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ALLIANCE PIPELINE'S LONG TERM ASSESSMENT OF HYDROPHOBIC HEPA FILTERS FOR IMPROVING AVAILABILITY OF PIPELINE GAS TURBINES

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Abstract

Getting maximum performance and reliability out of a turbine requires keeping the blades clean in order to reduce drag and improve the heat rate and power output. Inlet air filters play a significant role in the degree of fouling a turbine will experience. Turbine operators have been faced with a tradeoff between installing higher efficiency filters that remove more of the airborne particles but have a higher initial pressure drop and shortened life span compared to lower efficiency filters. Typically the solution has been to use the less efficient filters and then shut the unit down periodically for off-line water washing (OWW).

Alliance Pipeline tested new hydrophobic HEPA (High-Efficiency Particulate Air) filters developed by W.L. Gore & Associates on two of its pipeline compressors. After three years of field testing, Alliance found that the new HEPA filters not only had the same initial pressure drop as the existing lower efficiency filters, but they completely eliminated the need to shut down the compressors for OWW and have now lasted 3+ years. Based on these results, Alliance has installed the hydrophobic HEPA inlet air filters on the rest of its compressor fleet.

1. About the Pipeline

The Alliance Pipeline operates a 2,988 km (1857 mile) natural gas pipeline transporting high-energy, rich natural gas from producers in the Western Canada Sedimentary Basin to markets in the U.S. (see Figure 1 - Alliance Pipeline Map). The pipeline is owned by two entities. Alliance Pipeline Limited Partnership owns the portion that runs from the collecting fields in Northeastern British Columbia and Northwestern Alberta, through Saskatchewan and to the U.S. Border. Alliance Pipeline L.P. owns the portion that runs through North and South Dakota, Minnesota, and finally to customer receipt points west of Chicago. The pipeline connects with 52 receipt points in Canada and one in the U.S. and delivers to customers in Illinois.

Figure 1 - Alliance Pipeline Map

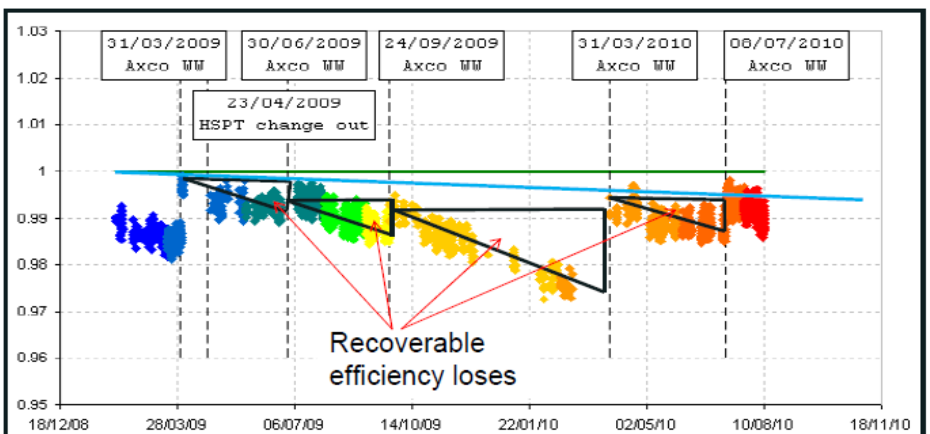
Alliance uses 19 Dry Low Emissions (DLE) gas turbines from GE, Siemens and Solar with a combined 517,000 HP to compress the gas and push it along the pipeline. A single 7700 HP Solar Taurus engine in Northeastern BC and a pair of Siemens SGT-200 Tornados (7,000 HP each) in Northwest Alberta are used in the collection fields. Two GE LM2500 Plus DLEs (42,070 HP each) and an LM2500 Plus G4 DLE (46,000 HP) provide compression at the first mainline station, two operating 24/7 and the other on hot standby. One LM2500 Plus DLE and 12 LM2500 Base DLEs (31,200 HP each) are situated at compressor stations spaced about 125 miles apart as the pipeline makes its way southeastward towards Illinois, maintaining the pressure at 1750 psi on the Canadian segment and 1945 psi on the U.S. side. Once it reaches its primary destination at the Aux Sable gas plant, the liquids are stripped out and household gas is distributed throughout the U.S. and Canada.

2. Coping with Fouled Compressors

Since the Alliance Pipeline started commercial operation in December 2000, the pipeline has continuously operated above 100% capacity. It can maintain this level even during maintenance shutdowns. As mentioned, the first mainline compressor station has a spare turbine on hot standby. The rest of the pipeline can maintain 100% capacity as long as there is a five unit separation between turbines that are offline for maintenance. However, the units needed to be shut down far too often, at a rate of 3 times per year. It is well known that the cleanliness of a gas turbine is the key to efficiency. Accumulated dirt in the compressor section results in increased fuel consumption, more frequent maintenance outages, and decreased hot section life. An example of dirty (fouled) blades from an Alliance unit can be seen in Figure 2.

Figure 2 – Dirt & fouling on front frame and Inlet Guide Vanes (IGV) on an Alliance Unit

The Alliance Pipeline compressor stations are located in a variety of rural locations and the turbines ingest different materials depending on the location - primarily dirt and dust, but also ice, snow and salt. To reduce the impact of compressor fouling, Alliance would schedule three Offline Water Washes (OWW) per year on each of its turbines--a total of 57 outages per year just for cleaning, in addition to other regular outages for inspection and maintenance. As shown in Figure 3, the OWWs did help recover efficiency losses, but the compressors would continually exhibit as much as a 2-3% efficiency drop in the few months between washes.



date	before	after	D hours	D E2D3	recover	DEG rate [%/1000h]
31/03/2009	0.987	0.997			1.0%	
30/06/2009	0.992	0.996	2184	-0.5%	0.4%	-0.23%
24/09/2009	0.987	0.992	2064	-0.9%	0.5%	-0.44%
31/03/2010	0.975	0.992	4512	-1.7%	1.7%	-0.38%
08/07/2010	0.988	0.995	2376	-0.4%	0.7%	-0.17%

Figure 3 – Efficiency Losses with Old Filters

As shown in Figure 3 above, turbine efficiency would gradually decline due to fouling, with routine OWWs bringing performance back close to the baseline. However, the use of OWW also creates problems of its own. To start, there is the cost of sending a crew out to a remote location to perform the wash. Then the cleaning fluids, in this case 13,000 liters of contaminated water and 120 liters of soap per year, need to be disposed of properly. Even the action of shutting down and restarting turbines can be problematic: cycling a unit that has been operating alarm free for months can cause other issues to surface so it is best to keep them running. When considering all the costs and reliability concerns associated with repeated OWW, it would be better to find an economical method of keeping the dirt from fouling the compressor in the first place.

3. A New Type of Hydrophobic HEPA Filters

Switching to early generation HEPA air inlet filters would be a way to keep compressors cleaner, but in the past they have traditionally associated with several drawbacks. First, early generation HEPA filters typically have a higher initial pressure drop, which counters some of the efficiency advantage of a cleaner turbine. Second, since these higher efficiency filters are removing more dirt from the air they often need to be replaced sooner than traditional lower efficiency gas turbine filters. Finally, many HEPA filtration systems for gas turbines require costly capital investments to modify the filter house for their specific solutions.

Then, Alliance learned about a new type of hydrophobic HEPA filter, developed by W. L. Gore & Associates, that was being used by TransCanada Corp. on two LM6000PDs at its Grandview Power Plant in New Brunswick. TransCanada had been shutting down the turbines every six weeks for cleaning, but was able to eliminate this by installing the GORE® HEPA Turbine Filters. The Gore filters are designed as simple retrofits for existing lower efficiency filters. They keep the compressor section of a gas turbine in near-new cleanliness (eliminating the need for washing), but have the same pressure drop as current filters and similar lifetime in operation.

The key to the improved filter performance is a novel 3-layer media construction which includes a hydrophobic membrane layer. The membrane layer gives the new filters a HEPA rating of E12 according to EN1822:2009. By this standard, this means that they are designed to remove 99.5% or greater of the hardest to capture particle size, known Most Penetrating Particle Size, or MPPS (typically about 0.1 microns in diameter). E12 filters have an even higher efficiency rate when removing larger particles (see Figure 4). By contrast, the EN779 or ASHRAE 52.2 standards are based on a specific particle size or range, 0.4um (EN779) or 0.3-1.0um (ASHRAE 52.2), and their reported efficiencies do not account for the MPPS.

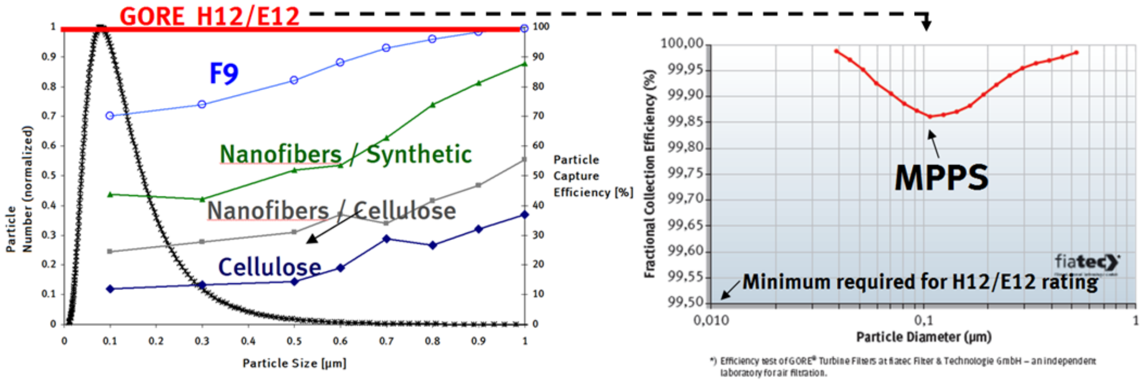


Figure 4 – Particle capture efficiency of various GT filtration media over full range of particle sizes

The membrane, made of ePTFE (expanded polytetrafluoroethylene), is extremely hydrophobic and stops water ingress through the filters. As a result, particles captured on the filter are prevented from being forced through the filter during rain or fog events. In locations that have salt in the atmosphere, the membrane stops its ingress through the filters in either deliquescent liquid or solid form thus preventing turbine corrosion.

Figure 5 shows the filter structure. The first yellow layer captures most of the airborne dirt and it's efficiency and dust holding capacity are similar to or greater than a customer's existing lower efficiency MERV (Minimum Efficiency Reporting Value according to ASHRAE 52.2) or F-rated filters (according to EN779). The middle white layer is the expanded PTFE membrane which stops both submicron particles and water that penetrate current filters. The third layer is a synthetic support layer added to provide strength and burst pressure resistance. This third layer gives the filter more than twice the required burst strength of filter standards, and unlike cellulose or microfiberglass filter substrates, will not degrade. This extra burst strength prevents filters from breaking before they reach their expected lifespan.

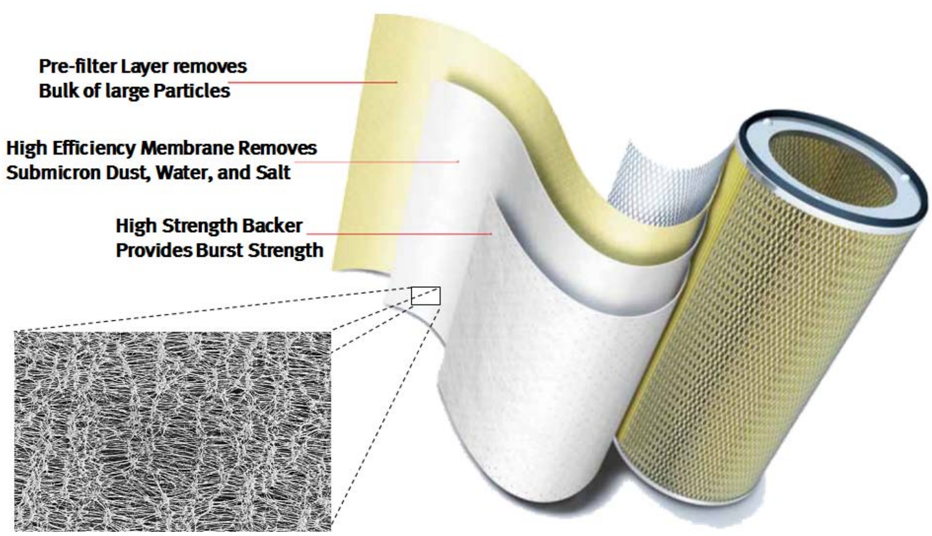


Figure 5 – Cutaway showing the three layers that make up the GORE® Turbine Filter

It is the three layer construction that also provides the long life of the Gore filters. The small particles that cause most of today's turbine fouling are less than 0.3 microns in size--below the measurement standard of current filters. These sub-micron particles have near infinitesimal mass, so the filter does not have to capture a huge amount of weight to prevent fouling. In most typical applications, each HEPA filter would only need to stop less than 50 grams of material per year to prevent turbine fouling. With the prefilter layer capturing the larger particles, the membrane will only be loaded with these 50 grams of dust. Most turbine users instinctively think a HEPA filter will have a shortened life if it stops all the dirt, however when one considers the small amount of dust the membrane has to collect, and then factors in the three layer design of the Gore filters, it is easier to understand why the life of Gore's HEPA filter is similar to the life of the lower efficiency filters.

4. Field Testing the Filters

In April 2010, Alliance began testing the hydrophobic HEPA filters at two locations with different operating environments: the LM2500 Plus G4 in the Windfall station at the start of the mainline, the highest HP unit in the fleet; and a midstream LM2500 base unit at Kerrobert in west-central Saskatchewan. As shown in Figures 6 through 8, both units showed a negligible initial total system pressure drop of less than 50 mmWG with the new filters, right in line with that of incumbent lower efficiency filters.

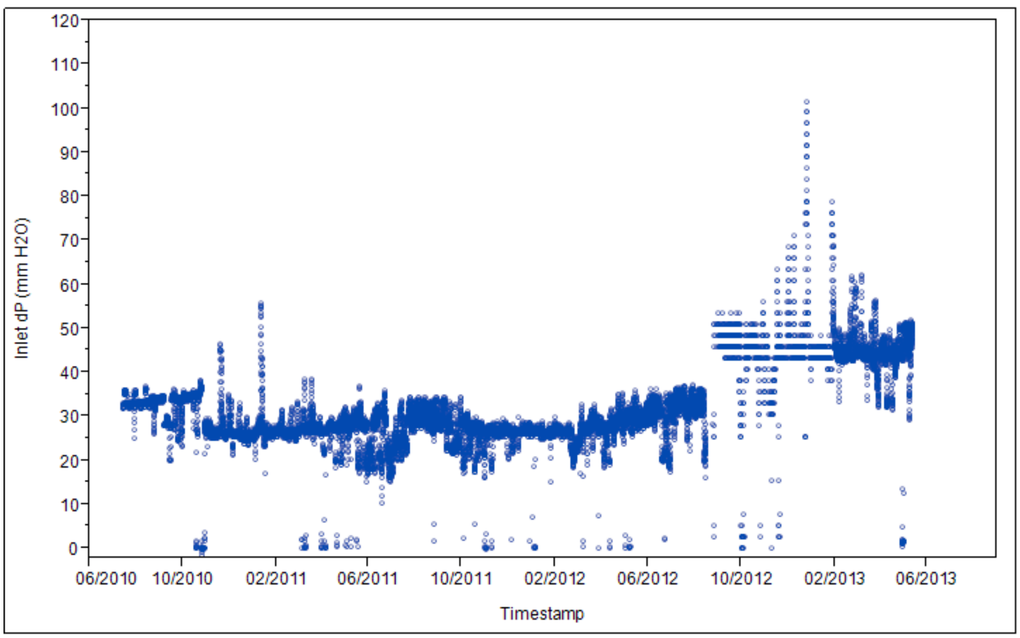


Figure 6 – Inlet dP: Total system pressure drop on the Kerrobert unit testing the HEPA filters

Figure 6 shows the total system pressure drop on the Kerrobert unit testing the HEPA filters, which has stayed below 50 mmWG for 2 years, only starting to rise and exhibit some spikes in the 3rd year.

Figures 7 & 8 show 3 years of dP data for the Windfall test unit. In this case the pressure drop was again below 50 mmWG for the first 2 years before beginning to rise in the 3rd year. The Windfall filters were installed without the standard coalescer wraps and will be more susceptible to high dP during high humidity near the end of life.

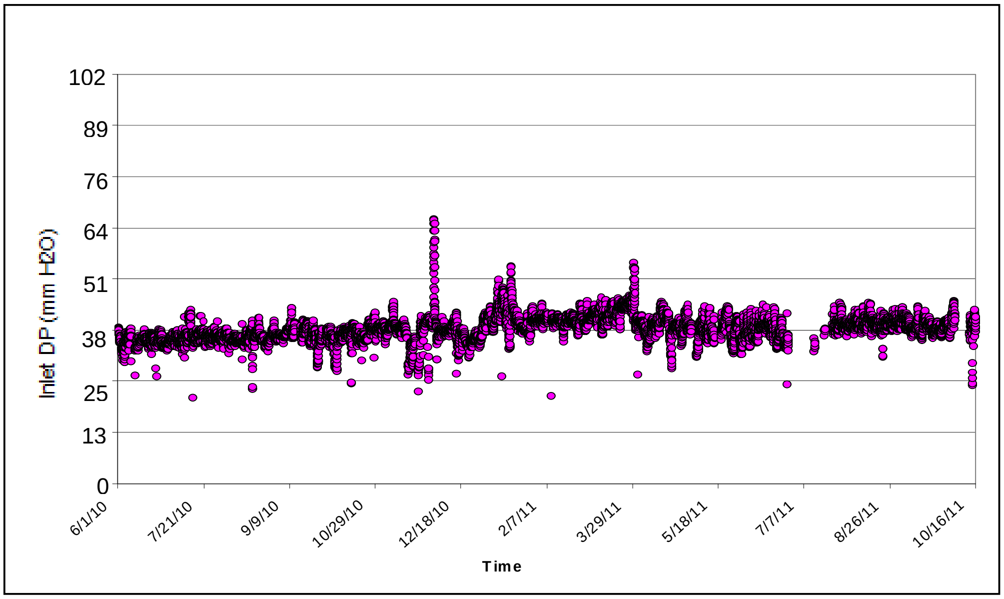


Figure 7 – Inlet dP: Windfall test unit (year 1+)

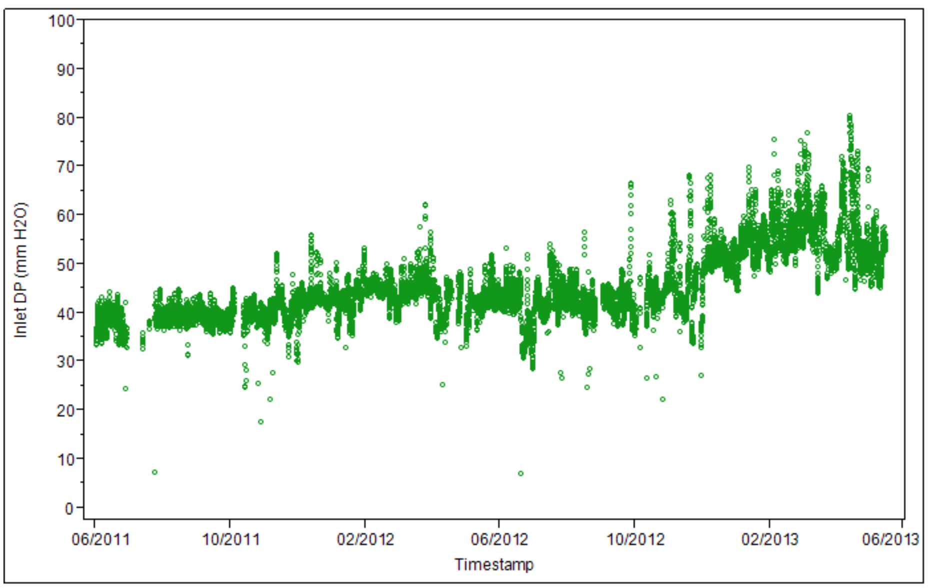


Figure 8 – Inlet dP: Windfall test unit (years 2-3)

After 6000 hours of operation at Windfall with the new filters, a borescopic inspection done on the LM2500 Plus G4 showed the bell mouth and visible stages of the High Pressure Compressor (HPC) were clean (see Figures 9 & 10). An OWW was carried out and the wash fluids came out white, rather than the usual dark gray or black. A wash with the original filters previously resulted in a 1-2% increase in efficiency. However, this time there was no efficiency gained following the water wash because there was no dirt to be removed, further proving that with HEPA filtration no power or efficiency losses had been incurred.

Figure 9 – Stage 1 HPC after 6000 hours with no water wash

Figure 10 - IGV after 6000 hours with no water wash

Since this last water wash at the 1 year mark, the unit was run for an additional 18,450 fired hours over the next 2.5 years with no further water washes. Again, a borescopic investigation was carried out to look for any evidence of fouling. Results are seen in Figures 11 and 12 below. Figure 11 depicts the outer bearing of the stage 2 variable stator vanes in very clean condition and even the serial numbers on the vanes in perfect visibility. In Figure 12, looking at an image of the stage 3 blade roots, there is still evidence of the streaks from the offline water wash fluid 2.5 years ago, but it appears as if no dirt or moisture has entered the GT to change or smear it in that time. The two sets of pictures show an engine in pristine condition, with no water washes over 2.5 years resulting in borescope pictures so similar that they look like they could have been taken during the same outage.

Figure 11 – Windfall Stage 2 Variable Stator Vanes outer bearing, 2.5 years (18,450 hours) after previous OWW and inspection

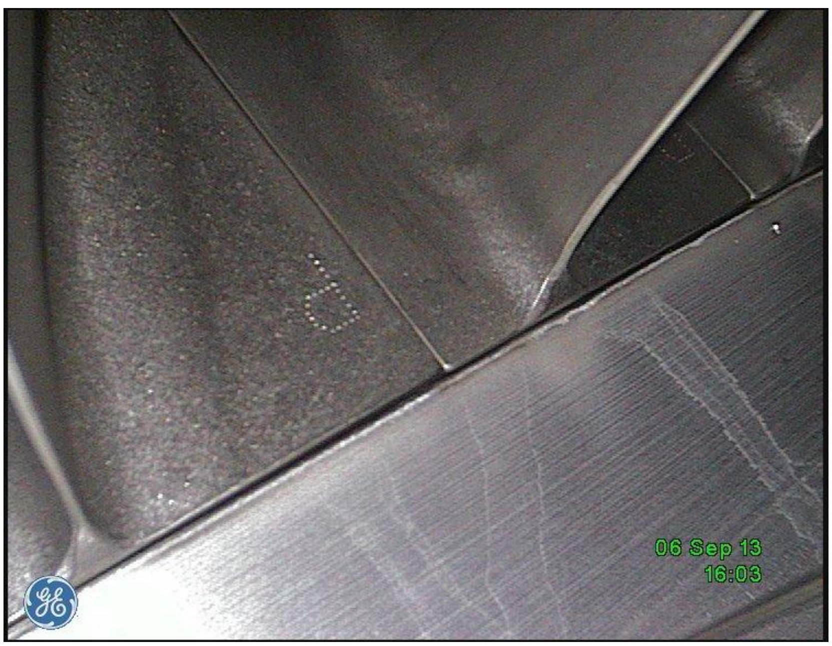


Figure 12 – Windfall Stage 3 Blade roots, 2.5 years (18,450 hours) after previous OWW and inspection

At the Kerrobert site, after 3.5 years of operation with the HEPA filters, a borescopic investigation again revealed extremely clean engine components. This unit had run for 21,906 hours since its last hot section rebuild with no water washes. Generally after that many hours, the bell mouth and stage 1-5 blades and vanes would be heavily fouled; but, as shown in Figures 13 and 14, the vanes and blades of the High Pressure Compressor (HPC) looked to be in near-new condition.

Figure 13 - Kerrobert Inlet Guide Vanes (IGV) after 21,906 hours operation with HEPA filters and no water washes

Figure 14 – Kerrobert HPC Stage 4 after 21,906 hours operation with HEPA filters and no water washes

5. Preventing Cold Weather Shutdowns from Hoar Frost

During the summer, turbine operators need to keep inlet air temperatures down to prevent power losses, so many install fogging or evaporative cooling systems to add moisture, lowering the air temperature and reducing compression losses. Come winter, it is the opposite problem: low air temperature coupled with high humidity leads to the buildup of hoar frost on the air filters.

This frost buildup increases pressure drop across the filter, and when it exceeds parameters, it trips an emergency shutdown of the turbine. Even worse is when some of the moisture migrates though the filters before freezing. Then, once the temperature starts to rise, chunks of ice can liberate from the downstream side of the filters and damage the compressor blades. If this FOD is severe enough, it can keep the turbine offline until new blades are installed and the unit recommissioned.

To address this situation, Gore developed a prefilter wrap which can be pulsed to remove the hoar frost. As further protection, a hydrophobic ePTFE filter membrane blocks liquid water from passing through the membrane before freezing on the clean side, where it can later produce Foreign Object Damage (FOD). In laboratory tests conducted at -10° C, the frost created a dP of 60 mm when there was no pre-filter. With a pre-filter and pulsing, the dP dropped to 30 mm within seconds and then settled down at 20 mm (see Figure 15).

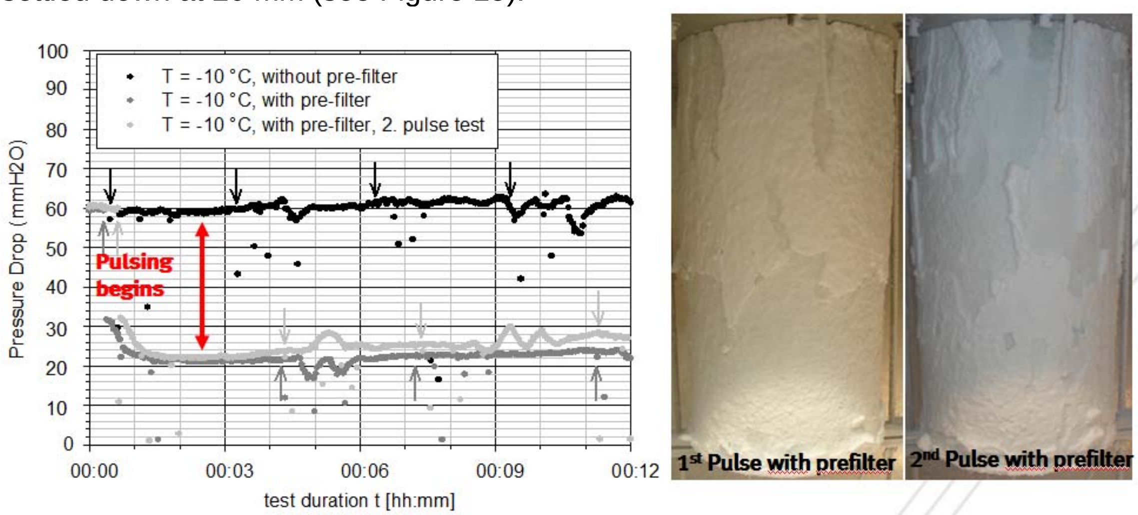


Figure 15 - Laboratory test of prefilter wrap and pulsing quickly removed frost buildup and returned dP across the filters to a safe range (arrows represent pulses).

This system was then field tested on the Alliance Pipeline LM2500 at the Wimbledon, North Dakota Pumping Station, where nighttime lows are below freezing for half of the year. The filters were installed in November 2011 and there were hoar frost events in February 2012, with as much of an inch of frost on the filters (shown in Figure 16).

Figure 16- Hoar frost build up on LM2500 turbine inlet filters at Wimbledon Pumping Station

Although the frost did increase the pressure drop, the dP stayed below 36 mmWG (1.4 in. H_2O) (see Figure 17) and the turbine continued to operate without having to pulse the filters (see Figure 18). No frost formed on the downstream side of the filters.

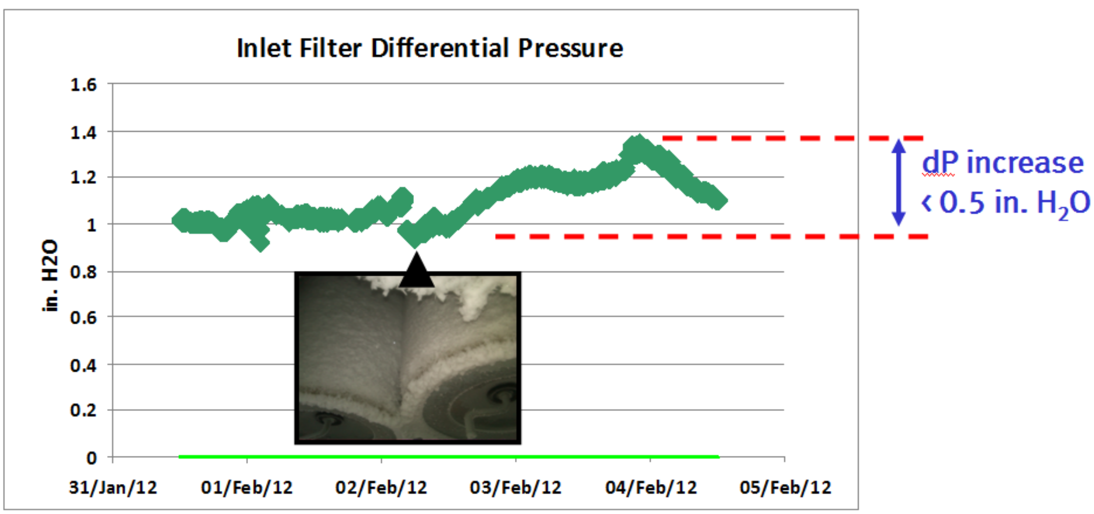


Figure 17 - Inlet pressure drop during hoar frost event on LM2500 unit in North Dakota

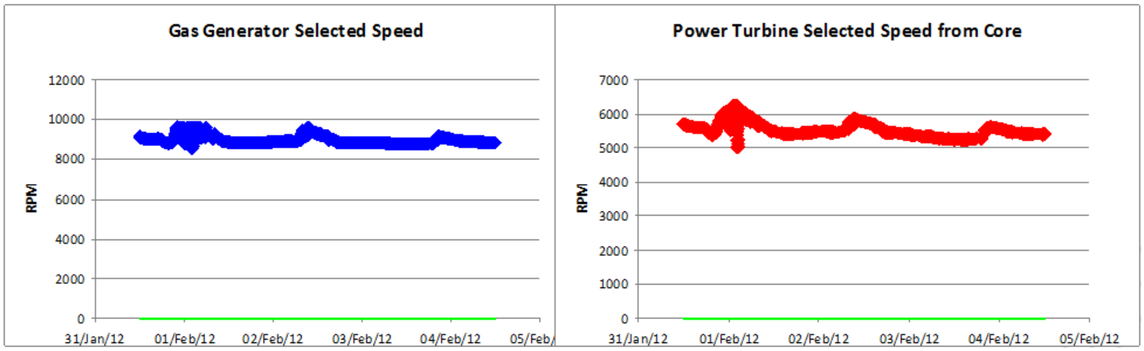


Figure 18 - Turbine continued to operate within range during the hoar frost incident

6. Equipping the Rest of the Fleet

It is now 3+ years from the start of the GORE® Hydrophobic HEPA filters test and the performance of the filters continues to be extremely impressive. As shown in Figures 19 and 20, the turbines continually maintain their efficiency levels without washing, thereby reducing fuel costs, emissions, and maintenance expenses.

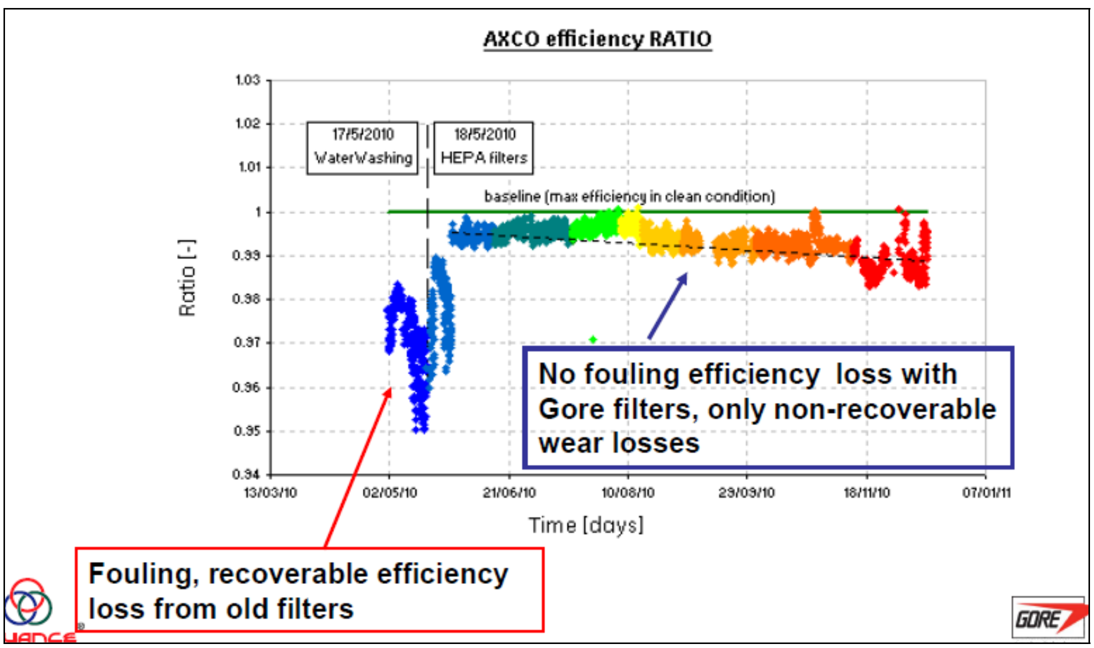


Figure 19 - One Year Efficiency

The blue section in Figure 19 shows the unit prior to installing the HEPA filters. The rest of the graph shows that with the HEPA filters the turbine was able to maintain a high efficiency level, only experiencing non-recoverable losses due to equipment wear. Figure 20 shows the isentropic axial compressor efficiency for the same unit remaining relatively linear over a 2 year time span with no water washes.

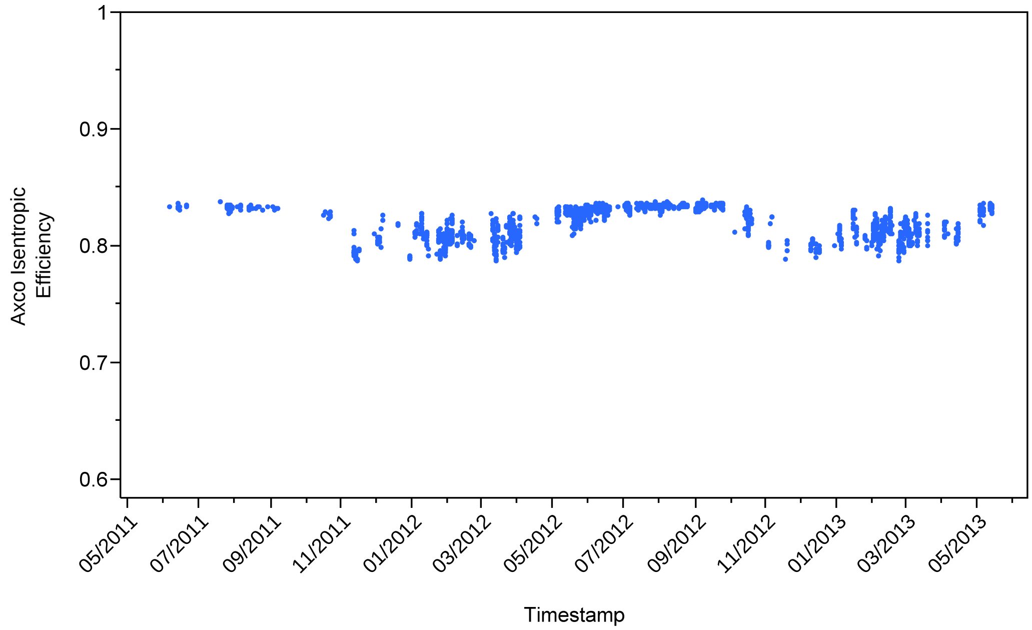


Figure 20 – Corrected axial compressor efficiency, years 2-3

The filters have demonstrated that they retain their low pressure loss over the long run (Figures 7 and 8, shown page 8). After 3+ years of operation without replacement, The GORE® Hydrophobic HEPA filters have proven comparable lifespan to the less efficient filters, while delivering clean, uninterrupted turbine performance.

Because of the successful tests on the Windfall and Kerrobert turbines, Alliance outfitted its entire fleet with GORE® Turbine Filters by the summer of 2012. OWWs have ceased with 57 outages having been removed from the annual schedule, eliminating more than 1000 man hours of work. There is no longer a need to purchase and then dispose of 13,000 liters of demineralized water and 120 liters of soap per year.

Perhaps the greatest benefit, though, comes from eliminating turbine cycles.
By allowing the compressors to operate without interruption, Alliance has eliminated the potential issues that can be caused by unnecessary shutdowns. Additionally, Alliance is hoping to reduce downtime even further in the future. Because the units are running more efficiently and at a lower heat rate, Alliance is investigating the potential for extending time between hot gas path maintenance cycles.

7. About the Authors

Rob McMahon is a Gas Turbine Fleet Manager with Alliance Pipeline. Prior to working at Alliance Pipeline, Rob served 22 years with the Canadian Air Force as an Aviation technician, then five years as a General Electric Field Representative. He is a graduate of the Canadian Forces School of Aerospace Ordnance and Engineering.

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