Improving the Energy Efficiency of an EAF Air Pollution Control System

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Introduction

Air Pollution Control (APC) Systems are large users of electrical energy in a steel plant. This paper will explore the operational results of an installation of new low resistance filter media at the Steel Dynamics Inc. - VA (SDI-VA) plant, which resulted a significant reduction in electrical energy used by the APC system. The reduced filter resistance of the new media allowed SDI-VA to remove one fan from operation while maintaining proper meltshop evacuation, resulting in an overall reduction in power requirements and a net savings of over $400,000 per year. Data and strategies will be analyzed for application in other EAF facilities.

Discussion

Air Pollution Control (APC) Systems in EAF Steel Plants

The primary form of pollution control for Electric Arc Furnace (EAF) meltshops in most of the world is a fabric filter, also known as a baghouse, filtering the gases drawn directly from the shell of the EAF. These gases are frequently combined with the secondary fugitive fume control gases drawn from the meltshop roof or overhead canopies[1]. These systems move hundreds of thousands of cubic feet of air, and in many cases millions. In fact, an average EAF APC system will move 9 pounds of air for every pound of steel produced! The APC systems' fans are large users of electricity, sometimes second only to the furnace itself.

While cost containment and control in the area of filter bag replacement costs is important and worthwhile, the annual costs associated with the purchase of filter bags represents only 7.5% of the total annual APC operating costs. 75% of those total costs comes from the energy usage at the fans, yet managers of these systems rarely pay the same level of scrutiny to these costs as compared to maintenance and materials. Part of the reason for this is that it has been difficult to affect APC energy costs in the past. APC systems, in order to reduce their upfront capital costs, are typically engineered with a static design set point, using fixed drive fans, inefficient (but robust) fan wheels, and system dampers to create different gas flow volumes and profiles to adjust to the various operations of the furnace and meltshop. In addition, with advances in EAF productivity, including the increased usage of chemical energy in the charge and furnace, older APC systems can become undersized; hence the APC manager is always looking for ways to increase flow, not reduce energy usage. Still, as a significant consumer of electricity within the steel plant, APC energy usage is a worthy area for efficient evaluation, either to minimize the additional energy requirements associated with a system capacity increase, or to reduce overall energy usage when the system capacity is deemed adequate.

Steel Dynamics, Inc. Roanoke Bar Division

Steel Dynamics Roanoke Bar Division (SDI-VA) began producing steel products for manufacture and distributors in 1955 as The Roanoke Electric Steel Corporation. From the beginning, the goal of the plant was to produce the highest quality products at the lowest possible cost, by continually integrating the latest in steel-making technology. This facility has expanded, modernized and computerized every area of their operation, with a continual emphasis on high quality, cost efficient, and environmentally responsible production of steel products. In 2006 the Roanoke Electric Steel Corporation was acquired by Steel Dynamics, Inc. and is now the Roanoke Bar Division. The meltshop includes a Danieli 90 ton EBT EAF with a nominal capacity of 585,000 metric tons/year.

The primary form of pollution control for the meltshop is a fabric filter (aka "baghouse"), filtering the gases drawn directly from the shell of the EAF, from overhead canopies, and from some additional processes in the meltshop. The combined gases are pulled through the ventilation system by three fans, which then discharge into a Siemens Voest Alpine positive pressure reverse air baghouse. The design data is presented in Figure 1. The baghouse was originally fitted with a knitted polyester fabric filter material that operated for 7 years with low pressure drops and acceptable emission rates, well below required levels.

Steel Dynamics Inc.-VA	
Flow Rate (ACFM)	1,000,000
Temperature (°F)	250 °F
Dust Load (grains/dscf)	1-5 grains/ft^3
Baghouse DP (inches w.g.)	9.5 – 10.5
# of bags/compartment	300
# of bags/baghouse	3600
Bag Material	polyester
Air-to-Cloth Ratio Gross (fpm)	2.45
Air-to-Cloth Ratio Net (fpm)	2.83
Cleaning Frequency	4 cycles/hour

Figure 1: *Baghouse operating conditions prior to filter bag change*

The APC system at SDI-VA was originally designed to run with three fans operating but still be able to run at a reduced capacity with two fans operating during fan maintenance activities.

In 2016, it was decided that the existing filter bags were reaching the end of their useful life, and should be replaced. At the same time, SDI as a corporation was looking at several projects aimed at reducing energy usage in their mills. It was at this time that SDI started to evaluate the potential APC fan energy savings associated with the introduction of a new kind of baghouse filter – GORE® LOW DRAG™ Filter Bags.

ePTFE Membrane Filtration Media[6]

Expanded Polytetrafluoroethylene (ePTFE) membrane filter media was invented by W. L. Gore & Associates, Inc. (Gore) and developed for multiple applications including the steel industry in the mid 1970's. This technology, in various forms, has been used by the steel industry to solve problems with baghouse temperature capability, hot particle resistance[2], high pressure drop operations, short bag lives, and improved baghouse particulate capture efficiency[3]. Today, it is widely available from multiple suppliers, and is recognized as a problem solving filter material. Its structure improves dust release during cleaning; therefore ePTFE membrane laminates have been successfully used to combat high pressure drop problems in applications with poor cleaning systems or sticky dusts[4]. In well-designed baghouse systems and "easy" particulate applications, its pressure drop/flow acceptance performance has been shown to be only marginally better than a well-made non-membrane filter bag ("conventional" filter media) costing much less. Part of this is due to the fact that even though an ePTFE membrane is an order of magnitude more efficient at capturing fume at its surface, it still allows some fume, especially sub-micron sized particulate, to penetrate into the membrane and "season" that filter, which in turn lowers its permeability and changes its filter surface (affecting its dust cake release properties). This seasoning continues over time, to varying degrees, depending on the application, particle size, filtration velocity, and other factors. Much work has been done over the last several decades to improve the efficiency and durability of these laminates – not as much work has been paid towards improving the dust cake release properties of these membranes (without sacrificing efficiency or durability).

By manipulating the ePTFE membrane structure to improve membrane capture efficiency at true sub-micron particle sizes, while maintaining the required permeability and membrane strength (durability), Gore has developed a new class of membrane laminates that truly act as surface filters in fume and very fine powders applications. The differences in the ePTFE membrane structures becomes very apparent when viewed at the same magnifications under a Scanning Electron Microscope, as presented in Figure 2. A representative twenty (20) micron circle is shown in each photomicrograph to illustrate the surface filter capability of the membrane structures.

It can be seen from the comparison in Figure 2 that there is very little, if any, particle penetration into the new membrane structure. Even sub-micron particles are captured at this membrane's surface, where they can be much more easily removed with typical baghouse cleaning procedures, making them true surface filters. Thus, these filters return to a near-new condition with each cleaning cycle, and do not season over time. This performance can be theoretically described comparing the residual pressure drops of various filter media over time as shown in Figure 6.

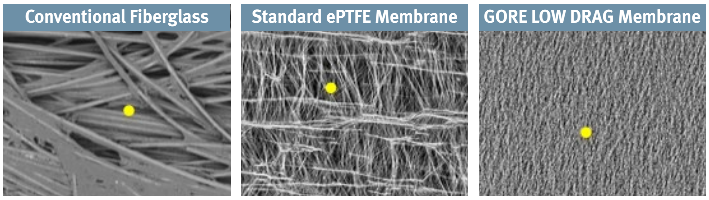

Figure 2: *SEM Photomicrographs of Filter Media surfaces at 500X – 20 micron particle*

GORE LOW DRAG Fabric Filtration

Understanding filter media flow acceptance performance requires an understanding of the concept of filter drag, or the resistance of that filter to flow, especially after the filter has seen process conditions and particulate. A "low" filter drag (low resistance to flow) can either be thought of as a decreased pressure differential across the filter for a given flow rate, or an increased amount of gas flow rate at the same pressure drop. This topic has been covered extensively in previous publications[7]. To review, the typical units used by the APC industry in the USA, filter drag can be expressed as presented in Figure 3:

$$\textbf{Filter Drag} = \frac{\text{Differential Pressure}}{\text{Air to Cloth Ratio}} = \frac{dP}{A/C} = \frac{\text{"wg}}{\text{cfm}/\text{ft}^2}$$

Figure 3

GORE LOW DRAG Filter Bags minimize the development of pressure drop by completely cleaning the accumulated dust/fume cake off of the filter bag surface with each cleaning cycle. This is accomplished by creating a durable, permeable membrane that is an order of magnitude more efficient at the filter surface than any other previous membranes or other filter materials. This allows for near perfect cleaning of the filters with each cycle, and prevents those filters from becoming "seasoned", or plugged with fume over time. This can be visualized by the following graphs: (Figures 4 and 5).

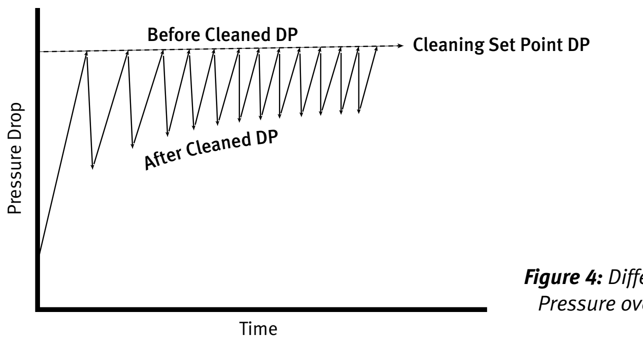

Figure 4: *Differential Pressure over Time*

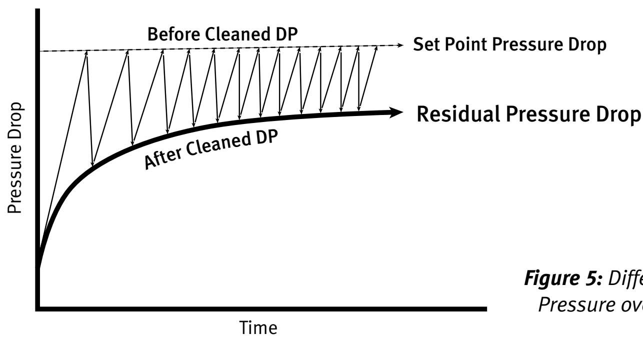

Figure 5: *Differential Pressure over Time*

Because fume does not penetrate into the membrane filter interstices and cross section, the cleaning performance of this class of membrane filters does not degrade with time – life is based only on the durability of the laminate, cleaning frequencies, and other cleaning parameters. This concept is generically shown in Figure 6.

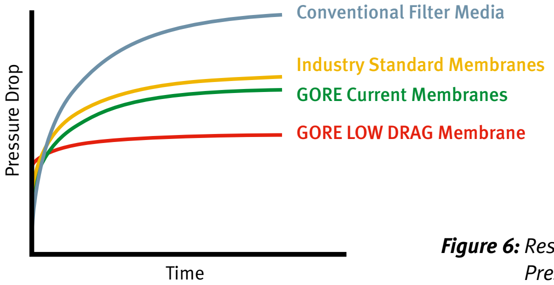

Figure 6: *Residual Differential Pressure over Time*

Cleaning to a lower residual pressure drop allows for many money-saving operational strategies – in the case of SDI-VA, they chose to operate the baghouse at a lower overall DP set point in order to allow their fans more capacity, and/or a reduction in overall system flow resistance that could lead to energy savings.

Steel Dynamics – Roanoke VA Experience

On startup after installing GORE LOW DRAG Filter Bags, there was a significant reduction in the total baghouse DP of 4 inches w.g. In terms of Filter Drag (FD), this equated to a filter resistance reduction from a FD of approximately 2.8 inches w.g./fpm (using average compartment pressure drops) to a new operating FD of approximately 2.0. This lower operating resistance has held constant since start-up, as shown in Figure 7.

Since the fans at SDI-Roanoke are direct drive, it was understood that energy savings due to a lower system resistance would be minimal with all three fans operating. Nevertheless, anticipating a reduction in fan energy consumption, SDI Roanoke began recording fan power usage prior to bag replacement. With all three fans

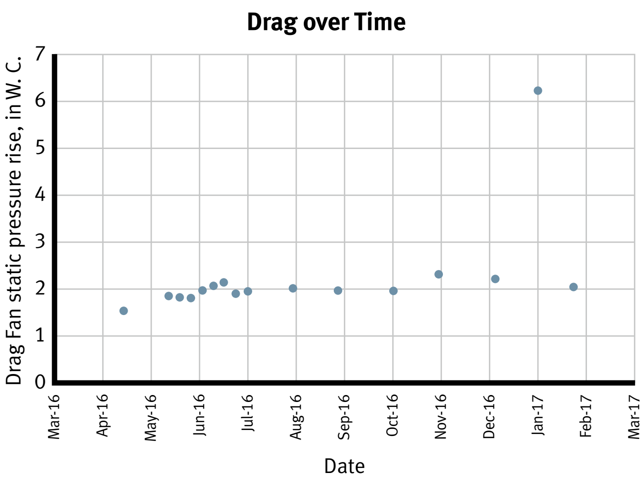

Figure 7: *It should be noted that the outlier data point for Jan-17 is due to a flow sensor malfunction.*

operating, and only adjusting fan dampers to find a more efficient operating point for the fans, power consumption with GORE LOW DRAG Filter Bags was reduced 9% resulting in energy savings of $50 – $60/day. However, after approximately three weeks, one fan was taken out of service while adjusting the remaining fans to continue to provide airflow sufficient to evacuate the meltshop. This resulted in energy savings of $1200/day. Since start-up, there has been no significant increase in baghouse DP, and SDI-VA continues to operate two fans today. In addition to the energy savings, this has also resulted in an easier maintenance schedule for the fans (having one off at all times) improving total APC system availability.

Finally, a recent baghouse stack test showed a welcomed side benefit of these new filters. Improving the efficiency of the filters to improve dust cake release also improves the overall Particulate Matter (PM) collection efficiency, especially in the PM10 and PM2.5 particle size ranges. Emissions testing showed filterable total particulate matter as defined by EPA Method 5I of 0.000022 grains/dscf, or about 0.05 mg/Nm^3 which is the lowest emissions results SDI has ever achieved. While these results should not be taken as the normal emissions capability of these filters, it nevertheless shows that an improved PM collection efficiency can be realized while concurrently improving overall baghouse and APC system operation.

Energy Benefits for Steel Plant Operators – a General Discussion:

While the specific situation at SDI-VA was somewhat unique, SDI's experience does show that a creative and calculated approach to understanding the true operating costs of an APC system (including the energy costs) can result in significant savings. As stated earlier in this discussion, the electrical energy consumed by the APC system fans is a significant cost to the entire plant operation. The theoretical power necessary to move air and gases through a ventilation system is represented by the following formula[5].

$$PWR = \frac{Q \times FTP}{CF \times \eta}$$

η = Mechanical Efficiency (of the fan)
Q = Volumetric flow rate, cfm
FTP = Fan Total Pressure, inches w.g.
PWR = Power requirement, hp
CF = Conversion Coefficient, 6362

In a simplistic scenario, if the gas flow through the ventilation system stays the same, the mechanical losses through the duct work and other parts of the system stay the same – only the pressure across the filters can then change if they are cleaning better. This reduction in resistance shows up as a lower Fan Total Pressure, or the static pressure rise across the fan. In a million cfm system, a reduction in baghouse resistance of 25% would typically represent a 2 inch w.g. reduction across the fan(s). Assuming a mechanical fan efficiency of 75%, this would represent a 420 horsepower reduction in fan energy. In a three phase AC motor, with a motor efficiency of 95%, and a transmission efficiency of 95%, this will represent approximately 1.5 million kW-hrs per year savings. If the resistance reduction is greater, the electrical savings potential goes up.

The reality of fan energy savings is much more complex. The easiest way to achieve these savings is to have a variable speed drive on your fan(s), and to slow them down. According to the Fan Laws,

$$PWR_2 = PWR_1\left(\frac{RPM^2}{RPM^1}\right)^3$$

But the mechanical efficiency of centrifugal fans also varies with fan speed. In some cases, slowing a fan will bring it to a more efficient operation than its former state, and the power savings will be further enhanced. In other cases, slowing a fan will decrease the fan efficiency, leading to a reduction in the overall amount of fan energy that can be saved.

In the case of a fixed drive fan motor, the only significant options are a change in the fan impeller design, to take optimum advantage of the new, lower system resistance; or, to completely shut off a fan in the case of a multiple fan system (as in the case with SDI-VA). In some systems, shutting off a fan allows for the remaining fans to be operated at their maximum efficiency, and provides for an easier maintenance set-up on the entire fan system.

In all of these cases, it becomes clear that a careful analysis and study of the fans and overall ventilation system is usually necessary to fully predict and obtain the optimum fan energy savings when using GORE LOW DRAG Filter Bags. Such an evaluation was conducted by SDI-VA, resulting in significant energy savings. SDI-VA is continuing this analysis with additional studies on the fan(s) operation and efficiencies at their new operating point.

Conclusion

In any economic environment, steel plants are always looking to reduce the costs associated with their air pollution control systems, while maintaining compliance in a reliable, predictable manner. The resistance of gas flow through the system is a key parameter that should not be overlooked when trying to either reduce operating costs or economically improve performance. New filter technologies are now available that allow for a significant, measurable reduction in the resistance of a typical EAF baghouse APC system. Laboratory and field data show that even in well designed, conservative systems the new GORE LOW DRAG Filter Bags operate at lower pressure drops and/or higher airflows than currently available filter media, including conventional and standard ePTFE membrane laminates. When combined with a careful study and survey of the existing ventilation system, including the fans and fan motors, GORE LOW DRAG Filter Bags have shown the potential to significantly reduce electrical energy used to operate the APC system.

Steel Dynamics Inc., Roanoke Bar Division, has demonstrated that by reducing the flow resistance in their baghouse filter system enough to remove a fan from normal operation, they can save over $400,000 per year in electrical energy associated with the APC system without a degradation in meltshop evacuation performance. This has been accomplished while at the same time reducing particulate emissions from the baghouse, further improving the environmental performance of the entire system. While the opportunity to remove a fan from service would not be considered a “normal” situation, SDI-VA has shown that with a creative, calculated approach, the opportunity for significant energy savings exists in these systems.

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