The Control of pH and Oxidation Reduction Potential (ORP) in Cooling Tower Applications

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Introduction

The importance of keeping cooling tower water in proper chemical balance is becoming clearer. Cooling tower treatment control systems can limit scale formation to improve efficiency, limit corrosion to increase the service life of the cooling water system, and maintain a residual halogen level to reduce liability associated with biological growth, particularly Legionellae.

The use of automatic control equipment rather than manual measurement and adjustment has increased dramatically in the past several years, motivated in part by the loss of on-site personnel to perform the task, in part by the safety aspects of chemical handling, and in part by efforts to conserve water.

Environmental concerns have also driven the increased use of pH and oxidation-reduction potential (ORP) controllers in cooling water systems. After the use of heavy metals was banned, the simple treatment method to control chromate passivation could not be used to protect the cooling systems. The newer, alternative methods can be more sensitive to pH fluctuations. For example, alkaline orthophosphate treatments can result in corrosion if the pH drops, and in calcium phosphate scaling if the pH rises. The use of automatic pH control minimizes this problem.

Similarly, the combination of pH control and ORP control can maintain chlorine and/or bromine residuals at the levels required to inhibit survival of bacterium and the biofilm that supports them. Maintaining a constant low-level halogen residual also minimizes the amount of chemical that is discharged into the environment.

Installation of automatic control equipment is also a great way for water treatment chemical providers to differentiate themselves from the competition by increasing their level of service to the owner of the cooling towers.

Typical System

A typical cooling tower control system consists of a conductivity electrode, a pH electrode, an ORP electrode, the controller itself, metering pumps, and solenoid valves, as shown by Figure 1. The electrodes are the most critical components in the control system, since they are in contact with the cooling water, measure the parameter in question, and send a signal to the controller. The controller then reads the signal and activates or deactivates the pumps or valves to correct the condition. Without a reliable measurement signal, the system will not perform. A pH electrode and an ORP electrode are very similar in their construction.

A pH electrode consists of pH-sensitive glass electrode, and a reference electrode, packaged together in the same body. For ORP measurement, a platinum or gold electrode replaces the pH-sensitive glass electrode.

In response to changes in hydrogen ion or oxidizer concentrations, the pH and ORP electrodes change their voltage outputs. Each is like a battery that outputs an extremely weak voltage that varies depending upon the liquid in which it is immersed. This signal can not be read using a standard voltmeter, but rather can only be read by a high impedance preamplifier, which reads the voltage generated by the measurement electrode against the voltage generated by the reference electrode. Without this preamplifier, the signal can only be transmitted a few feet, and it is extremely sensitive to interference from electrical noise.

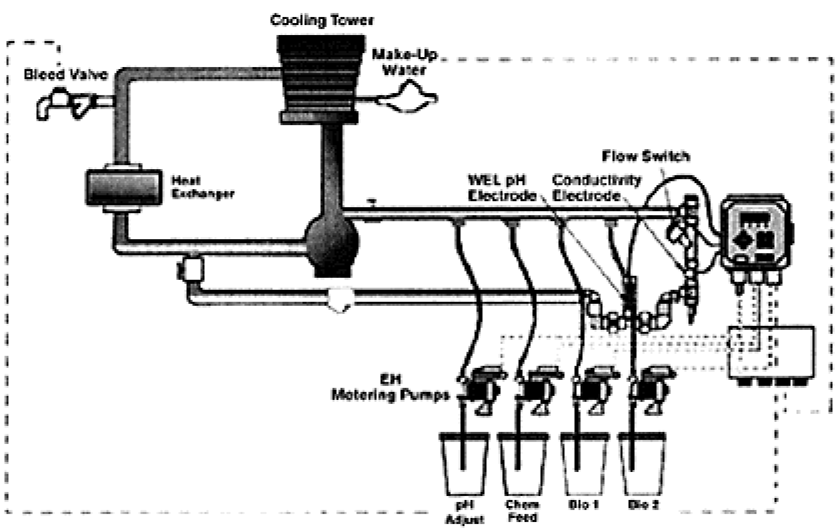

Figure 1 - Typical Installation Diagram

The most reliable electrodes will have the preamplifier built into the electrode body, and the cable will contain a metal shield that is connected to the ground to absorb any electrical noise. Even more reliability is achieved through a differential measurement, where the measurement electrode signal is referenced to solution ground, and the reference electrode signal is referenced to solution ground, and then these two voltages are subtracted. Any voltage in the solution that could shift the reading is thereby cancelled out and accuracy is maintained.

Measurement of pH

The pH electrode creates a voltage signal of approximately 0 millivolts (mV) when immersed in a solution at pH 7. This signal will change by approximately 59 mV for every pH unit away from pH 7 (at 25 degrees Celsius). A higher concentration of acidic hydrogen ions (H^+) results in a positive shift in the mV output, while more alkaline hydroxide ions (OH-) results in a negative shift in the mV output. The exact output for a given pH value shifts as the electrode ages; the mV at pH 7 will climb over time and the 59 mV/pH unit slope will decrease.

The output of the pH electrode is slightly temperature-dependant as shown in Figure 2. When the pH is close to pH 7 and the temperature is close to ambient, there is an insignificant temperature effect. In most cooling tower applications, there is no need for automatic compensation for the temperature of the solution. In this case, the approximate temperature is programmed into the controller, and the controller uses this value to calculate the temperature compensated pH value.

Because the voltage output of the electrode is not stable over long periods of time, it is necessary to calibrate the controller to the electrode periodically. The controller needs to "know" how to convert the mV value to the correct pH value. The reading will only be as accurate as the calibration. In most systems, a monthly cleaning and subsequent calibration is sufficient. The calibration is typically achieved using standard buffer solutions.

At some point, the electrode would not create a large enough mV change for the controller to recognize. At this point the electrode needs to be replaced. The average electrode will last between one and two years.

Measurement of ORP

The ORP electrode is not temperature sensitive, and therefore automatic temperature compensation (ATC) is not employed.

pH Temperature Compensation

C°	pH2	pH3	pH4	pH5	pH6	pH7	pH8	pH9	pH10	pH11	pH12
5	-.30	-.24	-.18	-.12	-.06	0	.06	.12	.18	.24	.30
15	-.15	-.12	-.09	-.06	-.03	0	.03	.06	.09	.12	.15
25	0	0	0	0	0	0	0	0	0	0	0
35	.15	.12	.09	.06	.03	0	-.03	-.06	-.09	-.12	-.15
45	.30	.24	.18	.12	.06	0	-.06	-.12	-.18	-.24	-.30
55	.45	.36	.27	.18	.09	0	-.09	-.18	-.27	-.36	-.45
65	.60	.48	.36	.24	.12	0	-.12	-.24	-.36	-.48	-.60
75	.75	.60	.45	.30	.15	0	-.15	-.30	-.45	-.60	-.75

Figure 2 - The Effect of Temperature on a pH Electrode

The more oxidizer in the cooling tower water, the higher the mV output of the ORP electrode as shown by Figure 3. At a given chlorine concentration, the ORP increases as the pH decreases. This is because the ORP electrode is responding to the flow of electrons from the organic molecule to the oxidizer molecule, not to the oxidizer concentration. If the oxidizer used is sodium hypochlorite (bleach), it disassociates into hypochlorite ions (OCl-) and sodium ions (Na^+). At low pH levels, hydrogen ions (H+) are available to form hypochlorous acid (HOCl), which is a more active oxidizer.

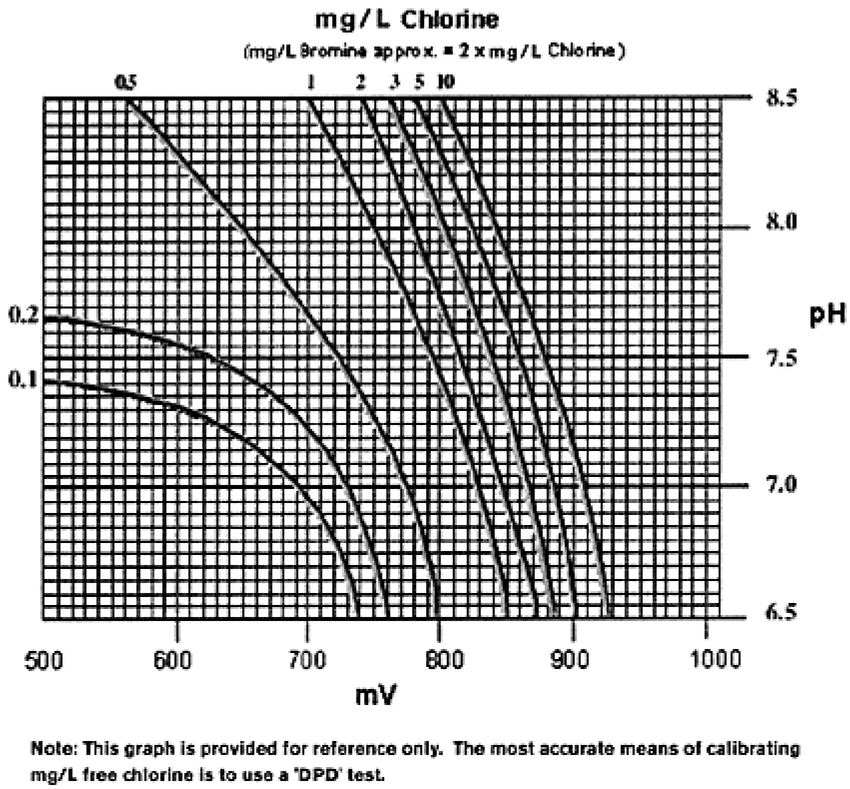

Figure 3 - The Correlation between ORP and mg/L Chlorine at various pH levels.

As shown in Figure 3, the higher the chlorine concentration, the smaller the change in ORP at a given pH. While there may be a 50 mV change in ORP between 0.5 and 1.0 mg/L, it may only be 25 mV between 1.0 and 2.0 mg/L, and once the concentration reaches 10.0 mg/L, the ORP reading changes only slightly. Thus, the chlorine residual must be below 10 mg/L in order to use ORP for control, and the pH must be held relatively constant. Bromine exhibits a similar effect. Each installation has a different response, so the ORP set point is determined on-site by bringing the halogen level to the desired concentration as determined by a chemical test kit, and then adjusting the set point to match the measured ORP reading.

Control of pH and ORP

The controller reads the mV signal from the electrodes, converts them to the true reading of pH or ORP using the calibration data, compares the readings to the programmed set points, and activates or deactivates the control devices (metering pumps or solenoid valves) based on these comparisons. In a vast majority of installations, simple on/off control is sufficient. A relay in the controller closes the supply power to the pump or valve, and opens again once the set point pH or ORP value has been reached.

In rare cases, more accurate control is necessary. Controllers are available that provide a pulse proportional signal to an electronic metering pump. Every time the pump receives a pulse signal, it strokes once. The further the pH or ORP is from the set point, the more frequently the controller supplies a pulse. Another option is for the controller to send out a 4-20 mA signal that is proportional to the process value. A metering pump or proportional valve can receive this signal. The controller must be programmed so that the pump receives 4 mA at the process value where the pump should be off, and 20 mA at the process value where the pump needs to at full speed.

It is important that the pump or solenoid valve be compatible with the controller. In the case of on/off control, this means that the device must operate at the same voltage as the controller provides, and the device must not draw more current than the rating for the control output. In the case of pulse proportional control, the device must accept a dry contact signal, delivered at the frequency that the control will provide, and the voltage drop when the contact opens is sufficient for the pump to recognize. In the case of a 4-20 mA signal, the impedance load that the device puts onto the 4-20 mA loop must be less than the maximum load specified for the control output.

Data Acquisition

It is one thing to have automatic control, and yet another to have a record that the control has been successful. Several options are available for achieving this goal. The simplest and least expensive is to use a controller that has a 4-20 mA output that is proportional to the pH and ORP. This signal may be sent to an inexpensive chart recorder for a paper record of the values. It may also be sent to a more sophisticated data logger, and later downloaded from that to a spreadsheet on a computer. The plant site may have a Distributed Control System (DCS) for recording the data electronically. The only limitation is that the 4-20 mA output cannot have a load connected that exceeds the rating of the output.

Another option is to use a controller that has a digital data output, generally using an RS232 serial port. These controllers are able to store data for 30 days or more, at which time the data can be downloaded into the data file onto a computer and manipulated using various software programs.

This type of setup has a modem installed in the controller. In this case, water treatment professionals may retrieve the date from their offices. These controllers can also notify the water treatment vendor if any alarm conditions exist. If a dedicated computer is connected to the phone line, the data may be sent automatically.

The ultimate data acquisition solution is a controller that is capable of sending the data automatically via email to the vendor's office. There is no requirement for the controller to be online at all times waiting for the information. Since these controllers are sending the information via the Internet, in most cases it is not necessary for a long distance phone call to be made. The controller dials a local Internet Service Provider (ISP) to send the email.

Installation Tips

The electrodes should be installed in a bypass-plumbing loop off the discharge side of the recirculation pump, returning to a point of lower pressure (the sump or the suction side of the recirculation pump). Isolation valves should be installed so that the electrodes may be removed for cleaning and calibration without shutting down the system. Most electrodes must be oriented vertically with the sensing end pointing down.

A flow switch should be incorporated so no chemical injection can take place if the electrodes are in a stagnant sample. Chemical injection should be downstream from the electrodes so that chemical additions are circulated through the sump before contacting the electrodes.

Care must be taken with the wiring between the electrode and the controller. If the signal is not preamplified, the distance between the electrode and the controller must be kept to an absolute minimum, preferably less than 20 feet. Under no circumstances should the cable for an unamplified signal be spliced. All connections must be kept clean and dry. The electrode wires and any other low voltage wiring must be physically isolated in separate conduit at least 6 inches from any AC power lines. Failure to do so will result in unstable, unreliable, and inaccurate readings.

In general, the distance between pumps or valves and the controller can be quite large, since they are AC powered devices. An electronic metering pump has a small suction lift, so it must be installed slightly above the chemical tank. Preamplified electrode signals can generally go 1000 feet, and 4-20 mA signals over 3000 feet. Shielded cable with twisted pairs is preferred.