EVALUATION OF INDUSTRIAL COOLING SYSTEMS USING RECLAIMED MUNICIPAL WASTEWATER

Takashi Asano*, Rafael Mujeriego** and Judith Dickson Parker***

*California State Water Resources Control Board, P.O. Box 100, Sacramento, CA 95801; and Department of Civil Engineering, University of California, Davis, CA 95616, U.S.A.
**Escuela Técnica Superior de Ingenieros de Caminos, Universidad Politécnica de Cataluña, Jorge Girona Salgado, 31, 08034 Barcelona, Spain
***East Bay Municipal Utility District, P.O. Box 24055, Oakland, CA 94623, U.S.A.

ABSTRACT

Evaluation of industrial cooling systems using reclaimed municipal wastewater was made. For an industry, three major conditions which can dictate considerations of water reuse for industrial cooling systems are: 1) scarcity of freshwater supplies, 2) public policy which encourages wastewater reuse, and 3) lower costs than those incurred with freshwater supplies. Several external treatment alternatives are available for the recirculating, evaporative cooling tower operation using reclaimed municipal wastewater (lime clarification, alum precipitation, and/or ion exchange). Internal chemical treatment of cooling tower makeup water is a component common to both freshwater and reclaimed water supplies. In spite of the higher costs of industrial cooling systems using reclaimed municipal wastewater, several conditions encouraging adaptation of wastewater reuse systems for cooling were identified and discussed.

KEYWORDS

Wastewater, water reuse, cooling tower, industrial cooling system, municipal wastewater, pretreatment, cost, institutional consideration.

INTRODUCTION

Use of municipal wastewater for industrial cooling occurs at many facilities worldwide. Total potential use, however, far exceeds these existing applications. The gap between potential and existing applications occurs in part because there remains uncertainty about the mechanics and cost of wastewater reuse for individual cooling facilities.

The purpose of this paper, therefore, is to evaluate specific components of industrial reuse as they affect potential industrial cooling system projects. This will allow identification of measures which potential users may take to facilitate and implement wastewater reuse and to identify their own feasibility of using reclaimed municipal wastewater for industrial cooling systems.

Use of reclaimed municipal wastewater in industrial cooling systems is not new. Bethlehem Steel at Sparrows Point, Maryland, U.S.A., began using Baltimore's Back River secondary treatment plant effluent in 1942 and now utilizes approximately 4.4 m³/s for primary metals cooling. In Oklahoma, Farmland Industries have been using the City of Enid's municipal effluent since 1974 for process cooling, and in California, the City of Burbank's power plant has used City effluent since 1967 (James M. Montgomery, Consulting Engineers, Inc., 1980). The impetus for most users has been a lack of available water supplies and provisions for supply reliability.

INDUSTRIAL COOLING SYSTEM

There are significant variations among large industrial cooling systems. The range includes once-through non-contact cooling such as at large power facilities or refineries near the ocean, direct contact cooling of relatively inert material as in the primary metals industry, and non-contact recirculating cooling at large inland industries with limited water resources.

Once-through cooling transfers process heat to water which is then wasted. Recirculating systems go one step further and transfer the heat from the warmed water to the air so that the water can again be used to absorb process heat. The heat is transferred from water to air primarily through evaporation. Figure 1 shows the basic features of the recirculating, evaporative cooling tower operation. Cool, dry outside air is pulled into the sides of the tower, at a rate of 600-750 m^3 air/m^3 recirculating water, up through and out the top by a fan rotated at the top. Warmed water from an industrial heat exchanger is pumped into the top of the tower and allowed to fall down through the upcoming air stream. Packing inside the tower breaks up the water into droplets to allow efficient air-water contact. A fraction of the water evaporates and leaves the tower as vapor. The cooled remainder falls into a collecting basin at the base of the tower, and is again ready for process cooling.

Evaporation is one of three mechanisms by which water is lost from the cooling system. Generally, evaporation loss comprises about two percent of the recirculating water flow per 10°C temperature drop. Drift, or water lost from the top of the tower to the wind is the second mechanism. About 0.005 percent of the recirculating water is lost in this way. The third mechanism for water loss is tower blowdown. Evaporation removes water from the system without taking salts, and in order to preserve a salt balance in the resultingly more concentrated tower water (such that the solubility of potential precipitants is not exceeded), a certain amount of this concentrated system water is bled off and replaced with low salt make-up water.

The total make-up flow for the cooling system includes all three of these water losses. Figure 2 depicts the water and salt balances in the recirculating, evaporative cooling tower. Quantitatively the water balance may be summarized as follows:

$$Q_m = Q_b + Q_d + Q_e \tag{1}$$

where Q_m is the make-up water flow replacing blowdown flow, Q_b; drift flow, Q_d; and evaporation, Q_e. Q_d is generally small enough to be ignored, and so drops out of the calculations.

In a similar way, the salt balance in cooling tower may be described as follows:

$$Q_m C_m = Q_b C_b + Q_d C_d + Q_e C_e \tag{2}$$

where the "Q" terms are the same in Eq. (1), and the "C" terms represent the concentration of a conservative salt in the specific flows. Again, Q_d is negligible so that the expression $Q_d C_d$ drops out. The concentration of salt in the evaporation water is also zero so that $Q_e C_e$ drops out. The resulting equation sets the low concentration of a conservative make-up salt, C_m, times the relatively larger make-up flow, Q_m, equal to the high concentration, C_b, times the relatively smaller blowdown flow Q_b:

$$Q_m C_m = Q_b C_b \tag{3}$$

The magnitude of the blowdown flow (and thus the make-up flow) is dependent upon the concentration of potential precipitants in the make-up water. These may be concentrated to just below their solubility limits, after which time they must be removed through blowdown and replaced with low salt concentration make-up water. The ratio of the concentration of the conservative salt C_b in the blowdown to its concentration C_m in the make-up water is known as the cycles of concentration: Cycles of Concentration = C_b/C_m. Combining Eq.
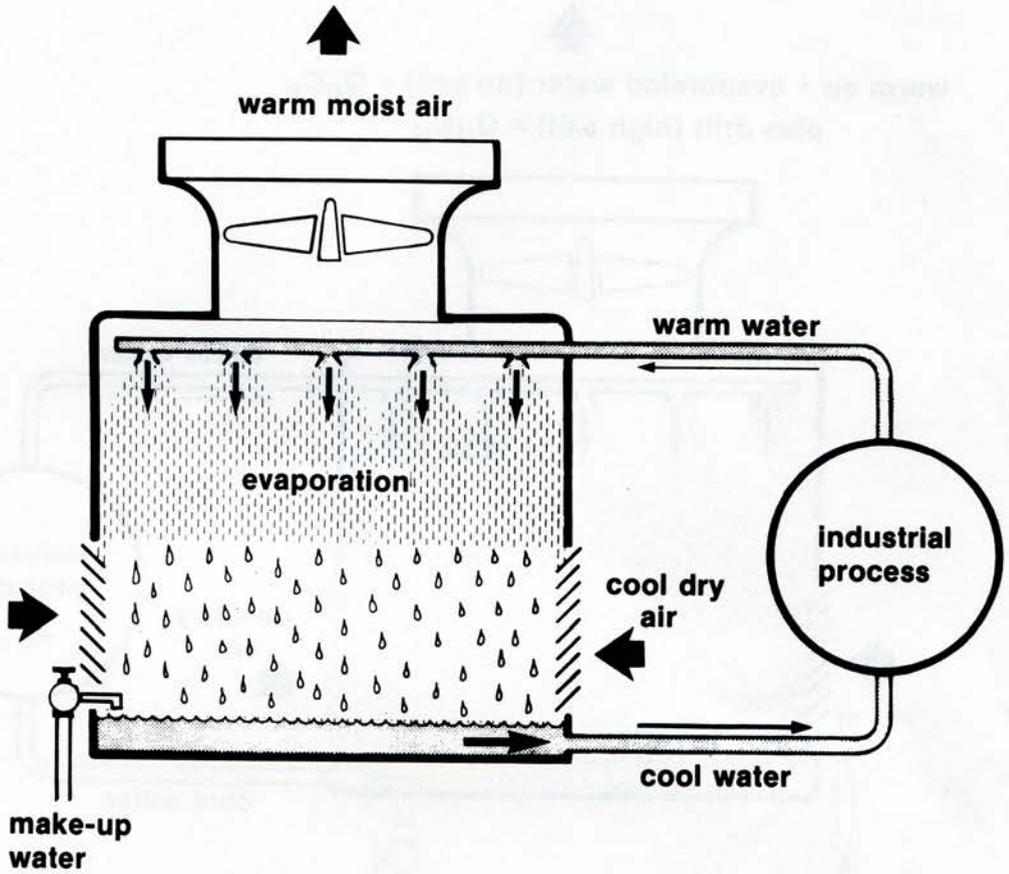
warm moist air

warm water

evaporation

industrial process

cool dry air

cool water

make-up water

Fig. 1. Recirculating, evaporative cooling tower operation

warm air + evaporated water (no salt) = Q_eC_e
plus drift (high salt) = Q_dC_d

warm water

industrial
process

cool dry
air

cool water

make up = Q_mC_m
(low salt)

blowdown = Q_bC_b
(high salt)

Salt in via make up = salt out via blowdown and windage
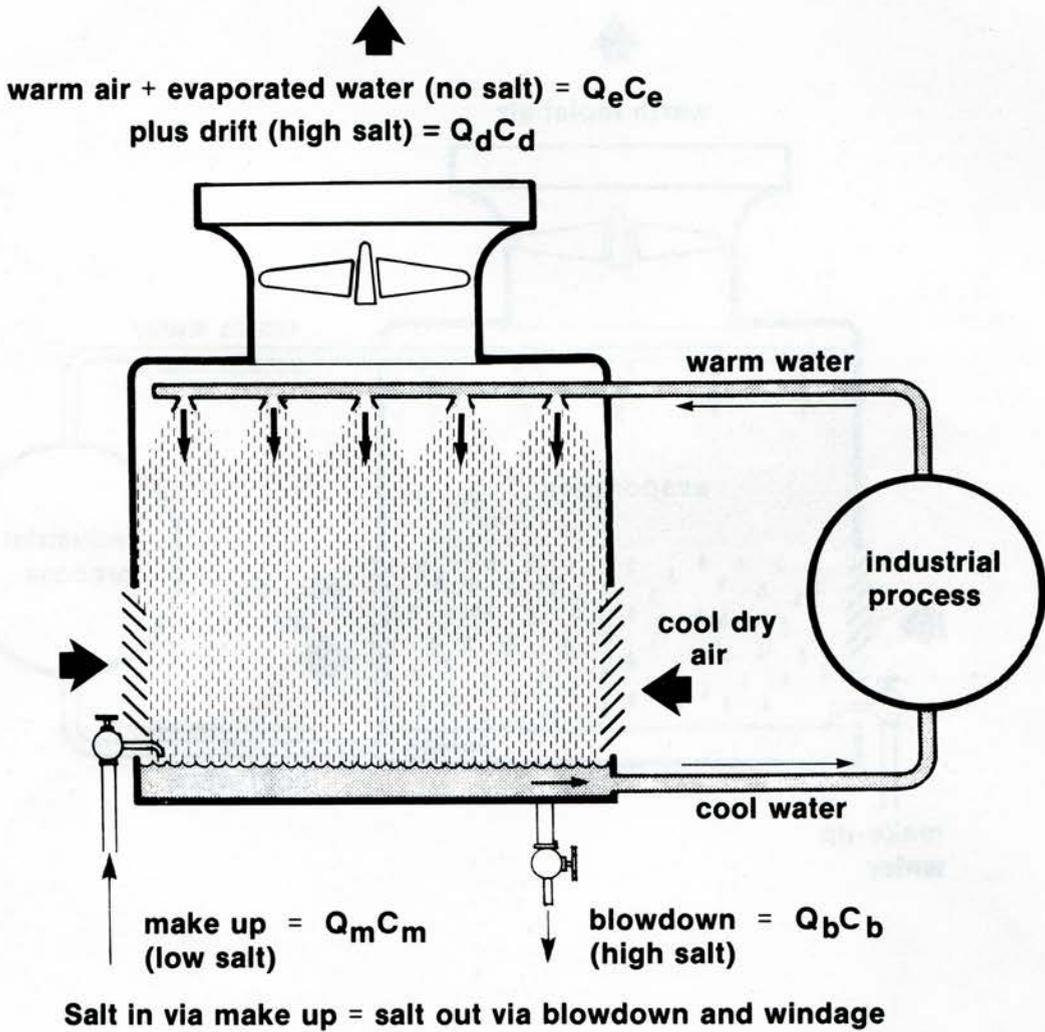
Fig. 2. Definition sketch for mass balance

(3) and the cycles of concentration above, it can be seen that the cycles of concentration are also equal to the ratio of the make-up and the blowdown flows:

$$\text{Cycles of Concentration} = Q_m/Q_b \qquad (4)$$

Figure 3 summarizes water and salt balances and defines cycles of concentration.

WATER QUALITY REQUIREMENTS

Industrial cooling tower operations face four general water quality problems: scaling, corrosion, biological growths, and fouling in heat exchanger and condensers. Both fresh-water and reclaimed municipal wastewater contain contaminants which can cause these problems, but their concentrations in reclaimed municipal wastewater are generally higher.

Scaling. Scaling refers to the formation of hard deposits, usually on hot surfaces, which reduce the efficiency of heat exchange . Calcium scales (calcium carbonate, calcium sulfate and calcium phosphate) are the principal cause of cooling tower scaling problems. Magnesium scales (magnesium carbonate and phosphate) can also be a problem. Silica deposits are particularly difficult to remove from heat exchanger surfaces; however, most waters contain relatively small quantities of silica.

Reducing the potential for scaling in wastewater is achieved by controlling the formation of calcium phosphate, which is the first calcium salt to precipitate if phosphate is present. Treatment is usually accomplished by removing phosphates in a sequence of chemical addition and sedimentation steps. Other treatments, such as ion exchange, reduce scale formation by removal of calcium and magnesium; however, these techniques are comparatively expensive and their use is limited.

Corrosion. Corrosion can occur in systems when an electrical potential between dissimilar metal surfaces is created. The corrosion cell consists of an anode, where oxidation (dissolution) of one metal occurs, and a cathode, where reduction (deposition) of another metal takes place. Water quality greatly affects this process. Contaminants such as total dissolved solids (TDS) increase the electric conductivity of the solution and thereby accelerate the corrosion reaction. Dissolved gases (oxygen) and certain metals (manganese, iron, and aluminum) promote corrosion because of their relatively high oxidation potential.

The corrosion potential of cooling water is controlled by the addition of chemical corrosion inhibitors. The chemical requirements to control corrosion in reclaimed wastewater are usually much higher than for freshwater because the concentration of TDS is often two to five times higher in wastewater. The alternative to chemical addition is to pretreat the reclaimed wastewater by reverse osmosis or ion exchange.

Biological Growth. The warm, moist environment inside the tower makes an ideal environment for promoting biological growth. Nutrients (phosphorus and nitrogen) and available organics (measured by biochemical oxygen demand, BOD) further encourage this growth which can attach and/or deposit on heat exchanger surfaces, inhibiting heat transfer and water flow. Biological growths may also settle and bind other debris present in the cooling water. This may further inhibit effective heat transfer. Certain microorganisms also create corrosive by-products during their growth.

Biological growths are usually controlled by the addition of biocides during the internal treatment process. Because reclaimed wastewater contains a greater concentration of organics it may require larger dosages of biocides. It is, however, possible that most of the nutrients and available organic matter is removed from the reclaimed wastewater during biological and chemical treatment and that the potential for reclaimed water to support biological growth may not be significant.

When reclaimed water is used for cooling, the assurance of adequate disinfection is a primary concern to protect the worker's health. The disinfection requirements for use of reclaimed water in industrial processes are made on a case-by-case basis. The most restrictive requirement, limiting total coliform concentration to 2.2 MPN/100 ml (most probable number per 100 ml), would be applied if there were a potential for workers to be exposed to spray (State of California, 1978).

Flow and Salt Balances

$$Q_m = Q_b + Q_d^{\;o} + Q_e \qquad\qquad \text{Eq. (1)}$$

$$Q_m C_m = Q_b C_b + Q_d^{\;o} C_d + Q_e C_e^{\;o} \qquad\qquad \text{Eq. (2)}$$

$$\boxed{Q_m C_m = Q_b C_b} \qquad\qquad \text{Eq. (3)}$$

Where: Q_m, C_m = make-up water flow and salt concentration

Q_b, C_b = blowdown flow and salt concentration

$$\boxed{\text{Cycles of Concentration} = \frac{C_b}{C_m} = \frac{Q_m}{Q_b}}$$

Fig. 3. Water and salt balances at the cooling tower

The addition of chlorine, chlorine dioxide, or ozone to the wastewater following treatment can disinfect the reclaimed wastewater to a safe level. Chlorine gas is most frequently used because it is readily available, relatively inexpensive, and most treatment plant operators are familiar with the operation of the process equipment.

Fouling. Fouling refers to the process of attachment and growth of deposits of various kinds in cooling tower recirculation systems. These consist of biological growths, suspended solids, silt, corrosion products, and inorganic scales. The resulting operational problem is inhibition of heat transfer in the heat exchangers.

Control of fouling is achieved by the addition of chemical dispersants which prevent particles from reaching certain sizes so that they do not settle. When reclaimed wastewater is used for cooling, the chemical coagulation and filtration processes required for phosphorus removal are also effective in reducing the concentration of contaminants that contribute to fouling. Dispersants are also added to the point of use as usual for freshwater cooling systems.

In many cases, the water quality requirements for the use of reclaimed municipal wastewater are the same as those for freshwater. An example of the water quality requirements for cooling tower make-up water is shown in Table 1. These water quality requirements could be achieved with advanced water treatment (AWT) designed to reduce concentrations of phosphorus (control scaling), suspended solids (control fouling), and microorganisms (control biological growth and pathogens). Additionally, internal chemical treatment such as zinc/chromate treatment would be required to minimize corrosion caused by other contaminants. These include total dissolved solids and minerals which are expensive to remove in conventional unit processes and operations.

TABLE 1 Water Quality Requirements for
Cooling Tower Makeup Water

Parameter[*]	Allowable Concentration[**]	AWT Effluent[***]
Calcium (Ca)	40	37
Sulfate (SO$_4$)	1,150	240
Magnesium (Mg)	30	11
Silica (SiO$_2$)	19	15
Phosphate (PO$_4$)	0.6	0.3
pH, pH Units	6.8 - 7.2	7.2
Chloride (Cl)	90	140
Total Iron (Fe)	0.06	0.1
Total Manganese (Mn)	0.06	0.01
Total Aluminum (Al)	0.06	0.1
Ammonia (NH$_3$)	1.3	0.5
Total Suspended Solids	13	1
Total Coliform, MPN/100ml	2.3	18
Biochemical Oxygen Demand	10	3
Chemical Oxygen Demand	50	19

[*]Concentrations are mg/l unless otherwise stated
[**]Operated at eight cycles of concentration in cooling tower
[***]See subsequent field demonstration project

TREATMENT FOR COOLING WATER

The effluent provided after secondary or tertiary wastewater treatment is acceptable for non-critical, once-through cooling. For recirculating cooling purposes, however, it still contains constituents which, if not removed, would limit industries to very low cycles of concentration in their cooling towers. Industrial pretreatment processes generally include lime clarification, alum precipitation, or ion exchange. Internal chemical treatment involves the addition of acid for pH control, biocide, scale and biofoul inhibitors.

Lime Clarification

Lime clarification is traditionally used for removing hardness from water, but in application to wastewater for industrial cooling purposes, the primary aim is phosphorus removal. The basic phosphorus removal reaction can be written as

$$3HPO_4^{-2} + 5Ca^{+2} + 4OH^- \rightarrow Ca_5(OH)(PO_4)_3 + 3H_2O$$
$$\text{(hydroxyapatite)}$$
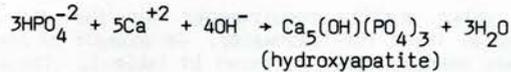
Other precipitants and reactions may occur with different stoichiometric ratios, but the above reaction is illustrative. Softening is a secondary reaction in wastewater lime clarification. Some removal of calcium and magnesium is obtained.
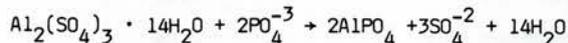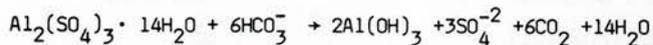
If there is not enough alkalinity in the water to remove sufficient hardness, then soda ash is added to provide necessary alkalinity. This treatment process is termed lime-soda softening. If the pH is sufficiently high, above 10.5, and there is sufficient magnesium in the water, then silica removal through adsorption onto the magnesium hydroxide floc will occur.

Magnesium and phosphorus removal is maximum around pH 11. The pH in the clarifier is controlled by the amount of lime addition, and normally an intermediate pH of 10.5 is selected. At this pH value, good phosphorus and adequate calcium, magnesium and silica removal generally occur.

A sludge of 3 to 4 percent solids is produced in large quantities from conventional lime clarification, and is one of the major drawbacks to operation. The sludge must be dewatered and disposed, or recycled.

Alum Precipitation

Alum is an effective coagulant for phosphate removal. The optimum pH of operation is around 6.0 to 6.5. The reactions may be represented as follows:

$$Al_2(SO_4)_3 \cdot 14H_2O + 6HCO_3^- \rightarrow 2Al(OH)_3 + 3SO_4^{-2} + 6CO_2 + 14H_2O$$

$$Al_2(SO_4)_3 \cdot 14H_2O + 2PO_4^{-3} \rightarrow 2AlPO_4 + 3SO_4^{-2} + 14H_2O$$

Both carbonate and phosphate are removed in the reactions. The pH of the reaction will be reduced somewhat due to the conversion of bicarbonate to carbon dioxide. Calcium and Magnesium are not affected by the alum addition. Some slight silica removal may occur, specially if high doses of alum are used. Generally, however, alum is not the recommended alternative if silica reduction is required.

As with lime clarification, alum precipitation produces a sludge which must be disposed. The amount of alum sludge produced per cubic meter of effluent is about one-third the amount of lime sludge; however, it is generally more difficult to thicken and dewater.

Ion Exchange

Three ion exchange processes which are suitable for treatment of reclaimed wastewater for cooling purposes are: 1) sodium ion exchange (NAX) 2) weak acid ion exchange (WAX), and 3) split stream ion exchange with sodium and hydrogen resins in combination (SANAX).

Sodium ion exchange can completely remove the hardness ions from water, replacing them with sodium. However, the NAX process does not remove the alkalinity of the water and, as a result, large amounts of acid are still required for pH adjustment in the cooling towers. Another disadvantage of the NAX process is that by replacing each calcium or magnesium ion with two sodium ions, the TDS of the product water is somewhat higher than in the effluent.

Weak acid ion exchange utilizes a weak acid resin in the hydrogen form. Cations replace the hydrogen ion functional groups and the released H^+ ions then react with the solution alkalinity and convert it to carbonic acid, which is subsequently stripped from the water as CO_2.

The main drawback of the WAX process is that the resin is operational only down to pH 4.5, after which point replacement ceases. In waters where the hardness exceeds the alkalinity, the resin will remove the alkalinity, the pH will drop and the excess hardness will remain.

In the split stream ion exchange process, a portion of the flow is sent through a sodium ion exchanger and the remainder through a strong acid exchanger in the hydrogen form. The strong acid process is similar to the weak acid described above, but it is not limited by pH; all the cations are removed and replaced with H^+ ions. The effluent from this exchanger is completely softened, but acidic. The two effluents are mixed and the residual acid from the strong acid stream neutralizes the remaining alkalinity from the NAX stream. The net result is a completely softened, neutral water.

Filtration

After clarification, filtration may be desirable to further reduce turbidity and suspended solids ahead of the cooling tower. Alternatively, or in addition, sidestream filtration of recirculating tower water can aid in maintaining a low suspended solids load.

Filters can be of either the pressure or gravity type design. Pressure filters are used whenever the incoming water is supplied under pressure. Although pressure filters are generally less expensive than gravity, for the same capacity, this will vary according to the specific application.

Sludge and Brine Disposal

Sludge disposal for either lime or alum treatment can constitute a major component of the pretreatment system. The appropriate system of sludge handling and disposal is site specific. Because alum sludge is quite dilute, it may be possible in some areas to discharge directly to the sewer. For lime and most alum sludges, however, if land is available and the climate dry, then direct disposal to lagoons is the easiest and cheapest method. Recycling of lime through recalcination is an attractive disposal alternative, but is generally not cost effective.

The waste stream from regenerating ion exchange systems can also present disposal problems. If groundwater contamination is not a problem, then lagoon spreading and evaporation are possible. Otherwise, evaporation in lined ponds may be a feasible alternative.

Internal Chemical Treatment

Internal chemical (and/or mechanical) treatment of tower make-up water provides further protection against scaling, controls pH, and retards corrosion, fouling, and microbiological growth. The types of chemicals utilized for freshwater or reclaimed make-up water supplies are the same, however, the specific formulations and doses may differ.

One of the two general treatment programs is utilized for quality control within the cooling system: acid or alkaline. An acid program is usually selected when scale is a problem; the low pH increases the solubility of many scale forming constituents. On the other hand, at these lower pH values, corrosion is enhanced, and corrosion inhibitors became an important aspect of the internal treatment. Chromate or chromate-zinc products are extremely effective corrosion inhibitors, however, their use is now often restricted by waste discharge limitations. To avoid or reduce corrosion problems, an alkaline treatment program may be utilized. Scale inhibitors or dispersants then become the primary components of internal quality control.

For some cooling operations, mechanical cleaning systems can be utilized to significantly reduce internal chemical requirements. These are soft rubber, plastic or metal devices which are specifically sized to scrape through the heat exchanger tubes and prevent deposition of contaminants. In the appropriate application, these can be very effective. Most of these systems are quite expensive and are most appropriate for single large heat exchangers such as are found in power plants. They may also be warranted for critical application for exchanges in the petrochemical industry where it is necessary to avoid removing the exchanger from service for periodic maintenance.

Blowdown Treatment and Disposal

Cooling tower operation is dictated to a certain extent by waste discharge requirements. For example, if an industry discharges to an open channel or to a wastewater treatment plant, limitations on specific constituents may force low cycles of concentration, industrial blowdown treatment, or use of alternative programs. At Burbank Power Company, for example, TDS discharge standards limit operations to 2.0-2.5 cycles of concentration.

Any constituents which exceed discharge requirements must be removed or neutralized. Continuing Burbank's example, even with their moderate cycles of concentration, the blowdown TDS must be diluted with additional reclaimed water before discharge. Waste discharge permits or pretreatment regulations for cooling tower operations generally place limits on temperature, pH, BOD, COD, suspended solids, and toxics (chromate and metals). Treatment can include dilution, ion exchange for metals removal, or more rigorous and expensive methods such as chemical or electrochemical reduction of chromium followed by alkaline precipitation (James M. Montgomery, Consulting Engineers, Inc., 1980).

The above descriptions of pretreatment and internal treatment provide a general background of currently accepted methods of treatment of reclaimed water for cooling purposes. Further information on principles and applications of the specific unit process or operation may be found in several references including James Montgomery Engineers (1985) and Culp/Wesner/Culp (1986).

FIELD DEMONSTRATION PROJECT

The East Bay Municipal Utility District (EBMUD), with headquarters in Oakland, California, conducted a pilot study to evaluate reclaimed municipal wastewater for industrial cooling. Studies conducted by the EBMUD have identified sources of reclaimable wastewater and potential users. Among them, the largest potential user is a local oil refinery where it is estimated that approximately 19,000 m^3/d of potable water currently used for cooling could be replaced by reclaimed municipal wastewater.

The refinery operates eleven recirculating cooling towers having a total potable water consumption of approximately 42,000 m^3/d. Water is cycled up in these towers to ten cycles of concentration before reaching an operating limit of 600 mg/l (as $CaCO_3$) of calcium hardness. Zinc/chromate treatment is used to inhibit corrosion. Other internal treatment chemicals include dispersants (to control scaling), sulfuric acid (pH adjustment) and chlorine (control biological growth).

The water quality requirements for use of reclaimed water are the same as those that already exist for use of potable water. Preliminary water quality requirements (Table 1) were provided by the refinery to minimize these problems (Parker et al., 1987).

Advanced Water Treatment Pilot Plant

The advanced water treatment (AWT) processed a maximum of 7.8 l/min in two parallel treatment trains. Treatment processes included chemical coagulation, flocculation, sedimentation, pH adjustment, filtration, and disinfection. In addition, single vs. two-stage recarbonation was evaluated during the dry weather period. Soda ash softening was added to the process, and single and two stage softening were evaluated.

Cooling Loop Pilot Plant

Stored AWT effluents were transferred to the other trailer, where they were tested in the two parallel cooling tower/heat exchanger loops, each having a recirculating flow of 3.8 l/min. These systems included the cooling tower, chemical injection pumps (sulfuric acid, zinc-chromate, phosphate/polymer dispersants), heat exchanger tubes, make-up rate control valves and on-line process monitoring equipment.

For this study, refinery conditions were simulated by: mild steel and admiralty brass tubes in the heat exchanger, skin temperatures at 92.2 degrees Celsius and bulk water temperatures in and out at 46.7 and 48.9 degrees Celsius, respectively. Process monitoring included corrosion rates, pH, fouling, and conductivity. During the dry weather test period, the conditions maintained in the recirculating water were: pH 6.0-7.1, dispersant dosage 150 mg/l, conductivity 6,000 μS/cm and calcium hardness 600 mg/l (as $CaCO_3$). For the wet weather tests, the conductivity was allowed to reach 10,000 μS/cm with calcium hardness at 800 mg/l (as $CaCO_3$).

Findings

1. Calcium hardness of 150 mg/l (as $CaCO_3$) limited the number of cycles to about five compared to 10 attainable with potable water. Both single and two stage high lime clarification processes produced the similar results.

2. The phosphate/polymer internal treatment program was more effective than the zinc-chromate program in reducing fouling and corrosion in heat exchangers when AWT effluent was used as cooling medium.

3. Both single and two stage softening achieved the target calcium hardness reduction to allow a minimum of eight cycles of concentration in the cooling tower/heat exchanger system.

The field demonstration project showed the suitability of the EBMUD reclaimed wastewater for industrial cooling. Initially, the main treatment goals were to reduce the concentrations of phosphate, suspended solids, and coliforms. Lime coagulation was effective in this purpose; however, its use resulted in excess effluent calcium and higher costs of internal treatment. As a result, the main treatment objective became softening. The best combination of phosphate and calcium effluent levels at the lowest cost of AWT and internal treatment was single stage lime/soda coagulation at a pH of 10.8.

ECONOMIC AND INSTITUTIONAL CONSIDERATIONS

The specific cooling systems examined in the Montgomery Engineers study (1980) and the EBMUD pilot study (Parker et al., 1987) demonstrated a direct relationship between water quality and number of feasible treatment options, and an indirect relationship between water quality and treatment costs.

In all cases, however, the cost of these systems is quite high. As an order of magnitude, to treat 8 m^3/min of reclaimed water to a level acceptable for cooling purposes costs about $600,000/year, which represents an average cost of $0.15/$m^3$. If lime sludge handling and disposal are required, then the cost increases to approximately $700,000/year, bringing the average cost of $0.17/$m^3$. The largest single cost is pretreatment O and M,* which represents around 55% of the water treatment total cost. Annualized pretreatment cost represents about 18%, and internal treatment about 27% (James M. Montgomery, Consulting Engineers, Inc., 1980).

For an industry, three major conditions which can dictate considerations of wastewater reuse for cooling towers are: 1) scarcity of freshwater supplies, 2) public policy which encourages wastewater reuse, and 3) lower costs than those incurred with freshwater supplies. While the first two conditions are likely to apply in many places, it will be rare that the costs of the operation with reclaimed water are lower than with freshwater. The most important aspect of industrial cooling systems is the reliability of supply provided by reclaimed municipal wastewater. As a locally developed supply, essentially unaffected by climate, its delivery can be easily assured even in drought years.

SUMMARY AND CONCLUSIONS

Evaluation of the use of reclaimed municipal wastewater in industrial cooling systems in the U.S.A. was made, and the following findings and conclusions are reported herewith:

1. Most existing industrial reuse applications occur where freshwater supplies are virtually unavailable. The industries concerned have typically selected those particular locations because other more important raw materials or resources were available.

*O and M = operation and maintenance

2. Some type of industrial pretreatment is required for reclaimed wastewater in order to allow operation of the cooling tower at cycles of concentration comparable to those achieved with freshwater supplies.

3. The treatment processes more appropriate for treating the reclaimed water supplies are: lime clarification, alum precipitation or ion exchange. Which process is most effective depends on the quality of water being treated and sludge and brine disposal.

4. Each of those external treatment alternatives produces either a sludge (lime or alum processes) or a brine (ion exchange process) which must be disposed. The availability of appropriate waste disposal facilities can be a determinant factor in the selection of a cost-effective pretreatment system.

5. Internal chemical treatment of tower make-up water is a component common to freshwater and reclaimed water supplies. The types and doses of chemicals required for the reclaimed water will depend upon the effectiveness and the preceeding external treatment in removing residual contaminants and allowing increased cycles of concentration.

6. Reclaimed water can usually be purchased for a much lower price than freshwater. However, the costs associated with reclaimed water pretreatment, internal chemical treatment, and sludge or brine disposal will typically exceed the costs associated with internal treatment of freshwater, some cases by about 75%.

7. A reclaimed water project includes necessarily several institutional components, among them the contractual arrangements for the purchase and delivery of reclaimed water, and health and environmental constraints on the use and disposal of reclaimed water, and the regulations on the disposal of sludges and/or brines. Most of these components will apply regardless of the type of water supply, reclaimed or freshwater, and their cost of compliance will be comparable in either case.

8. In spite of the higher costs of industrial cooling systems using reclaimed municipal wastewater, three conditions encourage adoption of this alternative: 1) the uncertainty of future freshwater supplies, 2) the reliability of locally-developed reclaimed water supplies, and 3) a public policy favoring reuse.

REFERENCES

Culp/Wesner/Culp (1986). Handbook of Public Water Systems. Van Nostrand Reinhold Co., New York, N.Y.

James M. Montgomery, Consulting Engineers, Inc. (1980). Evaluation of Industrial Cooling Systems using Reclaimed Municipal Wastewater: Application for Potential Users, prepared for Office of Water Recycling, California State Water Resources Control Board, Sacramento, California.

James M. Montgomery, Consulting Engineers, Inc. (1985). Water Treatment: Principles and Design. John Wiley and Sons, New York, N.Y.

Parker, J.D. et al., (1987). Evaluation of Reclaimed Wastewater for Industrial Cooling: A Pilot Study. Proceedings of the Water Reuse Symposium IV, AWWA Research Foundation, Denver, Colorado.

State of California, Department of Health Services (1978). Wastewater Reclamation Criteria. California Administrative Code, Title 22, Division 4, Sacramento, California.