



GEK 107158A
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GE Power Systems
Gas Turbine

**Water Supply Requirement for Gas Turbine Inlet Air
Evaporative Coolers**

These instructions do not purport to cover all details or variations in equipment nor to provide for every possible contingency to be met in connection with installation, operation or maintenance. Should further information be desired or should particular problems arise which are not covered sufficiently for the purchaser's purposes the matter should be referred to the GE Company.

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I. INTRODUCTION

Evaporative coolers supplied with GE Gas Turbines should provide reliable and trouble free operation for the life of the gas turbine. The GEK is intended to help the operator in the choice and treatment of water for the evaporative cooler. The use of suitable water is essential in minimizing carryover, preventing corrosion and scale formation and in obtaining the expected service life and performance from the evaporative cooler. The evaluation of the water supplies to be used in the evaporative cooler should be done as early as possible. All the critical factors, which bear on suitability, must be considered in making a choice. Details of the evaluation procedure are given in Section III and in Appendix 2.

Gas turbine operators must recognize that if suitable water treatment guidelines are not established and followed, the evaporative cooler and its media may need more frequent maintenance. In the extreme case the need for premature media replacement could result. Furthermore, poor water quality and/or the misoperation of the cooler can result in severe contamination of the gas turbine and have extremely serious consequences in terms of forced outage time needed for maintenance, repair and replacement of gas path components.

The scope of this GEK is limited to cellulose media type evaporative coolers and the water quality related to such equipment.(1) The water quality required to operate Gas Turbine Air Inlet Foggers and Inlet Air Chillers is not covered by the guidelines in this document.

A. Background

Evaporation of water is one of the simplest and oldest methods of cooling air. Even with the sophisticated technology available today, including mechanical chillers, absorption chillers and thermal energy storage systems, evaporative cooling remains a most cost-efficient method for temperature control of the gas turbine inlet air supply.

- Uses industrial quality water
- System is simple and reliable when installed and operated correctly
- Can provide an increase in output. For typical values refer to GER 3567.

Traditional evaporative coolers consist of recirculated water sprayed over an extended surface media mounted downstream from the inlet air filters. As inlet air passes through the media, evaporation occurs, cooling takes place and the water vapor content of the air approaches saturation. These two processes, cooling and approach to water vapor saturation, increase the density of the air, which in turn increases the mass flow and output of the turbine.

Due to the isolated locations of some of the installations, and the limited water sources often available, the use of the evaporative cooler to condition inlet air for the gas turbine results in some very challenging water control requirements. The water available ranges from brackish, with extremely high mineral concentrations, to demineralized water, which may have been prepared as HRSG feedwater or for turbine injection for NO_x control.

The media used in the coolers have been designed to give a highly efficient drift (carryover) free evaporative cooling surface over a wide velocity range. The use of high mineral content waters can result in scale formation in the media, which decreases the efficiency of the cooler and increases the static pressure drop. Conversely, the use of very high purity water can result in corrosion problems and have a destabilizing effect on the cooler media.

B. Evaluation of Water for and Evaporative Cooler

Prior to the commissioning of a new evaporative cooler, either in a new plant or as an add-on to an existing plant, the water to be used for the makeup supply must be evaluated. To allow a complete pre-operational evaluation, all the critical parameters describing the water chemistry must be determined.

Since the water will be used as a makeup source to the circulating water in the evaporative cooler, and not as a once through supply, its chemical properties must be calculated after a number of cycles of concentration. This is essential so that the water chemistry can be estimated at the design operating conditions of the cooler.

The methods for assessing the expected behavior of the water in terms of its potential for scaling, fouling and carryover to the gas turbine, are explained in detail in section III and in the appendices.

As the result of wide seasonal changes in temperature and rainfall, at many sites there may be significant variations in the chemistry of the water at different times of the year. It is essential that the effects of these changes on the water supply to the cooler be known and this will require water analyses which have been conducted at different times of the year.

No parameter should predominate in deciding how the water supply will be used; all critical parameters must be evaluated and the most limiting one will control.

An example of the calculation procedure for the evaluation of a water supply is given in Appendix 2 and the procedure for monitoring the water in the cooler during the first months of operation is given in Appendix 3.

II. DESCRIPTION OF THE SYSTEM

A schematic of an evaporative cooler is shown in Figure 1.

The correct installation, setup and checkout of the cooler are critical to its operation, particularly to the prevention of carryover (drift) of liquid droplets in the outlet air. The installation instructions provided by the manufacturer of the evaporative cooler shall be followed. In addition all evaporative coolers shall undergo commissioning per the latest GE Evaporative Cooler Commissioning procedure (1) prior to initial start up and, during service, a minimum of once a year, at the beginning of the evaporative cooler use season.

III. TREATMENT OF WATER IN EVAPORATIVE COOLING SYSTEMS

In order to give suitable control it is required that the chemistry of the water in the cooler should be monitored continuously.

The critical parameters are:

- Hardness
- Chloride
- Alkalinity
- Alkali metals (Na+K)
- pH

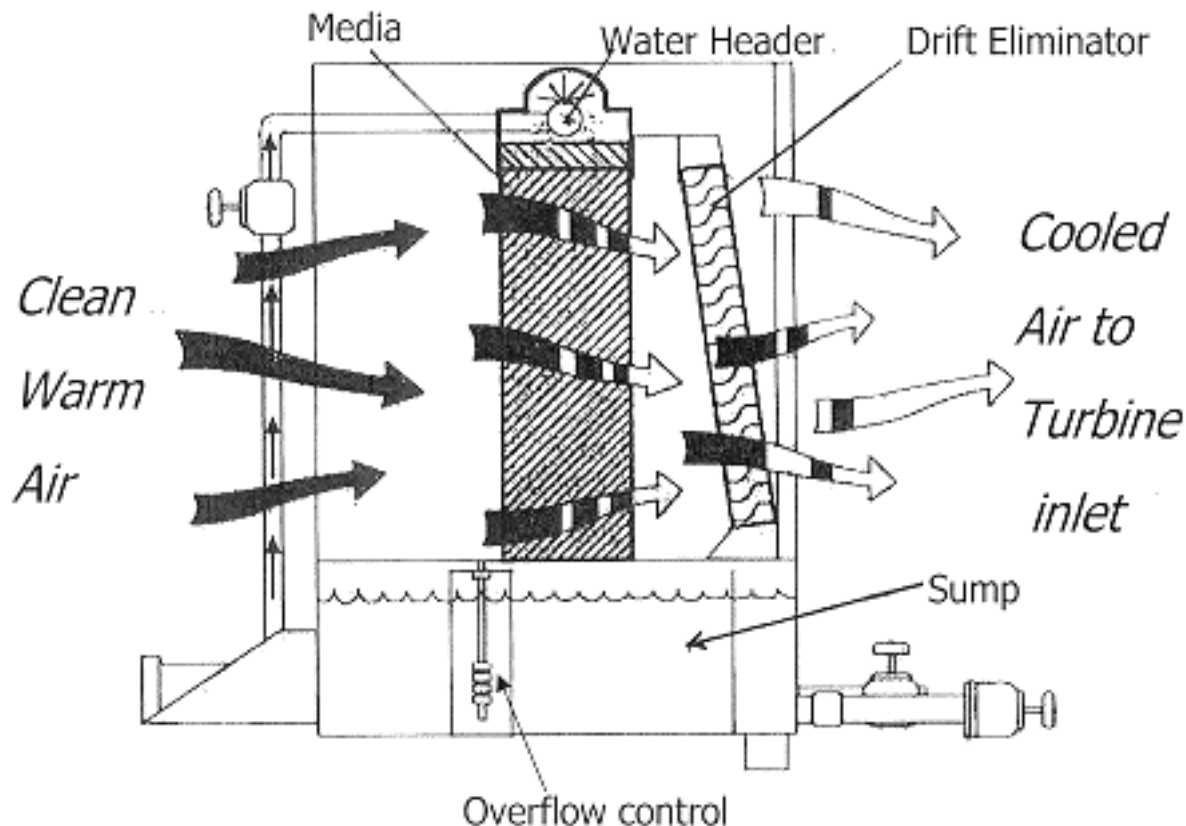


Figure 1. Schematic of Evaporative Cooler

- Scaling Index

The first five are measured properties and the sixth is calculated from them. The most convenient parameter to monitor continuously is conductivity of the sump.

Limits are given for all these properties in Table 3. In a particular water supply one parameter will be limiting and this will control the use of the water. The limiting parameter may be different from water to water. This is discussed in detail and an example of an evaluation calculation is given in Appendix 2.

In the evaporative cooler there are two main goals for the water treatment programs.

- Prevention of fouling, scaling, corrosion and media deterioration in the cooler.
- Prevention of corrosion from carryover of solid contaminants into the gas turbine

These are related but separate issues.

Scale build-up will foul the media, affect operating efficiency and reduce the service life of the media.

Corrosion will reduce the service life of the framing, sumps, piping, and support systems.

Microbiological infestation can foul the media and affect operating efficiency. It can also produce objectionable odors downstream, reduce the service life of the media, and induce corrosion in the piping and sump.

Carryover into the gas turbine can result in corrosion and fouling in both the compressor and turbine sections.

A. Scaling

Scale formations occur when soluble salts are deposited from the recirculating water and the principal factors affecting the rate of formation are:

- Temperature
- pH
- Dissolved solids and hardness contents of the recirculating water

Four problems are associated with scale formation in evaporative cooling units:

- Uneven airflow and water distribution.
- Increase in pressure drop through the unit, due to plugging of the media.
- Decreased evaporation surface area.
- Locally high pH conditions under deposits which cause loss of the binder and delignification of the fibers of the evaporative cooling pad.

Scale formation can be prevented in evaporative coolers by:

- a. Maintaining a scaling index which is slightly on the scale dissolving side of neutral, Puckorius Scaling Index (PSI) > 6.5 .
- b. Pre-treatment of the raw water by demineralization (reverse osmosis, ion exchange), to remove hardness.

CAUTION

Na Zeolite softened water should never be used. A voluminous deposit of sodium carbonate may form on the media.

- c. Inhibiting scale adhesion by using a crystal modifying chemical treatment.

1. Prevention of Scaling in the Cooler

The water circulated through the cooler must be compatible with materials of construction and particularly with the media. The blocks which comprise the media are molded from a composite of paper fibers and an inorganic binder. The geometric design of the blocks has been optimized for effective evaporation and minimal pressure drop. The chemistry of the circulating water is critical in maintaining a high operating efficiency and long life for the media

2. Scaling Index

The parameter which has been found to be most effective in defining the required chemistry for the circulating water in the cooler is its Scaling Index. Indices were developed for the specification and control of water in cooling towers and the water-side of shell-tube heat exchangers. There are three

indices in use and they relate the alkalinity, hardness and pH of cooling water, at its operating temperature, to its tendency to be scaling or corrosive.

The indices are:

Puckorius or Practical Index (PSI)

Ryznar Index (RSI)

Langelier Index (LSI)

Table 1 Scaling Index Values

Scaling Index Values		
PSI & RSI	LSI	Condition
3	3	Extreme Scaling
4	2	Very Severe Scaling
5	1	Severe Scaling
5.5	0.5	Moderate Scaling
5.8	0.2	Slight Scaling
6	0	Stable
6.5	-0.2	No Scale, very slightly corrosive/tendency to dissolve scale
7	-0.5	No scale, slightly corrosive/tendency to dissolve scale
8	-1	No scale, moderately corrosive/tendency to dissolve scale
9	-2	No scale, strongly corrosive/tendency to dissolve scale

Scaling indices are calculated using total dissolved solids, (which is not measured directly but is derived from the conductivity), temperature, calcium hardness, total alkalinity and pH of the water. Each parameter is used in weighted formulae to determine whether the water is scale forming or scale dissolving, and the extent to which it is either. For evaporative cooling, it is desirable to maintain the water so that it has a slightly scale dissolving index. In doing so, the recirculating water has the ability to dissolve mineral deposits. However, the water should not be so aggressive (scale dissolving) that it softens the media.

The definitions and methods for calculating the indices are shown below and specific examples, with different water chemistries, are shown in the Appendix 2, Calculation 1.

$$PSI = 2(pH_s) - pH_{eq}$$

$$RSI = 2(pH_s) - pH_{measured}$$

$$LSI = pH_{measured} - pH_s$$

$$pH_s = 9.30 + (A + B) - (C + D)$$

$$pH_{eq} = 1.465 (\log(TA) + 4.54)$$

The factors are defined in Table 5 of Appendix 2.

A – Factor for total dissolved solids

B – Factor for temperature

C – Factor for calcium hardness (as ppm CaCO_3)

D – Factor for alkalinity (as ppm CaCO_3)

TA – denotes total alkalinity

E - Factor for pH_{eq}

The recommended control ranges for the water in the evaporative cooler, in order to give high reliability and long life of the cooler media, are shown in Table 2.

Table 2
Recommended Values of Scaling Indices for Recirculating Water in Evaporative Coolers

Langelier Saturation Index (LSI)	0.5 +/- 0.25
Ryznar Stability Index (RSI)	6.0 +/- 0.5
Puckorius (Practical) Stability Index (PSI)	6.5 +/- 0.5

3. Control of the Scaling Index

The factors, which control the scaling index, are interdependent and controlling each of them separately is not possible. For example, changing the hardness, by deionizing, will also affect the alkalinity and pH of the water. Practically the scaling index is set by the chemistry of the makeup water and the number of cycles of concentration that it is put through.

B. Establishing the Chemistry of the Cooler Recirculating Water

The chemistry of the sump will be established by determining the maximum cycles of concentration that the makeup water can go through and give recirculating water, which has a Puckorius scaling index of 6.5 (+/- 0.5), as identified in table 2, and meets the other requirements shown in Table 3.

Makeup water is added to the sump of the evaporative cooler to replace the water lost by evaporation plus that removed from the sump as blowdown or bleed-off.

The following formula can be used for determining the evaporation rate for an evaporative cooler.

The formula is not as accurate as using a psychrometric chart; however, it provides the evaporation rate within an acceptable approximation of the true rate and it is easy to use.

$$\text{Evaporation} = \frac{\text{ACFM (Thousands)} \times (\text{EDBT} - \text{LDBT})}{500}$$

$$\text{Evaporation} = \text{Gallons per minute}$$

ACFM = Actual Cubic Feet Per minute of Air passing through the cooler.

EDBT = Entering Dry Bulb Temperature (°F)

LDBT = Leaving Dry Bulb Temperature (°F)

NOTE

When determining make-up water requirements for an evaporative cooler always use the evaporation and blowdown calculated for worst case.

The water added as makeup will have known total dissolved solids content as determined by its conductivity. For estimating purposes:

Conductivity (in $\mu\text{S}/\text{cm}$) * 0.6 = TDS (in ppm) (Ref 3)

The calculation procedure is shown in calculation 4 of Appendix 2. An example of a scaling factor calculation is shown in calculation 2 of Appendix 2.

Water always contains a certain amount of dissolved minerals. The process of evaporative cooling removes water as vapor from the recirculating flow and leaves behind the solids which had been dissolved in the water when it was added as makeup. Accordingly, enough water must be blown down from the recirculating flow to control the level of these solids and to avoid build-up of insoluble minerals on the pad surface (scaling), which results in an increase in pressure drop and a loss of evaporation efficiency.

The amount of bleed-off required is determined from the following formula:

$$\text{Blow Down} = \frac{\text{Evaporation Rate}}{(\text{cycles of concentration} - 1)}$$

When the blowdown and evaporation rates are known the makeup can be calculated.

$$\text{Makeup} = \text{Blowdown} + \text{Evaporation}$$

- a. At initial startup of an evaporative cooler, the makeup water required will be higher than the steady state makeup to allow for the initial wetting of the evaporative cooler.
- b. If conductivity control is used to control blowdown, the makeup water required while blowdown is on will be higher than the average identified by the formula “makeup = blowdown + evaporation” and while the blowdown is off, the required makeup rate will be equal to the current evaporation rate.

The maximum cycles of concentrations that can be maintained, using the available make-up water source and the maximum evaporation rate define the maximum required blowdown. Control of these parameters will in turn control the chemistry of the recirculating water. Conversely, knowing the chemistry requirements for the recirculating water, in terms of scaling index, alkali metal and chloride concentration, will allow the system designer and operators to define the cycles of concentration that a particular makeup can accept.

1. Iron and Manganese. (Ref 4)

The presence of dissolved iron and manganese in the makeup water can cause black oxide fouling of the cooler media and also can lead to severe bacterial infestation of the media, sump and circulating water system. The oxide fouling can severely affect the performance of the media and lead to the need for premature replacement.

Iron is present in all water supplies. At levels below 0.1 ppm in the makeup it should not cause fouling problems.

Manganese is less commonly found but should be controlled in the makeup below 0.05 ppm.

If use of iron or manganese bearing waters is necessary, pre-treatment to remove them, usually by coagulation and filtering, will be required. These heavy metals can also cause severe fouling in membrane pretreatment systems.

Copper will not usually be found in raw water but may be picked up if copper-bearing piping is in use.

The total heavy metals in the water used for makeup should not exceed the limit given in Table 3.

2. Silicates

Silicates form a number of different scale complexes with calcium, magnesium, aluminum, sodium, and iron. The usual control procedure is to maintain the silica level in the evaporative cooler recirculating waters below 100 PPM.

In most parts of the country maintaining this limit presents no problem and at least 4–5 cycles of concentration can be attained, based on silica content. However, in some southwestern areas, it is not unusual for raw water silica (as SiO) levels to reach 60–90 PPM. This severely restricts the cycles of concentrations that can be attained.

3. Blowdown Control

Two methods are commonly used for controlling blowdown, which is required to maintain the desired chemistry in the sump of the evaporative cooler.

Constant flow – The simplest is to set a valve on the pressure side of the recirculating pump to continuously discharge a constant flow of water to drain. Installing a flow meter at the point of blowdown will help operators monitor and set the blowdown rate. The amount of water discharged in this method is normally calculated using the highest evaporation rate and the method does not allow for any fluctuations in evaporation rates and often wastes water. The set point can be changed periodically to accommodate seasonal changes in evaporation rates.

Conductivity control – Evaporation rates fluctuate due to changes in ambient temperature and humidity. These fluctuations can be accommodated by controlling the blowdown, based on the conductivity of the recirculating water. This is accomplished by installing a conductivity controller in the system. It continuously measures the conductivity until the measurement surpasses the desired set point. It then opens a solenoid valve and blows down water until the conductivity is back within control range. This is the only practical continuous control method.

C. Makeup Water

Prior to the commissioning of the plant the first step in the water treatment process is the selection of a water source for the evaporative cooler. In most plants there are several sources of make-up water. There may be one or more supplies of raw water, from wells, lakes or rivers, potable water from a municipal source and treated water that has been demineralized by ion exchange or reverse osmosis. Evaluation of the various sources should be made to determine the optimum source of make up water, including not only the requirements of the gas turbines but also the costs of supply and discharge for the water sources evaluated.

The makeup water for the evaporative cooler should meet the following criteria :

- Capable of acceptable cycles of concentration, while maintaining a suitable scaling index
- Having sufficient flow available to support the maximum evaporation and blowdown rates expected, and the maximum flow rate required at startup of the evaporative cooler.
- Satisfy the requirements of this GEK.
- Water should be supplied to the cooler at ambient temperature. The use of makeup water with a temperature above the ambient air dry bulb temperature can significantly reduce the effectiveness of the evaporative cooler.

Makeup water is added to the sump to replace the water lost through evaporation. Since this makeup water contains dissolved minerals, the mineral content of the recirculating water gradually increases. Dividing the concentration of the minerals in the recirculating water by the same concentration of minerals in the makeup water gives a ratio that is referred to as "cycles of concentration."

In evaluating a makeup source all the requirements of the recirculating water must be checked.

In Appendix 2, concentration cycles have been calculated for a makeup and compared to the limits in Table 3.

Makeup and recirculating water with parameters that are outside the recommended levels must be evaluated on an individual basis.

1. Use of Demineralized Water

Where the available water supply is too hard or contains too high solids to be suitable for makeup, some treatment prior to use is required. This may involve demineralization by reverse osmosis or ion exchange.

Demineralized water is not recommended as a once through water supply for evaporative coolers or as the sole source of makeup for recirculating water systems in evaporative coolers, without appropriate chemical control.

The use of this high purity water is discouraged for the following reasons:

- Corrosion and corrosion-erosion of piping and metallic materials of construction in the cooler.
- Evaporative cooler media are a composite made from paper fibers supported by inorganic binders, or stiffening agents. High purity waters may dissolve the binders. This could result in loss of rigidity causing media "sagging" and a significant reduction in media life.
- The treated water may delignify the fibers in the media and shorten the service life.

Rather than have treated water as the sole source of makeup, or for once through use, it is usually both more cost effective and technically desirable to blend the demineralized product with raw water to produce a medium solids makeup, which meets the makeup requirements in Table 3, and can be recycled in the evaporative cooler to acceptable cycles of concentration.

If 100% pretreated water must be used, the system pH should be maintained at 7.5–8.0, which may require chemical addition for pH control.

The use of blended or treated water is appropriate when the raw water has a high silica content, in areas of limited makeup water, and in locations where water use and discharge restrictions exist.

2. Once-Through Water

While the use of once-through water for the evaporative cooler is not recommended, it is important that when this practice is utilized the following guidelines should be followed:

- a. If the raw water supply has a Practical Scaling Index in excess of 8.0, reduce the water flow to 0.75–1.0 GPM per square foot of top media surface area. Request information from your GE representative for optimum pipe size, hole size and spacing.
- b. If raw water supply has a Practical Scaling Index of 5.5–8.0, use normal recommended water flow rates.
- c. Do not use water which is strongly scale dissolving ($PSI > 8$) as a once through supply.
- d. Do not use water containing free chlorine or bromine.
- e. Water should be cool and pipes run underground, if necessary to prevent warming.

D. Recommendations for Makeup and Circulating Water in Evaporative Coolers

GE's recommendations for makeup and circulating water chemistries for evaporative coolers in use with gas turbines are given in Table 3.

Table 3
Recommended Concentrations in Water for Gas Turbine Inlet Evaporative Coolers

Constituent	Makeup	Circulating water (see note 3)
Specific Conductivity, $\mu S/cm$	> 50 (see note 2)	< 5000 (see note 4)
Total Dissolved Solids, ppm	> 30 (see note 2)	< 3000
Total Alkalinity, ppm (as $CaCO_3$)	> 15 (see note 2)	< 500
Calcium Hardness, ppm (as $CaCO_3$)	> 15 (see note 2)	< 500
Alkali metals, ppm, (Sodium + Potassium)	No minimum	< 550
Chlorides, ppm, (as Cl)	No minimum	< 300
Silica, ppm, (as SiO_2)	No minimum	< 100
Heavy metals, ppm, (Fe, Mn, Cu, V, Pb)(see note 1)	< 0.2 (Total)	1.0 Total
Fe	0.1	1.0
Cu	0.05	0.5
Mn	0.05	0.2
Oil and Grease, ppm	< 2.0	10
Suspended Solids, ppm	< 5	30
pH	7-8.5	7.0- 9.0

Notes

- 1) Iron, manganese and copper act as foulants at the pH conditions in the cooler and their levels in makeup should be controlled. In the sump, the limit for total heavy metals is 1.0 ppm and that for Mn is 0.2 ppm. Vanadium and lead are not found in ground waters and are mentioned only because of their severe corrosive effect in the turbine hot gas path.
- 2) The minimum values are for protection of the media when treated or blended water is being used. No maximum values are given for the makeup water since the values must be evaluated based on the capability of the makeup to give acceptable cycles of concentration.
- 3) The values are estimates for the circulating water to be maintained with six (6) cycles of concentration and an acceptable scaling index level.
- 4) A limit on the specific conductivity of 5000 $\mu\text{S}/\text{cm}$ is given. However in “Evaporative Cooler Commissioning Procedure Document” (ref 1) it is recommended that the control system is set so that blowdown from the sump of the evaporative cooler is initiated at 1000 $\mu\text{S}/\text{cm}$ and continued until a value of 800 $\mu\text{S}/\text{cm}$ is reached. When the cooler system is operational and sump water testing has been carried out, the conductivity range for the start and stop of blowdown can be set at values that match plant experience and the requirements of this GEK.
- 5) Each water supply should be evaluated as described in this GEK. Where operators have questions regarding the requirements, they should contact GE for consultation.

IV. OPERATING ISSUES

Maintaining a high purity air stream to the gas turbine is dependent not only on control of the recirculating water chemistry but also the following operating factors.

A. Water Flow Rates and Distribution

Using recommended water flow rates in conjunction with even water distribution across the entire media bank is the recommended, and most successful, means of minimizing or eliminating scale deposition. The constant washing of the face of the media with an acceptable volume of water will continuously clean and flush the media surface.

The evaporation rate is independent of the wetting rate. If less than the recommended water is supplied to the media, two things may occur, both of which have a negative effect. First, with lower water flow rates, concentrated mineral salts will accumulate faster, and secondly, there may be insufficient water on the face of the media to provide the washing action. There shall be 1.5 gallons per minute of water per square foot of top media surface area distributed over the media. This will result in a minimum of 1.0 gallons per minute of water per square foot of media surface area draining out the bottom of each bank of media. The water draining out the bottom will vary depending on the daily evaporation rate.

B. Proper Air Distribution

Uneven air distribution due to obstructions, fan placement, inadequate transitions, fouling, etc., will cause high velocity zones, which may lead to water droplet carryover.

C. Maintaining the Media

Heavily fouled or damaged areas in the media are often a source of carry over. Heavily fouled media should be replaced, minor damage to media should be cut out and smoothed off. Major damage to media requires the entire pad to be replaced.

D. Chemical Treatment of the Circulating Water

Chemical treatment programs which were designed for controlling scale in cooling towers should not be used for evaporative coolers.

In evaporative coolers the media surface has relatively much less water flowing over it and is subjected to many wet/dry cycles. When mineral concentrations in the water become too high, because of too many cycles of concentration and/or insufficient water flow over the media surface, mineral salts precipitate and deposit. In such a mechanism, the use of scale inhibitors will have little or no positive effect and in fact the scale inhibitors will become part of the scale deposit. Thus, conventional cooling tower water treatment methods do not apply to evaporative coolers.

E. Chemical Treatment for Scale Modification

Proper chemical residuals must be maintained in the system.

The recommended treatment approach is the use of crystal modifiers such as sulfonated polystyrenes and polymaleic acid.

F. Control of Biological Fouling

Uncontrolled growth of bacteria, and other organisms, can lead to plugged media, metal deterioration, and undesirable odors in the air supply.

An effective program to control algae, bacteria, fungi, molds and yeasts is an essential part of any water treatment program for the evaporative cooler.

A biocide program, appropriate for gas turbine application, should be implemented to provide effective control of the microbiological problems.

Biological control should not be used in place of good housekeeping.

The recommendations of the manufacturers of the evaporative cooler and its media should be followed in establishing a housekeeping program for the water system in the cooler.

G. Chemical Control of Corrosion

The following recommendations should be followed if corrosion of the materials in the cooler is observed:

1. Review the problem with GE Power Systems.
2. Establish a corrosion monitoring program utilizing representative corrosion coupons.
3. Do not use phosphate based inhibitors. They provide nutrients for growth of micro-organisms and interact with calcium salts to increase scale deposition.

4. Whenever possible use an all-organic treatment program since it combines effective scale and corrosion inhibition.
5. If a steel corrosion inhibitor is required, use molybdate.

V. PROTECTION OF THE GAS TURBINE

The gas path of the turbine is susceptible to fouling and deposition by contaminants entrained in the air, fuel, water and steam passing through it. The contours of airfoils, and the clearances between them, are affected and, when fouling becomes severe, reductions in both efficiency and turbine output occur.

The contaminants most commonly causing fouling are soot and other airborne carbonaceous particles, silica, iron oxides, calcium sulfate and carbonate, with lesser amounts of sodium and potassium chlorides and sulfates. With use of evaporative coolers, the deposits tend to contain more salts of the alkali (Na + K) and alkaline earth (Ca + Mg) metals. The increase in alkali metal salts can result in more rapid accumulation of deposits and more corrosion in both the compressor and turbine sections.

The carryover of solid contaminants can result in several problems:–

- chloride ion pitting of 400 series stainless steel compressor blades
- alkali metal (sodium + potassium) hot corrosion of turbine hot gas path components.
- loss of compressor performance due to fouling
- general corrosion of ducting

The corrodants of concern are chloride ion, which can cause pitting damage to the stainless steels in the compressor and the alkali metals, sodium and potassium, which can cause hot corrosion in the turbine gas path.

A. Corrosion of the Compressor

The airfoils of the compressor are subject to pitting corrosion when contaminated with deposits containing chloride ions. Since most of the stages of a compressor run dry, corrosion occurs during only shut-down periods when deposits become hydrated. The inlet stages 1–4 run wet and, if chloride contamination is present, may corrode during operation.

B. Hot Corrosion of the Turbine Hot Gas Path

Sodium and potassium salts react with sulfur oxides in the combustion gas to form sulfates, which are molten at the metal temperatures of the combustion system and hot gas path of the turbine. The high temperature gas turbine components are stable in the high temperature, oxygen rich environment because of a tightly adherent oxide layer on their outer surfaces. The molten sulfates dissolve this oxide scale and prevent its reformation. They also penetrate the metal structure causing sulfidation, which further weakens the alloys. The presence of only parts per billion (ppb) of alkali sulfates in the combustion gas is sufficient to cause condensation of salts on metal surfaces and very rapid corrosion the gas turbine hot gas path parts. The rate of attack is directly proportional to the level contaminants present and there is no materials solution for hot corrosion, which must be prevented by controlling contamination.

C. Protection of the Hot Gas Path - Contaminant Limits

The allowable limits, for sodium plus potassium in the turbine combustion gas, have been defined in references 5 and 7.

- Alkali Metal - 20 ppb in combustion gas for EA and FA turbines
- 10 ppb for FB, H turbines
- If Fuel/air(f/a) = 0.02 fuel alkali limit is 0.5 ppm (500 ppb) for EA and FA,turbines (GEI41047)

If f/a is higher than 0.02, as with a lower BTU synfuel, the allowable alkali is reduced accordingly.

- Air alkali metal limit is 0.005 ppm (5 ppb Na+K) as Na

Carry-over limits on contaminants in the individual flows to the turbine may be obtained from a mass balance .

$$T^*(X^T) = S^*(X_S) + F^*(X_F) + A^*(X_A) + W^*(X_W)$$

Where T = total mass flow to turbine,

X_T = alkali metal in flow = 20 ppbw

A = Air flow,

X_A = concentration in air

F = Fuel flow,

X_F = concentration in fuel

S = Steam flow,

X_S = concentration in steam

W = Water flow,

X_W = concentration in water

In GER 3419A, "Gas Turbine Inlet Air Treatment", it is stated on page 3: "When trace metals in the fuel, water or steam are not precisely known, a limit for these contaminants in the inlet air of 0.005 ppm will nominally be set."

Using this value of 5 ppb for Na + K in the air, the maximum alkali metal ion content which is allowable in the evaporative cooler water can be calculated.

1. Carryover Control.

Information from Munters, a leading manufacturer of the cooler media, states that based on laboratory test data, the maximum drift or carry over rate is 0.0033% = 33 lbs of water (4 gallons) carried over by the air per million lbs of water (120,000 gallons) passing through the evaporative cooler media.

If the only alkali metal contamination in the inlet air comes from water entrained as the air passes through the cooler medium then the allowable concentration in the cooler water may be calculated:

$$(A)(X_a) = (W)(X_w)$$

$$W = A * (X_a/X_w) = 0.005 (A/X_w)$$

$$X_w = (X_a)(A/W)$$

W = Water carry-over from media (drift rate) lbs/sec = Water flow through cooler x carryover rate (0.0033%)

A = Mass Flow of Air through Evaporative Cooler (lbs/sec)

X_a = allowable concentration of alkali in air (ppm) = 0.005 (5 ppb)

X_w = allowable concentration of alkali in water (ppm)

Table 4 — Sample Calculation - Allowable Sodium in the Cooler Circulating Water for 7FA GT

For 7FA	A	W	X_a	X_w	
Water flow in Evap. Cooler (lbs/sec)	Gas Turbine Inlet Air Flow (lbs/sec)	Carryover (lbs/sec)	Allowed Sodium in inlet air (ppm)	Allowed Sodium in cooler water (ppm)	Allowed Sodium in cooler water with 10x margin (ppm)
28	975	0.0009185	0.005	5306	531

NOTE

The values in table 4 are representative of the 7FA gas turbine and show an example of a calculation of sodium levels. Each model turbine, and its associated evaporative cooler, will have different air and water flows, which will be found in the operating manuals.

At a laboratory measured drift rate, the maximum, calculated, allowable sodium content in the cooling water is very high, over 5,300 ppm Na+K, and at least a 10X safety factor is recommended, since in an operating evaporative cooler there may be significant nonuniformities in air velocity compared to the laboratory test conditions.

The maximum alkali metal value of 550 ppm (Na + K) in the cooler circulating water, given in Table 3, accounts for only the expected drift from the media. All splashing, leaking and other by-passing of the design air flow path must be eliminated. Incorrect installation of media and other mechanical problems in the cooler can cause very serious carryover, which could cause damage in the compressor that can only be corrected by replacement of the airfoils.

D. Protection of the Compressor

Elimination of carryover of alkali metal salts to the turbine section is only one of the two major concerns for corrosion when using an evaporative cooler. The other is prevention of corrosion in the compressor.

The levels of contaminants in the air passing through the compressor, which are necessary to cause deposits, are not known.

Analogy can be made to steam turbines which see deposition of contaminants of similar chemistry, and have similar materials of construction as the compressor and hence similar corrosion problems (9).

A limit of 3 ppb chloride ion is set for the air entering the compressor, which, with the same safety margin set for the alkali metals, gives a limit of 311 ppm, as Cl, in the cooler circulating water. This is the basis for the chloride limit given in Table 3.

VI. SUMMARY

The evaporative cooler has been in use for many years conditioning inlet air for gas turbines. The cooler is a simple machine and should give reliable, long term service. The keys to this are firstly: understanding the requirements for the recirculating water and setting up a program which produces makeup of the quality needed. Secondly, ensuring that the cooler is installed and set up correctly, so that carryover of recirculating water into the compressor does not occur.

Acknowledgement

We would like to acknowledge the support of the Munters Corp who allowed us the use of their technical bulletins in the writing of this GEK.

VII. REFERENCES

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7. GEK 107230 "Specification for Alkali Metal Contamination in Fuels for the FB and H Model Gas Turbines."
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9. GEI 41047H "Gas Turbine Liquid Fuel Specifications."

Appendix 1 Definitions

A. Evaporative Cooler Efficiency

$$\text{Efficiency} = \frac{(\text{EDBT} - \text{LDBT})}{(\text{EDBT} - \text{WBT})} = \text{nominally } 85\%$$

Leaving Dry Bulb temperature (LDBT) can be calculated.

$$\text{LDBT} = \text{EDBT} - [(\text{Evap Cooler Eff})(\text{EDBT} - \text{WBT})]$$

B. Evaporation Rate (ER)

The amount of water evaporated in gpm as the air passes through the cooler can be approximated by the following formula.

$$\text{Evaporation} = \frac{\text{CFM (thousands)} * (\text{EDBT} - \text{LDBT})}{500}$$

C. Blowdown

Blowdown is a function of evaporation rate and the cycles of concentration. It is the flow of water which must be continuously removed from the cooler in order to maintain the chemistry of the recirculating water at the design value.

$$\text{Blowdown} = \frac{(\text{Evaporation Rate})}{(\text{Cycles} - 1)}$$

D. Makeup Water

The water added to replace that lost by evaporation and through blowdown.

$$\text{Makeup Rate} = \text{Evaporation Rate (gpm)} + \text{Blowdown Rate (gpm)}$$

NOTE

At startup of an evaporative cooler, the dry media will absorb about 0.5 lbs water per cubic foot of dry media resulting in a delay between the time that the pumps start and when water starts to return to the sump. As a result of this, at the startup of an evaporative cooler, a higher makeup rate will be required for a limited period.

E. Scaling Indices for Evaporative Coolers

These indices indicate the tendency of water to be scaling or corrosive as a function of four factors:—

- temperature
- hardness
- total alkalinity
- pH

There are three indices in use:—

Practical (Puckorius) Stability Index, Ryznar Stability Index (RSI), Langelier Saturation Index (LSI)

Methods for calculating the indices are shown in Appendix 2.

Recommended values for common indices for maintaining recirculating water systems are given in Table 2.

F. Drift (Carryover)

Water droplets which are carried over from the cooling media through the drift eliminator and are present in the airflow as it enters the compressor section of the turbine. Contaminants enter the turbine dissolved in this water.

G. Dry Bulb Temperature

The temperature as measured by a standard thermometer.

H. Wet Bulb Temperature

The temperature as measured by a thermometer which has a water moistened wick around its bulb. If the air is at a temperature above its dew point, evaporation of water will occur in the wick causing cooling and the reading of a temperature below the dry bulb temperature. At 100% humidity, the wet bulb and dry bulb temperatures are the same. The Dew Point of the air is the temperature of 100% humidity, the point at which the air is saturated with water vapor and where condensation of liquid water may occur.

Appendix 2 - Methods of Calculation

The choice of makeup water and the operation of the evaporative cooler are the responsibility of the owner. The methods of calculating the different operating parameters given here are illustrative and for guidance only. In addition to using the information in this section the operator should seek guidance, as needed, from a water treatment expert who is familiar with the water chemistry as it relates to the operation of an evaporative cooler with a GE gas turbine, and other conditions at the plant.

J. Calculation 1 - Scaling Indices

These indices indicate the scaling or corroding tendencies of water.

Table 5
Data for Rapid Calculations of Puckorius (Practical) Scaling Index for Evaporative

Conductivity		Calcium Hardness		Total Alkalinity		Alkalinity	
($\mu\text{S/cm}$)	Factor A	(PPM as CaCO_3)	Factor C	(PPM as CaCO_3)	Factor D	(PPM as CaCO_3)	Factor E (pHeq)
50–300	0.1	10–15	0.70	10–15	1.10	50	7.00
301 – 1001	0.2	16–25	0.90	16–25	1.30	100	7.50
1001– 3000	0.25	26–40	1.10	26–40	1.50	200	7.90
3000 – 5000	0.27	41 – 70	1.35	41 – 70	1.75	300	8.20
		71 – 100	1.55	71 – 100	1.90	400	8.40
Ambient Temperature	Factor B	101 – 140	1.70	101 – 140	2.10	500	8.50
F		141 – 200	1.85	141 – 200	2.25		
50 – 56	2.3	201 – 250	1.95	201 – 250	2.34		
58 – 62	2.2	251 – 300	2.05	251 – 300	2.45		
64 – 70	2.1	301 – 350	2.12	301 – 350	2.52		
72 – 80	2.0	351 – 400	2.18	351 – 400	2.58		
		401 – 450	2.24	401 – 450	2.63		
		451 – 500	2.26	451 – 500	2.68		

Method of Calculation

(1) Obtain values of A, B, C, D and E (pHeq) from Table 5

(2) $\text{pHs} = (9.3) + (A + B) - (C + D)$

(3) Puckorius (Practical) Scaling Index = $2 \text{ pHs} - \text{pHeq}$

EXAMPLE

Find the Puckorius (Practical) Scaling Index at 70°F of water, which has the following characteristics.

Conductivity = 700 $\mu\text{S/cm}$

Calcium hardness as CaCO_3 = 306 PPM,

Alkalinity as CaCO_3 = 234 PPM.

Then reading from Table 3 :

Factor A = 0.2

Factor B = 2.1

Factor C = 2.12

Factor D = 2.34

Factor E (pHeq) (based on interpolation with Alkalinity of 234 PPM) = 8.0

$$\text{pHs} = (9.3 + 0.2 + 2.1) - (2.12 + 2.35) = 7.13$$

$$\text{PSI} = (14.26) - (8.0) = 6.26$$

Based upon Table 1, the water is neutral - not scaling or corrosive.

K. Calculating Other Scaling Indices

Table 5 can also be used to calculate the Langelier and Ryznar indices as follows:

(1) Use the actual pH of the water in place of pHeq.

(2) Calculate the pHs using Table 5.

$$\text{Ryznar (RSI)} = 2 \text{ pHs} - \text{pH}$$

$$\text{Langelier (LSI)} = \text{pH} - \text{pHs}$$

L. Evaluation of a Water Supply for Use in an Evaporative Cooler

Prior to the commissioning of a new evaporative cooler, either in a new plant or as an add-on to an existing plant, the sources of water available for the makeup supply must be evaluated.

To allow a complete pre-operational evaluation, all the constituents of the water, which are listed in Table 3 and 5, must be provided.

Since the water will be used as a makeup source to the circulating water in the evaporative cooler, and not as a once through supply, its chemical properties after a number of cycles of concentration must be calculated or predicted. This is essential so that the can be estimated at the design operating conditions of the cooler. One important economic criterion is whether the water will perform satisfactorily at a minimum of two cycles of concentration.

M. Calculation 2 - Effect of Cycles of Concentration on the Scaling Index

A supply of water, with the parameters in the column of Table 2 headed "Makeup" is evaluated for the cycles of concentration that it could accept.

Simple multiplication by the concentrating factor (2, 3, 6 or 8) gives the values of the parameters at different cycles of concentration except for the alkalinity and the pH.

For Alkalinity, multiply by 0.67x (2, 3, 6 or 8).

For pH

$$14 - \text{pH} = \text{p}[\text{OH}]$$

$$10^{(\text{pOH})} = \text{OH concentration}$$

multiply [OH] by cycles of concentration

take base 10 log of [OH]

$$\text{pH} = 14 - \text{p}[\text{OH}]$$

Using the procedure described above in Calculation 1 the effect of different cycles on the values for PSI were obtained and are shown in Table 6.

It can be seen that the hardness and scaling index are more limiting on cycles than the limits for chloride, sodium or conductivity and that the operating limit to be planned for is 5.5 cycles.

Table 6
Evaluation of Effects of Cycles of Concentration

Cycles of Concentration							
Parameter	Make-up	X2	x3	x6	x8	Parameter limit from Table 3	Allowed cycles
pH	8.24	8.54	8.72	9.02	9.14		
Alkalinity	65	87.1	130.6	261	348	500	7.7
Cl	52	104	156	312	416	300	5.8
Hardness	91	182	273	546	728	500	5.5
Ca	25	50	75	150	200		
Mg	6	12	18	36	48		
TDS	182	364	546	1092	1456		
Na	34.7	69.4	104.1	208	277	550	15.9
Conductivity	367	728	1101	2202	2936	5000	13.6
PSI	9.30	8.34	7.35	5.87	5.30	6.5 +/-0.5	5.5

If the pH of the sump needs to be adjusted in order to give an acceptable scaling index this can be done by adding acid (sulfuric or hydrochloric) to reduce pH or by adding base (sodium hydroxide) to increase pH.

The evaluation of the makeup and circulating water and changes to chemical parameters such as pH should be done along with your water treatment engineer.

Appendix 3 - Sump and Makeup Water Sampling Plan

A. Water Sampling and Analysis Plan

GE's requirements for makeup and circulating water chemistries for evaporative coolers in use with gas turbines are given in Table 3. The sump and makeup waters should be sampled with sufficient frequency that the condition of the water in the evaporative cooler is known at all times.

The operator should confirm that the water samples for the site have been taken and analyzed and that the conductivity settings to control blowdown have been determined in accordance with the requirements of the latest revision to the GE Water Quality GEK 107158.

The scaling index for the sump water should be checked weekly for the first year and at least monthly thereafter. Accordingly, the parameters required to obtain scaling index, pH, alkalinity and hardness must be measured at least weekly. It is recommended that the data be trended since the chemistry of the sump and makeup waters may change seasonally.

Once the operation of the evaporative cooler has been established, many of the parameters need only be measured at startup, during troubleshooting of a problem or when a new source of makeup water is qualified.

The methods for testing are shown in Table 7.

Table 7
Test Methods for Water Analysis.

PARAMETER	ASTM Test Method
P and M Alkalinity, as CaCO_3	D 1067-92
Specific Conductivity	D 1125-95
Suspended Solids	D 5907-96a
Total Hardness, as CaCO_3	D 1126-96
pH	D 1293-95
Oil and Grease	D 3921-96
Sodium, Na	D 4191-93
Potassium, K	D 4192-93
Ammonium, NH_4	D 1426-93
Calcium, Ca	D 511-93
Magnesium, Mg	D 511-93
Silica, SiO_2	D 859-94
Iron, Fe	D 1068-96
Chloride, Cl	D 512-89
Sulfate, SO_4	D 516-90
Heavy metals, (Mn, Cu, V, Pb)	D 1976-96
Zinc, Zn	D 1691-95

B. Sampling and Testing During Initial Operation

Sample and analyze the sump makeup water and verify compliance with Table 3. Repeat make up water analysis twice per month for the first year of operation and determine a proper sampling period for the future.

1. Sampling the sump

Take the water sample from the sump when the automatic blowdown starts to direct water to the drain. Analyze this water sample to assure that all the recirculating water requirements are met and that the conductivity of the water matches the conductivity setting to initiate blowdown. Adjust the conductivity setting for blowdown as required to optimize the sump water makeup concentrations to assure that all the sump water requirements identified in Table 3 are met and to maximize the life of the evaporative cooler media as it relates to scaling and scale dissolving. Repeat this procedure until the optimal conductivity setting is identified. The turbine control system is set so that blowdown from the sump of the evaporative cooler is initiated at 1000 $\mu\text{S}/\text{cm}$ and continued until a value of 800 $\mu\text{S}/\text{cm}$ is reached.

2. Sample the evaporative cooler sump water chemistry parameters given below quality on a daily basis for the first 3 months of operation :

- Conductivity (convert to TDS by multiplying by 0.6)
- Alkalinity
- Calcium Hardness
- pH

From these parameters the Scaling Index can be calculated.

During the time that the sampling is taking place, document the following:

- time of day,
- ambient temperature, and the
- ambient relative humidity.

Verify that all the recirculating water requirements are met. Confirm that the conductivity of the sump water sample matches the conductivity of the sump water identified at the turbine control system at the time of sampling.

Also, based on the measured conductivity, ensure that this value, and the time which the sump has been blowing down, are consistent with the control value which has been set to initiate blowdown.

During startup, the turbine control system is set so that blowdown from the sump of the evaporative cooler is initiated at 1000 $\mu\text{S}/\text{cm}$ and continued until a value of 800 $\mu\text{S}/\text{cm}$ is reached. When the cooler system is operational and sump water testing has been established, a different conductivity value and blowdown time may be specified on a custom basis for the system.

3. During the first 3 months of operation, sample the sump and adjust conductivity set points as described in B.1 a minimum of once per week.
4. Following the first 3 months of operation, repeat B.1 a minimum of twice per month for the first year of operation. Following the first year of operation, repeat step B.1 on a regular interval that is based on the available test data.
5. Following the initial months of operation, using the available data, generate a water sampling / testing plan that is appropriate. Suggested parameters to be tested, and a frequency of testing are given in Table 8.

Table 8

Sample Frequency	Weekly		Monthly		Qualify and Trouble Shoot	
PARAMETER	Sump	Makeup	Sump	Makeup	Sump	Makeup
P and M Alkalinity, as CaCO ₃ (ppm)	X			X		
Specific Conductivity, μ S/cm	X	X				
Suspended Solids, g/l	X					X
Total Hardness, ppm as CaCO ₃	X	X				
pH	X	X				
Oil and Grease, (ppm)					X	X
Sodium, Na (ppm)			X	X		
Potassium, K (ppm)					X	X
Ammonium, NH ₄ (ppm)					X	X
Calcium, Ca (ppm)			X	X		
Magnesium, Mg (ppm)			X	X		
Silica, SiO ₂ (ppm)			X	X		
Iron, Fe (ppm)			X	X		
Chloride, Cl (ppm)			X	X		
Sulfate, SO ₄ (ppm)			X	X		
Heavy metals, (Fe, Mn, Cu, V, Pb),(ppm)					X	X
Zinc, Zn (ppm)					X	X



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