

OPERATIONS & MAINTENANCE

Gas Turbine Air Filter System Optimization

BY JAMES DICAMPLI, P.E., AND JACK PAN, GE POWER AND WATER,
AND MARK ARSENAULT, AMERICAN AIR FILTER

Proper air filtration is critical to the overall performance and reliability of gas turbines. Fuel costs approach 80 percent of the life cycle cost of electricity. Small gains in efficiency can mean huge savings. With fuel costs of around \$16.00/mmBTU and higher in certain global regions, operational savings can be achieved through improved compressor performance using High Efficiency (HEPA) air filters. Operators can see greatly reduced maintenance costs as a result of a much cleaner engine, quantified by less frequent inspections, fewer shutdowns, and higher availability. HEPA filtration can maintain optimum GT efficiency throughout the life of the filter. This article investigates the decision criteria required in selecting an optimum air filtration solution, with the goal of maximizing gas turbine availability and lowering operating costs. Through case studies and analysis, essential filter parameters and their impact on gas turbine operations and maintenance are reviewed.

AIR FILTRATION AND CONDITIONING OVERVIEW

Aeroderivative gas turbine ventilation and combustion air filter systems are designed to protect the gas turbine, generator, and equipment

compartments from the effects of airborne dirt, contamination and foreign objects. A number of inlet conditioning options are also available to maximize gas turbine performance.

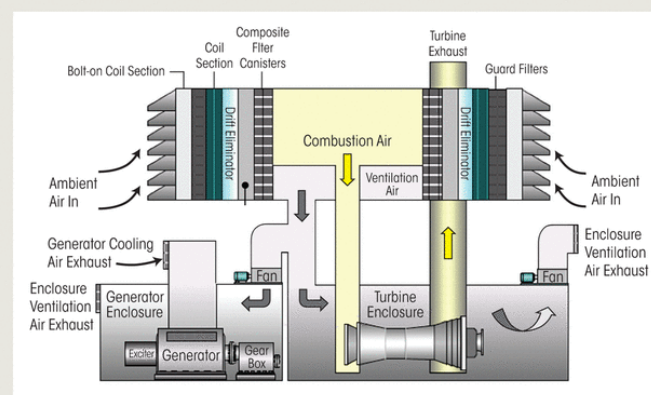
GE Distributed Power gas turbines

filter house is comprised of weather hoods, filter elements, chiller or anti-icing coils, and plenum chamber assembly. Air from the plenum assembly is ducted to the turbine engine intake for combustion and to the turbine and generator compartments for cooling and ventilation. An external ladder and walkway with access doors to the air filter structure enables filter servicing.

A temperature element in the air fil-

LM6000 Gas Turbine Generator Air Flow

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use a three-section inlet air filter that mounts directly above the turbine enclosure, conserving space and providing compact, low-pressure loss ducting to the turbine inlet. Figure 1 provides an illustrative example.

The ventilation and combustion air system consists of a filter house structure, roof-mounted silencers, fans, and associated ductwork all located on the turbine and generator enclosures. The

ter house combustion air section provides inlet temperature information to the control system. Relative humidity sensors measure moisture in the air before it enters the filter housing and activates an alarm if icing conditions exist.

Pressure transmitters sense the pressure difference between the outside air and the combustion air inlet plenum. For example, on a GE LM6000, if the

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Summary For Investigated Sites

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| Site Location | Environment | Engine Model | Air Filter | Filter Type |
|---------------|---------------------------------------|--------------|--|---------------------|
| USA | Continental | Lm2500+G4 | Static Air Filter; Additional Filter: Pre-Filter, Weather Hoods, Guard Filter | Synthetic Panel |
| Russia | Continental | Lm2500+G4 | Static Air Filter | Synthetic Panel(F8) |
| Italy | Industrial(Aerosol, Particles) | Lm2500+G4 | Static Air Filter; Additional Filter: Pre-Filter, Weather Hoods, Guard Filter | Synthetic Panel(F8) |
| Belgium | Continental | Lm2500+G4 | Static Air Filter; wAdditional Filter: Pre-Filter, Weather Hoods, Guard Filter | Synthetic Panel(F8) |
| China Site 1 | Heavy Industrial (Aerosol, Particles) | Lm2500+ | Static Air Filter: Pre-Filter, Duracel XI90, Hepa | G4, F8, H12 |
| China Site 2 | Heavy Industrial (Aerosol, Particles) | Lm2500+G4 | Asc Pulse Filter, Hepa | F8, H12 |

differential pressure reaches -5 in-Wg (-127 mm), the control system activates an alarm, an indication of filter clogging. If the differential pressure reaches -8 in-Wg (-203 mm), the control system activates a load reduction. Another pressure differential transmitter monitors total pressure drop at the ventilation air plenum and activates an alarm if the pressure differential reaches -5 in-Wg (-127 mm).

Ventilation air is ducted from the ventilation plenum directly into the turbine compartment. One of the two turbine compartment fan assemblies draws air from the inlet air filtration system through the turbine compartment and expels it to an air exhaust stack that is equipped with a silencer limiting the transmitted noise.

COMPONENT DESCRIPTION

Weather Hoods and Drift Eliminators

Air entering the filter house first passes through (optional) weather hoods, drift eliminators and inlet screens. Weather hoods protect filters from rain, snow and sun. Weather hoods are bolted to the inlet side of the left and right coil assemblies (for dual inlet systems). Weather hoods prevent rain and snow from entering the inlet filter house by drawing inlet air upward at lower velocities than that

of falling rain and snow. Snow hoods and tropical rain hoods are available for snowy or tropical environments. Inertial moisture separators (vane type separators) are also available to prevent heavy rain or heavy fog mist from entering the filter house.

Filters

A multi-stage filtration system is available which includes a guard filter upstream of the chiller coils and a set of composite canister "barrier" or panel-type filters located downstream of the coils. The guard filters (also known as pre-filters) keep the chiller coils clean for maximum heat transfer efficiency and provides supplementary filtration to extend the service life of the composite fine filters.

The fine filter elements are mounted to the filter face of the inlet plenum and extend into the clean air plenum. The elements have extended surface area, large dirt-holding capacity and low-pressure drop.

Air passes through the fine filters and enters the clean air plenum. This fabricated structure is the center section of the inlet filter assembly and separates ventilation air from combustion air. Combustion air flows through a transition duct from the clean air plenum to the combustion air inlet silencer. Ventilation air flows through transition ducts to the turbine and generator compartment. The inlet

silencer is a low-pressure-drop device located in the combustion air stream before the inlet volute. The silencer attenuates noise from the turbine and helps maintain the unit's low noise level.

Inlet Cooling and Heating

Air conditioning options include evaporative coolers or optional inlet air chiller coils to maximize gas turbine performance on hot days. Conversely, coils can be used for anti-icing and/or optimizing efficiency during partial power operations.

The evaporative cooling system uses the process of evaporation to create a reduction in inlet air temperature. Water is pumped to a header that distributes the water over media blocks that consist of corrugated layers of a fibrous material. Air passing through channels comes into contact with the falling water causing a portion of the water to evaporate, transferring heat from the air to the water.

Static and Pulse Filter Options

The correct type of filter (pulse or static) should be used for the specific project environmental conditions and specific contaminants.

In general, a pulse or self-cleaning type inlet air filter should be used when the dust loading approaches 0.300 mg/m³ or higher, or when operating in conditions where dust or sand storms can occur. The ambient air can

be tested using a direct read-out device, such as a laser photometer that counts particulates in the air sample.

The American Air Filter ASC Pulse filter system utilizes a unique inertial separation system that diverts over 90 percent of the dust particles from the gas turbine inlet into a secondary air system, via negative pressure. The remaining particles are captured on the

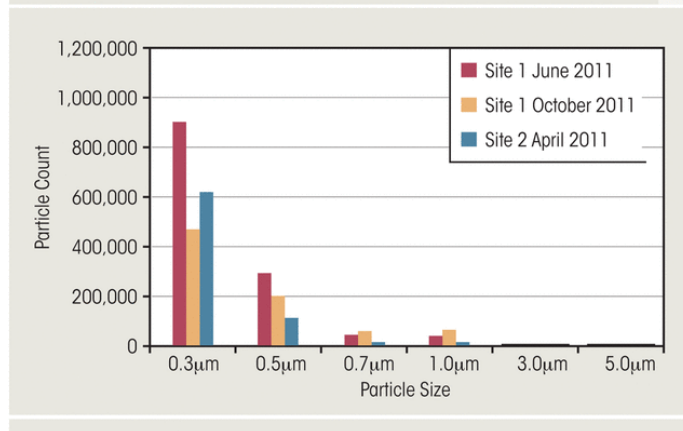
requires (e.g., based on filter pressure drop, ambient relative humidity, hourly, daily, or even continuously). For example, a common recommendation for an installation in a cement factory, is to minimize caking on the filters by automatically pulsing the filters whenever the relative humidity is greater than 80 percent.

Pulse filters are also utilized when

pre-filters can become a maintenance item and drive up costs over the life of the project. For example, for areas with a high hydrocarbon loading or areas with cement dusts and frequent high humidity, pleated composite type pre-filters, rather than the more standard fibrous type, are often required to prevent short barrier filter life. These pre-filters are less expensive and must be replaced (or possibly removed and cleaned) at somewhat frequent intervals.

Particle Test Result at China Sites

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surface of AAF's PanelPak filter element, which in turn is pulsed off the filters when required. The AAF system prevents re-entrainment of the pulsed particles as they are expelled into the same separation system during the pulse cycle. This allows for continuous operation of the GT during the pulse cycle, while the design provides for a lower pressure drop of the entire inlet system. AAF has over 900 of these units in operation to date, in many industrial areas and locations with very poor air quality.

Pulse filters can and have been successfully used in very dusty environments, such as steel mills, cement plants, Middle East environments, or areas where sand or dust storms are prevalent, even with high humidity. The pulse controller can be programmed to pulse as the loading

a turbine is being operated in an environment with significant loading of snow or ice crystals. Although a static filter can be used in these environments if there is a properly designed conditioning system upstream (e.g., heating coils, bleed air or other hot air conditioning), pulse systems are the most reliable for preventing filters plugging due to cold weather moisture.

Another advantage of pulse filter systems, particularly for peak loading turbines, is that the filters can be pulsed when the unit is not in operation, which provides maximum effectiveness to the pulse cleaning, so the filters can be "cleaned" and ready for the next start-up.

Static filters can be fitted with inexpensive pre-filters that can be replaced and/or cleaned to extend the life of the barrier elements. However, special

WATER WASH

Fouling deposits on gas turbine compressor airfoils reduce engine performance output. The water wash system provides a mechanism for cleaning engine compressor blades. The aim is to recover power output and heat rate performance by restoring the compressor's flow capacity and efficiency.

There are many types of compressor fouling. The type and rate of fouling depend on the environment in which the gas turbine operates and the efficiency level of the inlet filtration. Among the most common types of contaminants are dirt or soil, sand, coal dust, insects, salt, oil, and even turbine exhaust gas.

Salt also causes corrosion of blading and ductwork and subsequent ingestion of rust and scale. Oil increases the ability of contaminants to cling to compressor passages and airfoils. The type of material that is deposited on the compressor blading influences the method of its removal.

Keeping the compressor internals clean can alleviate a number of problems before they ever become apparent. Besides the obvious benefits of enhanced efficiency (increased power output, lower compressor discharge temperatures, etc.), keeping the compressor clean will help blades survive longer.

If the compressor is dirty, additional weight is added to the airfoil and this

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Summary For Filter Change Cycle & Water Wash Cycles

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| Project Location | Filter Change Cycle | | | Water Wash Cycle | |
|------------------|---------------------|-----------------|-----------------|------------------|-----------------------------------|
| | Pre-Filter | Static/Pulse | (H)EPA | Online | Offline |
| USA | 5.5 months | 11 months | No (H)EPA | 1-3 times/week | every 2-3 months |
| Russia | No change | No change | No (H)EPA | No | every 2 months |
| Italy | 9.7 months | No change | No (H)EPA | No | every 3-4 weeks: 700-900 hours |
| Belgium | every 18 months | every 18 months | No (H)EPA | Every 2 days | every 6 months |
| China Site 1 | 1 week-4 months | 2 - 8 months | 6 - 9 months | No | every 5.5 months |
| China Site 2 | | every 12 months | every 12 months | No | every 5.5 months |

increases the cyclic stress. Also, dirt in the dovetail slots will add to the existing friction loading at the dovetail/slot interface and between the two mechanisms making a blade dovetail failure more likely. Performing thorough water washes with high quality ingredients on a regular basis will help combat these conditions.

Washing utilizes liquid detergents, a concentrated solution of water soluble, surface active agents and emulsifiable solvents produced primarily for cleaning gas turbine compressors, where the intent is to restore performance by removing fouling buildup from compressor components.

Methods of Detection

The best method for detecting a fouled compressor is visual inspection. This involves shutting the unit down, removing the inlet plenum inspection hatch, and visually inspecting the compressor inlet, bellmouth, inlet guide vanes, and early stage blading. If there are any deposits, including dust or oily deposits that can be wiped or scraped off these areas, the compressor is fouled sufficiently to affect performance. The initial inspection reveals whether the deposits are oily or dry. For oily deposits, a water-detergent wash is required, followed by clean water rinses. The source of the oil should be located and corrected before cleaning to prevent recurrence of the fouling.

Another method for detecting a fouled compressor is performance monitoring. Performance monitoring involves obtaining gas turbine data on a routine basis, which in turn is compared to baseline data to monitor trends in the performance of the gas turbine. The performance data is obtained by running the unit at a steady base load and recording output, exhaust temperatures, inlet air temperatures, barometric pressure, compressor discharge pressure and temperature, and fuel consumption.

The data should be taken carefully with the unit warmed up. If performance analysis indicates compressor fouling, it should be verified by a visual inspection.

The compressor cleaning operation is conducted after turbine shut down (crank-soak cleaning) or while operating (on-line cleaning).

A consistent gas turbine water-wash strategy pays for itself many times over in power and efficiency improvement. A crank-soak wash is typically the only means to remove most deposits, including oily or tarry deposits which bind dirt to the blades. Because crank-soak wash cleans the suction (convex) side of the blade it has the greatest

influence on compressor efficiency.

There are no hard and fast rules for when to crank-soak wash because the schedule must be tailored based on type of atmospheric contaminants, temperature, operational frequency, gas turbine health, and site economics. In the absence of this information

"Keeping the compressor internals clean can alleviate a number of problems before they ever become apparent."

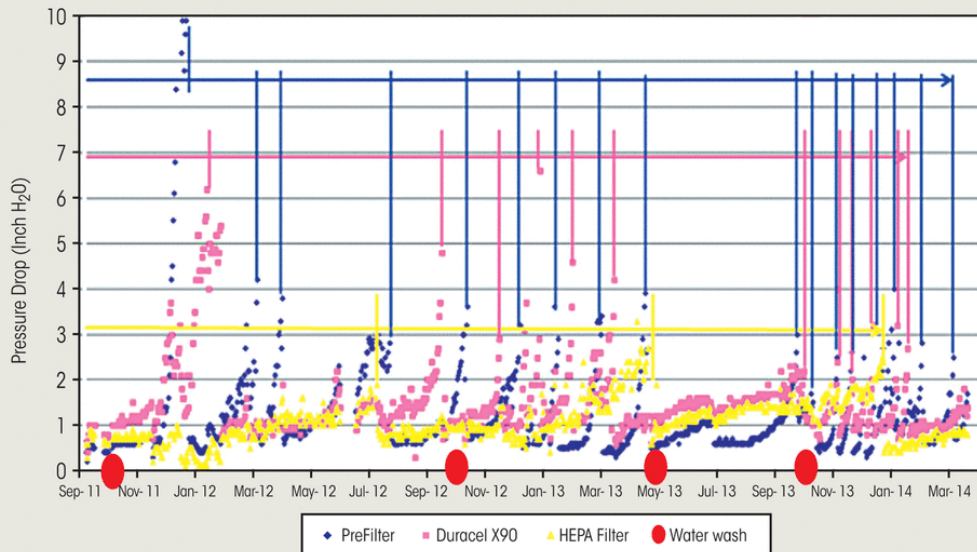
a prudent strategy would be to crank-soak (off-line), wash every 2 weeks. High concentration of oily deposits and dust will require more frequent crank-soak washing.

On-line washing serves primarily to maintain gas turbine performance between crank-soak washes. The primary effect of on-line wash is to remove deposits on the blade which adhere by impact. Also, dust and dirt are removed on the pressure (concave) side of the blade but not on the suction side which has a lesser influence on efficiency. For this reason, the use of water for on-line wash is often as effective as a detergent solution. The higher the concentration of oil and tars, the less effective on-line washing will be for improving performance.

In the absence of site-specific information, it would be beneficial to on-line wash with water daily. Use of detergent should be based on testing

Filter Change & Water Wash Data (Unit 2) – China Site 1

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which demonstrates measurable benefits for the site. Visual inspection of the rinse water is effectively used by some sites to set the wash schedule. If the rinse is mostly clear, the interval can be extended.

FILTER CLASSIFICATION

Filtration systems are optimized to minimize foreign contaminants entering the gas turbine, and are largely based on the operating environment. Seasonal pollutants, rain, ice and snow, sand, dust, local industry exhausts, and other air contaminants must be taken into consideration.

Filters are generally classified by several standard rating methods:

- United States: American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) in standard 52.2: 2007.
 - Europe: European Standards EN 779: 2012 and EN 1822: 2009 (Parts 1 through 5).
- High Efficiency Particulate Air

filters ((H)EPA) filters are generally defined as having an efficiency greater than 85% for particles greater than or equal to a filter's Most Penetrating Particle Size (MPPS). The MPPS for a filter varies depending upon the media, media velocity, configuration along with other factors, but is primarily between 0.07 and 0.2 microns for filters used in gas turbine inlet applications.

CASE STUDIES

Six General Electric Distributed Power LM2X gas turbine sites were investigated. The environment of these sites ranged from continental, relatively clean air to heavy industrial sites with significant amounts of hydrocarbon aerosols and particulates. The air filter configurations are listed in Table 1. The usage of high efficiency filters as a 3rd stage was installed at two of these sites, both with very poor air quality.

The following sections summarize each case.

U.S. Site

This site is an urban area with an interstate highway nearby. There are two filter stages in this system, a pre-filter and the AAF Duracel XL90N. The operator changed the pre-filters at 4,000 hrs and primary filters at 8,000 hrs. Online water washing was completed 1-3 times/week as a proactive measure to minimize off-line washes.

Off-line water washing has been performed approximately every 3 months, equivalent to 2,000 hrs of operation. Offline washing takes about one 8 hour shift, although it usually is performed in conjunction with other work to maximize overall availability. The operational history has shown ~1 MW power loss after the three month period.

Russian Site

The plant has been operating since 2012 in a relatively clean environment and uses only one stage filter, a static EU8.

Still, the HPC rotor blades and stator vanes have rust colored deposits on the

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Fifteen Year Return For HEPA Filtration, Base Load

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| Variable Title | Variable Value | Year | Power Loss Cashflow | Efficiency Raw Cashflow | Net Adj Annual Cashflow |
|----------------------------|----------------|------|---------------------|-------------------------|-------------------------|
| 3% Efficiency loss to wash | | 1 | \$0 | \$1,269,504 | \$1,103,917 |
| Fuel mmbtu/hr | 330.6 | 2 | \$0 | \$1,269,504 | \$959,927 |
| MW | 35.732 | 3 | \$0 | \$1,269,504 | \$834,719 |
| Fuel \$/MMBtu | 16 | 4 | \$0 | \$1,269,504 | \$725,843 |
| Sell price, \$(MW-hr) | 15 | 5 | \$0 | \$1,269,504 | \$631,168 |
| # years | 15 | 6 | \$0 | \$1,269,504 | \$548,842 |
| rate of return | 0.15 | 7 | \$0 | \$1,269,504 | \$477,254 |
| run time, hr/yr | 8000 | 8 | \$0 | \$1,269,504 | \$415,003 |
| | | 9 | \$0 | \$1,269,504 | \$360,872 |
| NPV w/o Cost | \$7,423,260 | 10 | \$0 | \$1,269,504 | \$313,802 |
| Equipment Cost Adder | -\$34,440 | 11 | \$0 | \$1,269,504 | \$272,871 |
| | | 12 | \$0 | \$1,269,504 | \$237,279 |
| NPV/3 | \$3,694,409.86 | 13 | \$0 | \$1,269,504 | \$206,330 |
| | | 14 | \$0 | \$1,269,504 | \$179,417 |
| | | 15 | \$0 | \$1,269,504 | \$156,015 |

surface. Compressor residue samples should be taken and analyzed at a lab to identify the corrosion mechanism. From this, changes to the filtration system and/or wash detergent can be recommended.

Italian Site

This site is a small industrial area, but the air is generally clean. The unit is running about half of the year.

There are 3 filter stages, two pre-filter stages and then the Duracel XL90N. The pre-filter was changed at 7,000 hours because of high dP. Offline water wash is performed every 3-4 weeks, or after 700-900 hours of operation.

The site does not perform any online water washing, but conducts off line water washes frequently to keep the compressor efficiency high.

Belgium Site

The plant operates near a refinery. The refinery fumes can be ingested by the gas turbine, causing oil contamination of the filters. Both pre-filters and fine filters are changed every 18 months. Offline water washing is performed every 6 months unless the

power loss exceeds 1MW, then an additional offline wash is performed. On-line washing is generally performed every 2 days.

China Sites

The two China sites investigated are in areas with very poor air quality. The particulate count and size are shown in Figure 2, taken at different times of the year.

The particulate count at the size level of 0.3um and 0.5um make up 99% of the contamination. At this level the particulates are captured by the 2nd and 3rd stage filters.

China Site 1

There are 3 filter stages: 1st stage is a G4 pre-filter, the 2nd stage is a Duracel F8, and the 3rd stage is a HEPA H12 filter. The filter change cycles and water wash cycle are shown in Figure 3 for Unit 2 at the site.

The 1st stage pre-filter change cycle is 3-4 months from March through October, then typically less than once/month from October through March. The 2nd stage Duracel change cycle is 4-8 months (Mar-Oct), and from 1 week-2 months (Oct-Mar). This is because of poor air quality in the winter months. The 3rd stage HEPA filter change cycle is quite stable, every 6-9 months. Offline water wash is performed at every 4,000 hours and requires 8-10 hours to complete.

China Site 2

The plant has a pulse filter system, and there are 2 filter stages. The 1st stage is an ASC Panel Pak element (F8), and the 2nd stage is a HEPA filter (H12). The filter change cycle and water wash cycles are shown in Figure 4 (Three gas turbines on site).

"The site analyses showed that EPA filtration results in cleaner compressors, longer cycles between water washing, and higher compressor efficiency."

Both the pulsed filter and HEPA filter have not been changed, and have been running almost one year.

Filter pulsing has proved very effective in removing particles. Offline water wash is performed at every ~4,000-5,000 hours.

No on-line water washing has been conducted.

compressors, longer cycles between water washing, and subsequently higher compressor efficiency and plant availability.

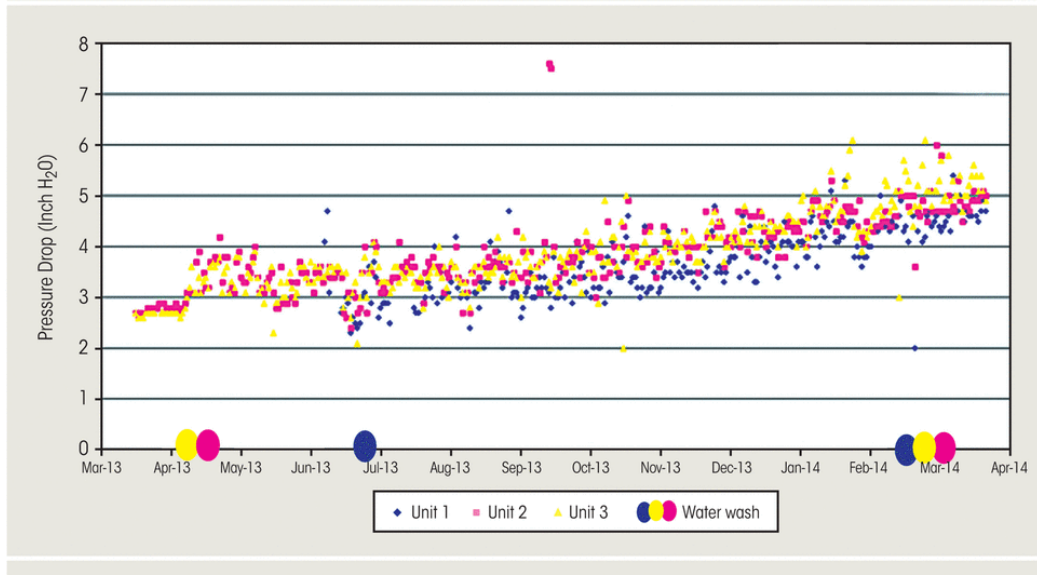
To illustrate the savings, costs are normalized, and assumptions are based on the site data summarized in this article. It is assumed that there is a 14 percent filter house cost adder

infrequent off-line water washing. (H) EPA filtration yields higher compressor efficiencies over a longer period saving fuel costs compared to non-(H) EPA filtration systems.

Proper filtration is essential for gas turbine peak performance. Selecting the optimal filters and configuration is based on operating and environmen-

Filter Change & Water Wash Data – China Site 2

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Filter Change Cycle/ Water Wash Cycle Analysis

The filter change cycle and water wash cycle data is summarized in Table 2. Not surprisingly, better air quality sites do not have to change the pre-filter as often. The filters at China site 2 performed better than those in China site 1 due to the effectiveness of the pulse cleaning mechanism. The water wash cycle, both on- and off-line, at the site with no (H)EPA is more frequent, meaning more downtime at the plant.

CONCLUSIONS

The site analyses showed that (H)EPA filtration results in cleaner

for (H)EPA filtration, and a negligible power loss due to higher filter differential pressure. Further assume a 3 percent efficiency drop occurs linearly over a 2 month period (non-(H)EPA) or 6 month ((H)EPA). Base natural gas price is \$16/MMBtu (Asia) and power sells for \$15/MW-hr. Using (H) EPA filtration, the loss of compressor efficiency is a rate 1/3 slower than without. For a 32MW turbine, the net present value is >\$550k for a base-load machine for one year and \$3.7M over 15 years, as shown in Table 3. That is, a net benefit for (H)EPA filtration. Another \$200k/year could be assumed for increased operating time due to

tal factors. Subsequent data collected since the case studies shows 1 percent degradation in power loss with HEPA over a year's time. Improper filtration will degrade turbine performance, including blade erosion, fouling, cooling passage plugging, and corrosion. These and other factors should be discussed with your OEM turbine manufacturer or filter supplier. Cost-benefit models for specific operating environments can be applied and account for filter purchase price, fuel price, power sale price, maintenance, inspections, wash cycles, power degradation, heat rate increase, pressure loss, labor costs and down time. **pe**