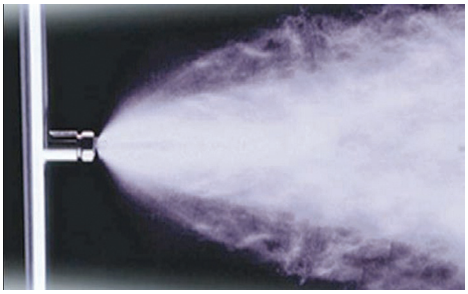
POWER Engineering

Inlet Fogging: Doing it Right

By Thomas Mee, CEO, Mee Industries

Since its introduction more than two decades ago, gas turbine inlet fogging has been installed on more than 1,000 turbines. As a measure of its success, original equipment manufacturers have added the technology to their product lines. The benefits are obvious: using water to cool the inlet air provides significant boosts to output, especially on hot afternoons when demand is at its peak.

Hot air, after all, is less dense than cold air. Turbines move a constant volume of air, but the power generated depends on the mass of the air moved through the turbine. Therefore, higher temperatures cause a drop in turbine output. Compressing hot air also takes more work than compressing cold air. When the inlet air is hotter, a greater percentage of the output goes to driving the compressor rather than spinning the generator. While the exact effect varies from one turbine design to another, typically a 1 C rise in ambient temperature lowers output by about 0.5 percent to 1 percent. Aeroderivative turbines tend to be the most sensitive to higher temperatures, but even a heavy-duty turbine can lose more than 10 percent of its rated capacity when temperatures hit 35 C (95 F). To counter this temperature rise, fogging systems use the natural cooling effect of evaporation to lower the air temperature, allowing greater mass flow and reducing the amount of energy spent on compression.



An additional power boost beyond that produced by cooling the air prior to entry into the compressor can be achieved by overspray fogging or wet compression. This is accomplished by adding more liquid water to the air than can evaporate given existing ambient temperature and humidity conditions. This extra mass flow of water is carried into the compressor where the heat of compression allows the droplets to evaporate and cool the aireven as it is being compressed. This reduces the work required to compress the air and further increases the gas turbine's output. Spraying 1 percent of the air mass flow as liquid water droplets can produce about a 5 percent increase in power.

Combining evaporative cooling and overspray fogging makes it possible to get a power boost of 20 percent to 30 percent over the gas turbine's rated output.

As with any technology, inlet fogging must be done properly to produce the desired result and care must be taken to avoid damaging the turbine. Large droplets or flowing water in the inlet ducting can damage compressor blades by liquid-impaction erosion. Research and experience have provided remedies and technological refinements to address these issues.

Droplet Size is Important

Fogging nozzles produce billions of droplets per second. Since evaporation only occurs at the water/air interface, the rate at which a droplet evaporates is a function of its volume-to-surface-area ratio. Surface tension causes fog droplets to become spherical in shape. The surface area of a sphere increases as a square of the diameter, but the volume increases as a cube of the diameter. This means that breaking the water down into smaller droplets exposes more surface area of the water to the air so it evaporates faster than larger droplets.

For example, a given volume of spray consisting of 40-micron droplets exposes one-fourth the surface area as compared to the same volume of spray consisting of 20-micron droplets. Therefore, a fog system that produces smaller droplets is more likely to cool the air to the target temperature (the ambient wet bulb temperature) before the air enters the compressor, thus ensuring the maximum power boost for a given water flow. Research and experience have shown that inlet fogging droplets should be no larger than 20-microns to fully evaporate in the one to two seconds they spend in the inlet airflow. This standard is achievable with a properly designed impaction pin nozzle.

Avoiding Compressor Blade Erosion

In addition to taking more time to evaporate, larger droplets are also less able to follow the airflow around obstructions such as inlet silencer panels and duct support structures. A 40-micron droplet has eight times the mass of a 20-micron droplet and its rate of fall is much faster.

Larger droplets are more likely to collect on duct obstructions or settle to the duct floor. If fog droplets impact on duct support struts, an accumulation of water will occur. This accumulated water can be stripped off by the high-velocity airflow in the form of large secondary droplets, which can have diameter of a millimeter (1,000 microns) or more. Droplets that impact on silencer panels or duct walls can create flowing and pooling water on the inlet duct walls or floor.

Compressor blade erosion can occur if large droplets or flowing or pooled water are suctioned into the compressor inlet. The high air velocity near the compressor inlet will cause large droplets to break up into smaller droplets, but these smaller droplets can still be large enough to cause erosion of compressor blades over extended periods of time.

Therefore, it is important to use properly designed drainage systems to remove water from the inlet duct before it can be suctioned into the compressor. U.S. Patent 7,204,670 B1 (to Meher-Homji & Mee) describes novel methods of suctioning water from support struts and duct walls and floors. In many cases, simple water diverters can be used to direct water to drainage points. A false floor above drain points can allow water to flow to the drain without being suctioned into the compressor.

Fog Nozzle Placement

If a fog system is used primarily for evaporative cooling or

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if it is installed on a gas turbine that is particularly sensitive to blade erosion, the fog nozzles should be installed as far upstream of the compressor inlet as possible to allow for maximum evaporation prior to entry into the compressor. In most inlets the ideal location for the nozzles is in the filter house, just downstream of the filter wall. This location often gives as much as two seconds of evaporation time, which is sufficient for a fog spray with droplets that are 20-microns or smaller to evaporate almost completely. Experience shows that the few remaining fog droplets are small enough that even the most sensitive compressor blades do not suffer from erosion.

When a fog system is used for overspray or wet compression, the intent is to introduce a significant flow of fog droplets into the compressor. For such installations, it is usually best to install the nozzles fairly close to the compressor inlet so the fog spray does not have to pass through inlet silencers or other obstructions on the way to the compressor inlet.

Proper Distribution of Fog Droplets in the Airflow

One challenge with inlet fogging is to get the small droplets evenly distributed in the airflow so they can evaporate quickly. There is little mixing of air in a typical inlet duct so it is important to design a nozzle array so that the full cross-section of the inlet air is treated with fog and so that gaps between nozzles are minimized.

Fog nozzles that have small spray plumes or large flow rates can result in too much water in the spray-plume volume. There also can be large gaps between nozzles where no fog is present. The smallest droplets in a spray plume evaporate quickly. This can cause the relative humidity in the plume volume to reach 100 percent before the larger droplets have evaporated. A fog system with a larger quantity of fog nozzles, each with a lower flow rate, will provide better evaporative cooling than a system having fewer, high-flow-rate nozzles. Such a system will also have less accumulation of flowing or pooling water in the inlet ducts.

Differences in airflow velocity should also be taken into account by placing a higher concentration of fog nozzles in areas of the duct cross-section that have higher airflow and few nozzles in areas with lower airflow. This insures sufficient fog to cool the air in high-velocity areas and avoids over-fogging in low-velocity areas. A computational fluid dynamics (CFD) analysis can be used to model the airflow in the duct, but actual measurements of air velocity will provide more dependable results.

A properly designed and maintained fogging system will minimize but not completely eliminate the possibility of water collecting in the duct, so it is always beneficial to install properly designed drainage systems.

Dirt and Rust

Inlet duct surfaces and silence panels should be thoroughly cleaned before operating a newly installed fogging system. Dirt that has accumulated on duct surfaces and silencer panels can be carried to the compressor possibly causing rapid fouling of the compressor. If fouling does occur, it may be an indication that the compressor is suctioning un-atomized water from the duct walls and floor so drainage systems may not be properly designed. Areas of rust or compromised coating should also be cleaned and recoated before operating a fogging system.

Pump Maintenance

Fogging systems require the use of demineralized water to prevent mineral build up on the compressor blades and hot-gas-path corrosion that could be caused by minerals in untreated water. Demineralized water, however, makes a poor lubricant, shortening the life of pump seals. Fog systems that operate for more than 500 hours a year should have seal-flushed pumps.

Flushed pumps feature a specially ported inlet manifold enabling a tap-water internal flush. The tap-water flush cools the seals and provides better lubrication than demineralized water. A normal pump seal might last only 500 hours before requiring seal replacement while a seal flushed pump can operate for more than 6,000 hours before seal replacement is required.

Compressor Surge

Compressor surge is not normally an issue with evaporative cooling or overspray fogging. However, if a fog system providing a large amount of evaporative cooling were to suddenly shut down, it is possible for the sudden introduction of much warmer air to cause a compressor surge. Fog systems are normally staged up and down over time to avoid this eventuality. But it is possible for a fog system to suddenly shut down due to a lack of inlet water, electrical failure and so on. U.S. Patent 7,028,485 B1 (Mee 2006) teaches methods for avoiding this by installing an inexpensive pressure accumulator on the high-pressure water lines. In the event of a sudden failure of the fog system, the pressure vessel allows the fog spray to be reduced over a few seconds thereby avoiding the potential for compressor surge.

Doing it Right

While solutions have been worked out for almost any problems, that really doesn't matter unless a compelling reason exists to use fogging in the first place. The biggest reason, of course, is increased output—up to 30 percent—for a fraction of the cost of a new gas turbine. Fogging has its biggest impact when ambient temperatures, user demand and electricity prices are highest.

Another gain is heat rate. Fogging improves the heat rate of a simple-cycle gas turbine by as much as 5 percent; more of the fuel spent goes to generating power instead of compressing air.

On the environmental front, fogging reduces NO_X emissions by up to 30 percent by reducing hotspots in the combustor. It reduces overall emissions since better efficiency means burning less fuel per unit of output.

Given its low capital and O&M costs, inlet fogging has been installed on well over 1,000 gas turbines from small aeroderivitives to G-class turbines over the past 20 years. It has a lower operating cost than chillers and, unlike media-type evaporative coolers, fogging systems do not produce a significant pressure drop in the inlet. pe

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