



## SET UP AND OPERATION OF A RECIRCULATING WETTED RIGID MEDIA EVAPORATIVE COOLER INSTALLED IN A GAS TURBINE COMBUSTION INLET AIR SYSTEM

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### ABSTRACT

A procedure for setting up and operating a recirculating evaporative cooler installed in the combustion air inlet system of a gas turbine is described. The procedure includes a recommendation for selecting the ambient operating wet and dry bulb temperatures. A description of the parameters used in the procedure and calculation methods are shown. In response to frequent inquiries about the rate at which water hardness (and elemental concentrations) increases with time, an equation to evaluate this increase with time is introduced. The time rate of change of water hardness and elemental concentrations for various blow-down rates and operating times are also evaluated.

### NOMENCLATURE

|           |  |
|-----------|--|
| B         | = Blowdown rate, gpm   |
| $C_e$     | = Equilibrium Concentration Factor ( $H/H_0$ )                             |
| $C_t$     | = Time Dependent Equilibrium Concentration Factor ( $H_t/H_0$ )            |
| D         | = Weight of water, lb/gal.   |
| E         | = Water evaporation rate, gpm  |
| H         | = Water hardness in the reservoir, as $\text{CaCO}_3$                      |
| $H_0$     | = Water hardness in the make-up water to the reservoir, as $\text{CaCO}_3$ |
| $H_t$     | = Water hardness in the reservoir at time t, as $\text{CaCO}_3$            |
| $m_1$     | = Moisture in incoming air, lb moisture/lb dry air                         |
| $m_2$     | = Moisture in leaving air, lb moisture/lb dry air                          |
| N         | = Evaporative cooler efficiency, %   |
| $P_a$     | = Density of air at dry-bulb temperature, lb/ft <sup>3</sup>               |
| R         | = Water holding capacity of reservoir, gal.                                |
| $T_{db1}$ | = Dry-bulb temperature of air entering the evaporative cooler, °F          |
| $T_{db2}$ | = Dry-bulb temperature of air leaving the evaporative cooler, °F           |
| $T_{wb}$  | = Ambient wet-bulb temperature, °F   |
| t         | = Elapsed time, minutes  |
| V         | = Gas turbine air volume flow rate, cfm                                    |

### CONVERSION FACTORS

|                   |                                |
|-------------------|--------------------------------|
| °C                | = (°F - 32)/1.8                |
| kg/L              | = 8.33 lb/U.S. Gal.            |
| kg/m <sup>3</sup> | = 6.25 E-02 lb/ft <sup>3</sup> |
| kg/s              | = 7.937 E+03 lb/hr             |
| L/s               | = 1.585 E+01 U.S. gal./min     |
| m <sup>3</sup> /s | = 2.120 E+03 cfm               |
| m                 | = 3.28 ft                      |

### INTRODUCTION

In a recirculating evaporative cooler (Figure 1), water is supplied to the reservoir and then pumped from the reservoir to the header pipe. Water is sprayed upward from the header pipe onto the top of the evaporative cooler. From there, it drains downward onto the distribution pad. The water is distributed evenly across the distribution pad and drains downward into the media strips below. The media pads become saturated with water, and water is evaporated into the air passing through the pads. Water that is not evaporated drains from the pads into the reservoir from which it originally came. This type of evaporative cooler is known as an irrigated media type and is by far the most common type used with gas turbines.

Water is also consumed by the evaporative cooler through blow-down. Blow-down is the term applied to the constant flow of water out of the reservoir. Blow-down is regulated to control the equilibrium hardness level of the water in the reservoir.

The water lost through evaporation, plus water lost through blow-down, is replaced by the water delivered directly from the user's water supply into the reservoir. The water supplied to the reservoir will contain dissolved solids, some of which contribute to its hardness. Hardness is typically measured as calcium carbonate ( $\text{CaCO}_3$ ). Since the dissolved solids in the water remain behind as water is evaporated, the hardness of the excess water draining from the pads into the reservoir gradually increases. Draining water out of the reservoir (blow-down) limits the dissolved solids and, hence, the hardness of the water.

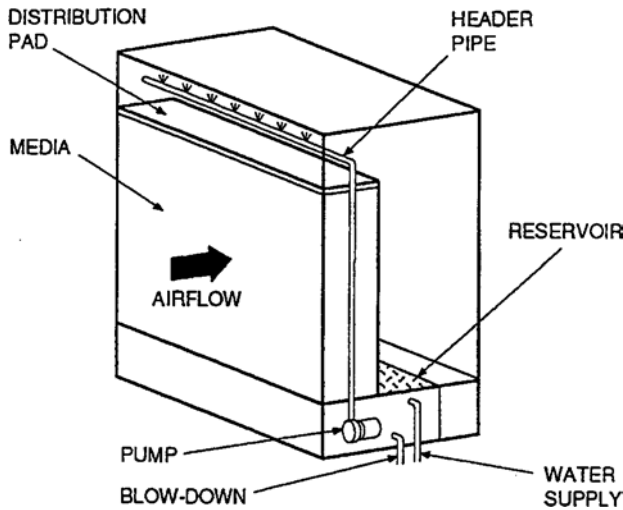


FIGURE 1. RECIRCULATING RIGID MEDIA EVAPORATIVE COOLER

in the reservoir. An equilibrium condition occurs in a recirculating evaporative cooler when the hardness level in the reservoir has reached an essentially constant value.

### RELATIVE HUMIDITY, DRY-BULB AND WET-BULB TEMPERATURES

In selecting the conditions at which the evaporative cooler will operate, it is customary to use the highest temperature and the lowest relative humidity that could be expected to occur during the evaporative cooler's operating season. However, this paper recommends using coincident dry and wet-bulb design temperatures. These temperatures can be obtained from Chapter 24 of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Handbook of Fundamentals (ASHRAE, 1981). The data in this handbook give design temperatures that will be equalled or exceeded 1%, 2.5%, and 5% of the average hours in the season. Use of the dry and wetbulb temperatures in the 1 % column is recommended, along with the procedure described below.

Using 1% coincident dry and wet-bulb temperatures from the data table (ASHRAE, 1981) instead of the estimated extremes of dry-bulb temperature and relative humidity, will result in a lower water use rate. This is because the estimated extremes are often just guesses, which are not accurate, and which represent environmental conditions that rarely occur.

As an example, the author was recently asked to evaluate the parameters of an evaporative cooler being installed on a gas turbine in El Paso, Texas. The estimated ambient conditions used in the evaluation were 110°F and 10% relative humidity, which translate to 110°F dry bulb and approximately 69°F wet bulb. These temperatures are more severe than the 1% coincident dry/wet-bulb temperatures of 100°F/64°F, obtained from the ASHRAE handbook. Calculating the evaporation rate for these two conditions gives 2.56 gal/min for the former, and 2.27 gal/min for the latter, conditions. For a gas turbine with a

combustion airflow rate of 36,000 cfm, the water usage rate for blow-down rates of 1 times and 4 times the water evaporation rate are 2.56 and 10.24 gal./min and 2.27 and 9.08 gal./min, respectively, for a 90% efficient evaporative cooler. This represents a savings of 418 gal./day for a blow-down rate of 1 times evaporation rate and 1670 gal./day for a blow-down rate of 4 times the evaporation rate.

### SETTING UP A RECIRCULATING EVAPORATIVE COOLER

Select coincident dry and wet-bulb design temperatures from the 1% column in (ASHRAE, 1981). These temperatures are  $T_{db1}$  and  $T_{wb}$ , respectively, in Equation 1.

$$T_{db2} = T_{db1} - \frac{N}{100\%} (T_{db1} - T_{wb}) \quad (1)$$

Calculate the dry-bulb temperature ( $T_{db2}$ ) of the air leaving the evaporative cooler using Equation 1. ( $N$ ) is the evaporative cooler efficiency.

Use a psychrometric chart (Figure 2) to find the density ( $P_a$ ) and the moisture of the incoming air ( $m_1$ ) at  $T_{db1}$  and the moisture in the air leaving the evaporative cooler ( $m_2$ ) at  $T_{db2}$ . Then, use Equation 2 to calculate the water evaporation rate (gpm):

$$E = \frac{V(m_2 - m_1) P_a}{D} \quad (2)$$

Using the hardness level of the water that will be supplied to the evaporative cooler, calculate the hardness of the water in the reservoir when the evaporative cooler reaches its equilibrium operating condition. Use Equation 3. (In a recirculating evaporative cooler, a steady-state condition is quickly reached and the hardness level in the water stabilizes.) In the following example, a hardness of 150 ppm as  $CaCO_3$  and a blow-down ratio of 4 are used. (The blow-down ratio is defined as the ratio of blow-down rate to the evaporation rate. A blow-down ratio of 4 means that the blow-down rate is 4 times the rate of evaporation.)

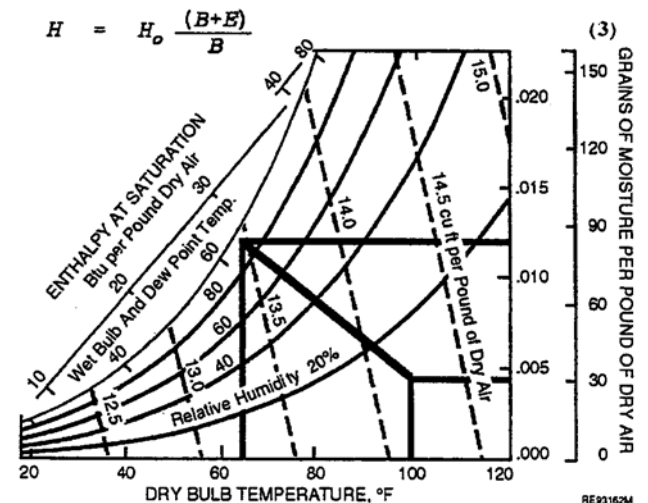


FIGURE 2. PSYCHROMETRIC CHART

After connecting the water supply, which is delivered directly into the reservoir, and the evaporative cooler blow-down line to the drain, turn on the water supply and fill the reservoir.

With the water pump operating, adjust the water flow rate to the evaporative cooler header pipe. The recommended water flow rate is based on the surface area of the distribution pad. Use 1.0 gal/min/ft<sup>2</sup> for coolers up to 6 feet high and 1.25 gal/min/ft<sup>2</sup> for coolers 7 to 12 feet high.

Adjust to the blow-down rate as calculated above. It is intended that this blow-down rate will remain constant for as long as the evaporative cooler remains in operation.

Allow the evaporative cooler to operate for 20 minutes before starting the gas turbine. After starting the gas turbine, observe the downstream surface of the media. Although there should be no water droplets leaving the surface of the media, an occasional droplet (one or two per minute) is acceptable.

Refer to Johnson (1989) for a more in-depth discussion of water carryover, and other aspects of evaporative cooler design and operating theory.

### CALCULATING THE EXITING DRY-BULB TEMPERATURE (T<sub>db2</sub>)

Equation 1 can be utilized to calculate the dry-bulb temperature of air leaving the evaporative cooler. As an example, for an evaporative cooler efficiency (N) of 90% and the 1% dry/wetbulb conditions for El Paso, Texas (100°F/64°F), the exiting drybulb temperature is calculated to be:

$$T_{db2} = 67.6^{\circ}F$$

$$T_{db2} = 100 - \frac{90}{100} (100 - 64) \quad (5)$$

### CALCULATING THE WATER EVAPORATION RATE

Calculate the water evaporation rate using Equation 2, using T<sub>db2</sub> to obtain the value for m<sub>2</sub>.

Continuing with the El Paso example, refer to a psychrometric chart (Figure 2) to find the values for the parameters in Equation 2, for the temperature and relative humidity given above.

- m<sub>1</sub> = 0.0045 lb moisture/lb dry air
- m<sub>2</sub> = 0.01195 lb moisture/lb dry air
- P<sub>a</sub> = 0.0704 lb/ft<sup>3</sup> (density of ambient air)
- D = 8.33 lb/gal. of water
- V = 36,000 cfm (engine inlet air flow rate)

Solving for the evaporation rate:

$$E = 36,000 \frac{(0.01195 - 0.0045) 0.0704}{8.33} \quad (6)$$

$$= 2.27 \text{ gal./min} \quad (7)$$

For this example, E is rounded to 2.3 gal./min in the later calculations.

### CALCULATING THE EQUILIBRIUM HARDNESS CONCENTRATION

In a recirculating evaporative cooler, the equilibrium condition occurs when the elemental concentrations are in a steady state. The equilibrium elemental concentration is calculated with Equation 3, where H is the final (equilibrium) elemental concentration in ppm and H<sub>0</sub> is the initial elemental concentration in ppm.

For the example, the reservoir hardness is calculated to be:

$$H = 150 \frac{(9.2 + 2.3)}{9.2} \\ = 187.5 \text{ ppm, as CaCO}_3$$

### CALCULATING BLOWDOWN FOR A SELECTED MAXIMUM HARDNESS

Alternatively, the blow-down rate required to give a desired maximum concentration at equilibrium can also be calculated. For an initial condition with a hardness of 50 ppm, assume that a hardness of 100 ppm at equilibrium is selected. The blowdown rate required to reach this level at equilibrium is calculated with Equation 4:

$$B = \frac{EH_0}{H - H_0} \quad (4)$$

$$B = \frac{2.3 \times 50}{100 - 50}$$

$$\text{For } E = 2.3 \text{ gpm, } H_0 = 50 \text{ ppm, and } H = 100 \text{ ppm:} \\ = 2.3 \text{ gpm}$$

Thus, a blow-down rate equal to the evaporation rate, i.e., a 100% blow-down rate, produces an equilibrium condition with elemental concentrations and total hardness double the initial values.

### THE EQUILIBRIUM CONCENTRATION FACTOR

The equilibrium concentration factor (C<sub>e</sub>) is commonly used to readily find the equilibrium hardness concentration in the reservoir. It is defined in Equation 5, which is derived from Equation 3, and shown graphically in Figure 3.

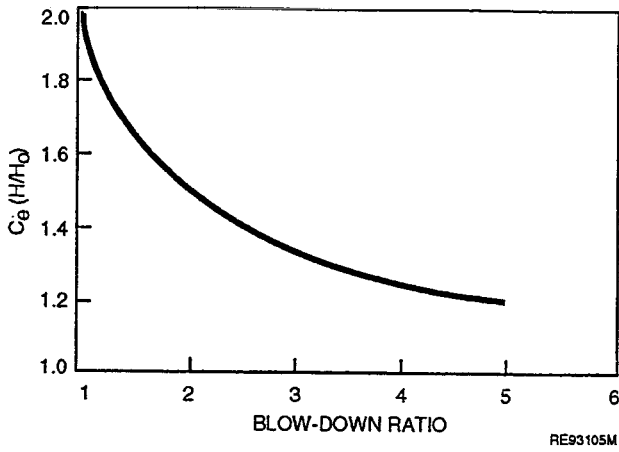


FIGURE 3. EQUILIBRIUM CONCENTRATION FACTOR ( $C_e$ ) VS BLOW-DOWN RATIO

$$C_e = \frac{H}{H_o} = \frac{(B+E)}{B} \quad (5)$$

As an example, for a blow-down ratio of 4:1 (i.e., blow-down (B) is four times the water evaporation rate (E)), enter the abscissa at 4, move upward to intersect the curve, move left toward the ordinate to read 1.25. For an initial hardness of 150 ppm, multiply 150 by 1.25 to get 187.5 ppm. This is the same result obtained from Equation 3.

#### CALCULATING ELEMENTAL CONCENTRATIONS AS A FUNCTION OF TIME

The elemental concentration (or hardness) in the water in the reservoir at a time "t" is calculated with Equation 6. Iterative techniques with the use of a computer are most practical in evaluating this relation for large operating times. The variable R introduced in this equation is the quantity of water in the reservoir. Assume that the evaporative cooler reservoir holds 155 gallons.  $H_t$  is the elemental concentration in the water in the reservoir at time "t".

$$H_t = \sum_{i=0}^{i=t} \left[ \left( \frac{H_i}{R-E} \right) (R-E-B) + \left( \frac{B+E}{R} \right) H_o \right], \quad \text{ppm} \quad (6)$$

Figure 4 illustrates the rate of concentration increase using Equation 7, which is derived from Equation 6 and normalized to  $H_o$ . This quantity is defined as the time-dependent concentration

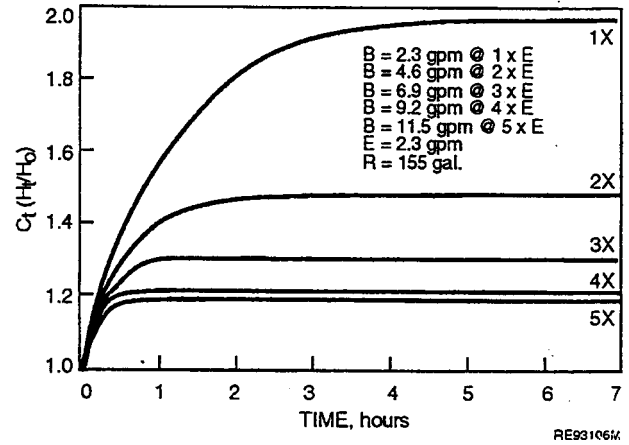


FIGURE 4. WITH BLOWDOWN CONCENTRATION FACTOR ( $C_t$ ) VS TIME

factor ( $C_t$ ). Figure 4 plots  $C_t$  for blow-down rates of 1, 2, 4, and 5 times the evaporation rate.

$$C_t = \frac{H_t}{H_o} \quad (7)$$

Tracing along the graph for blowdown at two times evaporation rate in Figure 4, it can be seen that after 30 minutes the concentration of any element in the water in the reservoir is 1.28 times the initial concentration. With initial hardness measured as 150 ppm as  $\text{CaCO}_3$ , after 30 minutes it becomes  $150 \times 1.28 = 192$  ppm.

After 60 minutes, the concentration has increased to 1.4 times the initial concentration or  $150 \times 1.4 = 210$  ppm. The parametric value for blowdown at two times evaporation reached equilibrium after 4 hours.

#### CALCULATION OF ELEMENTAL CONCENTRATIONS ( $C_t$ ): NO BLOWDOWN

Operating a recirculating evaporative cooler without blowdown is not practical because the hardness level in the reservoir increases linearly with time. To demonstrate this condition, the hardness level in the reservoir at time t (mins.) is calculated with Equation 8.

This relationship is shown graphically in Figure 5.  $C_t$  in Figure 5 is calculated from Equation 9, which is Equation 8 normalized to  $H_o$ :

$$H_t = H_o \left( \frac{tE}{R} + 1 \right) \quad (8)$$

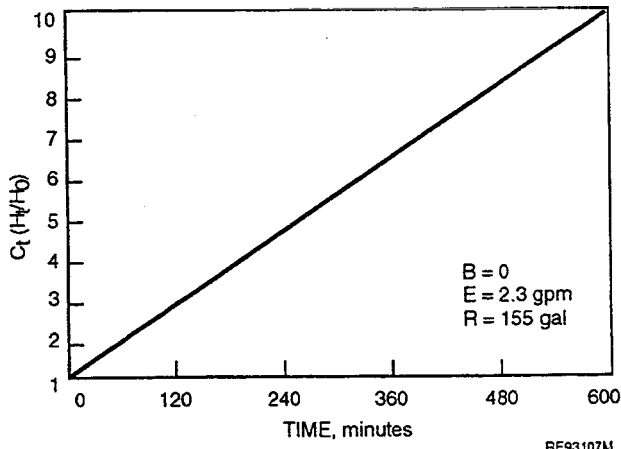


FIGURE 5. WITHOUT BLOWDOWN CONCENTRATION FACTOR (Ct) VS TIME

$$C_t = \frac{H_t}{H_0} = \frac{tE}{R} + 1 \quad (9)$$

#### SUMMARY

A procedure for setting up and operating a wetted media recirculating evaporative cooler has been described. The advantage in using the ASHRAE coincident design temperatures, instead of estimating these temperatures, has been shown. Equations have been presented for calculating the existing dry-bulb temperature, water evaporation rate, equilibrium hardness concentration, and blowdown for maximum hardness. Finally, an iterative equation has been introduced for use in evaluating the elemental concentrations (or hardness level) of the water in the evaporative cooler reservoir, as a function of time.

#### REFERENCES

ASHRAE Handbook of Fundamentals, Chapter 24, Table V-1. 1981.

Johnson, Sr., R. S., "The Theory and Operation of Evaporative Coolers for Industrial Gas Turbine Installations," ASME Journal of Engineering for Gas Turbines and Power, April 1989, Vol. 111, No. 2, pp 327-334.