# Water quality considerations for evaporative turbine inlet cooling techniques

By Marcus Bastianen, P.E., and Bill Escue

Turbine inlet cooling continues to prove an economical power augmentation proposition to increase the output of an engine as ambient air temperatures rise and inlet air density falls. The intake of a gas turbine is volumetrically limited. Therefore, improving the density of the inlet air to the turbine compressor section allows for greater mass flow to the engine thus creating more power output while improving the engine efficiency/heat rate.

Different water-based methods are currently available to provide turbine inlet cooling. These include direct evaporative techniques such as wetted media and fogging systems. An alternative to direct evaporative methods is *indirect* evaporative cooling; a water-based chilling process that lends itself well to hybrid designs. The water quality requirements vary for each of these methods and should be considered as it can result in added operational costs to the turbine user.

There are generally three concerns associated with direct evaporative cooling specific to water quality in the gas turbine power generation industry:

1. Water ingestion into the compressor section of the engine.
2. The air quality when water vapors are introduced into the inlet air stream through the evaporation process.
3. The quality of the water available for cooling.

To get a better understanding of what drives these concerns, we need to have a general understanding of how the cooling mechanisms work. Direct evaporative cooling is essentially an adiabatic (isocaloric) process where no heat is transferred to or from the working fluid. The process cools the surrounding air through the vaporization of water. In turn, the added water vapor increases the latent heat and the relative humidity, but retains total heat at a constant value. Although the air "feels" cooler, the total air enthalpy remains unchanged.

However, this process does improve the density of the air that is ingested by the compressor section of the gas turbine; consequently, it improves the mass flow of the machine. Two common ways to use direct evaporative cooling is through wetted media and fogging.

### *Wetted media*

This method requires the distribution of a controlled volume of water over fluted media where the air and water can interact. The inlet air is exposed to a fine water curtain promoting evaporation of water into the air stream. The evaporation process cools the inlet air dry bulb temperature up to as much as 90% of the difference between the ambient air dry-bulb and wet-bulb temperatures, often referred to as the wet bulb depression. Water quality requirements are typically specified by the media supplier. One large supplier wetted media recommends the following limits for make-up water for evaporative turbine inlet cooling:

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|---|---|
| Calcium Hardness (as CaCo3) | 50-150 mg/l |
| Chlorides | <50 mg/l |
| Conductivity | 50-750 micromhos/cm |
| Total Dissolved Solids (TDS) | 30 – 500 mg/l |

Furthermore, the same manufacturer states that "Seawater, brackish water and reclaimed water are not recommended." (Munters Engineering Bulletin [WTGT-0406])

Irrespective of the media supplier recommendations, some water vapor is added to the inlet air stream going to the gas turbine; therefore users should also consult with the turbine OEM guidelines which may be more stringent regarding water quality used in the specific application.

Depending on the operational location and the water quality that is available, it may only be possible to maintain acceptable water quality limits through water treatment methods.

### *Fogging*

Fogging techniques make use of a high pressure spray through atomizing nozzles. The droplets of varying sizes introduced into the turbine inlet airstream evaporate and can cool the air by up to 95% of the wet bulb depression. (Turbine Inlet Cooling Association – Technology Overview) As water is directly evaporated in the intake air stream, it must be clear of any mineral salts and other impurities. Therefore, the water used in fogging systems is generally de-mineralized which can be produced by reverse osmosis among other methods.

### *Indirect evaporative cooling*

An alternative to direct evaporative methods, indirect evaporative cooling, uses cross-flow heat exchangers to cool the turbine inlet air. Water is evaporated in a secondary air stream that is then used to extract heat from the primary turbine inlet air stream via heat exchangers. This heat transfer means that primary air enthalpy is lowered as energy is actually removed from the primary to the secondary air flow allowing for denser inlet air than evaporative techniques. Inlet air to the turbine can be cooled up to 95% of the wet bulb depression. The primary air passing to the turbine does not come in contact with the secondary cooling air stream or the moisture it contains, therefore, not contaminating the inlet air with salts, minerals, or water vapor. As such, water quality requirements for this technique are less stringent than direct evaporative methods. In addition, the threat of cooling water impingement with the compressor section of the gas turbine is removed.

## Water Quality Case Study

During the last several months Everest Sciences has been conducting a water quality testing program initiated by a specific application in the Middle East. Potable water at this location arrives by truck daily and is highly valued making it impractical for use on inlet air cooling. However, there is ample ground water available for cooling purposes, albeit very brackish. Laboratory testing of this groundwater indicates the following values:

| | |
|---|---|
| Calcium Hardness (as CaCo3) | 1165 mg/l |
| Chlorides | 2116 mg/l |
| Conductivity | 10,420 micromhos/cm |
| Total Dissolved Solids (TDS) | 7060 mg/l |

As a point of reference, seawater is typically at a level of 56,000 micromhos/cm. (*Heyda, M., A Practical Guide toConductivity Measurement, Retrieved 19 October, 2009 from www.mbhes.com/conductivity_measurement.htm*)

Water used in the indirect evaporative cooling process is isolated from coming into contact with the primary turbine inlet air stream; therefore, Everest Sciences technology appears to fit this application well. The client is interested in the Everest Sciences cooling technology to minimize concern for inlet air contamination while using available brackish water that could otherwise foul the gas turbine. To ensure that the application of the technology is sound, Everest Sciences undertook the testing program with a two-fold approach that includes heat exchanger performance analysis as well as the possible degradation of installed components through the use of severely brackish water. Part selection for the Everest Sciences indirect evaporative cooling system makes use of components designed to operate in poor quality water conditions.

Nearly 2000 hours of small-scale proof of concept testing has been conducted using manufactured test chambers simulating the operation of the Everest Sciences indirect evaporative cooling system. Water used during these tests replicated the actual Middle East groundwater previously discussed. Through the evaporation process, mineral concentrations increase with time and a feed and bleed technique was used to maintain conductivity values typically ranging from 10,420 micromhos/cm to 35,000 micromhos/cm. After several hundred hours of testing, results indicated a slow but steady mineral scale forming on the water/secondary air side of the heat exchangers.

The next phase of the testing program involved full-scale testing on an Everest Sciences indirect evaporative cooling system using the same brackish concentration for the cooling water used in the test chambers. Operational testing revealed no degradation of performance of the Everest Sciences indirect evaporative process as a result of the use of the brackish cooling water. Additionally, laboratory testing of the heat exchanger surfaces revealed no mechanical changes to the heat exchanger material as a result of the extensive testing.

Even though maintaining water quality through mechanical methods (feed and bleed) indicated no degradation in the performance, a potential concern remained for the long term operation of indirect evaporative cooling using severely brackish water. Therefore, additional testing was conducted using water additives. The purpose of this testing was to prove or disprove if additives could keep the mineral scaling agents in solution rather than forming on solid surfaces. After over 1,200 hours of testing with additives, the heat exchanger surfaces and component surfaces show minimal scaling. In addition, small scale testing results show that conductivities can run much higher without significant scaling appearing (Figure 1),

thus reducing the feed and bleed rates required to maintain target water controls (Figure 2). By reducing the feed and bleed rates, less water usage is projected over the long term operation of the Everest Sciences indirect evaporative cooling system. This extensive testing program has shown that the use of additives in extremely brackish cooling water minimizes the scaling on the Everest Sciences heat exchangers and components as compared to the non-additive treated control samples. Furthermore, the heat exchanger performance does not show degradation by use of brackish water in the system.

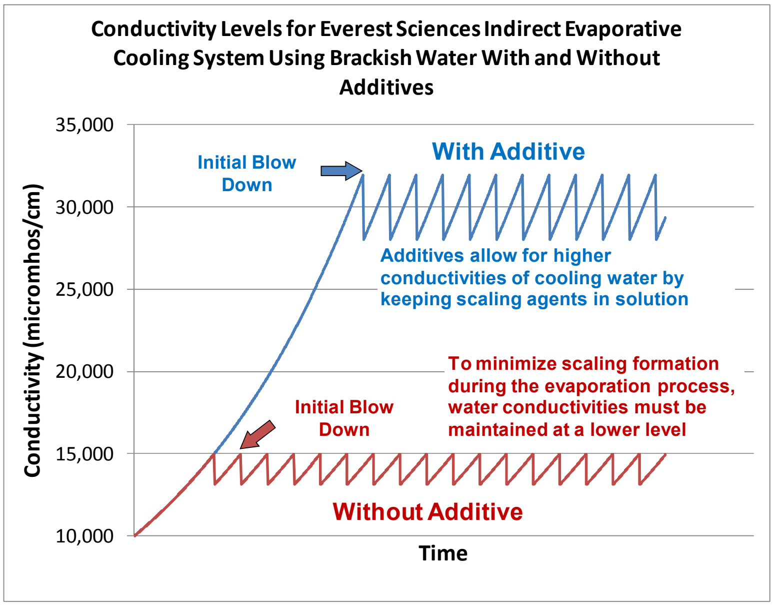


*Figure 1*

Additional analysis is ongoing to determine the possible operation of the Everest Sciences indirect evaporative cooling system using seawater. Initial indications are that the use of seawater is plausible while maintaining cooling performance consistent with the testing program undertaken to date. However more testing is needed to confirm this. Careful considerations of both the operation of the heat exchangers and corrosion related issues have been analyzed. A cathodic protection system has been designed and will be installed for the Everest Sciences' HydroFlex™ line in addition to specific metallurgical selections to minimize the potential corrosion issues that can be experienced using water with high conductivity and chloride content.

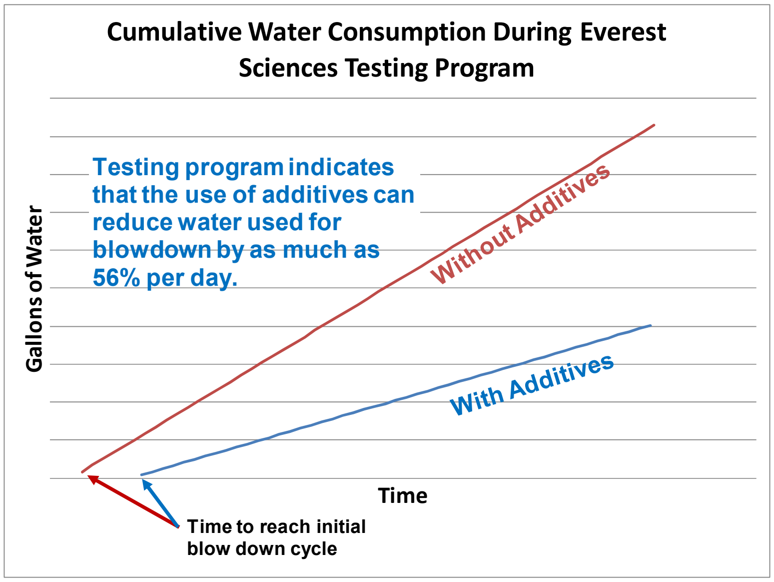


*Figure 2*

Water quality considerations are a factor that the turbine user needs to fully consider when contemplating turbine inlet cooling. Clean water, when available, is usually not free. In order to use conventional evaporative techniques with brackish water could require significant chemical treatment or other methods such as Reverse Osmosis in order to safeguard inlet air contamination for the gas turbine. Indirect evaporative cooling offers a simpler and less expensive solution by cooling the air without allowing water to come into contact with the turbine inlet air. Everest Sciences testing indicates that the indirect evaporative cooling process can take advantage of using poor quality water and still maintain a high level of operational performance. However, it is imperative that safeguards are taken to absolutely minimize the risk of water leakage from the secondary air flow to the primary air flow to ensure the gas turbine does not risk the potential of fouling from the ingestion of poor water quality. This can be accomplished through using multiple redundant safeguards and taking a conservative approach to the design characteristics of the indirect evaporative cooling system.

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