Doing It Right The First Time

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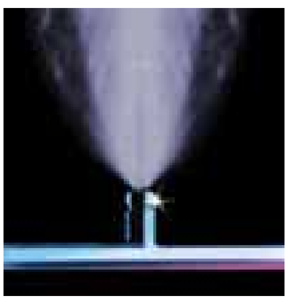
High-pressure Fogging:
The Cost-effective Gas Turbine Inlet Air Cooling Alternative



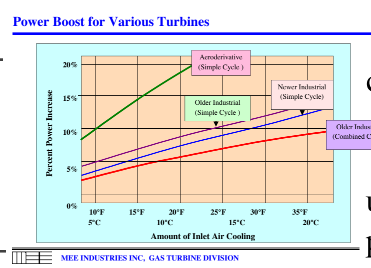
When Portland General Electric Co. (PGE) built the Coyote Springs Combined Cycle Plant in 1997, the companies concern about the effects of climate on generator performance led them to customize it with MeeFog cooling even before bringing it online. Boardman, on the south bank of the Columbia River in Eastern Oregon, experiences hot, dry summers. PGE calculated that during the long summer months performance of its 159 MW GE Frame 7-FA turbine could be reduced by 15 percent or more. Accordingly, the plant conducted a comprehensive evaluation of inlet air cooling.

The typical turbine on a summer's day produces up to twenty percent less power than in winter. By feeding in cooler air, mass flow is increased, resulting in higher output (See Figure 1, Turbine Performance Chart).

PGE checked out all widely used forms of inlet cooling. "We found that most cooling methods were expensive and required structural modifications to buildings and air inlet housing," says Cheryl Bryant, the PGE mechanical engineer in charge of specifying and implementing the cooling system at Coyote Springs. The plant narrowed the field down to two main candidates – media type evaporative cooling and high-pressure fogging.

PGE found that in order to create a large enough evaporative surface to adequately cool inlet air, media-type cooling would entail substantial duct enlargement and higher operating costs. "Media-type evaporative cooling worked out to be 250 percent more costly to install than inlet fogging," says Bryant "After we factored in maintenance and running costs, we decided to go with high-pressure fog." The result – a 16 MW output increase and a significant improvement in heat rate.

Figure 1, Turbine Performance Chart.



As combustion turbines are constant volume machines, at a given shaft speed they always move the same volume of air. But the power output of a turbine depends on the flow of mass through it. On hot days, when air is less dense, power output falls off. Furthermore, the work of compression is proportional to the inlet air temperature, so cooler inlet air means less power is consumed by the compressor.

Status Quo

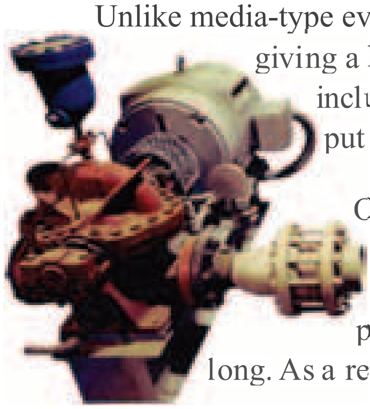
For many years, two technologies dominated the inlet air cooling field – media-type evaporative coolers and mechanical chillers.

Media-type Evaporative Coolers

Evaporative coolers are the most common method of inlet air cooling, capable of increasing power output by five to fifteen percent. In this system, air is pulled through a wetted, honeycomb-like material, normally composed of cellulose fiber. Inside, the air evaporates off the convoluted surfaces of the wetted media, thereby cooling the inlet air. As this form of evaporative cooling does not require compressors, chiller coils, or cooling towers, it is relatively inexpensive to install and functions over a wide range of conditions.

There is a downside to media-type cooling, however. As relative humidity increases, so does the dollar per kW cost of evaporative cooling. Additionally, retrofitting an evaporative cooler often requires enlargement of ducts and inlet air housing, raising capital costs even higher. Overall though, if installation modifications are minimal, evaporative coolers generate cost-effective cooling. Generally speaking, the effectiveness of an evaporative cooling system depends on the surface area of water exposed to the air stream and the water's residence time. That's why duct modification is often required – to enlarge the evaporative surface and thereby the amount of cooling accomplished by evaporative cooling. PGE found that in order to create a large enough evaporative surface to adequately cool inlet air, media-type cooling would entail substantial duct enlargement and higher operating costs. "Media-type evaporative cooling worked out to be 250 percent more costly to install than inlet fogging," says PGE's Bryant.

Mechanical Chillers



Unlike media-type evaporative coolers, chillers are not restricted by ambient conditions and are capable of giving a larger power boost at high humidity levels. There are various different types of chiller, including compressor, thermal storage and absorption chillers, with some increasing output by up to 20 percent.

One example is Ripon Cogeneration, a Modesto, CA company that supplies power to the grid and steam to an adjoining paper mill, which requires 45,000 lbs of steam per hour when running at full capacity. Ripon added a chiller system to increase summer peaking capacity. This cogen facility now keeps inlet air temperature at 45F all year long. As a result, power output has risen from 42 to 48 MW on hot days.

Chillers do, however, have significant installation costs and can be energy intensive. "If it's 100°F outside and the dew point is at 80°F, it takes an awful lot of energy to squeeze the water out of the air to chill it," says Tim Kemp, Inlet Systems Engineer at GE Power Systems. "But depending on ambient conditions or such factors as the availability of a cheap source of chilled water, it can work out cheaper in the long run for some." In drier climates especially, chillers (at $150/kW) compare poorly against evaporative coolers ($100 to 120/kW). But once relative humidity rises above 60 percent, chillers come into their own.

High-pressure Fog

High-pressure fogging represents a significant advance in evaporative cooling technology. Instead of a convoluted media arrangement as in standard evaporative coolers, fog systems create a large evaporative surface area by atomizing the supply water into billions of super-small spherical droplets.

The size of the droplet plays an important role in the amount of cooling that takes place. To a meteorologist, airborne water droplets less than 40 microns in diameter comprise a fog. Over that it's called a mist. In inlet air cooling, it is vital to make a true fog, not a mist. True fogs tend to remain airborne due to Brownian movement—the random collision of air molecules that slows the descent of the droplets—while mists tend to descend relatively quickly. In still air, for example, a 10 micron droplet falls at a rate of about one meter in five minutes, while a 100 micron droplet falls one meter in three seconds.

"As well as increasing water residence time in the air stream, small droplets speed up the evaporation process," says Thomas Mee III, CEO of Monrovia, CA-based Mee Industries, the largest fogging company in the world. "Further, the surface area is greater per unit of water in inverse proportion to droplet diameter. Water atomized into 10 micron droplets yields ten times more surface area than the same volume atomized into 100 micron droplets."

At Coyote Springs, for example, the Mee Fog system droplets have an average diameter of 15 microns. Thus they provide maximum evaporative potential and high efficiency. (See Figure 2, Mee Fog Droplet Size Chart]

Figure 2, Fog Droplet Size Chart.

Other factors being equal, the speed of evaporation of water depends on the surface area of water exposed to the air. For this reason, the size of droplet generated by the fog system is a critical factor. For instance, because of the geometry of spheres, a given amount of water atomized into 10 micron droplets yields ten times more surface area than the same amount of water atomized into 100 micron droplets.

PGE System Components

The Mee Fog system installed at Coyote Springs comprises a series of high-pressure pumps connected to a demineralized water supply. Computerized controls operate an array of tubes containing the fog nozzles (See Figure 3, Diagram of Fog System).

Computerized Controls:

The Coyote Springs fog pump skid includes a programmable logic controller (PLC) that monitors water flows and pressures to ensure proper function of the skid components. Weather sensors, measuring ambient temperature and humidity, are connected to the PLC. The control software then automatically turns on or off each stage of fog cooling depending on the capacity of the inlet air to absorb water vapor. PGE engineers also have the option of manually operating the system.

Nozzle Manifolds:

Nozzle manifolds are composed of a series of stainless-steel tubes and specially designed fog nozzles. The manifolds at the Boardman plant consist of half-inch diameter tubes, spaced 8 to 12 inches apart. Because such an open latticework of small pipes does not impede air flow, pressure drop is negligible.

Fog Nozzles:

The nozzles themselves are made of high-grade stainless steel and are known as impaction-pin nozzles. These nozzles have orifice diameters of 6 thousandths of an inch and produce fog droplets in the 3 to 30 micron range, ideal for inlet air cooling (See Figure 4, Impaction Pin Nozzle).

At Coyote Springs, 1120 impaction pin nozzles spray a maximum of 50.4 gpm of fog into the inlet air duct, depending on how many of its eight stages are activated. Air flow through the system averages 3,315,600, lb/hr.

Installation

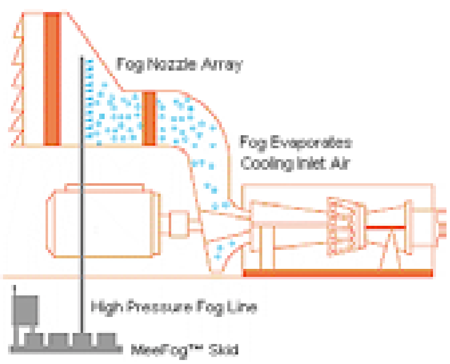
With fog cooling, little or no modification of the inlet air duct or housing is required. This proved to be the case at the PGE facility. However, the plant engineers added access doors and drains to permit easier servicing and provide for the drainage of excess water.

Like many plants, PGE elected to install its Mee Fog system downstream of air filters/upstream of silencers and trash screens. “This is by far the most common location for high-pressure fog manifolds,” says Mee, whose company has installed over 100 fog systems in gas turbines throughout the World. “Installation usually requires one or two outage days. It calls for only minor modifications to the turbine air inlet structures and pressure drop is virtually nil.” (See Figure 5, Coyote Springs Fog System Configuration).

Fog System Results

Overall, the PGE facility reports an output increase of around 16 MW (2MW per cooling stage), a 10 percent improvement. During the hot summer days, the fog system achieves as much as 30F of cooling. “We wanted increased megawatt output and lowered heat rate, and that’s exactly what the Mee Fog system delivered,” says Bryant. “For us, it proved far more economical than other cooling options.”

Figure 3, Diagram of Fog System.



Fog systems use high-pressure water pumps to pressurize demineralized water to between 1000 and 3000 psi. The water then flows through a network of stainless steel tubes to fog nozzle manifolds that are installed in the air stream. These nozzles atomize the water into micro-fine fog droplets which evaporate quickly.

Figure 4, Impaction Pin Nozzle.

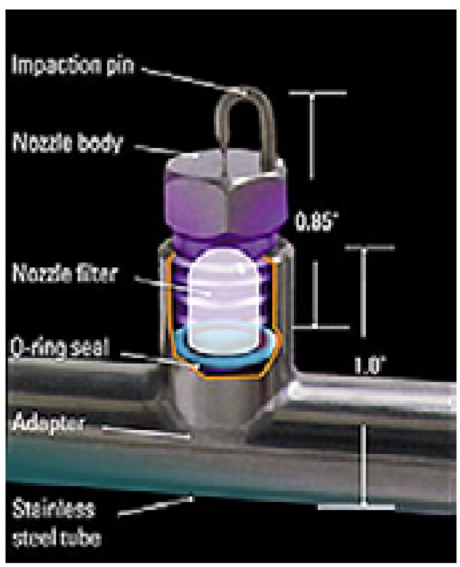


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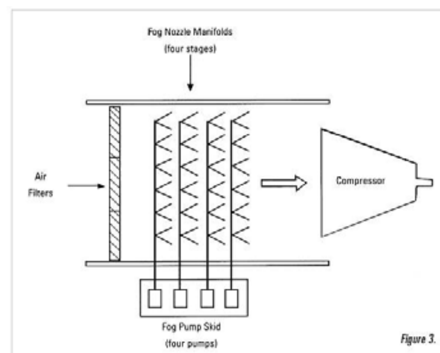
Figure 5, Mee Fog Droplet Size Chart.



This facility installed high-pressure fogging before putting the plant’s GE Frame 7-FA gas turbine on-line. There are 1,120 nozzles arranged in eight stages, with each stage providing 3.75 degrees F. of cooling for a total of 30 degrees. Overall, the facility reports an output increase of around 2 MW per cooling stage, a 10 percent improvement. Its interesting to note that with a simple-cycle turbine, the power increase would be closer to 20 percent.