GAS TURBINES: How to select the optimal inlet air filters for your engine

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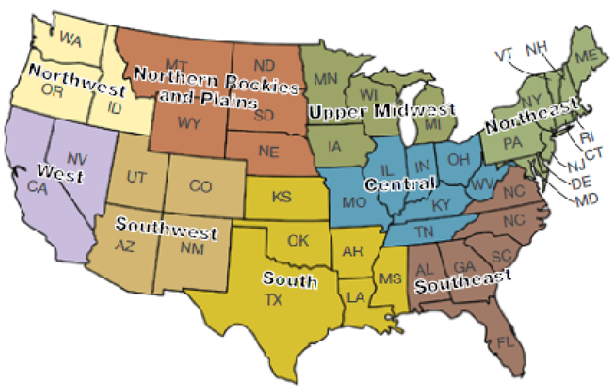
A typical 7FA in baseload service ingests 3.5-million lbm/hr of air containing a significant amount of particulate matter. How much? Based on data compiled by EPA nationwide, more than 1300 lb of particulates smaller than 10 microns likely will enter your gas turbine in one year of operation (8760 hours). While this may seem like a relatively small amount compared to the total amount of air ingested, such fine dirt can wreak havoc on efficiency and reliability.

However, there are multiple options available to owners and operators to prevent unit degradation. This article reviews filtration basics and offers a guide for choosing the preventive strategy to optimize the performance and health of your engine. Finally, results of a four-year study suggest the performance gains you could expect from several popular filtration options.

Table 1: Nominal concentration of particulate matter under 10 and 2.5 microns by region, in μg/m³

Region	PM10	PM2.5
Central	47.6	8.4
Upper Midwest	48.8	7.4
Northeast	41.3	7.6
Northern Rockies and Plains	NAv	NAv
Northwest	47.3	6.8
South	50.6	8.2
Southeast	34.13	7.8
Southwest	80.83	7.0
West	75.66	8.9



The basics

Choosing the right filter is based upon several factors, including these:

- How clean is the air around the plant?
- What is the right level of filter efficiency for your plant?
- How often should you water wash?

Particle size matters

It is important to understand the impact of the size of the dirt particles on unit performance and reliability. Choosing the right filter strategy requires that you know the cleanliness of the air around the plant. Here are some things to keep in mind:

- Particles larger than 5 microns have the capability to erode critical compressor and turbine parts. Resulting degradation can be recovered only through repair or replacement. Fortunately, most filters readily remove such large particles.

  Particles smaller than 1 micron contribute the lion's share of compressor deposits responsible for performance degradation. The actual loss depends on the efficiency and condition of the filters installed. While deposits of fine particulates reduce compressor efficiency, partial recovery of performance is possible with online water washing, full recovery with offline washing.
- In coastal environments, salt also can be an issue. Salt mists tend to be smaller than 5 microns and may cause compressor corrosion. They can be captured by filters but can also migrate through the filter system. Frequent online water washing may help mitigate salt-induced corrosion in the forward stages of the compressor.

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- Small particles—such as metal oxide, smoke, carbon black, smog, and fumes—may be smaller than 1 micron and pass through all but the highest efficiency filters.

To find out the amount of airborne particulate matter at your plant, a first step might be a detailed air sampling onsite; in the absence of this, the EPA provides average PM10 and PM2.5 trends by region, county, and city (visit https://www.epa.gov/air-trends/air-quality-cities-and-counties). PM10 and PM2.5 data report the concentration of particulate matter under 10 and 2.5 microns, respectively, in micrograms per cubic meter.

While site-specific conditions, such as a coal unit or nearby farming, can impact the local concentration of particulates, the EPA data provide a good baseline. Table 1 summarizes 2016 EPA data by region. Operators at sites with high PM10 concentrations may want to choose filters with a high dust-holding capacity to avoid frequent change-outs. At sites with high PM2.5 concentrations, the best strategy may be to choose high-efficiency second-stage filters to reduce compressor fouling.

Filter selection

To choose the optimal filters for your site, it’s important to understand selection criteria. In a conventional two-stage static panel filtration arrangement, the pre filter serves to remove the large, erosion-causing particles and reduce the loading on the final filter, thereby extending its life. The final stage removes the remaining large particles and a majority of the small particles that contribute to compressor fouling. A simplified way to think about it is that the pre filter captures the PM10 particles and the final filter captures the PM2.5 particles.

To complicate matters, several filter rating systems are used in the power industry. So, before discussing recommendations, a good understanding of filter lingo is needed. Key terms are below:

- Rated airflow. You want to be sure filter airflow is sufficient for your site. Filters can operate above or below their rated airflows, but operating at higher-than-designed flow rates can lead to increased pressure drop which hurts performance.
- Initial pressure drop. Most filter data sheets provide an initial pressure drop. This impacts performance. While every unit is different, a good rule of thumb is that every additional inch of pressure drop—in. H2O a/k/a in. WG (water gauge)—decreases power output by 0.3% and increases heat rate by 0.1%.

  Filter pressure drop will increase as the filter loads. A fair assumption is that filter delta-p increases proportionally to the dust loading. So, if a filter has a 1-inch initial pressure drop and a 3-inch final pressure drop, the filter is approximately 50% through its life at 2 inches. For performance-impact estimates, users should assume the average of the initial and final pressure drops.
- Efficiency. This is the most confusing parameter since there are multiple rating systems. The ASHRAE filter class assigns a MERV rating from 1 to 16. As the scale increases, the filters become more efficient at filtering out larger, and then smaller particles. MERV ratings between 6 and 8 are appropriate for pre filters. These ratings filter out between 35% and 70% of particles between 3 and 10 microns—the size range most likely to cause unrecoverable damage to the rotating turbomachinery.

Choosing final filters requires additional rating scales. MERV ratings of 13 to 15 are good for basic filtration and will filter out more than 90% of the larger particles not caught by the pre filter. While this may seem low, consider that a 70%-efficient pre filter and 90%-efficient final filter means that only 3% of the large particles will make it through to the compressor.

MERV 13 – 15 filters still let through up to 25% of the small particles that can contribute to fouling. Thus they will help reduce the fouling rate, but water washing will still be necessary to retain performance. MERV 16, the highest ASHRAE rating, provides filtration of at least 95% across all particles sizes.

To distinguish among high-efficiency filters, you need to look at the EN rating scale. Rather than identifying the average filtration efficiency for different particle sizes, the EN 1822 scale provides the minimum efficiency at the most penetrating particle size, which typically is about 0.2 to 0.4 microns for most filters.

The majority of filters with a MERV rating of 16, or a EN 1822 rating of E10 to E12, filter out more than 99% of all particles larger than 1 micron. A “cheat sheet” is provided to help you keep all of this information straight (Table 2).

Table 2: Filter selection chart

Best use	ASHRAE filter class	ASHRAE 52.2: 2007 Collection efficiency (percent) by particle size (microns) E1	E2	E3	EN filter class	EN 1822: 2009 Total filtration separation efficiency, %
	MERV	0.3 – 1.0	1.0 – 3.0	3.0 – 10.0		
Pre filter	1			<20	G1	
	2			<20	G2	
	3			<20		
	4			<20		
	5			20 – 35	G3	
	6			35 – 50		
	7			50 – 70	G4	
	8			>70		
Pre filter (very dirty environment)	9		<50	>85	M6	
	10		50 – 65	>85		
	11		65 – 80	>85	M7	
	12		>80	>90		
Final filter with regular washing	13	<75	>90	>90	F7	
	14	75 – 85	>90	>90	F8	
	15	85 - 95	>90	>90	F9	<85
Final filter with no washing	16	>95	>95	>95	E10	85
					E11	95
					E12	99.5

Table 3: Options for filter selection and wash type/frequency

Pre filter	Final filter	Offline wash?	Online wash?
G4 or above	MERV 13 – 15 (EN F7 – F9)	Yes, nominally quarterly, adjust through performance monitoring	Yes, if capacity is critical
G4 or above	MERV 16 (EN E10 - E11)	Yes, annually	No appreciable gain
G4 or above	MERV 16 (EN E12 or higher)	Only as needed through performance monitoring or inspection	No appreciable gain

Another common configuration for air inlet systems uses self-cleaning (pulse) conical/cylindrical filters. These typically are used in a single-stage configuration, or they may be followed by a very-high-efficiency stage. They can be more expensive than panel/V-bank filters, but have much higher dust-holding capability. This means they can operate longer at lower pressure drop, and therefore with less performance impact. However, over time they must be replaced due to wear and/or increasing pressure drop—the latter because some small particles are retained rather than released during cleaning.

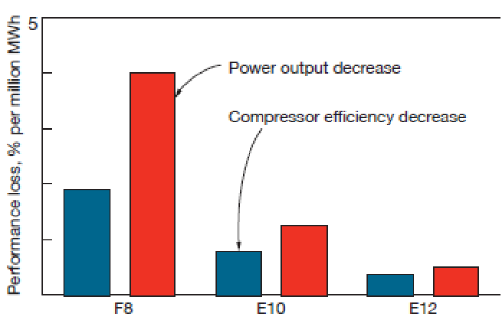
Making your decision

Choosing a good pre filter with adequate dust-holding capacity is relatively simple. Selecting a final filter, which is impacted more by unit location, requires greater thought and analysis. Over the last four years, EPRI has led a systematic study—in cooperation with an EPRI-member utility and Turbine Logic—of 15 7FAs protected by two-stage panel filtration systems to identify the real-world impacts of final filtration efficiency.

Results indicate that the performance impact of high-efficiency filters can be summarized in terms of performance loss per millions of megawatt-hours of operation, which normalizes results across units of varying operating cycles and capacity factors because it accounts indirectly for the total mass of air entering a unit.

While the full results can be found in ASME paper "Evaluation of Air Filtration Operations for an Industrial Gas Turbine", the bar chart compares results across the 15 sites. All the gas turbines in the study were equipped with pre filters with a rating of at least G4.

F8 filters are fairly standard across the fleet investigated and could be considered the default level of filtration. Notice the sharp drop in power per million MWh for the F8 over time. While the cost of better filters and the increased inlet pressure drop associated with them offsets this to some extent, there is also an aspect of diminishing returns.



Data for 15 sites using at least G4 pre filters indicate the sharp drop off in power per million megawatt-hours when using an F8 final filter compared to an E10 or E12; note too that the E12's benefit over the E10 is not as significant

The E10 final filters provide significant benefit over the F8; however, the E12 benefit over E10 is not as much. Nonetheless, plants in this study were able to run with E12 final filters for more than 12 months without water washing, significant performance impacts, or visual signs of fouling. In all of the studies conducted, offline washes were able to recover most of the performance degradation caused by fouling.

Proactive versus reactive maintenance

In addition to selecting the most appropriate filtration strategy, the plant operator must develop an effective maintenance strategy, which may be proactive, reactive, or a combination of both. Filtration is a proactive strategy, because it prevents dirt from entering the compressor; compressor washing is reactive, because it allows performance to degrade before cleaning the unit. Obviously, the two methods are not exclusive and can be used in combination. But keep in mind that while online washing allows the unit to remain operational, it is not as effective as offline washing at removing contaminants.

Optimizing among wash type and frequency, and filter type, requires an in-depth lifecycle cost analysis. Table 3 can help guide users without the time or resources for such a detailed study. However, the plant operator should have a performance monitoring strategy in place to adjust for site-specific conditions. Example: Sites with high PM10 loadings may choose pre filters with higher ratings.

EPRI publications focusing on inlet air systems

"Inlet Air System Procurement Guideline and Specification: For Gas Turbines in Power Generation Applications," assists owner/operators in the development of comprehensive and complete bid and procurement specifications. It enables users to understand the characteristics and important aspects of inlet air systems.

The specification will save staff time and money by providing a comprehensive template with all of the key aspects needed to assemble inlet air system purchase specifications. The template specification comes with a Microsoft Word document attachment that EPRI-member utilities can tailor to the specific needs of projects and corporate procurement procedures and policies.
"Inlet Air Filtration Assessment: 2016 Update" is a comprehensive, practical technical assessment of inlet air filtration and conditioning technology used in generating plants powered by gas turbines. As the main article shows, appropriate selection of inlet air filters can have a multimillion-dollar impact on plant profitability over time.

This report assists O&M personnel reduce lifecycle costs and improve plant performance. It provides a comprehensive description of various styles of filters for GT inlet-air applications, as well as a listing of filter manufacturers and their styles and brands of filters. Several assessments of remaining useful lives of filters removed from service are provided, along with laboratory test results based on ASHRAE 52.2 and EN 1822 standards. The background developed for this report also led to development of the "Air Filter Life Cycle Optimizer" software for economic analysis of filter selection as it interacts with GT fouling and performance impacts.

Case studies

Using the EPRI Air Filter Life Cycle Optimizer (AFLCO) software tool, a few detailed notional case studies have been assessed to provide users with estimates of the order-of-magnitude savings they can expect. A case was examined for a unit in the Southeast (90% service factor) operating most hours at baseload with evening turn-down.

Three scenarios were examined. In the first, an F8 filter is used in conjunction with quarterly offline washes and weekly online washes. The same unit then was examined with an E10 final filter, a reduction in offline washings to two annually, and elimination of online washing. Finally, a high-capacity HEPA E12 final filter was evaluated with an annual offline wash.

Pre filters were assumed to be changed out every six months and the final filters were changed as required by the pressure drop. The E12 filters were assumed to be twice as expensive as the F8 on a per-filter basis.

Obviously, the price of gas, electricity, and other assumptions would change the results, but the pertinent assumptions are presented in Table 4. The analysis takes into account performance degradation attributed to compressor fouling using a detailed time-dependent analysis. The AFLCO model can be tuned to specific site data as required.

The results of these lifecycle (10 years) cost analyses are presented in Table 5. By moving from an F8 to E10 filter the unit can eliminate online washing, reduce offline washing frequency, and retain power output. Note that fuel costs actually increase because of increased power production at base load.

Table 4: Case-study data input to Air Filter Life Cycle Optimizer			
Data/assumptions	**F8 final filter**	**E10 final filter**	**E12 final filter**
Gas turbine	7FA.04		
Plant configuration	2 x 1 combined cycle		
Service factor, %	90		
Hours at part load per day	4		
Avg load at part load, % of rated output	60		
Avg price of electricity, $/MWh	36.25		
Avg fuel cost, $/million Btu	2.75		
Inflation, %	2		
Discount rate, %	10		
US location	Southeast		
Pre filter	G4, change semiannually	G4, change semiannually	G4, change annually
Final filter	F8, change as needed	E10, change as needed	E12, high capacity/change as needec
Online wash frequency	Weekly	None	None
Offline wash frequency	Quarterly	Semiannually	Annually

Table 5: Case-study results using AFLCO based on input data/assumptions in Table 4			
Financials, net present value	**F8 final filter**	**E10 final filter**	**E12 final filter**
Power produced, $	1,055,190,420	1,060,970,857	1,087,793,213
Fuel, $	(478,449,078)	(482,342,296)	(495,143,971)
Water wash, $	(240,185)	(120,244)	(61,288)
Filter change/installation, $	(1,091,051)	(1,263,080)	(1,240,219)
Total value, $	**575,410,106**	**577,245,236**	**591,347,735**

The impact of compressor performance retention tends to have a larger impact on power than on heat rate. As a result, increased power output often increases total fuel costs even though the unit is more efficient. Water wash costs in the E10 case are cut in half. The filters are marginally more expensive, but approximately 2-million current day dollars can be saved over 10 years.

Looking at the E12 case provides insight into the benefit of using filters of higher efficiency and capacity. Here, the filter change-out costs are actually reduced over the selected E10. This is because the higher-capacity filter requires less frequent change out. The increased efficiency also significantly boosts power production.

Final thoughts

While there are many avenues for proper filter selection, it is important to gather as much information as possible on candidate filters before making a purchase decision. Before fleet purchase decisions are made, A/B tests on sister units should be conducted—time and resources permitting—based on the results of a preliminary analysis. Finally, water wash schedules should be re-evaluated using performance data after any filter-efficiency change to ensure you're getting the expected value out of the investment. **CCJ**

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