Technical Review of Inlet Fogging Decision
For Power Bridge CCGT Power Generation Systems

"In this paper, the researchers have conducted thermal performance simulations for combined cycles with and without an inlet fogging system under various ambient conditions. The results show that the combined cycle power augmentation by inlet fogging is around 3 MW to 15 MW. It is about 1% to 5% power output of the combined cycle under study. However, the efficiency of the power plant with inlet fogging is slightly lower than the no fogging case. In other words, combined cycles with inlet fogging are at the expense of a small efficiency reduction in order to boost the power output." ***Power Augmentation Study of a Combined Cycle Power Plant Using Inlet Fogging****, Chiang, Hsiao-Wei, and Wang, Pai-Yi, pp. 1272-1281,* ***JSME International Journal****, Series B, Vol. 49, No. 4, 2006.*

"Inlet fogging includes a series of high pressure reciprocating pumps providing demineralized water to an array of fogging nozzles located after the air filter elements. The nozzls create a large number of micron size droplets which evaporate cooling the inlet air to wet bulb conditions….The control system of most inlet fogging sytems incorporates a programmable logic controller (PLC), which is mounted on the high-pressure pump skid. Sensors are provided to measure ambient relative humidity and dry bulb temperature.

"…Programming algorithms within the PLC use these measured parameters to compute the difference between the dry bulb and wet bulb temperature to quantify and control the amount of evaporative cooling that is possible at the prevailing ambient conditions. …Control of the inlet fogging skis is based on climatic conditions and as the overall utilization of the fogging systems at any location, is a strong function of the climate conditions. It is this reason that makes an accurate understanding of the variations in climatic conditions an imperative…

"…Even the most humid environments allow for up to 8˚ C (15˚ F) of evaporative cooling during the hotter part of the day. The term "Relative Humidity" refers to the moisture control in the air "relative" to what the air could hold at that temperature. In contrast "Absolute Humidity," is the absolute amount of water vapor in the air (normally expressed in unit mass of water vapor per unit mass of air). …Since inlet air fogging causes a very small pressure drop in the inlet air stream, and is relatively inexpensive to install, these systems have been successfully applied in areas with very high summery time humidity such as the Texas Gulf Coast region or the state of Florida in the USA and in the other high humidity locations in the world. This is because during the hot hours, the coincident relative humidity is typically low..." ***Inlet Fogging of Gas Turbine Engines: Climatic Analysis of Gas Turbine Evaporative Cooling Potential of International Locations****, Chaker, Mustapha; Meher-Hamji, Cyrus B., Mee Industries Inc., Document 2002-GT-30559,* ***Proceedings of ASME Turbo Expo 2002,*** *3-6 June 2002, Amsterdam, The Netherlands*

"Gas turbine inlet cooling is extremely effective in counteracting the decreasing GT performance during hot and humid summer when the power demand reaches maximum. South Louisiana's summer is especially hot and humid, inlet cooling is an option: The capital cost for an inlet-cooling device is cheaper than installing a stand-by GT unit only for peak-load needed.

"…The options to improve GT performance output through inlet cooling are numerous including both indirect evaporative "pre-cooling" systems, active "chiller" refrigeration based systems (bth electrically driven and thermally driven), desiccant cooling systems, and a number of water spray / fogging options.

"…Active refrigeration systems can chill inlet air to just about any temperature that does not result in ice buildup on the cooling coils from the ambient relative humidity. For optimization and practical reasons, systems ae usually designed to operate above 48 ˚ F. Refrigeration, whether by direct chilling or ice storage, is relatively costly requiring considerable maintenance, has a fairly high parasitic load, and requires a fairly large area to accommodate the refrigeration equipment. The basic difference between direct chilling and ice storage is that direct chilling has a sustained and relatively constant parasitic load while the combustion turbine is operating, whereas ice storage has a high parasitic load that is uwed to make ice during off-peak hours that is then melted to provide refrigeration during peak hours. The required instsallation space for ice storage is also considerably larger than the space required for direct chilling and can often eliminate the viability of that option…

"…Evaporation cooling has an advantage in that the mass of the water used for cooling also contributes to the turbines' performance by increasing mass flow through the GT. The major disadvantage of evaporation is that its effects diminish with rising wet bulb temperatures, associated with hot and humid days when power is usually most valuable, and that it is rarely possible to cool the inlet air below about 42˚ F, which providesa limit on the potential performance improvement.

"…Evaporation also uses a considerable amount of water and can lead to compressor section and turbine section maintenance problems, if operating parameters are not carefully observed.

"…Evaporation can be relatively inexpensive to install. But maintenance costs can be high. Performance can suffer if water of required quality is not used – which is an area where operators often try to reduce costs – at their peril. The best approach is to utilize high quality, demineralized water…

"…Comprehensive parametric analysis on a wide range of existing gas turbines covered both evaporative and overspray fogging conditions. It shows that the performance parameters indicative of inlet fogging effects have definitive correlation with the key gas turbine design parameter. They indicated, also, that aero-derivative gas turbines in comparison to the industrial machines, have higher performance improvement from inlet fogging.

"…Active refrigeration systems can chill inlet air to just about any temperature – for optimization and practical reasons, systems usually operate above 48 ˚ F. Refrigeration, with by direct chilling or ice storage, is relatively costly requiring considerable maintenance, has a fairly high parasitic power load, and requires a fairly large area to accommodate the refrigeration equipment….Evaporation cooling has an advantage in that the mass of the water used for cooling also contributes to the turbine's performance (i.e., increases the mass flow through the turbine).

"…Obviously, not all systems are cost effecige for any gas turbine plant. Careful consideration to system parameters and investment criteria must be examined. Installed costs for inlet cooling systems vary drastically. On larger, industrial and utility gas turbine sytems, fogging systems have been installed to increase power outputs at minimal costs in the $25.00 to $50.00 per kW range, while active chilling systems can exceed $500.0 per kW installed costs.

"…A project optimization analysis needs to be performed to determine which are the objectives of such a project and which technology(s) beset meet those objectives.

"…TVA selected MEE Industries for an eight million dollar contract to install high pressure fog cooling sytems on 48 of their utility peaking gas turbines. One of the single largest inlet air fogging projects in history at the time, TVA decided t install high-pressure fog in order to gain additional output, especially during the hot summer months in their service areas. These fog sytems were installed on peaking turbines at four different plant sites and were designed to provide 20 ˚ F. of fog cooling and an additional 6 ˚ F. of intercooling.

"…Research indicated that fogging offered considerable benefits with minimal risks for most gas turbine applications…An example list of benefits suggested by Fog technology inlet cooling are:

- Increases output by up to 20%
- Improves heat rate up to 5%
- Reduces NOx emissions
- Field tested and proven technology with hundreds of system installations
- Lowest capital, installation, and O&M costs compared to other cooling technologies
- ~100% evaporation efficiency with low inlet pressure drop
- Easy retro fit, typically 1-3 days outage
- Optional fog compressor inter-cooling for additional power boost

"…In most situations, evaporative / fogging options will offer the best and quickest return, assuming a fresh water source is not a 'fatal' issue – fogging and overspray system should utilize a high quality, demineralized water supply source. …In addition, they still allow other power augmentation technologies to be effectively installed for even greater value." ***Assessment of Inlet Cooling to Enhance Output of a Fleet of Gas Turbines**, Wang, T., Braquet, L., **Proceedings of Industrial Energy Technology Conference IETC 30th**, New Orleans, May 6-9, 2008.*

***Economic Benefits of Replacing Gas Turbine Media Based Evaporative Cooling with Inlet Fogging Systems**, **MeeFog Technical Application Note AN-GT-205**, 5 Jan 202, Rev. 1*

"…Some of the benefits of fog evaporative cooling compared to traditional media type evaporative cooling involving the following areas:

- Economics
- Performance, Efficiency and Effectiveness
- Installation Flexibility
- Control Flexibility
- Operation and Maintenance

"…Replacing media type evaporative coolers with high pressure fogging introduces higher effectiveness and power boost, ability to fog intercool, lower operation and maintenance costs and lower parasitic inlet pressure drops.

"…Traditional media based evaporative coolers have been widely used in the gas turbine industry especially in hot arid areas. The basic principle of evaporative cooling is that as water evaporates, 1,160 BTUs of heat (latent heat of vaporization) are absorbed from the air and thus reduces the ambient air temperature. Water is distributed over the media blocks which are made of fibrous corrugated material. The airflow through this block evaporates the water.

"…A typical value for effectiveness is 85%, which means that the wet bulb temperature can never be attained. While higher efficiency numbers are often quoted by media suppliers, they tend to deteriorate over time and result in efficiencies at best of 85%. The thickness of the media will define the efficiency and pressure drop for a given air flow velocity. For most gas turbine operations, thicknesses of 12 inches are common.

"…The presence of a media type evaporative cooler inherently creates a pressure dorp that results in a significant drop in turbine output. As a rough rule of thumb, a 1" WG increase in inlet duct losses will result in a 0.48% drop in power and a 0.12% increase in heat rate. These numbers would be somewhat higher for an aero-derivative gas turbine. The key issue with a traditional media evaporative cooler is that this increased pressure drop loss occurs year round even when the evaporative cooler is not in use. Increases in inlet duct differential pressure will cause a reduction of compressor mass flow and engine operating pressure. Increase in inlet differential pressure results in a reduction of the turbine expansion ratio.

"…The inherent loss of efficiency and increased inlet pressure loss in a traditional evaporative cooling system never allows for the maximum cooling effect to be attained. Water quality requirements are, however, less stringent than those required for direct fog cooling systems."

"…The coolers used for most gas turbine operations are of the recirculating type which have the requirement for blowdown in order to avoid the accumulation of minerals in he water. Thus make up water will equal the blowdown water plus the wter evaporated. The blowdown rate is dependent on the hardness of the water and curves are available to calculate this. Typically, blowdown rate should equal 4 TIMES the evaporation rate. Accurately maintaining the blowdown and checking on the water quality is an important maintenance task with media type evaporative coolers.

"…Mist elimination is necessary as the water is not treated and contains minerals, it is imperative that none enter the compressor. Employing a mist eliminator on the downstream side ensures the air entrained large water droplets are removed. This mist eliminator also induces an increased and continuous pressure drop on the overall system.

"…Water flow rates are typically between one and two gallons per minute for each square foot of surface area of the distribution pad but water volume can be higher for larger evaporative coolers. Higher flow rates minimize the potential of mineral build up but increase the risk of entrainment of the water into the air stream. For this reason, the amount of water flow should be carefully adjusted during commissioning and should not be "tuned" constantly as this often leads to excessive dry spots or water carryover.

"…Carryover of mineral dust can also occur, which causes damage to the cold and hot components. Some oeprators attempt to minimize this problem by running the media evaporate at 50% of the operating efficiency. Dust carryover also occurs when the media evaporating system is not operating and the media elements dry out.

"…By contrast, demineralized waater is converted into a fog by means of special atomizing nozzles operating at 2000 pounds per square inch to effect direct inlet fogging. This fog provides cooling when it evaporates in the air inlet duct of the gas turbine and allows close to 100% effectiveness in attaining wet bulb conditions at the turbine inlet which gives the lowest temperature possible without refrigeration.

Parameter	***TRADITIONAL MEDIA TYPE EVAPORATIVE COOLING***	***HIGH PRESSURE INLET FOGGING***
First Cost	$100/Augmented kW	$25/Augmented kW
Duct Modification needed for retrofit applications	Significant duct modifications required.	Not needed. Easy to retrofit existing media system.
Need for high quality water	Not required. Potable water ok	Demin water required
Incremental inlet Delta P	Higher, typically 1 inch water in practice which degrades output and heat rate even when evap cooler is not in use.	Low- practically nil
Size Foot Print	Large	small
Effectiveness	0.85 (may drop to 0.8 with deposit of salts on media). May have to be as low as 0.5 if water reduction is needed to avoid mineral carryover.	0.98-1.0
Maintenance activities	Higher	Comparatively lower
Aux. Power consumption	Requires pump for circulation	High pressure pumps needed , but power consumption is <1% of augmented power
Sensitivity to Relative Humidity	High	Lower
Installation down time	Extended outage required (3-4 weeks)	Can be done in 2-3 days
Possibility to intercool compressor	Not Possible since this is a passive system.	Possible and has been done on several gas turbines providing significant power boost.

Table 1. Qualitative comparison between traditional Evaporative Cooling and High Pressure Cooling

"…The presence of a media type evaporative cooler inherently creates a pressure drop and this will create a drop in turbine output. This pressure drop occurs year round and can cost hundreds of thousands of dollars. The pressure drop exists regardless of the evaporative cooler is used or not.

"…the effect on output and base load revenue over 8,000 hours of operation are provided in the tabulation below to give a feel for the revenue loss due to the inlet differential pressure alone.

GAS TURBINE	BASE kW (4 and 5" WG inlet and out Delta P)	kW (1"WG Additional Inlet Delta P)	Revenue Loss at $0.06/kW-hr
Alstom Tornado	6,527	6,498	$ 132,200
Solar Mars 100	9,789	9,754	$ 16,800
Alstom GT 11N	79,381	79,054	$ 156,960
GE 5371PA	25,942	25,649	$ 44,640
GE 6531B	37,254	37,103	$ 72,480
GE 7111EA	82,786	82,468	$ 152,640
GE 7241FA	170,314	169,737	$ 276,960
GE 9171E	123,054	122,642	$ 193,440
GE 9351FA	254,565	25,3731	$ 400,320
LM 2500	16,940	16,869	$ 34,080
LM 6000PD	40,695	40,542	$ 73,440
P&W FT4C-3F	28,953	28,831	$ 58,560

Table 2. Effect of 1" WG Inlet Pressure Drop on Generation Revenue.

"…With evaporative efficiencies of around 85%, media type evaporative coolers can never approach wet bulb conditions. At every ° F. of cooling results in approximately 0.4% power boost, there is a considerable loss in power when compared to an inlet foging system. This situation compounds the losses due to the increased inlet pressure drop that is induced by a media type evaporative system. Examine the importance of media evaporative efficiency in Table 3 that follows. One can see that the gas turbine power output is significantly affected by the media cooling efficiency – a 100% efficiency which is NOT possible with a media type system results in a power output of 79.599 kW. In reality, the fogger would attain 79,947 kW the additional power (348 kW) being due to the reduced inlet pressure drop that is experienced. This table shows that media type evaporative coolers have an inherent problem in approaching the wet bulb temperature.

	Case 1	Case 2	Case 3	Case 4	Case 5
Computation Result, Thermoflow - STQUIK	OK	OK	OK	OK	OK
Evaporative cooler Efficiency	**80**	**85**	**90**	**95**	**100%**
GT gross power [kW]	**77,602**	**78,110**	**78,607**	**79,102**	**79,599**
GT gross LHV eff [%]	**32.48**	**32.53**	**32.57**	**32.61**	**32.66**
GT gross heat rate [BTU/kWh]	10505	10491	10477	10463	10449
Compressor inlet massflow [lb/s]	611.1	613.2	615.2	617.3	619.3
Compressor inlet temperature [F]	76.97	75.28	73.59	71.9	70.21
Turbine inlet massflow [lb/s]	572.7	574.6	576.6	578.5	580.5
Turbine inlet temperature [F]	2020	2020	2019.8	2019.5	2019.2
Turbine exhaust massflow [lb/s]	621.6	623.7	625.8	627.9	630.1
Turbine exhaust temperature [F]	999.7	998.9	998	997	996
GT fuel HHV input [kBtu/hr]	904610	909273	913848	918374	922927
GT fuel LHV input [kBtu/hr]	815248	819451	823574	827652	831755
GT fuel flow [lb/s]	10.52	10.58	10.63	10.68	10.74

Table 3. Simulation of a Frame 7111ea Gas Turbine Operating With Media Evaporative Cooler, with Varying Evaporative Cooler Efficiency.

[6] As a practical matter, the higher efficiencies often quoted on new and clean media, is not retained due to media deterioration and salt up, which causing a dramatic drop in efficiency. Further, several operators of media type evaporative coolers have deliberately curtailed water flow in order to avoid carryover problems that had resulted in blade erosion.

The situation of cooling with evaporative media systems and with high pressure fogging systems from a condition of 104 ˚ F. and a relative humidity of 18% (as may be summer peak conditions in Bakersfield, California) is shown in Table 4 below. The table illustrates simulations run with several gas turbines.

GAS TURBINE	KW with Media Type cooler	KW with High Pressure Fogger	Revenue Gain by using Fogger $0.146/kW-hr, 2000 hr period.
Alstom Tornado	6150	6302	$ 44,320
Solar Mars 100	9357	9533	$ 51,480
Alstom GT 11N	75,298	76972	$ 489,645
GE 5371PA	24135	24978	$ 193, 927
GE 6531B	34938	35821	$ 245,115
GE 7111EA	78110	79881	$ 537,323
GE 7241FA	160584	164161	$ 1,046,273
GE 9171E	115882	118515	$ 770,153
GE 9351FA	241130	246052	$ 1,439,685
LM 2500	20535	20777	$ 124,020
LM 6000PD	36542	38083	$ 450,743
P&W FT4C-3F	26920	27662	$ 217,035

Table 4. Output Differences with Media and Fogger Type Coolers. This simulation takes both the cooler efficiency and the incremental inlet pressure differential into account.

"…Dry bulb temperature and the relative humidity have a significant impact. As one would expect, the benefits of the fogger become more dramatic during he lower humidity operation. There is still approximately a 0.5% boost in output when the humidity is close to 100% with a fogger. This is because the fogger can operate and boost power even with very high humidities, while the media type evaporative cooler is limited by its inherent lower efficiency and the inlet pressure loss.

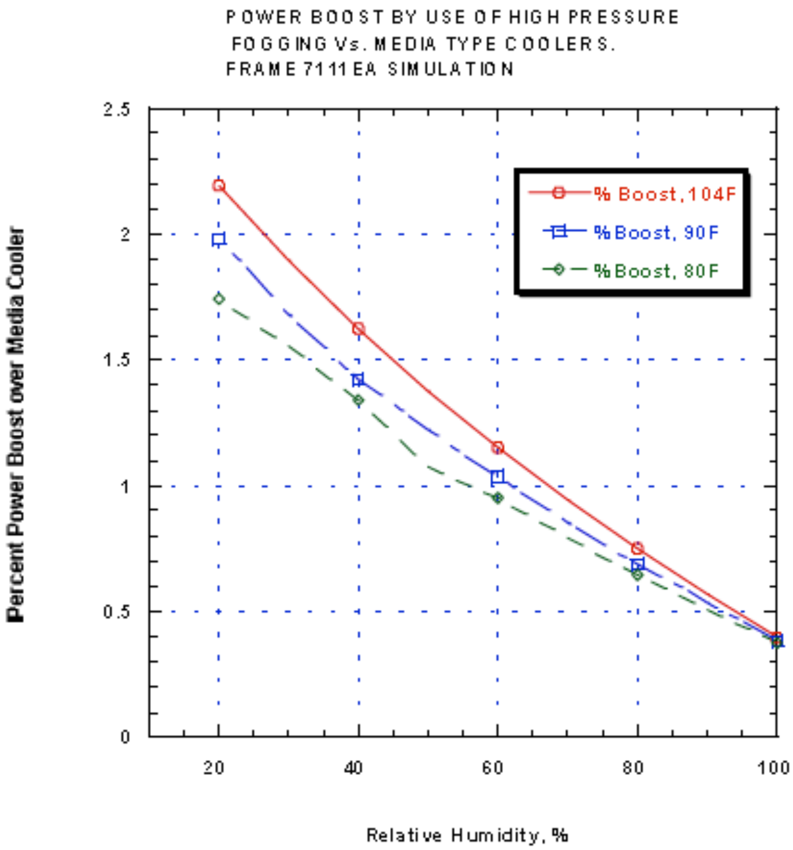


Figure 4. Power Boost by the use of High Pressure Fogging vs. Media Type Coolers

"…Water carryover with Media type Evaporative coolers has caused problems in the axial flow compressor including fouling degradation and blade erosion. Causes of water carry with media type evaporative include:

- Incorrect media polarity
- Damaged media (occurring after field reinstallation and can result in improper alignment and cracks between media. Poor handling often crushes Media
- Improperly aligned media strips – if strips are not properly aligned together the resultant gap may allow water carry over.
- Poor media seal against retainers.
- Excessive water flow – media flooding can cause carryover
- Uneven water distribution from the header – this is often caused by improper initial design of the holes or clogging of the holes resulting in an imbalance of flow over the media
- Uneven or distorted airflow throughout the evaporative cooler
- Scale deposits on the media

"…Media type evaporative coolers do not normally require demineralized water; in fact, demineralized water can damage the media. Compressor fouling is caused by carryover wof water that has high levels of mineral content. While this can be mitigated with mist elimators downstream, there is an increased pressure drop penalty. Maintenance to clean and flush the header, to deal with potential problems of microbiological fouling, corrosion and scaling have to be done on a regular basis.

"…The cost per incremental kW for a fogging system is approximately $25 incremental kW. Swanekamp (1999) have indicated costs for media type evaporative coolers at $100 / kW. The costs required to modify the inlet housings for media type cooling systems are hidden by incorporating them into the costs of filter housing upgrades, which are not at all necessary.

"…In retrofitting a gas turbine with existing media evaporative cooling, the existing media and associated equipment would be removed and an inlet fogging manifold located. Details would be project specific but a typical installation can be accomplished within one to three days. In the case of a system that has no evaporative cooling,a fogging system can be installed in 3 days versus the 30 days that would be required for a media type system.

"…It is estimated that about 50 man-hours of maintenance are required in 1 year of an inlet fogging system operation. This consists to replacement of sub-micron filters, routine checks, replenishment of oil in the pumps and winter precautions. A major cost with an evaporative cooler is the periodic replacement of the media that is required typically every three years. The costs involve not only the media costs itself, but the considerable labor costs required to change the media. The media also requires frequent inspection, cleaning and maintenance resulting in additional turbine downtime and costgs. Water quality most be constantly monitored and check to avoid dangerous carryover issues.

"…the operating costs for a media type evaporation system is the pump motor, and the chemical treatment required for the water and associated chemical treatment. With high pressure fogging, the pump power would rarely exceed 50kW (less than 1% of the power increase from fog cooling. Demineralized water quantities are not high (10 to 40 gallons per minute depending in ambient conditions and turbine size).

"…High pressure fogging systems can provide fog intercooling (overspray) capability. 1% overspray rates of the mass flow rate are attainable with most gas turbines. The performance parameters of a Frame 7111 EA Gas Turbine operating with overspray are shown in Table 5.

TABLE 5. ESTIMATED G.T. SITE PERFORMANCE
Plant Configuration: Simple Cycle Gas Turbine
1 x GE 7111EA Engine, (2020°F TIT)
Fuel=Nat Gas, supplied @ 77 F, LHV = 21517.58 BTU/lb
G.T. @ 100 % rating, inferred TIT control model, CC limit
Site ambient conditions: 14.7 psia, 95 F, 20% RH
Total inlet loss = 4 inch H_2O, Exhaust loss = 5 inch H_2O
Duct & stack = 5, HRSG = 0 inch H2O(no HRSG)

PARAMETER	**Base Case**	**Fog Saturation**	**0.25% OS**	**0.5% OS**	**0.75% OS**	**1.0 % OS**
PR	11.5	12.2	12.2	12.3	12.3	12.4
TIT, °F	2020	2020	2019	2019	2018	2017
EGT, °F	1006	992	991	990	989	988
M_a, lbs/sec	593	628	628	628	628	628
Compr in flow, lbs/sec	593	627.5	629.22	630.79	632.36	633.92
Output, kW	**72,569**	**81,211**	**83,275**	**85,345**	**87,267**	**89,132**
Heat Rate, Btu/kWhr	**10,642**	**10,390**	**10,317**	**10,246**	**10,190**	**10,141**
Tamb, °F	95	95	95	95	95	95
CIT, °F	95	66	66	66	66	66
CDT, °F	708	672	652	632	613	594
CDP, psia	167.16	177.42	178.04	178.66	179.28	179.89
M_f, lbs/sec	9.969	10.893	11.09074	11.288	11.4799	11.6683
Compr kW	94273	98956	97766	96570	95518	94521
Turbine kW	168673	182106	183008	183911	184808	185702
Efficiency, %	28.88	29.59	29.81	30.01	30.18	30.33
Fog Water, lb/sec	-	4.171	5.74	7.309	8.878	10.45

Table 5. Estimated gas turbine performance simulation including overspray cases.

GAS TURBINE	**GE 7111EA, (2020°F TIT); Simple Cycle**	
Pressure Drop due to Media Evap Cooler	1 inch WG	
Base Inlet/Outlet Delta P	4 and 5 inch WG	
Fuel	Natural Gas, Fuel=CH4, supplied @ 77 F, LHV = 21517.58 BTU/lb	
GT Model	G.T. @ 100 % rating, direct TIT control model CC limit	
Base Load Avg. Conditions	14.7psia, 59°F, 50% RH	
Peak Load Avg Conditions	14.7psia, 95° F, 20% RH	
Media Evap Cooler Efficiency	85%	
Fuel Cost	2 $/MMBTU	
Peak Elec Rate, $/kwhr	0.18; Duration 2000 hrs	
Base Elec Rate, $/kWhr	0.05; Duration 6000 hrs.	
==================	==	
BASE CONDITIONS	Media Evap Cooler	Mee Fog System
Net Output, Base Conditions, kW	85,384	86,178
Net Heat Rate, Base Conditions, Btu/kW-hr	10,261	10,236
Fuel Flow, kBTU/hr	861,135	822,135
PEAK CONDITIONS		
Net Output, Peak Conditions, kW	79,572	81,211 **89132 (1%OS)**
Net Heat Rate, Peak Conditions, , Btu/kW-hr	10,440	10,390 **10,141 (1%OS)**
Fuel Flow, kBTU/hr	830,761	843,809 / **903,871(1%OS)**
Differential Revenue Stream , Base Period	$238,200	
Differential Revenue Stream, Peak Period	$ 590,040 **$3,441,600 (1% OS)**	
Total	$ 828,240 **$3,679,800 (1%OS)**	
Incremental Fuel Cost	($ 124,192) **($400,440) 1% OS** Note <u>Heat Rate Improves</u>, but fuel flow increases due to incremental power.	
Benefit of Fogging over Media Type	<u>$ 704,048 (No Overspray)</u> **<u>$3,279,360 (with 1% OS)</u>**	

Table 6. Economic Analysis for 1 X 7111 EA Gas Turbine, Media vs. Fogging Inlet Cooling System. Analysis has also been run for 1% Overspray, for peaking period, shown in **bold**. The dramatic effect of overspray capability can be clearly seen.

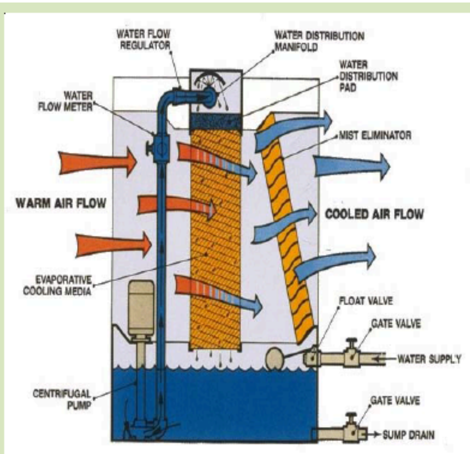
CONTROL.COM dialog on Inlet Fogging versus Evaporative Media Cooling, *2 May 2012.*

Q: What are details about differences of Inlet Fogging and Evaporators in Gas Turbines?

A: Both are methods for decreasing the temperature of the air entering the axial compressor inlet, which increases the density of the air, which increases the mass flow of air through the axial compressor and turbine and therefore increases the power than is produced by the gas turbine. Both types of systems are designed to be operated when the gas turbine is at Base Load, with the InletGuide Vanes fully open and air flow can be at its highest volume for maximum effect.

An evaporative cooler is a series of corrugated media, usually upstream of the inlet air filters. Water (demineralized is best but "tap" water has been used with mixed results) is pumped to headers above the tops of the media and allowed to run down the media.

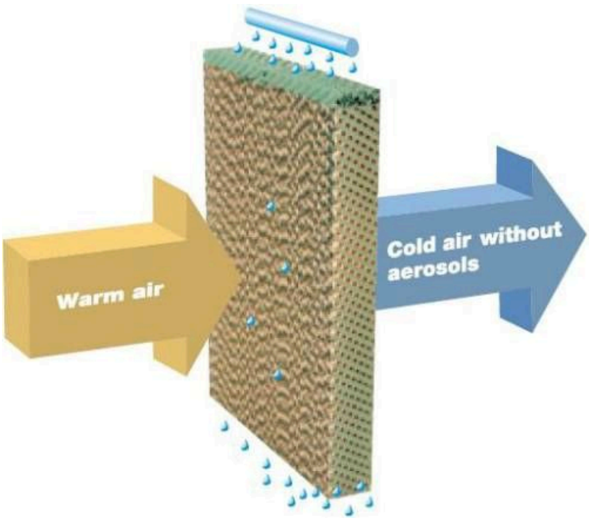
Fogging is similar, but instead of relying on "passive" vaporization high-pressure pumps are used to spray tiny streams of water through banks of nozzles into the inlet air stream. Because the water is already high atomized, it vaporizes quickly, reducing the air temperature which increases the air density and the mass flow.



Even in moderate climates, the evaporative cooler increases power and reduces turbine power dips to justify its installation.
Example: a gas turbine with generator using a Donaldson evaporative cooler at a site having an ambient temperature of 100°F and a relative humidity of 30 % will deliver 20 to 21 megawatts, so an additional 3 megawatts to the 18 megawatts without an evaporative cooler are produced.
During the hottest part of the day, evaporative cooling can decrease inlet air temperatures up to 20° C.

Neither method is a 'set-it-and-forget-it' solution – both of them require adjustment and maintenance. The flow of water down evaporative cooler media must be sufficient to rince any dirt and salts of the media, prevent dry spots, and yet the flow-rate must not be so high that large drops of water (called carryover) are pulled off the media by the air flow across it. As ambient temperature changes throughout the day, the amount of evaporation will necessarily change, as well. This change may require some manual inspection and possible adjustments during the day or longer period of operation.

Another unseen problem with evaporative cooler media is that it is essentially made of paper, impregnated with chemicals (including formaldehyde in some cases), and can ignite when dry. I have personally seen fires caused during erection and maintenance when fire "blaneks" were not used to protect the media from welding sparks and hot slag. I have also seen evaporative coolers burn when a fuel leak beneath the inlet filter house was ignited and the flames were drawn into the media – quite a spectacular fire, actually.



Fogging requires high-pressure pumps, that use more electricity than the low-pressure pumps used with evaporative coolers. The nozzles also get plugged very easily since the orifices in the nozzles are very small. Even though demineralized water (also expensive) is used along with stainless steel pipe, there always seems to be dirt and foreign materials entering the system at some point and causing problems with pumps and nozzles.

When the spray is not properly atomized it dribbles, and the water droplets are entrained in the inlet air flow and enter the axial compressor. While a small amount of this carryover is not problematic, large amounts can be.

Both are "inexpensive' ways of increasing mass flow on warm days (usually above 22 ˚ C., minimum) in ambients where the humidity is low when ambient temperature is high. (Neither works well in tropical environs) Both are seemingly simply, but for the most optimal operation both require attention and adjustment.

This operational maintenance seems to be more than most power plant operators can adequately perform – so myst system are either so ineffective that the cost of operating them in demineralized water and electricity outweighs the benefit, or there is so much carryover that inlet duct work eventually rusts and creates Foreign Object Damage (FOD) which is quite costly to repair and causes significant generation losses from down time.

I have both evaporative cooler and fogging systems in my systems and my preference is the fogging system using demineralized water. The MegaWATT incrase by fogging is 8 MW, compared to a 5 MW increase by evaporative coolers."

"**To Fog Or Not To Fog**," pp. 105–111, **Combined Cycle Journal, Third Quarter 2008 Issue**.

"…Negative impacts of compressor fouling include reduced compressor air flow, pressure ratio, and efficiency, which causes a 'rematching' of the turbine and compressor as well as a drop in power output and thermal efficiency. …It is estimated that fouling is responsible for 70% to 85% of the total performance loss experience by GTs during operation. Output losses of between 2% (favorable conditions) and 15% to 20% (adverse conditions) are blamed on fowling.

"…Impotrant from the foregoing – the injection of water into the inlet air stream and/or directly into the compressor are industry best practices critical to achieving plant pro forma performance and power production goals.

"…Owners with OEM service agreements presumably would jeopardize their contracts if they didn't implement the 1603 directives. Those not bound by GE agreements might decide to do otherwise, but could run afoul of insurors convinced OEM guidelines must be followed.

"…TIL 1603 is said to present intervals for so-called "dental-mold" impressions of the leading edges of R0 blades to determine if erosion is within what the OEM considers safe limits. If it si not, repairs may be required to mitigate cracking risk. Several users expressed concern that the recommended intervals between inspections for erosion were of relatively short duration (in some cases, 100 hours of "west" operations or less). Re the expenses associated -- who pays?

"…A few plant personnel also expressed concerns about a level playing field. They said that the inspection interval associated with a non-OEM evaporative cooling system was five times that of the interval suggested for the OEM's offering.

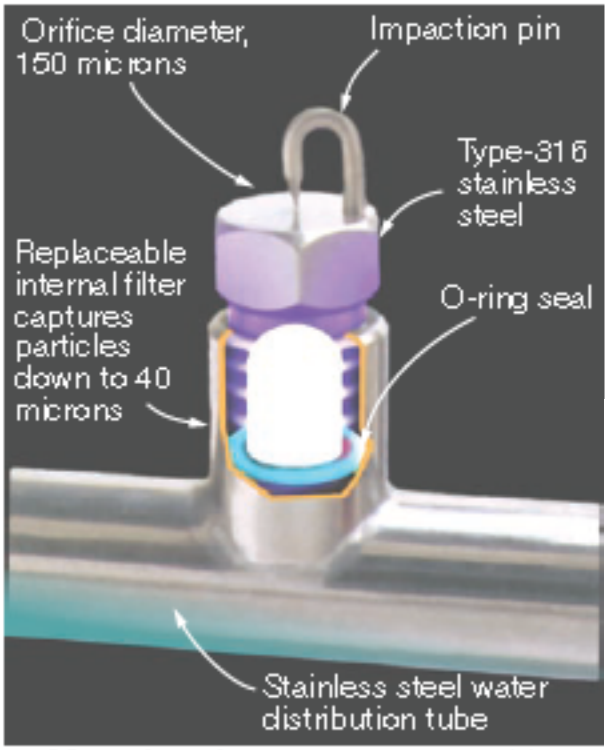
"…At least one user considered that unfair, since he was convinced his third-party vendor's evaporative system is superior to that of the OEM.

"…With the current state of the economy, it is not unusual to hear that capital budgets have been frozen and also that maintenance intervals are being extended. Short-staffed and under-funded some plant managers say they no longer can afford to do online water washes, just offline washes a couple of times annually. …There are obvious fuel and capacity penalties associated with this operating philosophy.

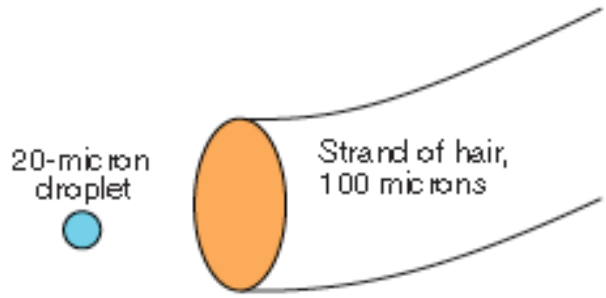
"…There is a strong connection between compressor fouling and the effectiveness of inlet-air filtration. Thomas Mee addressed delegates of the CTOTF 2008 Fall Turbine Forum, in response to the roiling controversy over whether evaporative inlet cooling systems and / or online washing systems can be held accountable for R0 blade erosion.

"…Mee's message was that fog droplets don't directly cause erosion. While compressor suctioning of unatomized, flow, and pooling water is potentially conducive to problematic wear and tear of R0 blades, proper design of fog and drain systems can prevent damage from these sources.

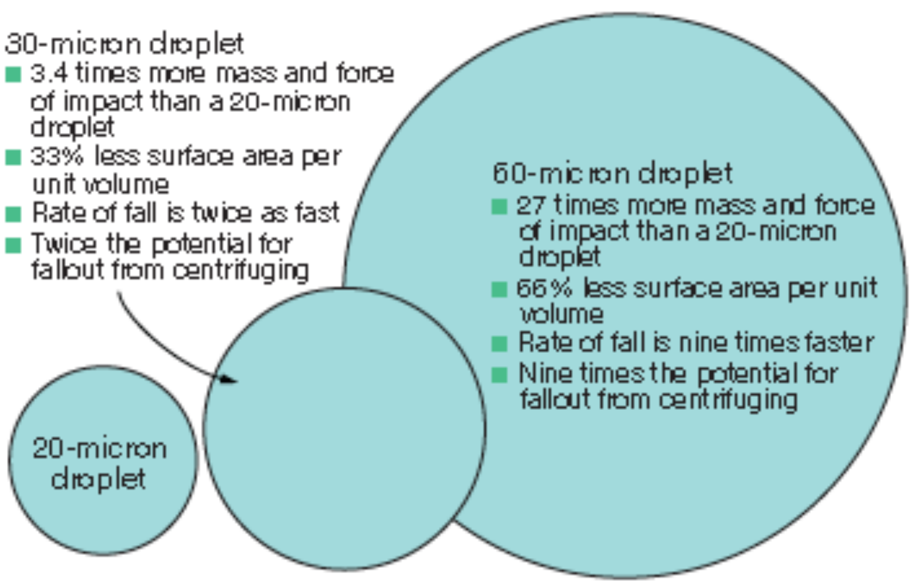
"… Mee says that droplet size is of primary importance because small droplets evaporate quickly. Those too large to evaporate in less than two seconds – he approximate time it takes air passing through the inlet filters to reach the compressor – will either fall out on the duct floor or enter the compressor.



1. Most fogging systems use either the impaction-pin (shown) or swirl-jet nozzle. Both create an expanding



2. Impaction-pin nozzles produce a fog with 90% of the droplets 20 microns or smaller, Thomas Mee told



3. Droplets are spheres and thinking of them only in terms of diameter can be very misleading

"…Mee explained that 'Droplets are spheres, and thinking of them only in terms of diameter can be very misleading. A 30-micron droplet seems very small, but it has nearly 3-1/2 times the mass of a 20-micron droplet and falls out of the air stream twice as fast. Lab tests conductec by Mee Industries determined that 20-micron droplets were 'table stakes' in a fog system designed for sensitive GTs such as the 7F frame.\"…

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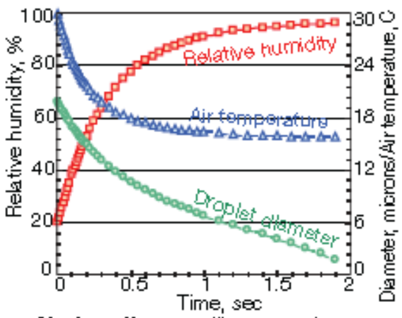
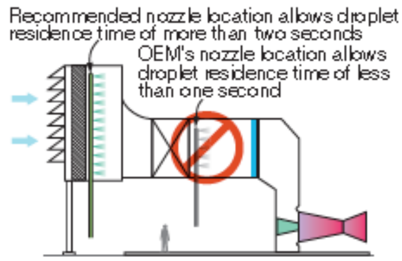


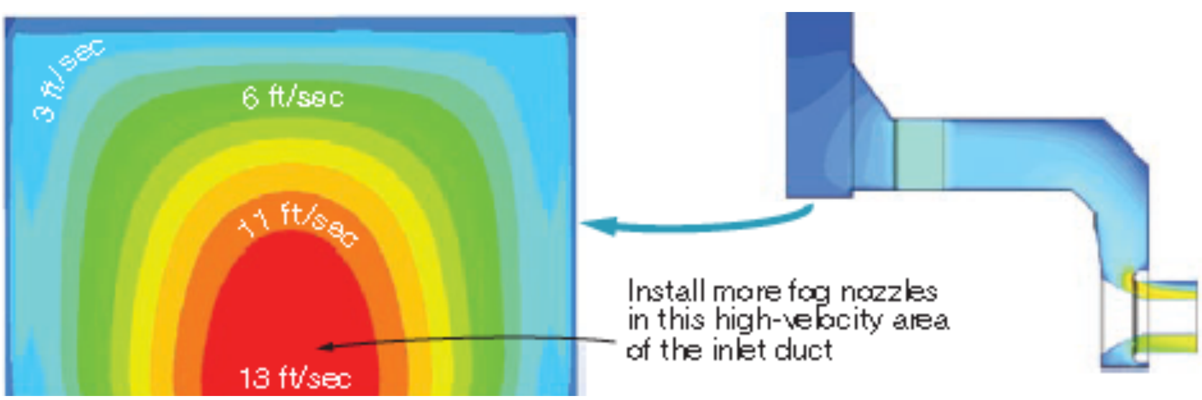
5. Chaker diagram illustrates how quickly 20-micron droplets evaporate on a dry summer day



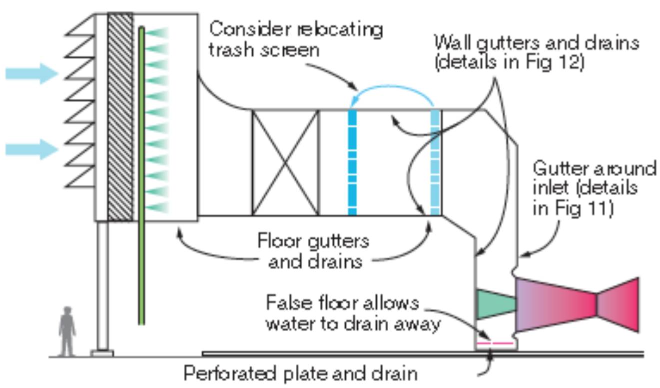
6. OEM's recommended location for fog nozzles in its F frames generally does not allow sufficient time for droplet evaporation and can lead to flowing water at the compressor inlet

7. Fog-nozzle manifold immediately downstream of the air inlet filters allows about two seconds for droplet evaporation in a typical 7FA

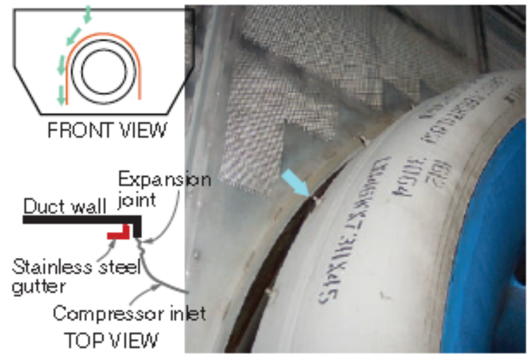
"…Mee explained why he believes the 7F series of machines is seeing more water at the compressor inlet than necessary. The OEM's recommended location for fog nozzles in its F frames (Fig. 6) generally does not allow sufficient time for droplet evaporation and can lead to flowing water at the compressor inlet. Note in Fig. 5 that the droplet diameter after one second of evaporation time is about five times larger than afte two seconds. It follows that the more time you allow for evaporation the less likely it is for an R0 blade to experience erosion on the leading edge. Mee pointed out that locating the nizzle array immediately downstream of the air filters (Fig. 7) allows about two seconds for evaporation – twice the time available than when following the OEM's guidelines for fog-nozzle location. "…Mee explained that there is a large variation in air velocity across the inlet duct. See below:



"…More nozzles are needed in areas of high velocity, fewer where the velocity is relatively low.



10. A proper system for removing flowing water minimizes the probability of erosion damage



11. Small gutter installed around the compressor inlet prevents suctioning of water over the bellmouth. Details provided here are patent-protected

We came to the conclusion that inlet fogging, with overspray could co-exist with steam injection and thus fit our 'front-end' requirements before combined cycle and flow acceleration sub-systems….ENERGY GIANT LLC