

The economic benefits of HEPA-grade filtration for gas turbine operation in the power generation industry.

| A report by

James Kenneth Ross

*Aftermarket Business Manager,
AAF Power & Industrial, Cramlington, UK*

Everywhere we look these days, one message stands above all the rest: energy must be used with greater efficiency.

Global energy demand is estimated to rise between 25 and 30 percent between now and 2040, fueled by growth in economic output and by a growing population in which billions of people — despite working hard to advance their standards of living — subsequently and inevitably end up consuming ever greater amounts of energy.

The DOE Energy Information Administration predicts that total electricity consumption, including both purchases from electric power producers and on-site generation, will grow from 3,879 billion kilowatt-hours in 2010 to 4,775 billion kilowatt-hours in 2035, increasing at an average annual rate of 0.8%.

In the countries belonging to the Organization for Economic Cooperation and Development (OECD), including those in North America and Europe, energy use is predicted to remain flat — even as economic growth progresses. One underlying factor is the assumption that increased investment in new technology will create efficiency gains in production and distribution that will in turn converge with a reduced consumption profile resulting from a more energy-conscious industrial and commercial customer base.

The electricity generation sector is witnessing the arrival of new, advanced-class, highly efficient natural gas plants and continuing to invest in the use of renewable sources of production.

This backdrop places even greater pressure on the present installed base, consisting of many thousands of gas turbines, to help the electric utilities develop more competitive business models capable of meeting demand with clean, efficient and reliable modes of generation.

If operators hope to achieve peak business performance, finding new ways to extract a greater number of megawatt hours at reduced fuel usage rates and with lower overall operational costs has never been more important.

The question is: can maintaining a gas turbine (GT) engine in an as-new state of cleanliness help electric utility companies meet this challenge?

Overview

In order to combust fuel, GTs consume vast amounts of atmospheric air heavily contaminated by natural pollutants such as wind-blown dust, agricultural pollution and salt and seawater spray in coastal locations, plus pollutants created by chemical refining, along with hydrocarbon emissions from industry and traffic. As an accumulated mass in fluctuating humidity, these pollutants seriously impact the performance and operating efficiency of precision GT engines.

To protect the turbine from these pollutants, most GT original equipment manufacturer (OEM) specifications — both past and present — call for air inlet filtration using a final “fine” filter with a classification of MERV 15/F9 (98 grade efficiency) or less. These are filters that deliver initial particle removal efficiencies of 60% or less at 0.5 microns.

HEPA (high-efficiency particulate air) filtration, now also known as EPA, was originally developed for clean room and pharmaceutical applications. HEPA H12 (EPA E12) filters, with efficiency levels thousands of times greater than the MERV 15/F9 classification and capable of removing 99.5% of particles as small as 0.07 microns, are increasingly being used to protect gas turbines. The initial demand for H-class filters came from oil companies seeking to maintain a very high level of cleanliness for turbine compressor blades, which eliminates the requirement for offline water wash and, consequently, production downtime.

Since introducing HEPA filters onto gas turbines over ten years ago, AAF has carried out long-term studies on a large sample of GTs — both with and without HEPA (EPA) filtration — totaling hundreds of thousands of operating hours. This work has led to the counter-intuitive conclusion that more power is obtained with HEPA (EPA) filters than with only fine filters. The consistent finding: initial power lost due to increased differential pressure is more than offset by the maintenance of a clean condition within the first four weeks of operation. In other words, the energy payback period of HEPA (EPA) filtration can be measured in days.



GAS TURBINE DIVISION

Proven HEPA Benefits

Turbine operational performance, availability and component life can be considered as direct functions of the total mass of ingested contaminants. These deposits decrease the air-flow performance of the inlet compressor due to degradation in blade shape and surface finish. Ultimately, the overall performance of the turbine is greatly affected.

HEPA filtration provides the important particle efficiency required to remove submicron-sized contaminants, resulting in laboratory-like clean air for engine combustion. **The primary technical benefits derived from enhanced filtration technology include:**

- Greater machine availability and reliability
- Maintenance of high initial power output
- Improved fuel efficiency
- Increased hot-end component life
- Zero production downtime with elimination of offline water wash
- Lower emissions

The potential commercial upside considers:

- Increased plant revenue
- Greater production yield (i.e., electricity, steam)
- Lower fuel and labor costs
- Lower component spend
- Greener technology use

Until ten years ago, HEPA (EPA) filter technology was employed only by niche performance-focused operators and in relatively small quantities. However, its success has expanded application around the world to a variety of filter configurations operating in demanding environments.

During the past decade, more than 45,000 AAF HEPA (EPA) filter elements have become operational on systems varying in size from 5MW up to 260MW. These systems are located in vastly different environments across a significant number of machines. Some of the earlier-installed systems have run past 50,000 hours, making them very useful for measuring machine availability, output and efficiency.

Reduced Productive Hours

Pollutants that are $<5\mu\text{m}$ in diameter do not have sufficient mass to cause wear, but they will impinge on the surface of the turbine's rotating and static components. In just a short period of time, pollutants can alter the blade profile from its optimum shape. This is commonly referred to as "fouling of the gas turbine."

Fouling is partly reversible. It is addressed by washing—using detergents and fresh water—during operation to inhibit day-to-day performance degradation, and by offline washing once the limit of operational performance is reached. **(A comparison of turbine compressor blades with and without protective HEPA [EPA] filtration is shown in Figures 3 and 4.)**

Benefits of Improved Filtration

Gas turbines are constant-volume machines, and their performance is affected by:

- Compressor efficiency
- Ambient air temperature
- Ambient pressure
- Inlet pressure drop

Compressor efficiency can be linked to the cleanliness of the compressor blades, which is affected by environmental conditions and air inlet filter performance.

Data from more than 75 operational GTs has indicated a definitive link between compressor efficiency and GT output (see Figure 1), compressor efficiency and heat rate (see Figure 2), filtration class, and compressor efficiency. The filtration class has been found to have a measurable impact on GT output and heat rate.

Figure 1: GT Output versus Compressor Efficiency

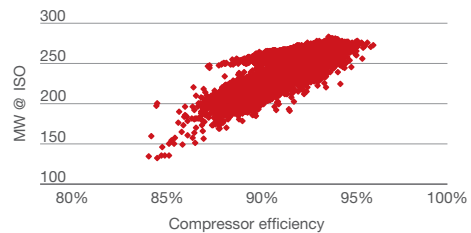


Figure 2: Heat Rate versus Compressor Efficiency

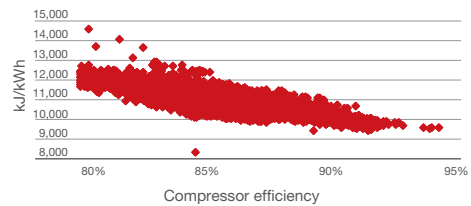


Figure 3: GT compressor blade with AAF HEPA (8,000 hours)



Figure 4: GT compressor blade without AAF HEPA (2,000 hours)

What Has Been Learned

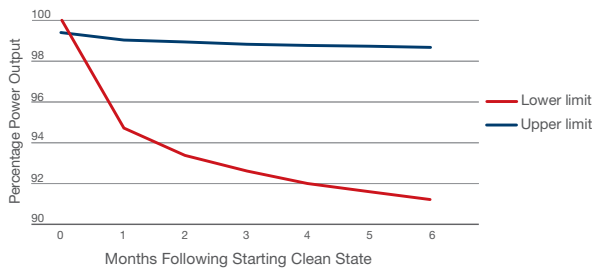
Detailed analysis of compressor efficiency and machine output—assessing both differential pressure and fouling impact—has shown that, in all cases, compressor efficiency and output correlate directly. This serves to quantify the link between the output of the machine and the compressor stage. Furthermore, a direct correlation has been established between filtration efficiency, compressor efficiency, and GT output.

Data collected by AAF measuring the impact of HEPA (EPA) filtration on GT performance provides two very important benchmarks for future work on this subject and for the development of future filter systems:

Benchmark 1: As shown in Figure 5, it is clear that the effect of the increased pressure differential from employing HEPA (EPA) registers an impact on performance only during initial operation; the fouling impact of less-effective filtration offsets this small loss after a matter of just two weeks. The “upper limit” data depicted in Figure 5 represents employment of AAF HEPA H12 (EPA E12) filtration. The “lower limit” data, which represents the worst-performing GTs studied, is more complex. In some cases, these GTs—equipped with a straight, self-clean or 2-stage static filter (typically MERV 13/F7)—were operating in an environment that is either regularly dry or subject to moderate dust levels. In other cases, the “lower limit” data involves GTs operating in an urban environment with higher levels of hydrocarbons and/or in wet/humid climates like those found in coastal and tropical regions, in which case even typical filtration products rated as high as MERV 15/F9 would be insufficient at preventing contamination of the combustion system.

Benchmark 2: Because we now have a baseline from which to compare existing systems in use worldwide, we are able to provide the operator with a relatively accurate forecast of the potential gain.

Figure 5: Power Loss over Time Measured from New or As-New Clean State



Machine Health

Gas turbine rotating parts are complex in design and structure and have a critical profile for maximum working efficiency.

Poor-quality air affects the life and performance of a large number of components within the engine core:

- Air compressor rotor and stator blades, variable stator vanes and labyrinths
- Burners, combustion chambers and transition ducts
- Center bearing, labyrinths and buffer ports
- Compressor turbine rotor and stator blades
- Cooling passages and labyrinths
- Power turbine rotor and stator blades

It is impossible to quantify the exact effect on every GT and each of its components. However, the most visible indication of poor filtration is found on the compressor blades and in the hot gas path section. These components are made of very sophisticated alloy metals that provide strength and durability.

Hot gas corrosion is of particular concern, especially in coastal environments where NaCl is prevalent both as a dry particle and solution in water. Salt entering the hot gas path causes two phenomena: first, as an airborne contaminant, the salt adheres to the hot section nozzle vanes, blocking the important cooling passages and increasing their working temperature. Second, when the NaCl is mixed with poor-quality or sour (sulphurous) fuel, it will cause accelerated degradation of key hot section components, leading to premature and extended outages for major machine overhauls.

Inspections of engines employing HEPA (EPA)-quality air showed massive improvement in hot end condition, with results for one Rolls Royce RB211 machine in the UK North Sea recording 84,000 hours of hot gas path life.

Reliability

A GT operating with clean parts has shown to be far less likely to incur a trip caused by component failure, forcing an unplanned shutdown. Components such as seals, bleed valves, actuators, and nozzles work more freely within a clean engine core, and thus an ancillary failure becomes less likely.



GAS TURBINE DIVISION

Detailed Performance Improvement

A Frame 7FA gas turbine located at sea level has a rated ISO output of 172 MW, and a heat rate of 9,358 BTU/kWh. Individual plant capability will depend upon location (climate and altitude), equivalent operating hours and environment. Even without the actual data from a specific plant, the following results can be anticipated from examining the filtration class protecting the gas turbine.

A Frame 7FA gas turbine protected by MERV 14/F8 filters will see peak output decline from 172 MW to 163 MW every 6 months, assuming quarterly offline water wash. If the same engine had the protection of HEPA H12 (EPA E12) filters, such as AAF's HydroShield™ Canister, Astrocel or Hydrovee filters, the ISO power output after 12 months would be a minimum 168 MW, with no crank wash required, inclusive of filter differential pressure.

Over a 12-month cycle at peak load, this represents an extra 2.9% power available, (more than 38,000 MWh per year).

With respect to fuel consumption, a Frame 7FA gas turbine protected by MERV 14/F8 filters will observe a growth in nameplate heat rate from 9,358 BTU/kWh to 10,030 BTU/kWh every 3 months. The corresponding heat rate with HEPA H12 (EPA E12) filters would be 9,517 BTU/kWh after 12 months.

Because the ratio of heat rate to compressor efficiency actually exceeds the ratio of power output to compressor efficiency, it is possible to consume less total fuel over 12 months while generating more power. In this case the total fuel saving over 12 months is 2.1%, or 278,000 million BTUs of natural gas. Note that heat rate improvement due to cleaner inlet air occurs at all load conditions.

It would be prudent to note this projection is made based upon empirical models developed from our sample collected across various turbine types with different filter systems, operating under changing environmental challenges in a cross section of countries worldwide. What results is therefore an excellent real-world expectation, given that the differing turbine environments and associated maintenance cycles allow for the normalization of the performance foundation baseline. Note, too, that the real engine performance output is also considerate of performance degradation not attributable to the HEPA (EPA) filters themselves. For example, many systems may have been operating with a gasket bypass on one or more filters and perhaps in their combustion duct system where leakage is common.

James Kenneth Ross is the Aftermarket Group Manager for North America, Europe and the Middle East at AAF Power & Industrial. His main area of interest is the development of high-technology, high-efficiency particulate air filtration technology for gas turbine machinery, and he leads the design engineering division responsible for the work in the field of engine performance optimization and compressor efficiency. James has a degree in business and finance and diplomas in both mechanical engineering and industrial acoustics.

Table 1: Frame 7FA Summary

	MERV 14	E12
MW after 6 months	164.5	170
Extra MWh	-	20,000
BTU/kWh after 6 months	10,030	9,520
MMBTU saved	-	133,000

Economic Payback

Experience has demonstrated that while HEPA (EPA) filters are more expensive and the inlet system may have to be redesigned to achieve the best solution, the benefits are huge in comparison (see Table 1). Extended hot-end component life, improved availability and increased revenues can in some cases reduce filter payback time to mere days. It is proven that air quality can be provided that is in excess of traditional levels specified for rotating machinery.

This has huge financial and technical benefits for the user, benefits that greatly exceed the additional capital cost and the cost of the consumable filters.

In summary, clean air can advantageously change the economics of GT operation through:

- Better machine availability
- Lower operating costs
- Longer hot-end component life
- More predictable performance
- Improved preventive maintenance

It is important to note that even higher air quality than H12 (E12) can be provided, which is far in excess of anything considered presently for rotating machinery. European and US test standards (ASHRAE 52.2-2007, EN779, EN1822 and ISO) together list 17 grades of filter efficiency for which H12 (E12) grade may be only the beginning.

Conclusion

Proven filtration is available from AAF today that allows operators to benefit from the technology without risk. The ambition of an operator may be to remove the need to offline and online wash rotating and static components to maximize productive hours with fewer repair intervals, to enhance machine output, or to reduce emissions. In any case, HEPA (EPA)-class filtration, or—more accurately—clean air delivered consistently and reliably, offers the turbine user realizable and proven benefits that can be reduced to a set of assured economics.



GAS TURBINE DIVISION