MEE INDUSTRIES INC.
GAS TURBINE DIVISION
204 West Pomona Ave. • Monrovia, CA 91016-4526
tel. 800-732-5364, 626-359-4550 • fax 626-359-4660 www.meefog.com

MeeFog TECHNICAL APPLICATION NOTE AN-GT-205

Economic Benefits of Replacing Gas Turbine Media Based Evaporative Cooling with Inlet Fogging Systems

AN-GT- 205

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1. INTRODUCTION

There are a large number of gas turbines both in the USA and internationally that utilize media type evaporative cooling systems to boost power during the hot periods when power rates are at a premium. Several of these Media type systems are now being retrofitted with the more cost effective and simpler inlet fogging systems. This application note focuses on the technical and economic factors that underlie this change.

While any decision relating to inlet cooling has to be made based on economic analysis which depends on site specific conditions, this document enumerates some of the benefits of fog evaporative cooling compared to traditional media type evaporative cooling. These have been broken into the following areas:

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

Several sample economic analyses have been run to provide a feel for the different factors involved in retrofitting existing evaporative coolers with high pressure fogging systems.

High-pressure fogging systems are the system of choice today with Mee Industries Inc having installed or on order over 422 MeeFog systems. The technology is mature, proven and has been applied to a wide range of gas turbine engines ranging from 5-250MW. The benefits of replacing media type evaporative coolers with high pressure fogging include higher effectiveness and power boost, ability to fog intercool, lower operation and maintenance costs and lower parasitic inlet pressure drops. Paybacks depend on specific economic criteria but could well be between 2-6 months.

1.1 Market Factors Leading To the Need for Power Augmentation.

Dramatic changes have occurred in both the US electrical and international markets with deregulation and privatization. In the US there are severe power margin shortages especially during the hot summer months when gas turbine output drops due to the high ambient temperatures[1]. There has been a sustained increased in summer peak power demands in the US, and an escalation of power rates ($/Kwhr) that can be earned by utilities and IPPs during the peak periods. New and existing power plants in the US must carefully consider what approaches can be taken to boost power to take benefit of the premiums that are available for power generation capacity during the hot summers. In the US, the profitability of several plants is driven by the high peak energy rates that can be achieved over a relatively short period of time. Plants that can dispatch a large

[1] As a rule of thumb the power drop for a heavy duty gas turbine is of the order of 0.4% /°F increase in the ambient temperature (0.8%/°C).

quantity of augmented power can derive large profits. This is especially true for merchant power plants which do not operate under a power purchase agreement.

While several power augmentation techniques can be used including expensive options such as refrigeration, a very great number of users have opted for a technology that provides significant power boost for an exceedingly low capital cost *during the time frame when power is most needed*. This technology is inlet fogging which is a direct active evaporative cooling method as opposed to traditional passive media type "swamp" coolers.

A detailed study by Tawney et al (2001) evaluated several options for power augmentation for combined cycle power plants. The results indicated that the option with the minimal EPC cost impact was inlet fogging. Inlet fogging was the only option that provided a small augmentation in heat rate, while the other options all worsened heat rate. As a practical matter, several new plants are adopting fogging as a power augmentation strategy. This trend is being noted not only in the USA but in several parts of the world. Jones and Jacobs (2000) have also studied various power enhancement techniques of combined cycle power plants.

There are a large number of existing gas turbines that have the older technology media type evaporative coolers that could derive greater profits by retrofitting these old units with high pressure fogging systems. This application note focuses on this market niche.

2. HIGH PRESSURE FOGGING COMPARED TO TRADITIONAL PASSIVE MEDIA EVAPORATIVE COOLING

Traditional evaporative coolers that use media for evaporation of the water have been widely used in the gas turbine industry especially in hot arid areas. Some of the salient points relating to media and fogging type evaporative coolers are presented here to provide the reader with a background of the two technologies.

2.1 Traditional Media Based Evaporative Cooling Technology

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 this reduces the ambient air temperature. In a traditional media evaporative cooler, water is distributed over the media blocks which are made of fibrous corrugated material. The airflow through this block evaporates the water. Traditional Evaporative Coolers are described in detail by Johnson, (1988).

Evaporative cooler effectiveness is given by:

$$\eta = \frac{T_{1DB} - T_{2Actual}}{T_{1DB} - T_{2WB}} \qquad (1)$$

Where,

T_1 = Inlet temperature
$T_{2\ actual}$ = Exit temperature of evaporative cooler
DB = Dry bulb
WB = Wet bulb

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, thickness of 12 inches are common.[2]

The temperature drop is given by:

$$\Delta T_{DB} = 0.85\left(T_{1DB} - T_{2WB}\right) \qquad (2)$$

A psychometric chart can be used to obtain the values. The exact power increase depends on the particular machine type, site altitude and ambient conditions.

The presence of a media type evaporative cooler inherently creates a pressure drop 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 aeroderivative machine. The key issue with an 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.

<u>2.1.1 Blow down issues.</u> There are two types of traditional evaporative coolers-circulating and non-circulating. The coolers used for most gas turbine operations are of the recirculating type and consequently there is a requirement for blowdown in order to avoid the accumulation of minerals in the water. Thus make up water will equal the blowdown water plus the water evaporated. The blowdown rate is dependant on the hardness of the water and curves are available to calculate this (Johnson, 1988). Typically, blowdown rate should equal 4 X the evaporation rate. Accurately maintaining the blowdown and checking on the water quality is an important maintenance task with media type evaporative coolers

<u>2.1.2 Mist eliminator</u>. As the water is not treated, and contains minerals, it is imperative that none enter the compressor and many installations incorporate a mist eliminator on the downstream side to ensure that the air entrained large water droplets are

[2] There is a trade off between efficiency and pressure drop. For a given face velocity (600 fpm is typical) thicker media will provide higher efficiency but at an increased pressure drop.

removed. This mist eliminator also induces an increased and continuous pressure drop on the system.

2.1.3 Water flow Rates. Water flow rates are typically between 1-2- gal/min for each square foot of surface area of the distribution pad but this number 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 in the air stream. Thus the amount of water should be carefully adjusted during commissioning and, should not be "tuned" constantly as this often leads to excessive dry spots or the other problem of water carryover.

In many cases carryover of mineral dust can occur, causing damage to the cold and hot components and some operators attempt to minimize this problem by running the media evaporator at 50% of its operating efficiency. Dust carryover also occurs when the media evaporating system is not operating and the media elements dry out.

2.2 Inlet Fogging (MeeFog) Technology

Direct inlet fogging is a method of cooling where demineralized water is converted into a fog by means of special atomizing nozzles operating at 2000 psi. Details pertaining to the thermodynamics and practical aspects of fogging have been described in Meher-Homji and Mee, (2000A/B). Chaker et. al. (2001) provides a detailed analysis of the evaporative cooling capacity in numerous locations in the USA. The fog provides cooling when it evaporates in the air inlet duct of the gas turbine and allows close to 100% effectiveness in terms of attaining wet bulb conditions at the gas turbine inlet thereby giving the lowest temperature possible without refrigeration.

Direct high pressure inlet fogging can also be used to create a compressor intercooling effect by allowing excess fog into the compressor, thus boosting the power output considerably. In this application note, consideration is only made of *evaporative* fogging alone, however, it should be noted that that fog intercooling provides a significant power boost in addition to the evaporative effect. The importance of this is discussed in the economic analysis section. A photograph showing a typical high pressure fogging skid is shown in Figure 1. The MeeFog Skid is a fully proven and tested device designed for simplicity and ruggedness. Customer connections are just water (at 2-4 barg) and electrical power. The skid is shipped fully tested and installed on a concrete pad as shown at a location near the inlet filter.

Figure 1. Typical high pressure fogging skid. The feed lines from the high pressure pumps to the inlet system can be seen here. Retrofit installations can be accomplished in 2 days on most gas turbines.

The skid includes a series of high pressure reciprocating pumps providing demineralized water to an array of high pressure fogging nozzles located after the air filter elements. The nozzles create a large number of micron size droplets which evaporate rapidly cooling the inlet air to wet bulb conditions. A photo of a nozzle array fogging an inlet duct for a large frame gas turbine is shown in Figure 2. A typical fog plume emanating from a single nozzle is shown in Figure 3.

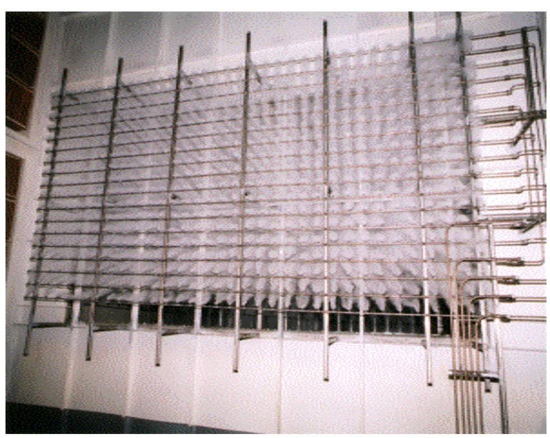

Figure 2. High pressure fogging manifold system installed in the duct of a heavy-duty gas turbine. All stainless steel (316L) construction is used. Induced pressure drop is exceedingly small and not measurable.

Figure 3. Typical fog plume of MeeFog Nozzle. The high surface area of the billions of droplets permit rapid evaporation in even high humidity conditions.

A comparison of Media and Fog type evaporative systems is presented in Table 1.

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[3]
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

[3] Effectiveness would depend on design features and in the case of fog systems, the location of the fog nozzles and residence time.

3. PROBLEMS RELATED TO TRADITIONAL EVAPORATIVE COOLING

In order to compare traditional evaporative cooling with direct fog evaporative cooling, it is helpful to review some key issues relating to Media type evaporative cooling and to compare these in context of inlet fogging.

3.1 Inlet Differential Pressure Drop.

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 if the evaporative cooler is used or not.* For most gas turbines, media thickness of 12 inches will result in pressure drops of approximately 1" water gauge[4]. As a rough rule of thumb, a 1" WG increase in inlet duct losses will result in a 0.25- 0.35% drop in power and a 0.12% increase in heat rate. These numbers would be somewhat higher for an aeroderivative machine. 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 mass flow and the turbine expansion ratio. This factor is important when considering that this loss due to inlet pressure will be experienced by the gas turbine throughout the operating year, regardless if the traditional 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. Results are based on simulation runs using GTPRO software. Conditions are taken at 70°F inlet temperature, Natural gas fuel, and inlet and outlet pressure drops of 4 and 5" Water. This table just indicates the effect of an incremental 1" pressure drop on output. For example for the GE 7111 EA the effect of the 1" Water Gauge increased pressure drop results in a power change of 0.362%. In contrast to this situation, the pressure drop caused by an inlet fogging system is practically nil[5] and certainly not directly measurable.

[4] New and clean pressure drops should not be used for any evaluation as practice has shown that drops tend to increase significantly with media deterioration and plugging. Further, often claims are made that retrofitting a inertial seperator with a media cooler can reduce overall pressure drop. This reduction is attained by the removal of the inertial seperator and also considers new and clean conditions.

[5] Pressure drop across the fog manifold. The filter pressure drop is a function of flow rate (i.e. velocity) hence increased mass flow may slightly increase the overall filter house pressure drop though this effect is common to both media and fog type coolers.

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.

3.2 Inability of Media Cooler To Attain Wet Bulb Temperature Conditions.

With evaporative efficiencies of around 85%, media type evaporative coolers can never approach wet bulb conditions. As every ° F of cooling results in approximately 0.4 % power boost, there is a considerable loss in power when compared to an inlet fogging system. This situation compounds the losses due to the increased inlet pressure drop that is induced by a media type system.

To examine the importance of media evaporative efficiency consider Table 3 below for a Frame 7111EA Gas turbine (2020°F Turbine inlet temperature) that has been modeled with varying evaporative cooler efficiencies from 80% to 100%. Cooler efficiency has been varied from 80% (Case 1) to 100% (case 5). *Efficiencies higher than 90% are not attainable under normal conditions with media evaporative coolers* and so the relevant cases would only be Case 1-3. Case 5 would approach the performance of a high pressure fogging system. Other salient gas turbine parameters are also presented in the table.

In examining the table, 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*. It is not uncommon to find existing media type evaporative coolers that have been in operation for some time with deteriorated and plugged media to have efficiencies in the 80-85% range[6].

	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 shows 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[7]; 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.

3.3 Power Boost using a Fogger over a Media Type Evaporator Cooler- Sensitivity to Ambient Conditions.

The boost in power that a Fogger can attain over a media type cooler is a function of:

1. The Dry Bulb Temperature
2. The Relative Humidity
3. The Efficiency of the Evaporative cooler
4. The Efficiency of the Fogger
5. Gas Turbine sensitivity in terms of Power boost/°F inlet temperature change.

Of these, the first two items have a significant impact as the other factors are quite constant, As one would expect, the benefits of the fogger become more dramatic during the 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 cooler is limited by its inherent lower efficiency and the inlet pressure loss benefit also exists.

[7] This rate has been derived from the price duration curve of Figure 5 by time averaging the rates for 2000 hours.

Simulation runs done on Frame 7111EA provide the power boost attained by the use of foggers over media type coolers for a range of ambient temperature and humidity are shown in Figure 4.

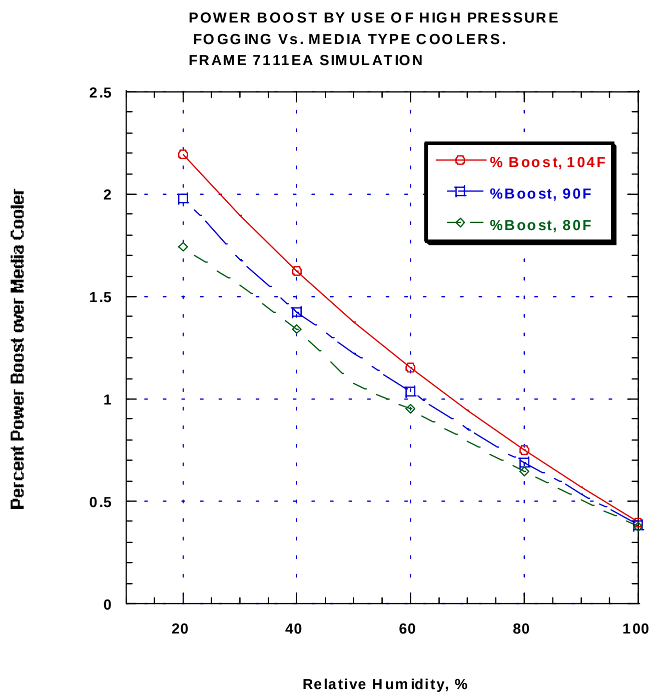

Figure 4. Power Boost by the use of High Pressure Fogging vs. Media Type Coolers

3.4 Water Carryover with Media Type Evaporative Coolers

This is a very serious problem that has caused problems in the axial flow compressor including fouling degradation[8] and blade erosion. Causes of water carry with media type evaporative coolers are listed below:

- Incorrect media polarity
- Damaged media (can occur 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

[8] Details on Axial Compressor Fouling may be found in Mee Industries Inc.'s application note AN-GT-150.

- Scale deposits on the media.

Media type evaporative coolers do not normally require demin water; in fact demin water can damage the media. However some operators have reported compressor fouling caused by carryover of water with high levels of dissolved minerals. This can be avoided by installing mist eliminators downstream of the cooler (with an increased pressure drop penalty) or by ensuring that the air velocity through the media is not so high as to cause carryover. Some form of water treatment is required in order to deal with potential problems of microbiological fouling, corrosion and of course scaling. Maintenance activities to clean and flush the header have to be done on a regular basis.

Tests have indicated that feed water used for evaporative coolers may have significant sodium and potassium, calcium and magnesium and carryover for any reason can have catastrophic consequences to the gas turbine hot section. Any of the reasons above can cause carry over into the gas turbine. The criticality of this is now accentuated given that OEM specifications are being tightened especially for the higher firing temperature gas turbines. Typical maximum limits on total alkali metal contamination range from as low as 0.2 to 0.5 ppmw. For some engines, the airborne limit for Sodium is 0.005 ppmw (with an air/fuel ratio of 50:1 this is equivalent to 0.25ppmw in the fuel). Consequently, it is imperative that carryover be absent- but several media type systems exhibit problems in this area especially after some time of use and media deterioration. Details on problems caused by evaporative coolers and other items that degrade gas turbine performance can be found in Meher-Homji et al (2001). Hsu (1988) provides quantitative methods to evaluate ingestion of contaminants into a gas turbine .

As the MeeFog system utilizes demin water none of these problems exist.

4. ECONOMIC CONSIDERATIONS IN RETROFITTING MEDIA EVAPORATIVE SYSTEMS WITH INLET FOGGING

4.1 First Cost

Historically, the capital cost of fog type cooling systems is 25% to 30 % of traditional evaporative cooling systems**.** The cost per incremental kW for a fogging system is approximately 25$/incremental kW. Recent reports such as Swanekamp (1999) have indicated costs for media type evaporative coolers at $100/kW. Certain costs for modifying the inlet housings for media type cooling systems are hidden and incorporated into costs of filter housing upgrades, which are not at all necessary. Consequently, the initial investment for fog cooling is very small and the benefits accrue rapidly.

4.2 Down Time

Minimal down time required for installation (retrofit situations) can, at times, have a positive impact on project economics. In a retrofit situation, the existing media and associated equipment would be removed and a inlet fogging manifold located. Details would be project specific but typically installation can be accomplished within 1-3 days. In the case of a system that has no evaporative cooling, a fogging system can be installed in 3 days vs. 30 days that would be required for a media type system. If a cooling system is urgently required to overcome a power crisis, a MeeFog System is an ideal fit. Further, the tuning and startup time is considerably less than that required for a media type cooler system.

4.3 O&M Effort and Cost

Maintenance requirements for the 'MeeFog' system are very low. These are confined to the replacement of sub-micron filters, routine checks, replenishment of oil in the Pumps and winter precautions. It is estimated that about 50 man-hours of maintenance are required in 1 year of operation. The MeeFog Skid is a stand-alone system with a built in control system. 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 in changing the media. The "media" also requires frequent inspection, cleaning and maintenance resulting in additional turbine downtime and cost. Water quality must constantly be monitored and checked to avoid dangerous carryover problems. Nozzles for high pressure fogging systems typically will not deteriorate provided good water quality is maintained. Special on-skid filters to 0.35 microns ensure a long life of the nozzles.

4.4 Operating Costs

The operating costs for a media type 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. Demin water is usually available in most gas turbine/CCPP plants and the quantities used are not high (10-40 gpm depending on ambient conditions and turbine size).

4.5 Fog Intercooling (Overspray) Considerations.

A major advantage of high pressure fogging systems is that the system can provide fog intercooling (overspray) capability. Mee Industries has experience with intercooling several gas turbines. Overspray rates of 1 % of the mass flow rate are attainable with most gas turbines[9]. The availability of fog intercooling

[9] The amount of overspray is a function of the compressor aerodynamics, and surge margin available. Most on-line water wash systems run at approx 0.4 –0.6% of the air mass flow of air. Specific choice of overspray amount will be gas turbine dependant.

capability is of *supreme importance for peaking operations or in merchant plant situations where maximum benefit has to be taken of high peak power rates.* As shown in the economic analysis of Section 4.6, the availability of overspray capability can have a dramatic impact on plant revenue.

Performance parameters of a Frame 7111EA Gas Turbine operating with overspray are shown in Table 5. The boost in power from the base case can be clearly seen along with the improvement in the heat rate. Some graphic results are shown in Figure 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.

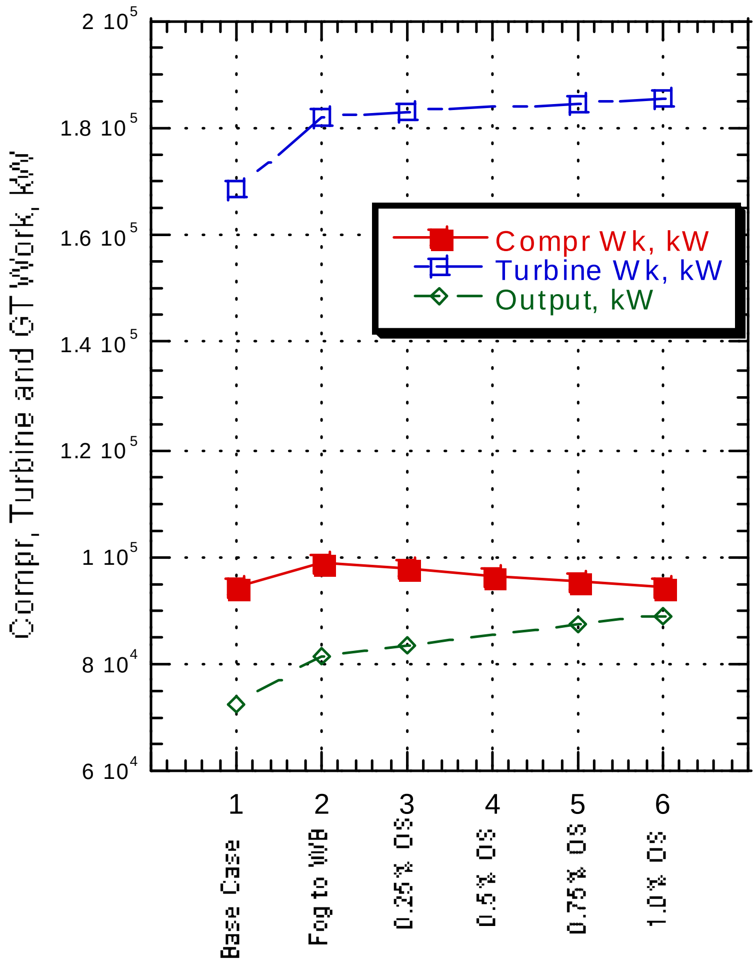

Figure 5. Variation of Compressor and Turbine Work from Base case (1) through Satration (Case 2) and overspray upto 1% Overspray. The fog intercooling of the compressor causes the compressor work to decrease as shown while the turbine work increases, resulting in net increase in output. Overspray capability can be very profitable during peak periods when peak rates are very high.

4.5 Simulation Analysis for Frame 7111EA, Gas Turbine comparing Media and Fog Type Evaporative Cooler

A study has been done below of a Frame 7111EA gas turbine to compare the operation with a media type cooler and with a fogger type system. The assumptions are provided in Table 6. The Peak energy rate variation as a function of operating hours is shown in Figure 5 and is derived from Jones (2000). This curve was used to determine the time weighted peak revenue and base period revenue. The simulation of the gas turbine includes effects of inlet pressure drops and includes the incremental fuel costs that are deducted from the increased electrical revenue. It is important to note that the efficiency of the gas turbine will improve with inlet fogging, but the increase in efficiency (i.e., drop in heat rate) would result in increased fuel usage due to the greater power output.

Fog intercooling (overspray) could significantly boost power and could be used to derive very high revenues for the very high peak rate time frames. The results of overspraying to 1% (only for the peak period) is shown in the tabulation in "bold". The dramatic effect on revenue explains why this capability is of extreme importance in today's market environment.

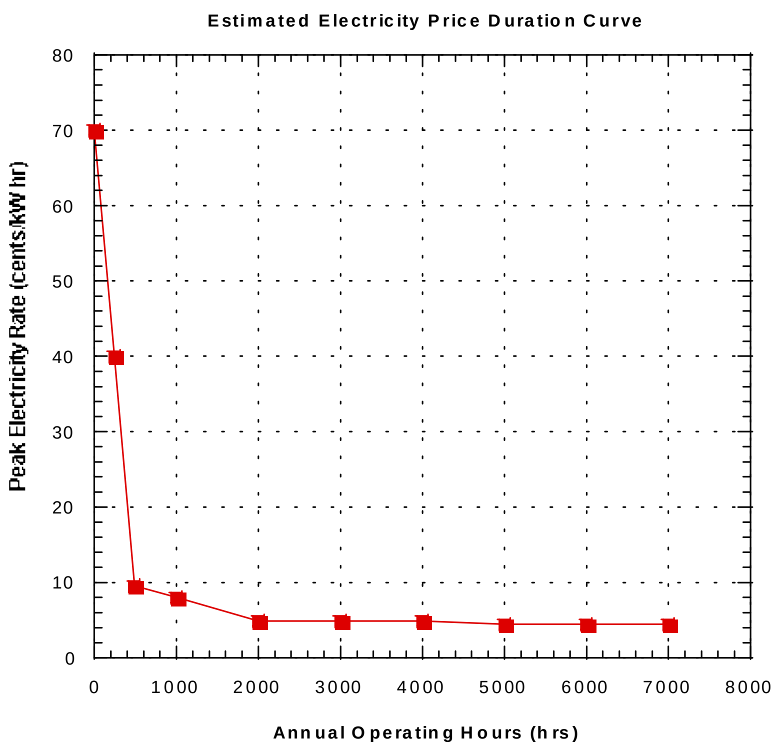

Figure 5. Estimated Price Duration Curve, Jones (2000)

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	14.7 psia, 59°F, 50% RH.	
Peak Load Avg Conditions	14.7 psia, 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	MeeFog 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 Heat Rate Improves, but fuel flow increases due to incremental power.	
Benefit of Fogging over Media Type	$ 704,048 (No Overspray) **$3,279,360 (with 1% OS)**	

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.

5. CLOSURE

This application note makes the case for retrofitting existing media type evaporative coolers with high pressure fogging systems. High-pressure fogging systems are the system of choice today with Mee Industries Inc having installed or on order over 422 MeeFog systems. The technology is mature, proven and has been applied to a wide range of gas turbine engines ranging from 5- 250MW. The benefits of replacing media type evaporative coolers with high pressure fogging include higher effectiveness and power boost, ability to fog intercool, lower operation and maintenance costs and lower parasitic inlet pressure drops. Paybacks depend on specific economic criteria but could well be between 2-6 months.

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For more information contact:

Mee Industries Inc.
GAS TURBINE DIVISION
204 West Pomona Ave. • Monrovia, CA 91016-4526
tel. 800-732-5364, 626-359-4550 • fax 626-359-4660 www.meefog.com