Gas Turbine
Performance Assurance©

GT-
PASS

# Industrial Evaporative Cooler for **Gas Turbines Performance-Enhancement** Options



GT-PASS
Gas Turbines
Performance Assurance Inc.

# Introduction

## 1-1 Gas Turbine Inlet Air Cooling

For applications where significant power demand and highest electricity prices occur during the warm months, a gas turbine air inlet cooling system is a useful option for increasing output. Inlet air cooling increases output by taking advantage of the gas turbine's characteristic of higher mass flow rate and, thus, output as the compressor inlet temperature decreases.

Industrial gas turbines that

- 7LM6000
- 7LM2500+/Base/HSPT
- MS6001
- MS9001EA
- Mitsubishi
- Turbomach
- EGT Typhoon
- Siemens GTX

run at constant speed are constant-volume-flow machines. The specific volume of air is directly proportional to the temperature. Because the cooled air is denser, it gives the machine a higher air mass flow rate and pressure ratio, resulting in an increase in output. In gas turbines applications there is also a small improvement in thermal efficiency.

Several methods are available for reducing gas turbine inlet temperature. There are two basic systems currently available for inlet cooling.

The first and perhaps the most widely accepted system is evaporative cooling. Evaporative coolers make use of the evaporation of water to reduce the gas turbine's inlet air temperature.

The second system employs various ways to chill the inlet air. Chilling, however, can cool the inlet air to temperatures that are lower at a significantly higher cost.

### Evaporative Cooling

Evaporative cooling is a cost-effective way to add machine capacity during warm weather when peaking power periods are usually encountered on electric utility systems, provided the relative humidity is not too high.

As examples assume that the ambient temp is 100°F (37.8°C) and the relative humidity is 32%.

### Evaporative Cooling Methods

There are two basic systems for achieving evaporative cooling.

- The first uses a media paper (wetted-honeycomb) type of medium and is typically referred to as an evaporative cooler.
- The second system is known as an inlet fogger.

### Evaporative Cooling Theory

Evaporative cooling works on the principle of reducing the temperature of an air stream through water evaporation. The process of converting the water from a liquid to a vapor state requires energy. This energy is drawn from the air stream. The result is cooler, more humid air.

A psychometric chart (Figure 1) is useful in exploring the theoretical and practical limitations of evaporative cooling.

Theoretically, the minimum temperature that can be achieved by adding water to the air is equal to the ambient wet-bulb temperature. Practically, this level of cooling is difficult to achieve. The actual temperature drop realized is a function of both the equipment design and atmospheric conditions. Other factors being constant, the effectiveness of an evaporative cooling system depends on the surface area of water exposed to the air stream and the residence time. The effectiveness of the cooler is a function of its design and is defined as follows:

Cooler Effectiveness = T 1DB – T2 T1DB -T2WB

- 1 refers to entering conditions.
- 2 refer to exit conditions.
- DB equals dry-bulb temperature.
- WB equals wet-bulb temperature.

Typical effectiveness levels are 85 to 95%. Assuming the effectiveness is 85%, the temperature drop can be calculated by:

Temperature drop = 0.85 ($T1_{DB}$ – $T2_{WB}$)

Referring to Figure-1, which is a simplified psychometric chart.

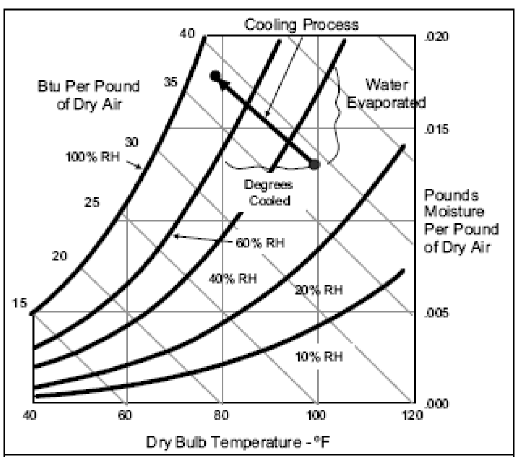



Figure-1
Psychometric chart, simplified

Wet-bulb temperature is 75°F (23.9°C). The air temperature drop through the cooler is then 0.85 (100–75), or 21°F (11.7°C) (equals a compressor inlet temperature of 79°F [26°C]). The cooling process follows a line of constant enthalpy as sensible heat is traded for latent heat by evaporation.

The effectiveness of evaporative coolers is typically at 90 to 95%.

The exact increase in power available from a particular gas turbine as a result of air cooling depends upon the machine model and site altitude, as well as on the ambient temperature and humidity. However, the information shown in Figure-2 can be used to make an estimate of this benefit for evaporative coolers. As would be anticipated, the improvement is greatest in hot, dry weather.

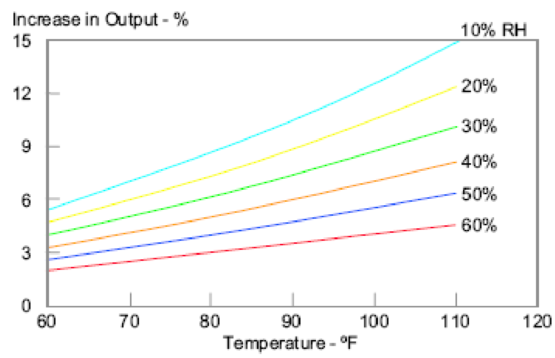



Figure-2
Effect of evaporative cooler on available output – 85% effective

## Wetted-Honeycomb Evaporative Coolers

Conventional media types of evaporative coolers use a wetted honeycomb-like medium to maximize evaporative surface area and cooling potential. For gas turbines, the medium is typically 12 or more inches thick and covers the entire cross-section of the inlet air duct or filter house. The media and drift eliminator result in a pressure drop in the inlet air duct. Typical values are approximately 80-100 Pascal.

Retrofit installation does not require substantial ducting modifications due to GT-PASS design is compact and can be fitted easily. The effectiveness of the system is fixed by the media selection and condition to the inlet air temperature can be controlled by the system water flow. By this way the operator gets the maximum possible increase in plant output.

A typical self-cleaning filter/evaporative cooler design are shown in Figure 3. Water is pumped from a tank at the bottom of the module to a header, which distributes it over the media blocks. These are made of corrugated layers of fibrous material with internal channels formed between

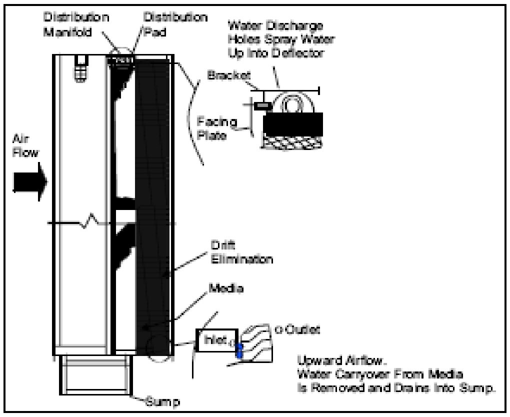



Figure-3
Media pack cooler design

layers. There are two alternating sets of channels, one for water and one for air. This separation of flows is the key to reducing carryover. Drift eliminators are installed downstream of the media to protect against the possibility of water carryover. The water flows down by way of gravity through the water channels and diffuses throughout the media through wicking action.

Any excess returns to the tank. The level of water in the tank is maintained by a float valve, which admits makeup water.

A controller is provided that regulates the operation to a minimum ambient dry-bulb temperature. The minimum temperature must be 47°F (~8°C) or higher. If evaporation were permitted at too low a temperature, this could cause icing. When there is a possibility that the dry bulb temperature will fall below freezing, the whole system must be deactivated and drained to avoid damage to the tank and piping and the possibility that the porous media would plug with ice.

## Water Requirements for Evaporative Coolers

Evaporative coolers are most efficient in arid regions where the water may have a significant percentage of dissolved solids. If makeup water is added in sufficient quantity to replace only the water that has been evaporated, the water in the tank (which is also the water pumped to the media for evaporation) will gradually become laden with more minerals. In time, these minerals would precipitate out on the media and reduce evaporation efficiency. This would increase the hazard of some minerals becoming entrained in the air and entering the gas turbine. In order to minimize this hazard, water typically is bled continuously from the tank to keep the mineral content diluted. This is termed blow down.

The corresponding value for an MS7001 or MS9001 machine can be estimated by respectively doubling or tripling the quantity shown.

The amount of makeup water, which must be provided, is the sum of evaporation and blow down. The rate at which water evaporates from a cooler depends upon the ambient temperature and humidity, the altitude, cooler effectiveness and the airflow requirement of the gas turbine. Figure-4 shows the evaporative water requirement of gas turbine cooler at sea level.

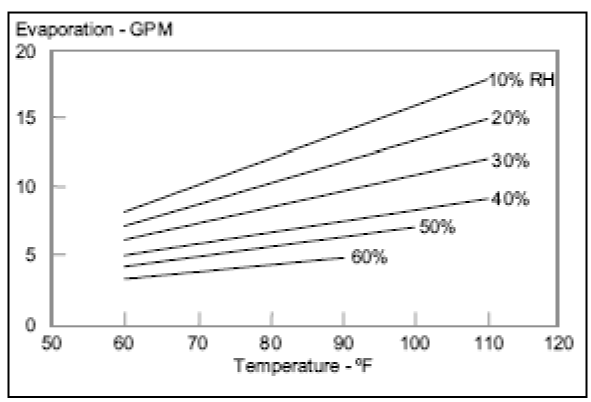



Figure-4
Evaporation rate for gas turbines 90-95% effective

## General arrangement

The structure of the Pre-Cooler (Evaporative Cooler) consists of 2 Pre-Cooler modules. They are connected to the carbon steel housing. The Pre-Cooler modules are located in front of the filter stages outside the clean room of the filter house. Within the modules, the evaporative structured media also described as pads, which The Pre-Cooler panels are equipped with media pads, and water supply pumps are installed on each module. The pads are on the inlet side of the Pre-Cooler. In front of the pads, there is suitable space for checking the air entering side of the cooler. The moisture separators, pre-filters on the air entering side and the droplet separators (called as drift eliminator) on the air leaving side must be provided and installed by the BUYER, in order to prevent any contamination by the site conditions such as sand storm etc. and catch any droplets which may be released from the pads.

The pump skid is placed on the direction each pre-cooler models itself. The piping (2 supply pipes) connect the pump skid with Pre-Cooler modules. The cables for the instrumentation measure temperatures, 1 measure the temperature after the pads, 1 measures the ambient temperature. In most cases air filter house instruments are used and combined with pre-cooler system. Ambient temperature controls the cooler. Temperature after cooler is only for display.

The RTD's are used to turn evaporative system ON/OFF and for monitoring. In existing packages there are already temperature sensors before and after evaporative location. Two temperature sensors are used for;

1-To turn on &off system
2-To monitor temperature on local panel

In general, Pre-Cooler requires very little care, but a few things have to be carefully monitored, i.e. water quality to run the equipment trouble free water quality shall be blended water with low calcium and magnesia contents-conductivity from 50 up to 300µS/cm.

## Function and design of system-Principle of operation

Pre-Cooler is installed to reduce the air temperature by humidifying the air adiabatically. This increases the density of the air and thus increases the mass flow of air through the gas turbine, increasing the output compared to a turbine which is operated at ambient air conditions. The Pre-Cooler consists of a pump skid with switchboard (controls), frames containing pads. Cabling for temperature probes inside the filter house is laid into cable trays. The function is achieved by distributing water equally over rows of structured media, so that this media is wetted from the top to the bottom (vertically). Through the media, air is flowing horizontally and is both humidified and cooled simultaneously traveling through the media. Due to the high efficiency, the air temperature behind the pads is very close to the wet bulb temperature of the air entering the Pre-Cooler, i.e. the humidity is significantly higher than 90 % rH. If ambient temperatures go closer to the freezing point, it is necessary to empty the system from water. Pads have to be removed in winter time where necessary. If all the above temperatures and temperature differences allow the Pre-Cooler to operate, the water pump is started and circulates the required amount of water through the pads. 2-2.5 m³ of Water is needed to initially fill the each tank. Start up and wetting of the pads are instantaneous but reaching to the full performance may take 30-35 minutes depending on the ambient conditions. It is important that the tanks are filled with water completely, because after start much water is required to wet the pads completely, before water is returned to the tanks. If the tanks are not sufficiently filled, the water pump will stop temporarily until the water level has reached a minimum level again. A sieve integrated into the tank prevents larger particles to be sucked through the pumps. This sieve has a large surface and thus, it takes a long time, to get clogged, but it is required to check the condition of the sieve once in a season.

There is a manhole to inspect the tank and sieve. To prevent minerals to concentrate up and to form a layer on the pads, the water conductivity is monitored by a conductivity measurement and a bleed-off is initiated, when conductivity exceeds the set value. It closes again when a second set value lower than the first one is achieved.

Technical data of cooler; Cooling efficiency is defined as:

CE = [T amb- T out ]/ [T amb - T wet-bulb]

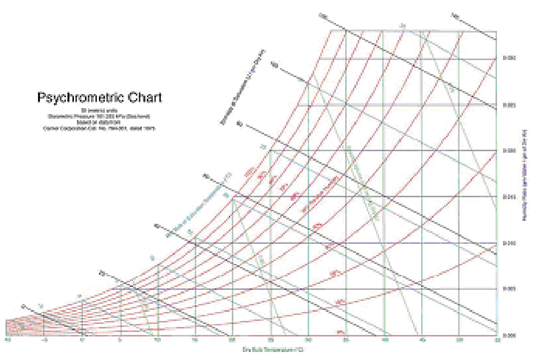
Value for new and clean cooler CE is ~ 90% temperature range 8-50 °C.

CE = Cooling Efficiency

T amb = Ambient Temperature

Tout = Temperature behind cooler

T wet-bulb = Wet bulb Temperature




## Operating media specifications

Operating fluid is water with the following recommended specifications (incoming water):

- This Pre-Cooler system is designed for blended water (feeding)
- The conductivity should be not lower then 50µS/cm and not higher then 300µS/cm. The lower the conductivity the less water will bleed off. Circulating water will become higher concentrated. This is important for the pads and their lifetime. The bleed off switch must be set to 650µS /cm.

### Biocide dosing

To avoid biological fouling on water contacted surfaces, it is recommended that a routine inspection of the water quality, according to the operation conditions and surrounding influences on the air cooler system (especially on the water system). During commissioning time there should be a short interval inspection to get a feeling if biological fouling (growth of slime or algae) in the water system takes place. Initiate biocide dosing only after positive test. A detailed description to determine the right amount of biocide dosing and how to proceed during biocide dosing is described into manuals of different biocides. H202 is one possible biocide.

## General safety for operation

It has to be understood that, on the pump skid, open water through leakages has to be avoided, because the controls and the motors and other electrical devices are installed, in order to avoid the danger of short circuits and the danger associated with them. The temperature measurements and controls shall be checked regularly (and adapted, if deemed necessary under the site conditions) to avoid any danger for the gas turbine through a lower than specified air intake temperature. The gas turbine manufacturer may have specified certain temperature limits for the intake air after the Pre-Cooler, and those shall be kept in order to avoid any possible danger to the gas turbine. Work on the pump skid shall only be carried out, if the motors, of the pump skid have been locked through the main switch at the switchboard. If people are working on the skid during the operation, it may cause damage to the people and to the pump skid. Further, it is important to check the water quality regularly in order to avoid mineral deposits on the pad surfaces, because this could cause water carryover on the pads and/or higher pressure drops and performance reduction, which have to be avoided. Running the system in manual mode is for testing only.

## System Description

The offer includes 1 set per gas turbine generator set (each set has two modules) Evaporative Cooling System manufacturing and supervision of installation to GTG package. Evaporative Cooling System conditions the air intake (which approximately 105 cubic meter/sec air flow for LM6000PC GE gas turbine). Evaporative Cooling System typically is designed before existing droplet separators and primary air intake filters and after existing moisture separator and pre-filters. The modules casing depends on the filter housing design dimensions and (width x height x length) before manufacturing phase and after agreement of contract definite dimensions are taken physically from air filter house. Evaporative Cooling System designed with following requirements;

• Maximum 46°C water supply temperature and

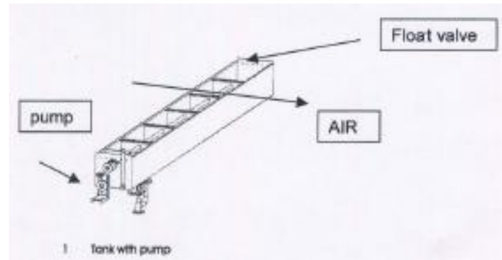
• 85 Pa pressure drop (At the site summer extreme conditions 41.1 °C, 50% relative humidity)

Evaporative Cooling System circulation pump is installed on each module (right and left side). Evaporative cooling system tank height is designed as approximately 600mm. Typical Evaporative Cooling System Design;

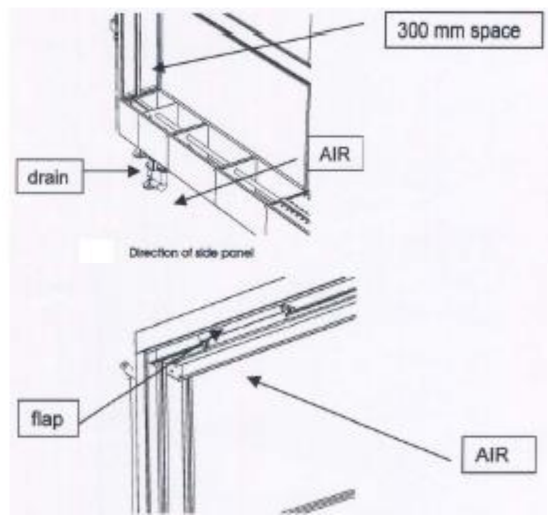
Main parts as tank, side panels and roof with column(s).

Tank with pump;

Bolted at the modules itself.




Side panels and the roof; there is a right and a left part of side panel.



# Comparison Fact Sheet : Evaporative Media vs.Inlet Fogging vs.Chiller

The following list highlights some of the important advantages-disadvantages and the features of the two main types of inlet cooling;

| EVAPORATIVE MEDIA | INLET FOGGING | CHILLER |
|---|---|---|
| • LOW investment cost<br>• VERY LOW water quality requirements (less severe than fogger system)<br>• LOW water consumption<br>• LOW Power consumption (~5kWh)<br>• LOW maintenance cost<br>• LOW operation cost<br>• NONE spare part cost (Only media paper in 5 years)<br>• LOW Installation cost (ZERO down-time)<br>• NO OUTAGE for start-up<br>• NO ADDITIONAL area or foundation required<br>• NO ADDITIONAL auxiliary equipment required<br>• SHORT DELIVERY as 4 weeks<br>• No evidence of rust<br>• NO substantial duct modifications required due to compact and modular design.<br>• EXTRA FEATURE as additional filtration and life extension for fine filters…<br>• SIMPLE controls. | • HIGHER first investment cost<br>• HIGH de-mineralized water cost<br>• HIGH water consumption<br>• HIGH power consumption (high parasitic load than evaporative media due to high pressure pumps)<br>• HIGH maintenance cost<br>• HIGH operation cost<br>• HIGH spare part investment required<br>• HIGH Installation cost (Shut-down required)<br>• LONG OUTAGE required for start-up<br>• Foundation and civil work and area required for the pumps skid<br>• Set of pumps required<br>• LONG DELIVERY 10-14 weeks<br>• RUSTING after fine filters where area is not stainless steel.<br>• Clean air room work required<br>• NO EXTRA FEATURES<br>• COMPLEX controls | • HIGHEST intensive capital cost<br>• HIGH water treatment cost<br>• HIGH power consumption up to 1,5MW<br>• HIGH maintenance costs<br>• HIGH operation cost<br>• HIGH spare part investment required<br>• LONG OUTAGE required for start-up<br>• Foundation and civil work and area required for Mechanical room (Indoor placement)<br>• Cooling Tower &Condenser Pumps required<br>• LONG DELIVERY up to 1 year<br>• NO substantial modifications required (due to auxiliaries are installed in the field)<br>• NO EXTRA FEATURES<br>• COMPLEX controls<br>• HIGH operating noise………<br>• Higher parasitic loads<br>• Larger tonnage capabilities<br>• Refrigeration containment |

## APPENDIX-A

The following applications are TYPICAL and may vary depending on the package dimensions and site conditions. The best applicable design must be decided after site evaluations.