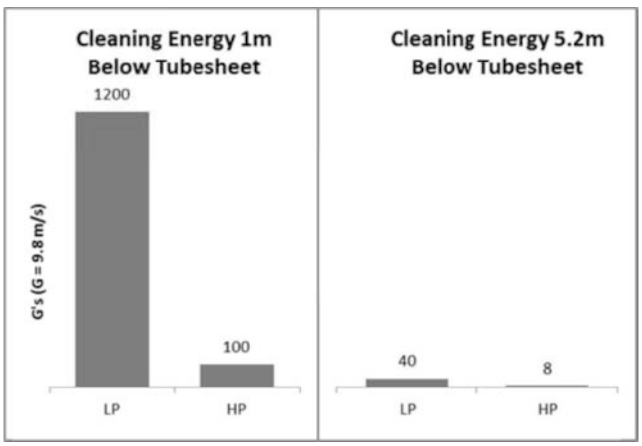



Chart I. Cleaning Energy of Medium and Low Pressure Pulse Cleaning Systems [1]

* Table 1 was obtained from graphical information provided in reference [2] for the purpose of this article.

If the LP pulse system carries more energy further down the bag during the cleaning cycle then it is possible that longer filter bags may be applied to this module type – the longer the filter bags, the greater the cloth area available per module for the same (or smaller) GTC footprint. While this is true, this assumption must be checked against the method by which the filter bags are arranged within the module cross section. This also plays an essential role in the development.

To evaluate the configuration of the packing of the filter bags, the design assessed the accumulative bag filter perimeters within a fixed module cross section thereby ignoring the contribution from the filter bag length. Refer to Figure 1 for typical MP and LP filter bag arrangements at the tubesheet level:

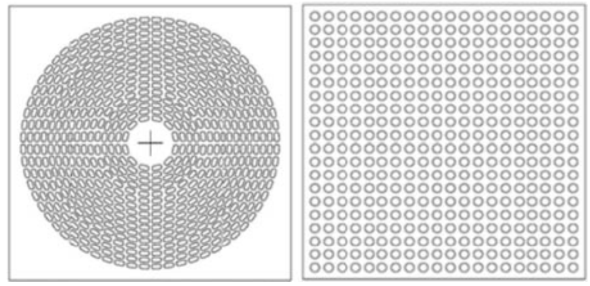


Figure 1. Plan View on Tubesheet
Left Side – Low Pressure Pulse System
Right Side – Medium Pressure Pulse System

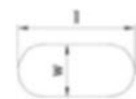
For the MP pulse system, the filter bags are arranged in a rectangular array and the total filter perimeter would be:

$$P_{MP} = \sum \pi d \qquad (1)$$

Where $P_{MP}$ = Sum of filter bag perimeter for medium pressure
d = bag diameter

The LP pulse system utilizes oval filter bags in a circular array and the total filter perimeter would be:

$$P_{LP} = \sum(\pi w + 2(l - w)) \qquad (2)$$



Where $P_{LP}$ = Sum of filter bag perimeter for low pressure
w = oval bag width
l = oval bag length

Using the equations above, the sum of filter bag perimeters were calculated for both a MP and LP pulse cleaning system for a filter module with varying square cross sections. The resulting trends are presented in Figure 2 below:

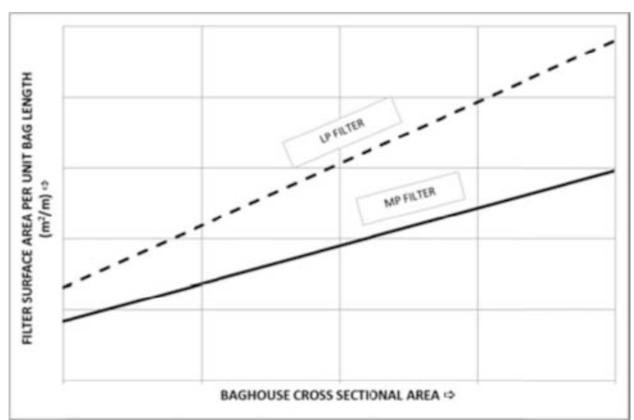



Figure 2. Trending of Filter Bag Surface Area
for Varying Module Cross Sections
for Low and Medium Pressure Pulse Cleaning Systems

The trend line for the total filter bag perimeter of the LP pressure pulse system has clearly a higher slope than for the MP pressure pulse system. This indicates that a tighter filter bag arrangement could be achieved in the LP module. This means that the larger the individual module, the more compact the overall design can be. Please note that in Figure 2 a particular limitation of the MP pulse system is not considered. The MP pressure system may not necessarily be adaptable to very large modules. For MP, each pulse is delivered from an independent valve on the outside of the module through the blow pipe which is length-limited to approximately 18-20 filter bags deep. Therefore, the trend line for the MP system cannot continue indefinitely with increasing cross section. The LP system is hampered by this limitation to a much lesser degree as it could be integrated into much larger modules; approximately 7000 x 7000mm cross section based on experience.

To achieve the most compact GTC configuration, it appears that the LP pulse cleaning system can pack the largest conventional filter cloth area into a single module. Now, this is based on conventional filter bag technology and the next question is what if this arrangement could be integrated with modern filter bag technology to further increase the surface area within the module? Reference is made to the extended surface bag technology such as offered by Advancetex International.

In the past the extended surface filter bag technology has typically been applied to retrofit and refurbishment applications, but is now also making an appearance in Greenfield installations. This filter bag development was originally targeted to increase the gas volume and/or decrease pressure loss at existing GTCs that were faced with the increased loads from amperage creep in the potline. This work uncovered the extended surface bag technology to be available on the market for LP pulse systems. They are currently manufactured by Advancetex International [2] as illustrated in Figure 3.

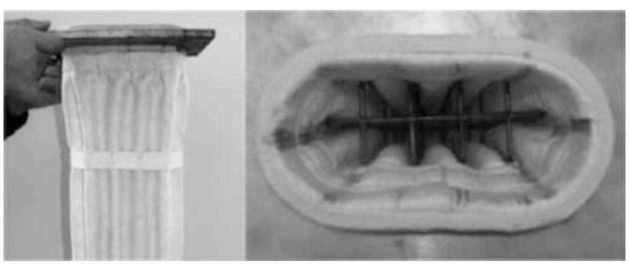


Figure 3. Oval type Extended Surface Bag Technology for Low Pressure Pulse Cleaning Systems [3]

For Greenfield applications it was concluded that the extended surface filter bags could further increase the surface area of filter cloth available in a baghouse module. This presented the option to either reduce the number of filter modules or to possibly shorten the overall height of the filter bags while still providing sufficient surface area to maintain acceptable filter velocities. Alternatively, substituting the extended surface bags for traditional bags of the same length would result in considerable energy savings since the filter velocity would effectively be lowered by 20-30% under the same gas flows. Preliminary estimates indicate that the energy savings alone by going to a lower filter velocity could more than offset the increased cost of the extended surface filter bags and cages.

If it was opted to reduce the number of modules by using the extended surface bags it meant a direct reduction in number of reactors since one reactor is assigned to each module. Therefore each reactor is expected to treat more process gas placing unnecessary strain on the alumina injection system. If the extended surface filter bags were applied, the preference was to maintain the traditional filter bag length and reap the benefits of lower filter velocity such as reduced pressure drop, an improved bag life due to less frequent cleaning requirements and reduced particulate emissions. In support, a more detailed investigation into the extended surface applicability with the LP pulse system GTCs is required since the increase in cloth area is substantial. As a part of this a field demonstration phase has been initiated to quantify the process improvements on an existing Gas Treatment Center.

While calculations showed that the LP filter module had the mechanical advantage in terms of holding the most available cloth area within, it needed to be further evaluated against a number of key performance criteria:

- Flow Distribution and Can Velocity;
- Equipment maintainability;
- Adaptable to extended surface filter bag technology.

Flow Distribution and Can Velocity

The can velocity refers to the theoretical velocity of the treated gas as it passes upward between the filter bags. The formula for calculating can velocity is:

$$\frac{V}{100} = \frac{Q}{(L \times W) - (n \times a)} \qquad (3)$$

Where V = Can Velocity (cm/s)
Q = Actual Gas Flow ($m^3$/s)
L x W = Cross Sectional of Baghouse ($m^2$)
n = number of filter bags
a = cross sectional area of one filter bag ($m^2$)

The calculated can velocity is actually a theoretical average as in reality there will be areas of higher and lower velocities due to the way the flow is distributed within the module. When the MP and LP systems are compared in terms of can velocity, it can be noted that the effective can area is generally equal between the two systems with varying module cross sections as shown in Figure 4:

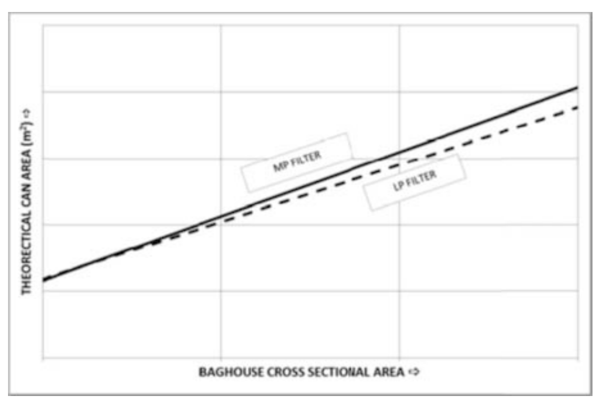



Figure 4. Trending of Effective Can Area For Varying Module Cross Sections in Low and Medium Pressure Pulse Cleaning Systems

However, when the packing of the bags within the module is compared there is a notable difference found in Figure 1. The filter bags with the MP baghouse are evenly distributed from side to side and corner to corner. However, there are some unique and notably large areas in the corners and in the center of the LP tubesheet referred to as chimneys. This is the result of the circular bag array in the square module. It creates these chimneys and these have little resistance and become the preferred path of the gas flow toward the filter bags. This is modeled using CFD and illustrated in Figure 5:

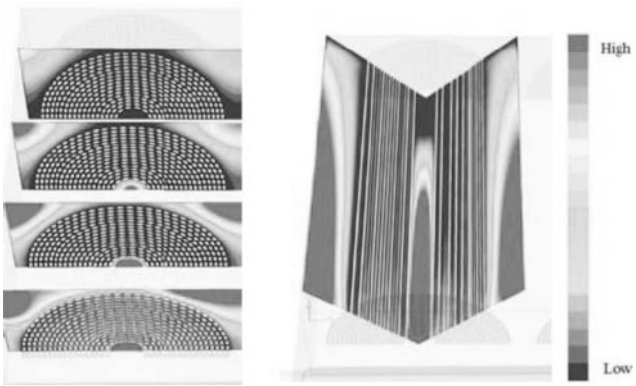



Figure 5. CFD Model Illustrating Vertical Velocity of Dirty Gas Within The Filter Module.
Left Side – Horizontal Slice through Module
Right Side – Vertical Slice through Module

The majority of the flow travels upwards through these chimneys and then turns to penetrate the filter bags horizontally. Therefore the actual vertical velocity in between the filter bags is relatively low when compared to the theoretical average can velocity calculated in equation (3). Nevertheless, during filter bag exchange it has been noted that there is little difference in the failure rate between bags adjacent to the chimneys and those in the middle annular rows. This would suggest that the filter bags are generally equally loaded with particles despite the side loading theory. So although the theoretical can velocity is approximately the same between the two pulse cleaning systems, there is a noticeable difference in the <u>actual</u> upward velocity between the filter bags with the LP system.

What does this mean? It means there is a major benefit of the LP system as it ensures the majority of dust particles fall downwards after being released off the filter bags. Additionally, the chimney effect allows the LP filter module to manage much higher gas flows (for example longer filter bags or extended surface filter bags) without concern for "average" can velocity. It means that the LP baghouse module can cope with higher can velocities than what is was typically recognized as industrial standard.

<u>Equipment Maintainability</u>

As with any piece of mechanical equipment, the pulse cleaning systems need to be accessible and require a degree of maintenance. Although the LP system is the preferred method with regards to reducing GTC footprints, it has to be accepted industrially in terms of performance, maintenance and accessibility. Both MP and LP filter modules have equipment that is easily accessible from local platforms and both systems have to be accessed when removing or changing the filter bags.

Figure 6. Pulse Cleaning Blow Pipes
Left Side – Low Pressure Pulse Cleaning System
Right Side – Medium Pressure Pulse Cleaning System

As can be seen in Figure 6, the cages and filter bags on the LP system can simply be removed from the top of the tubesheet as they are not obstructed by the rotating pulse header. Unfortunately, with the MP system each blow pipe has to be removed to access the cages and filter bags below. There is the time required to unfasten each blow pipe and storing of the pipes when the bags are being changed. So for changing the filter bags, the LP pulse system arguably requires less effort.

**Module Configuration**

In the next step the configuration of the modules within a full GTC was investigated. In general, many GTCs are of the parallel module design as illustrated below:

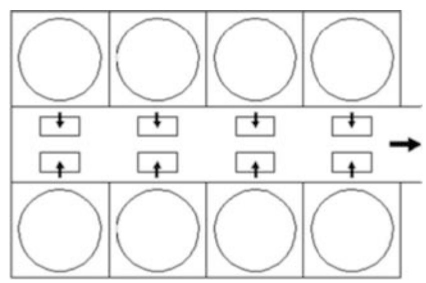


Figure 7. Typical Module Configuration with
Parallel Rows of Filter Modules

If the size of the filter module is increased, it is possible to align the modules in a single row:

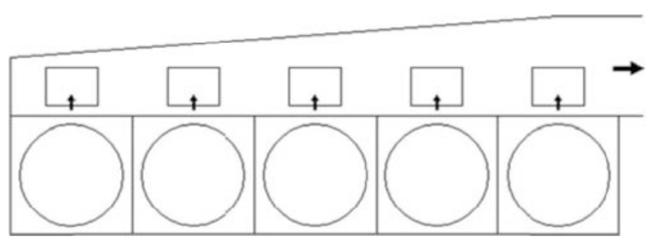


Figure 8. Enlarged Filter Modules in Single Row

There are significant advantages when a GTC is configured in a single row. It provides for a smaller footprint, it makes the configuration of the alumina handling equipment simpler, and lastly, it could provide the option for future expandability by simply adding modules at the discharge end. Some preliminary layouts and steel weight calculations confirmed that a GTC based on an aligned, "oversized" filter module was the most favorable option. However, there are some challenges with the oversized module such as 1) pre-fabrication and transport, 2) N-1 process conditions means the standby module is very large and 3) the practicality of an extreme size LP pulse cleaning system. Discussions with LP pulse cleaning system manufacturers indicated that the extreme size of the LP system required has been largely unexplored and has not found its way into the market.

While this poses a challenge, the confidence remained that the approach for the aligned configuration was correct and as such the thought process was not altered in further work. However, it did bring us to the concept of combining two (2) smaller, more conventional LP pulse systems in a single rectangular filter module. It means that the concept of increasing the flow per module can be retained while incorporating a LP pulse system that is readily available and well proven. It was interesting to see that when the dual LP system was drafted, the similarities with a Chinook type helicopter from Boeing became very apparent. Because of this similarity Danieli Corus now dubs this module design as the "Chinook" module as shown in Figure 9.

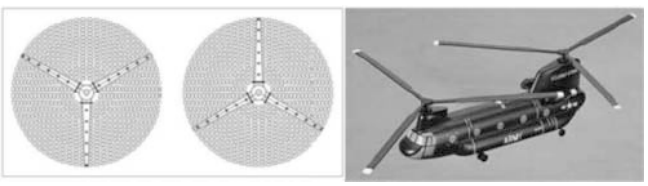


Figure 9. Danieli Corus Chinook Module Design
Left Side – Plan View Chinook Module Tubesheet
Right Side – A Boeing Chinook Helicopter

Essentially, two (2) smaller LP modules are combined and the middle wall is removed. The result is that the modules can be placed side by side in a single row while handling 40-50% more gas flow per module – exactly the system being sought after.

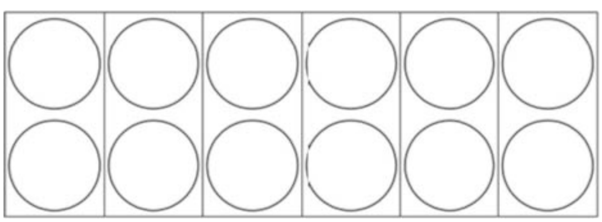


Figure 10. GTC Configuration with Chinook Modules

Flow Distribution

Since the elongated module is a new concept, the gas distribution within the filter module had to be investigated. This starts at the inlet. The gas distribution at the entrance of the module serves to:

- Drop the majority of the alumina into the hopper by directing the particles downwards. This action reduces the alumina load to the filter bags;
- Minimize the gas velocity across the bed of alumina to reduce re-entrainment of particles that have already settled;
- Achieve a proper upward flow distribution in the direction of the filter bags.

If no flow distribution device is installed, all the gas will travel uninterrupted to a small area with filter bags resulting in rapid abrasion of the bags. Similarly to conventional GTCs extensive CFD modeling confirms that baffle plates are required along the entire length of the filter module to force the flow downwards. This is shown in Figure 11:

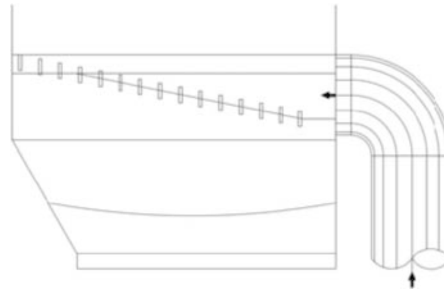


Figure 11. CFD Model Illustrating Gas Velocity within the Chinook Module
Vertical Slice through Module

The CFD model shows that the velocity in the module hopper is low enough to disengage majority of alumina particles and that the possibility of particle re-entrainment is very low. As the flow turns upwards from the hopper, it is observed that the gas flow continues to follow the path of least resistance, which is found in the chimney areas (shown in red color). This is shown in Figure 12:

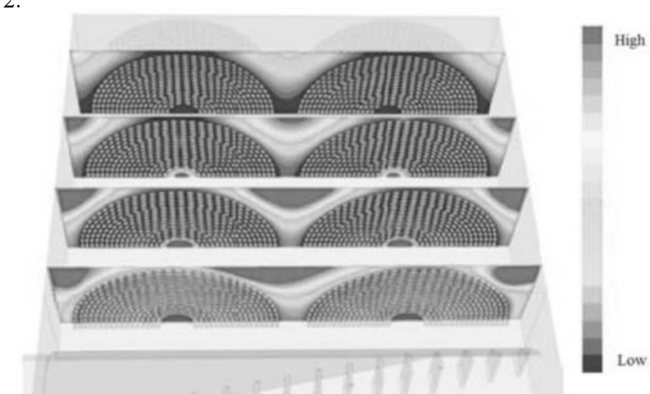



Figure 12. CFD Model Illustrating Gas Velocity within the Chinook Module
Horizontal Slice through Module

With this process characteristic now confirmed we meet our objective, which is that a filter module design is obtained to handle significantly more flow and that can be arranged in a very compact configuration. The Chinook module will without doubt reduce capital costs while still providing the superior performance. Furthermore this concept is based on proven technology and standard equipment so there is also very little additional risk foreseen with its implementation.

**Fan and Stack Position**

In general, most GTCs are equipped with a cluster of fans on the discharge side of the filter modules to provide a negative pressure within the GTC, the ventilation ducts and ultimately the cells. The benefits of this are:

- The fan impeller is exposed to clean gas;
- Air leakages on the dirty side will draw ambient air into the system and no fumes leak to the outside. Operators are not exposed directly to raw gas constituents.

In some cases a circular array of fans around a common stack is used and in other cases a long outlet and fan discharge plenum. The primary reason for this fan layout is that the modules were placed in parallel rows, which meant there was not enough space on the sides of the GTC to place the cluster of fans. When using the Chinook design, there is enough space available alongside the GTC where the fans can easily be located. The overall achievement consists of less steelweight and 40% reduction in footprint as illustrated in Figure 13.

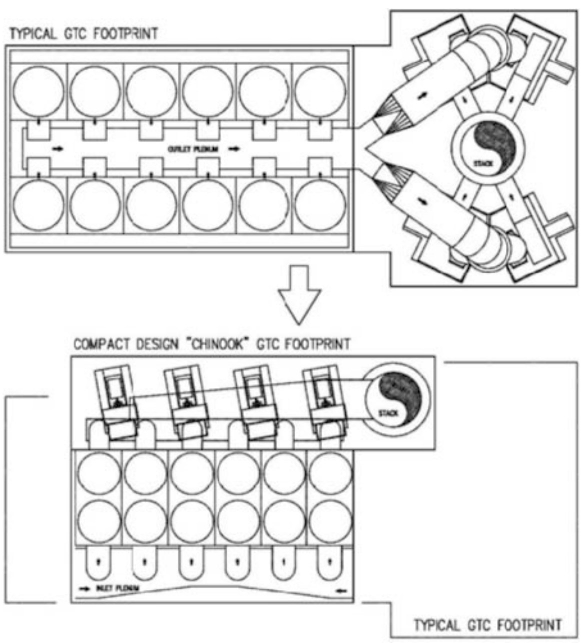



Figure 13. Reduction in Footprint of
Gas Treatment Center

### Conclusion

The development work has resulted to a new concept for a GTC where the combination of the Chinook design with the new fan / stack configuration leads to an extremely compact GTC arrangement. In summary, it provides:

- A module that could filter significantly more gas flow thereby reducing the number of modules required;
- A simple configuration with reduced amount of structural steel, platforms, etc.;
- A fan and stack placed tightly against the filter modules.

This potentially frees up a vast amount of space in the courtyard and requires significantly less civil foundations and structural steel.

### Future Development

During the compact design investigation, the discussions about the exhaust fan placement led to a further potentially improved GTC footprint. If a single exhaust fan was assigned to a single Chinook module then it is possible to locate the fan at the inlet side of the baghouse module thereby creating a positive pressure inside the filter module. The concept of having the induced drafts located upstream of the baghouse has been applied in several operating potline GTCs. Reference is made to Alcoa's A-398 Fluidized Bed Scrubbing Process first used in 1971 [4] that can be found in smelters such as Alcoa Portland, Alcoa Point Henry and Alumar. There are some significant advantages:

- Single exhaust fan assigned to each module provides simple way of balancing gas flows;
- Slight positive pressure reduces the "actual" volume of gas being filtered;
- When applied to the Chinook design, a further reduced footprint area as illustrated below in Figure 14.

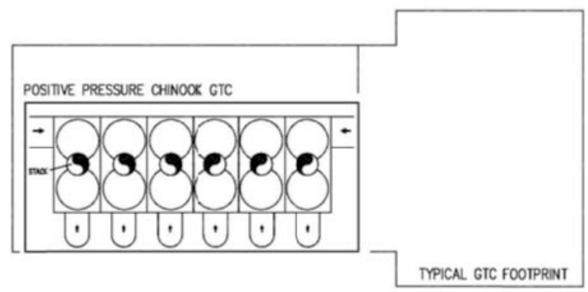



Figure 14. Future Development
Reduction in Footprint Area with Positive Pressure GTC

Once the independent fans are placed on the inlet side of the filter module there is potentially no reason to re-collect the gas on the clean side. There are some exceptions such as re-collection for entry to a common $SO_2$ scrubber or in cases of extreme stack height. However, each Chinook module can also be equipped with an individual stack on the roof of the module. While there are still some challenges to overcome in this concept, there is a real potential for a GTC that will occupy up to 60% less space than the ones installed previously.

### References

[1] El Hani Bouhabila et al, *"Electrolytic Cell Gas Cooling Upstream of Treatment Center",* Light Metals TMS2012 p.545-550.

[2] C. Jean Bustard et al., "*The Potential of Pulse-Jet Baghouses for Utility Boilers. Part 2. Performance of Pulse-Jet Fabric Filter Pilot Plants",* Journal of the Air and Waste Management Association, Vol 42. No.9, Sept 1992.

[3] Michael Neate, "*New Technology to Reduce Emissions from the Potline",* Arabal Conference 2011.

[4] *"Research-Cottrell A-398 Fluidized Bed Scrubbing Process – Emission Control and Fluoride Recovery for Primary Aluminium Production Potlines",* Research-Cottrell – An Air and Waters Technology Company. Branchburg NJ 08876, 1997