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Water Use and Related Costs with Cooling Towers

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ABSTRACT

Methods of water use for heat dissipation are evaluated, with emphasis on simplification of annual cooling tower cost estimates. Tower costs for initial equipment and installation, annual fixed costs, and operating costs are considered. Results of the study are presented in an easy-to-use, step-by-step form so that estimates for specific cases may be made and compared with estimated costs of non-conservation practices. It is recommended that if costs of once-through and conservation methods are within about 30 per cent of each other, a thorough study of cooling water needs is justified.

INTRODUCTION

In studying the water resources of northeastern Illinois to determine their ultimate availability in relation to predicted requirements, considerations of reuse and conservative measures are necessary corollaries which demand attention. Economic factors as well as water availability determine whether conservation practices are adopted. The fact that water conservation measures are a common practice, which has led to the development of a now sizeable allied industry, testifies to a degree that localized needs do exist and that such measures can be economical. This study is primarily concerned with an economic evaluation of cooling towers for water reuse plus comparable evaluation of self-supplied or purchased water for once-through use.

In judgment on use of cooling towers for conservation of water it should be recognized that the quantitative need for make-up water for cooling towers is low, but such water is largely consumed (evaporated) and the small remainder is degraded for subsequent reuse when released from the tower because of the accumulation of minerals. For once-through use of water for cooling the quantitative needs are relatively high, but usually less than one per cent is consumed and the discharge is generally degraded only by a rise in temperature.

This report presents the results of an examination of cooling tower costs in a ready and easy-to-use form, so that approximate costs for specific cases may be estimated and compared with the costs of non-conservative practices. If the derived costs are inclose range to or less than the present or projected costs of existing water use systems, a complete and thorough study of cooling water needs is justified. It is not the purpose of this report to replace the specialized competence of the consulting engineer or the water treatment consultant.

Although this report is concerned primarily with northeastern Illinois which has suffered from what is probably one of the greatest ground-water recessions in the world, the results and factors considered are applicable to most areas where preliminary estimates for relative economic evaluation are desired.

Of particular interest from this study was the chemical savings that can be realized by permitting mineral concentrations in the cycled water in cooling towers to increase 5- to 10-fold rather than 1.5- to 2.0-fold as commonly practiced. Although by percentage the greatest water savings are experienced at 1.5 to 2.0 concentrations of minerals, significant reduction in water needs can be obtained when greater controlled concentrations of minerals are permitted in the cycled water. This has greater significance for the larger installations, and can amount to several million gallons in a few months.

The specific areas of cooling costs considered in this report are:

1) Initial cost of equipment and installation exclusive of alterations to the existing system

2) Annual fixed costs including amortization, depreciation, interest, taxes, insurance, rent

3) Annual operating costs including water, treatment, power, maintenance, etc.

Suggestions for relating these to self-produced and purchased water use on a comparable basis are included.

Acknowledgments

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ESTIMATION OF COOLING TOWER COSTS

Cost data, provided by many cooling tower manufacturers on their respective types of towers, were assembled and compared on a common basis.

Although a number of factors influence the relative costs of cooling towers, the type of construction -- whether all wood, metal with wood trim, galvanized iron, aluminum, stainless steel, or other material -- is a primary factor.

The ratio of air to water flow is also a factor because the higher this ratio the smaller the tower frame. The smaller tower frame results in lower initial cost, but at the sacrifice of higher operating costs due to greater fan power required for increased air flow. This operating cost is further related to the type and location of the fan.

Initial costs are also related to pump head requirements. High pump head towers generally have a lower initial cost, but again the operating power and maintenance costs are greater. The efficiency of the packing design is another factor in this respect, since many different types of packings can be used to break up the water so that it will have good surface contact with the air. The two most common types are the film flow packings and the splash packings.

Correlating costs for equipment with this number of variables is therefore difficult and hazardous and has necessitated numerous assumptions. The relative rating factor developed by The Marley Company provided a common denominator for the correlation. As applied in this report, the derived costs should be within approximately 10 to 30 per cent of the actual costs providing the proposed installation complies reasonably well with these primary assumptions:

1) The tower is installed on-grade
2) The tower is in reasonably close proximity to the equipment it is to serve
3) No special provision is made to conceal the tower's existence (aesthetic appeal).

Special considerations not included in these assumptions will require additional expenditures, and are necessarily omitted from the correlations in this evaluation. Aesthetic appeal, for instance, could dictate supplementary expenditures greater than the combined tower, accessories, and installation costs.

To compute individual cooling costs based on the methods in this report, the following information (also see list of abbreviations) is required:

1) Required cold water temperature (CWT)
2) Expected hot water temperature (HWT)
3) Design wet bulb temperature (WBT); see table 1
4) Circulation rate of water in gpm (L), or the heat dissipation rate (Q) in Btu per hour (Btuh)

ABBREVIATIONS

R	Range (HWT-CWT)*
A	Approach (CWT-WBT)*
HWT	Hot water temperature*
CWT	Cold water temperature*
WBT	Wet bulb temperature*
RRF	Relative rating factor
L	Circulation rate, gallons per minute (gpm)*
MU	Make-up water, gallons per hour (gph)
Q	Heat dissipation rate in Btu per hour (Btuh)
C	Concentrations

**From the Cooling Tower Institute Bulletin NCL 109*[2]

5) Mineral analysis of the water supply
6) Cost of water
7) Cost of power
8) Knowledge of the variables involved in the fixed cost of ownership (taxes, interest, etc.)

With this information it is then possible to use this report to estimate initial cost, the costs of power, maintenance, water treatment, make-up water, and basic fixed costs for cooling tower installations and operation. Certain descriptive matter is included for clarification, and supplementary explanations of derivations are discussed.

Initial Cost

The relative rating factor (RRF) is a measure of the degree of difficulty to obtain the required performance. A relative rating factor of 1.0 has been assigned to the arbitrary standard conditions of range (R) = 10F, approach (A) = 10F, and design wet bulb temperature (WBT) = 70F. The range and the approach parameters define the relative rating factor for specific design conditions. Design wet bulb values may be obtained from table 1. The relative rating factor used for selection of tower size can be obtained from figure 1, and the total initial cost may then be derived from the nomograph in figure 2. This cost includes installation of the tower, and all pumps, controls, piping, and wiring associated with the tower.

Table 1. Wet Bulb Temperatures

City	Summer 24-hour average*	Summer 9-hour** average	
Chicago	63	65.1	
Joliet	62.8	----	
Peoria	63.9	68	
Springfield	65.3	68.3	
St. Louis	66.6	68.8	
	Annual 24-hour average	**Annual 9-hour** average**	**Design*** wet bulb**
Chicago	45.2	47.3	74.8
Joliet	----	----	75.3
Peoria	----	----	75.6
Springfield	----	----	76.8
St. Louis	49.7	51.6	76.8

(Data tabulated by meteorology 'section, Illinois State Water Survey, from U.S. Weather Bureau airport records 1949-56 and from Fluor Products Company 3)

* *Median values are about 1.5F higher*

** *8:00 AM to 5:00 PM*

*** *Design wet bulbs are those which will be exceeded only 5 per cent of the hours in the period June 1 through September 30.*

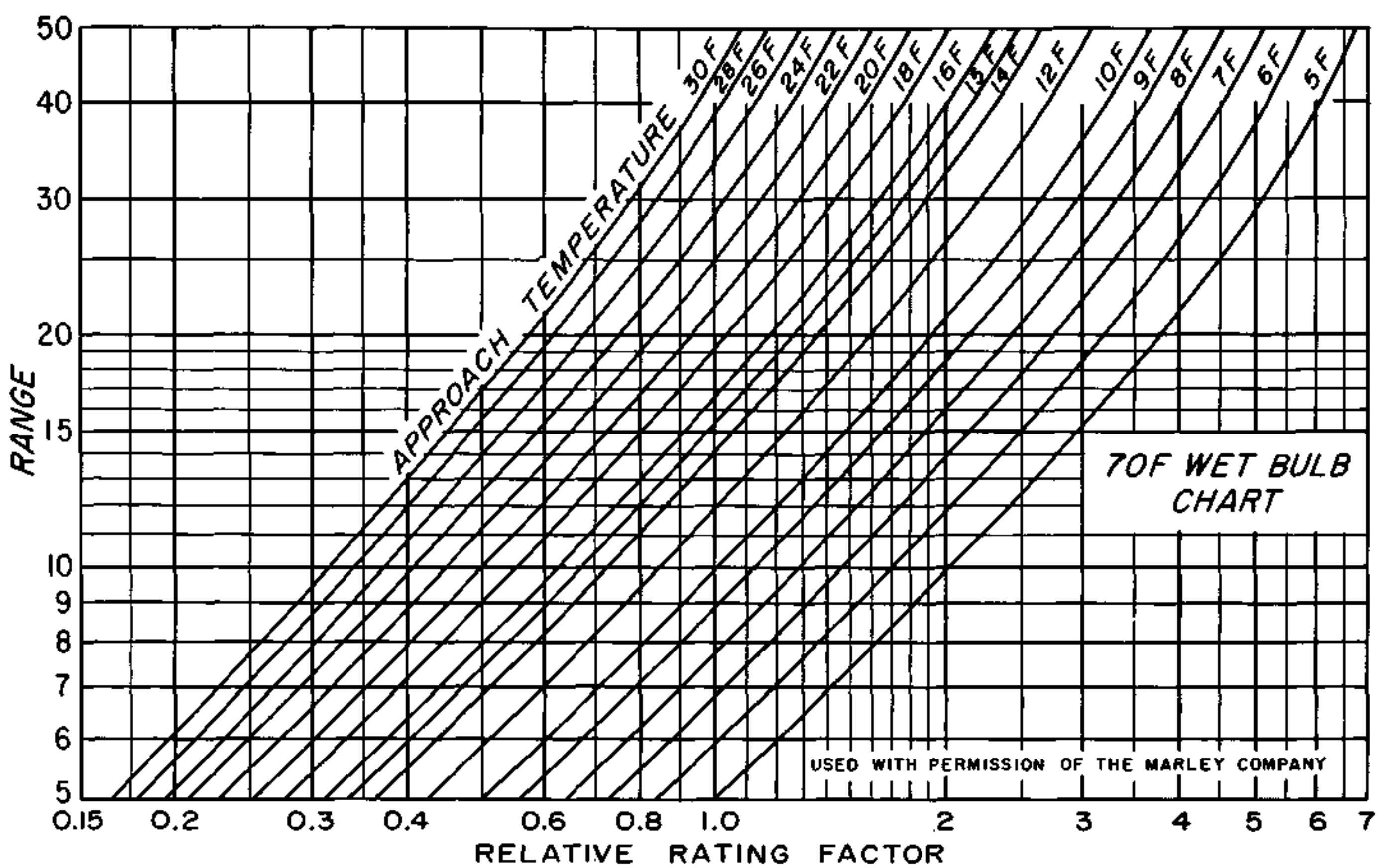

Figure 1. Relative rating factor chart

To determine total initial cost, first calculate the range (R) and approach (A), then enter figure 1 with these values to select a relative rating factor (RRF). With this relative rating factor, the water flow rate (L), and the design wet bulb temperature (WBT), enter figure 2 to obtain the total initial cost as in the illustrative example below.

If the cooling water circulation rate is not known, it can be determined (ingallons per minute), from the heat dissipation rate (Q) in Btuh and the temperatures (HWT and CWT) by using the equation

$$L = \frac{Q}{500\ (HWT - CWT)}$$

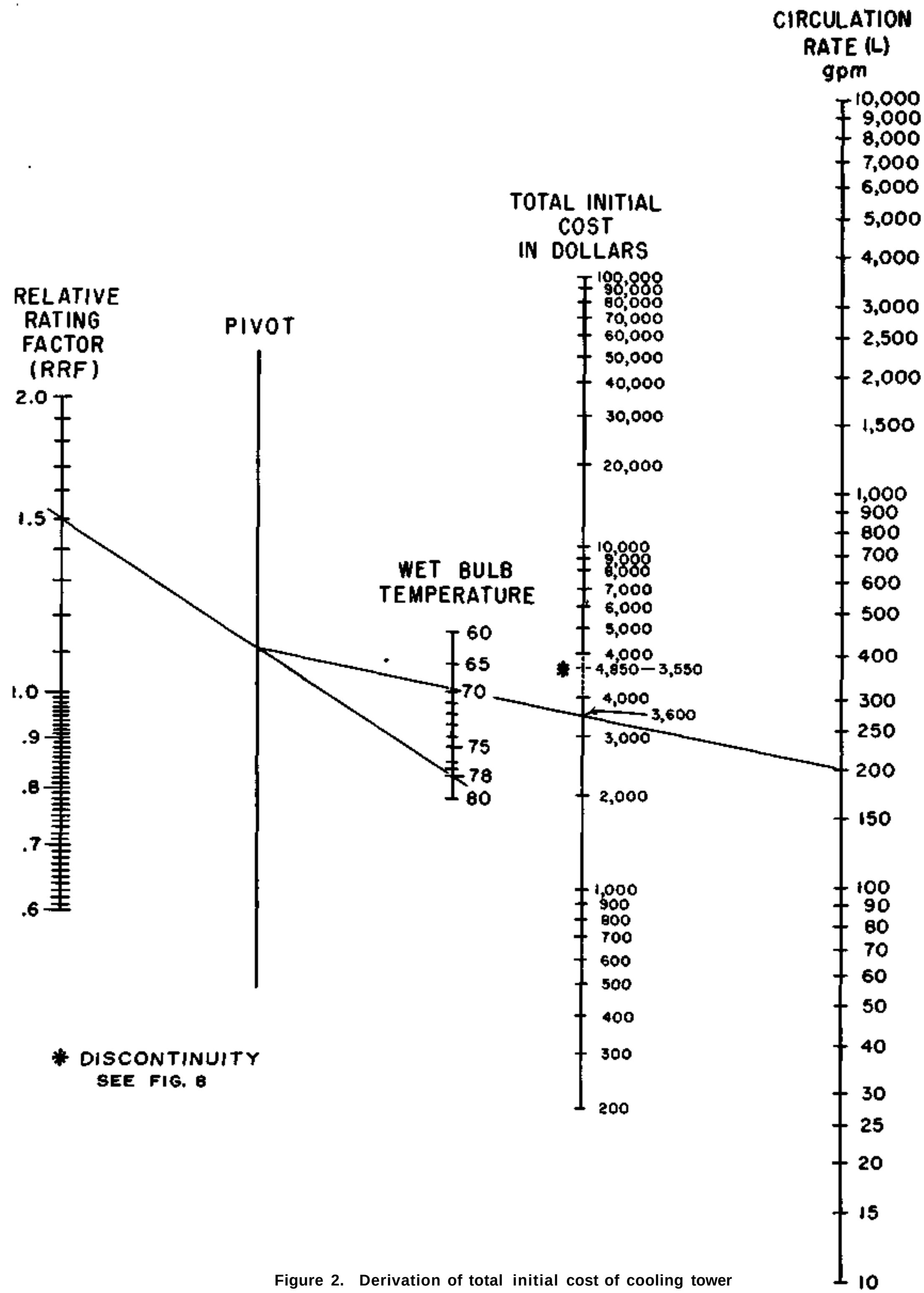

Figure 2. Derivation of total initial cost of cooling tower

Example problem:

Estimate the total initial cost required to cool 200 gpm from 94.8F to 84.8F when the wet bulb temperature is 78F:

R = 94.8 - 84.8 = 10F
A = 84.8 - 78 = 6.8F
From figure 1, RRF = 1.5

Enter figure 2 and place a straightedge between the 78F WBT point and the RR F = 1.5 point. Place a straightedge between the intersection point on the pivot line and the 200 gpm point on the Lscale. The cost scale thus reads $3,600. This is the approximate initial cost of a complete cooling tower installation (includes tower, pumps, piping, controls, and, electrical wiring) to cool 200 gpm from 94.8F to 84.8F when the wet bulb temperature is 78F.

Fixed Costs

The fixed cost of ownership can now be determined according to individual accounting procedure. This cost should include such items as taxes, depreciation, insurance, and interest.

Power Costs

Figure 3 is a nomograph for the determination of the power requirement in kilowatts per hour. This requirement includes the fan power and pumping power attributed to the tower only. The prevailing power costs must be used with these values to determine a per hour cost-of-operation figure. A straightedge is used with this figure following the same procedure outlined for figure 2.

The power consumption will not be constant over a whole year or season. This is due to capacity modulation which is dependent upon the type of control system, the type of service, and the weather conditions. For this reason, it is necessary to either correct the full load operating hours as calculated or given in table 2, p. 11, or to adjust the power requirement.

For estimation purposes, the power requirements can be corrected for a particular CWT and R by using an <u>average</u> wet bulb temperature for the period of operation instead of the design wet bulb temperature. With these values the RRF chart (figure 1) can be used with the average approach (CWT-WBT), and the same procedure can be followed in figure 3 as that outlined for figure 2.

Table 1 lists the average wet bulb temperature for some locations in and near Illinois, as well as the normal design wet bulb temperatures.

Maintenance Costs

For lack of a specific application, maintenance costs may be assumed equal to the power costs. This assumption is recommended[4] as a good preliminary estimate.

Additional Power Costs

The pump power for existing heat transfer equipment (heat exchangers, etc., exclusive of connecting piping) in remodeled systems can be estimated by the following elementary procedure.

Estimate the new head loss as

$$\text{new head loss} = \left(\frac{\text{L, new}}{\text{L, old}}\right)^2 \times \text{old head loss}$$

Additional head loss for connecting piping must be added to this head loss. With the combined new head loss, and an assumed per cent efficiency of 40 to 70, the pump power in kilowatts per hour may be calculated from the following equation

$$\text{pump power} = \frac{(\text{L, new})\ (\text{head, in ft.})\ 100}{3960\ (\text{per cent efficiency})}$$

For new heat transfer equipment, it will be necessary to refer to manufacturers' data for the prediction of head loss. The ASHRAE Guide[5] provides greater detail on head loss calculations for an entire system.

Water Treatment

The role of water treatment in cooling tower operations is an important economic consideration, since equipment maintenance and operation efficiency as well as water savings are dependent upon it. Scale and corrosion problems, which can be serious in once-through cooling systems, are usually accentuated when water is recirculated in cooling tower systems. However, with proper water treatment, water savings of nearly 99 per cent are possible.

The cooling tower is designed to evaporate water as it is circulated through the tower. This evaporation lowers the temperature of the remaining circulated water. As the evaporation takes place, the mineral salts (present in all water sources) remain in the circulated water and increase in concentration. As water is evaporated, make-up water is added to maintain the volume of circulated water.

The concentration (C) refers to the number of times that the original minerals in the circulated water are concentrated or increased by continuous evaporation. The circulated water volume may therefore develop 2, 3, 10, or 20 concentrations of mineral salts, depending on the chemical treatment design and corresponding operation criteria.

The first necessity for avoiding excessive concentration of minerals in the water is to withdraw periodically, or continuously, a portion of the circulated water and to dilute the remainder with fresh water. This withdrawal is similar to that practiced in the operation of boilers for steam generation and is called blowdown. Excessive blowdown rates are wasteful, and efficient operation dictates that minimum blowdown be practiced and that maximum minerals be retained as consistent with economy and freedom from scale and corrosion.

Chemical treatment is therefore primarily designed to prevent the problems which result from

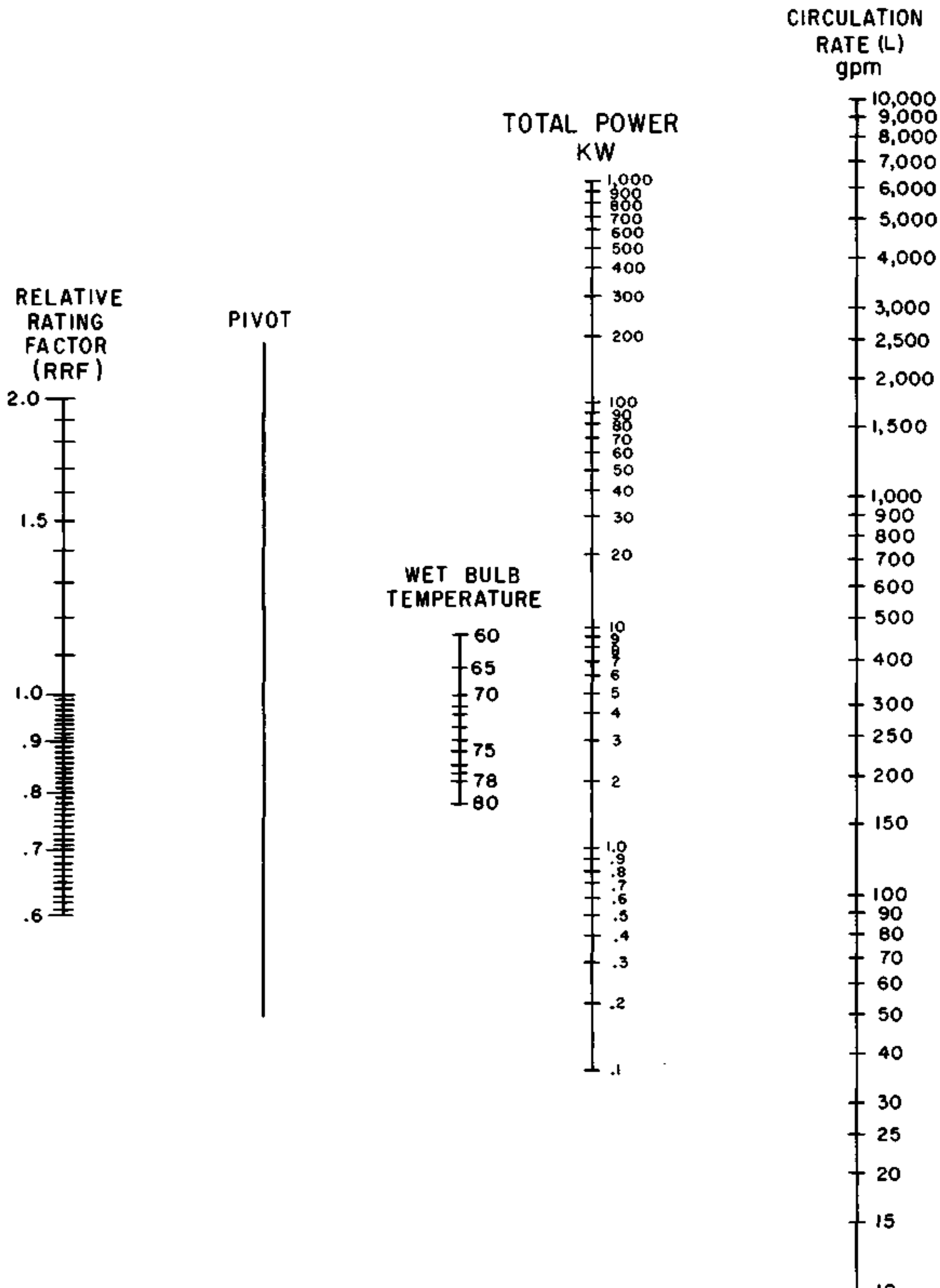

Figure 3. Total power requirement for tower

high mineral concentrations. Either internal or external treatment or both may be applied. Internal type treatments, involving addition of chemicals including scale and corrosion inhibitors, often prove to be less expensive than external pretreatment since the equipment costs are low (less than $600) and the chemical costs are reasonable.

During evaporation, carbon dioxide (carbonic acid) is lost to the atmosphere and thereby causes the circulated water to become more alkaline. In the presence of calcium hardness this causes scale deposits. To avoid this, the water may be treated with acid, and because of cost, sulfuric acid is usually specified.

Other methods of treatment are designed to reduce or remove the hardness in the make-up water. The two most generally used are external softening methods, the cold lime softening process and the sodium zeolite softening process. These are discussed in the third section, p. 15. Others may be competitive in effectiveness and in cost.

The direct acid application (along with scale and corrosion inhibitors) as an internal treatment preferably requires proportioning equipment for controlled application of the chemicals to the make-up water. The cost of treatment in cents per 1000 gallons of make-up water (MU) may be calculated from the following formula, where *A* is the alkalinity (as $CaCO_3$) of the make-up water:

$$\text{cost} = 0.033A + \frac{74}{C}$$

Concentrations

Assuming proper scale and corrosion prevention treatment, the maximum cooling tower concentration (C) is usually limited bythe calcium and sulfate contents in the circulated water. These limits are dictated by the solubility of calcium sulfate. Since hardness (H) is related to the calcium concentration and is also a reasonable empirical measure of the "effective" sulfate concentration in acid-treated make-up waters, this readily available parameter can be employed in the following equation for estimating the maximum permissible concentration ratio (C) for minerals in the circulating water to the minerals in the make-up water. The equation is

$$C = \frac{2400}{H}$$

In order to demonstrate savings in water and chemical costs by maintaining high concentration ratios in the circulating water, graphical examples are provided in figures 4a and 4b. The make-up in gallons per hour for selected concentration ratios can be obtained from figure 5, p. 10.

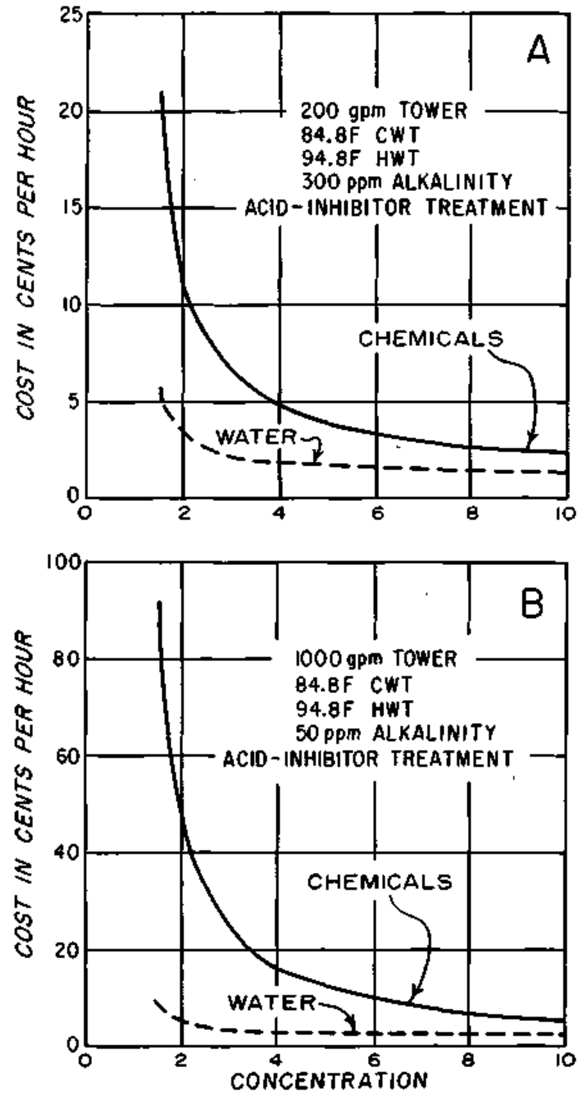

Figure 4. Decrease of operating cost with increasing mineral concentration for circulation rates of 200 gpm (A) and 1000 gpm (B)

Example 1:

In figure 4a, a 10F range with a 94.8F hot water temperature, a 200 gpm circulation rate, and a cost of 15 cents per 1000 gallons were assumed. Using the derived make-up requirements, the water cost per hour is indicated by the dashed line. With internal acid treatment and an assumed alkalinity of 300 ppm in the make-up water, the estimated cost of chemicals per hour from the treatment cost equation is indicated by the solid line. The combined cost is 4.3 cents per hour at C = 10.

By way of comparison for the same heat load and hot water temperature, and a water supply temperature of 60F at a cost of 15 cents per 1000 gallons, the once-through water cost would be $1.80 per hour without water treatment.

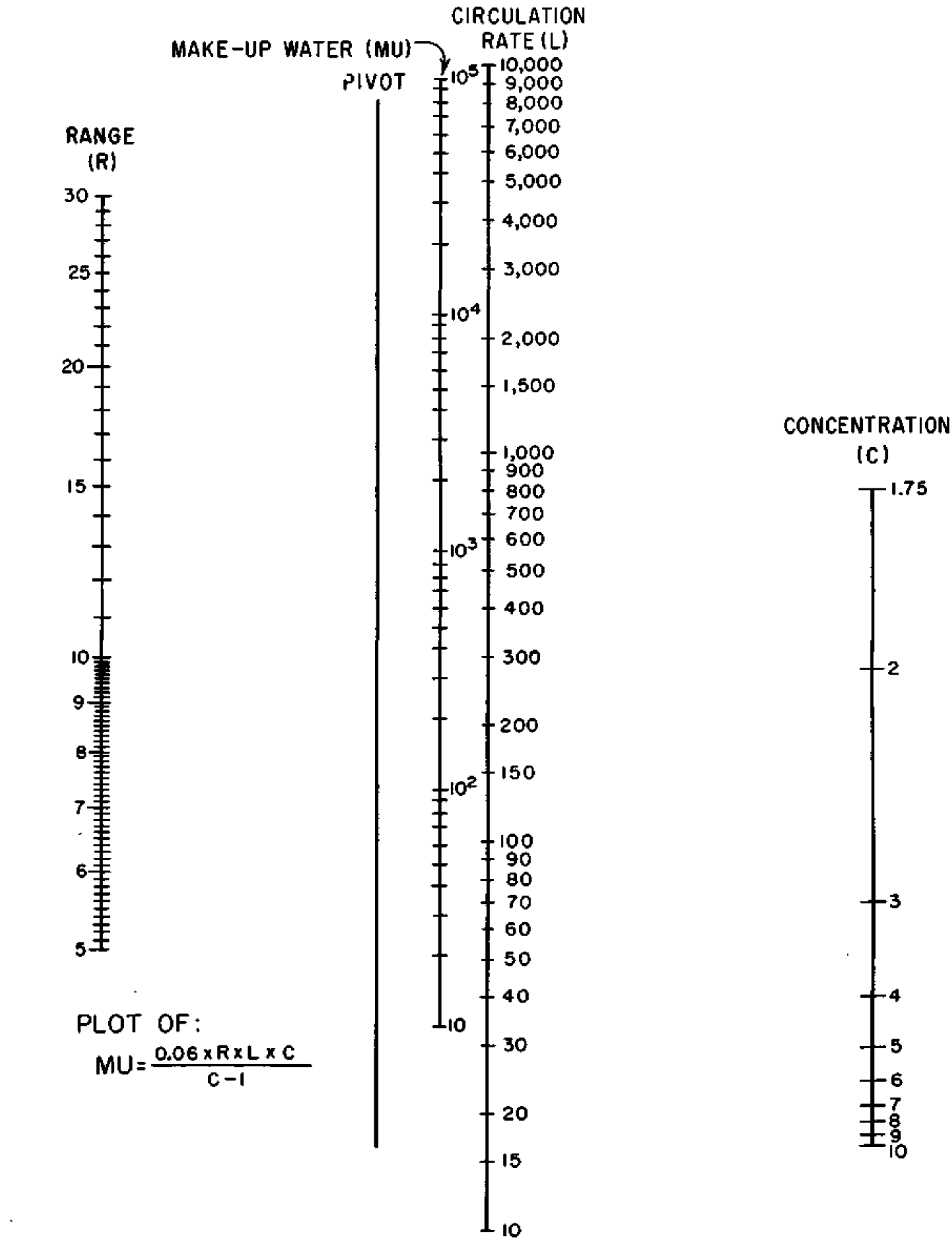

Figure 5. Make-up water requirements for varying mineral concentrations

Example 2:

In figure 4b, a 10F range with a 94.8F hot water temperature, a 1000 gpm circulation rate, and a water cost of 5 cents per 1000 gallons were assumed. For the derived make-up requirements, the water costs are shown by the dashed line. For a make-up water with 50 ppm alkalinity, the estimate of cost of internal acid treatment is shown by the solid line. The combined cost is 9.5 cents per hour at C = 10.

For the same heat load and hot water temperature, and a water supply temperature of 60F at a cost of 5 cents per 1000 gallons, the once-through cost would be $3.00 per hour without treatment.

In normal practice where treatment control with minimum supervision is not rigid, maintenance of 1.5 to 2 concentrations is not uncommon for smaller towers. This practice provides a factor of safety where costly shut-downs due to failure in application is a necessary consideration. With greater assurance of proper chemical applications, 3 to 5 concentrations may well be practiced. For larger towers, concentration of 3 to 4 may be common for similar reasons, but may well be increased to obtain the efficiencies indicated in figures 4a and 4b by greater attention to properly controlled chemical application and blowdown.

For conversion of costs per hour for chemical treatment and for water to an annual basis, adjustment must be made in the make-up requirements for hours of operation and for reduced load operation.

Make-up Water Costs

Figure 5 is a nomograph of make-up water requirements based on avariable dissolved solids concentration ratio. Make-up is equivalent to blowdown, windage loss, and evaporation losses. Place a straightedge on figure 5 between the appropriate L and R and mark the intersection on the pivot line. Place a straightedge between this point on the pivot line and the appropriate concentration. Where the straight line intersects the make-up scale, read the required make-up water in gallons per hour.

To determine the number of hours of operation per year, multiply the number of calendar days by the number of operation hours per day. This number is applicable only for constant heat dissipation as would be found in some process applications. If the heat dissipation rate is not expected to be constant during this period, as in air conditioning applications, it is necessary to modify the operating hours accordingly. This can be accomplished by converting to an equivalent full load basis. For example, if it is expected that the heat load to the tower will be a certain percentage of full load capacity for a predetermined period, the number of equivalent full load hours is the ratio of the expected load to the full load capacity times the number of hours in the reduced load period. That is

$$\text{equivalent full load hours} = \text{no. of full load hours} + \left(\frac{Q\ \text{reduced}}{Q\ \text{full}} \times \text{reduced load hours}\right)$$

Table 2 lists some equivalent full load operating hours recommended for some typical air conditioning applications. To determine the annual make-up water costs and chemical treatment costs, multiply the total number of gallons times the cost per 1000 gallons, thus

make-up cost =[(gal/hr) (cost/1000 gal)]x hours

Table 2. Typical Equivalent Full Load Operating Hours for Air Conditioning *

Application	Hours ** open for business	Chicago	St. Louis
Barber shops	1280	720	890
Department stores	940	610	750
Drug stores	2100	1060	1420
Funeral parlors	600	330	400
Offices	1100	720	910
Restaurants	2100	930	1300
Specialty shops	1090	590	720
Theaters, neighborhood	900	450	.550

** From ASHRAE Guide*[5] *** Hours between May 15 and October 15*

Check List

Table 3 may be used as a check list for the costs involved in the comparison calculations. No attempt is made hereto list power, water, interest, and tax rates as these are variables which each user must include in order that the estimate may apply specifically to the particular circumstances.

Table 3. Cost Sheet

Initial Investment

1. Cost of total installation
2. Other costs (alterations or additions required to complete the conservation system)

Total Initial Investment (T)

Annual Fixed Costs

1. Amortization and depreciation period (Y years)
2. Interest rate (i)
3. Amortization and depreciation (T/Y)
4. Interest $\frac{Y+i}{2Y} \times i \times T$
5. Taxes
6. Insurance
7. Rent

Total Fixed Costs, 3-7 (Tf)

Annual Operating Costs

1. Power (pump and fan of tower)
2. Maintenance
3. Power (other)
4. Water treatment
5. Make-up water
6. Sewer charges
7. Miscellaneous

Total Operating Cost, 1-7 (To)

Annual Fixed and Operating Cost, Tf + To

ESTIMATION OF ONCE-THROUGH COOLING COSTS

The cost of once-through water cooling may be obtained by using the estimated initial cost of the water supply (source and facilities) and determining the fixed and operating costs according to the check list in table 3. If purchased water is used, the applicable costs, both fixed and operating, should also be determined.

The quantity of once-through water is dependent upon the heat to be dissipated, the maximum allowable temperature (HWT), and the temperature of available water (CWT). The available water temperature can be as low as 50F from shallow wells or as high as 90F for some surface waters. The two limiting temperatures indicate the allowable temperature difference (Range) for once-through water. The once-through flow rate is therefore equal to 60Q/500(HWT-CWT) in gallons per hour. This quantity multiplied by the unit cost of the water, whether purchased or self-supplied, gives the cost per hour. It is then necessary to multiply this number by the expected full load operating hours to determine the total annual operating cost.

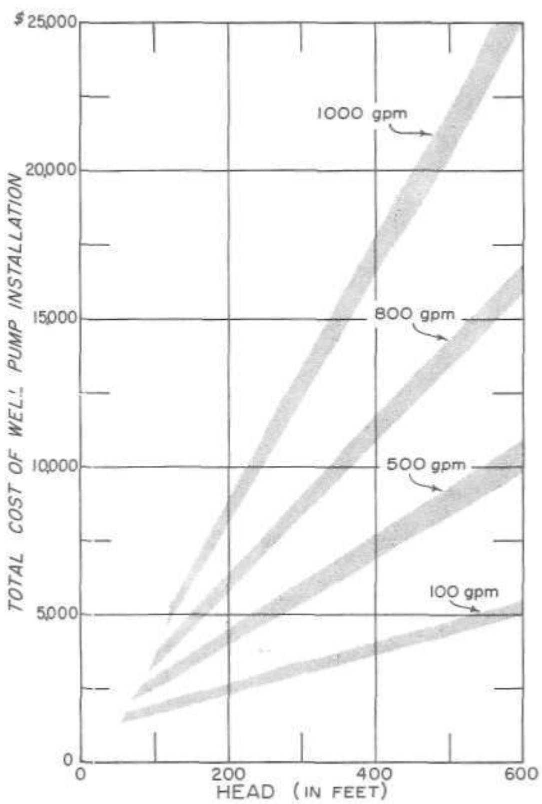

Figure 6. Total cost of well pump assembly and installation

Initial Costs, Self-supplied Water

To approximate the cost of a well installation, start with the flow rate determined above which

Table 4. Well Size Requirements

Pumping rate, gpm	Minimum casing sizes, inches
120	6-8
300	8-10
600	10-12
1200	12-14
2000	14-16
3000	16-18

will designate the minimum hole and casing size as indicated in table 4.

Drilling costs for rock wells with casings may then be estimated at $1.50 to $2.00 per inch diameter per foot of depth to 600 feet (including cemented casing), and $1.50 to $3.00 per inch diameter per foot at greater depths (including liners). These values are rules-of-thumb for rock wells and do not include the cost of pumping equipment.

The well pump assembly and installation cost maybe estimated from generalized data assembled in figure 6. The pumping head is taken to be the pump setting from ground surface to the top of the bowls. These estimates were obtained from a single vendor. Competitive estimates may be significantly greater or lesser depending on circumstances and specifications.

For surface water supplies, no attempt has been made to indicate estimates on costs for surface water inlets with attendant maintenance problems or the cost of pumps for this type of installation, as these are beyond the scope of this report.

Power Costs

In general, power costs may be estimated from an approximate 0.525 kilowatt requirement per 100 feet of head per 1000 gallons pumped.

DERIVATION OF COST RELATIONSHIPS

Relative Rating Factor

Rating charts for cooling towers are generally developed from experimental data. The relative rating factor (figure 1) is obtained from an average of a number of cross flow and counter flow rating charts developed for a constant air flow rate.

Figure 1 was developed[1] by superimposing the various rating charts for different towers upon one another so that the arbitrary standard conditions of 10F range, 10F approach to a 70F wet bulb temperature coincided, and this point was arbitrarily assigned a rating factor of 1.0. Other conditions of range and approach were then assigned relative values (RRF) which are fractions or multiples of this. These rating factors have the dimensions of square feet per gallons per minute (sq ft/gpm). In this instance the relative rating factor has no relationship to the physical size of a tower; it is a number for comparison only. To use this number with the dimensions of sq ft/gpm to determine the plan size would yield a tower (depending on the packing) from 2 to 5 times too large.

Figure 7 illustrates the general trend of two 10F approach curves when compared with the curve plotted from figure 1. All the 10F approach curves pass through the point RRF = 1.0 and R = 10F. For each different tower, the 10F approach curve will rotate about this point as shown. The inherent error within this method of reducing all towers to one set of performance curves lies in the deviation of the approach curves when conditions greatly different from RRF= 1.0 are chosen. The system, therefore, is acceptable for conditions close to a RRF of 1.0, but larger errors are expected as more adverse conditions prevail.

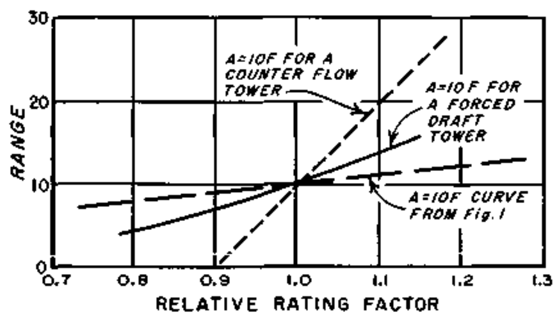

Figure 7. Deviation of approach curves for varying tower types

For simplification, only the 70F wet bulb temperature chart is used, and for other wet bulb conditions, standard wet bulb correction factors have been incorporated in the nomographs. Wet bulb correction factors have been used frequently to simplify cooling tower rating procedures and preliminary estimates.

The possible net error which is introduced by both the relative rating factor and the wet bulb correction factors does not exceed 9 per cent in the range of 70 to 80F WBT and an RRF between 0.6 and 1.7.

Tower Costs

Because equipment pricing is not standard, and reflects business judgment, deviations from the values obtained from these charts must be anticipated. The tower cost is represented by a faired curve through the scatter of points shown in figure 8. This scatter indicates a possible error of - 24 per cent. If an additional 9 per cent inaccuracy for the method of reduction is considered, a total error of approximately 33 per cent in the tower cost is possible. The inherent errors of "rules-of-thumb" for the total installation costs will add to, or compensate for, some of this inaccuracy.

This evaluation of dependability clearly indicates that the derived costs must be used only as estimates and should not be used for other more refined purposes. For a generalized preliminary estimate, however, this can be considered acceptable.

Installation

The complete tower installation costs were arrived at by using the customary "rules-of-thumb" which are recommended for estimates by manufacturers. Two types of towers are involved. The smaller towers (10-400 gpm) are generally fully packaged for delivery and priced fob factory and the larger (400-10,000 gpm) are assembled on site and priced as site as sembled. This is indicated

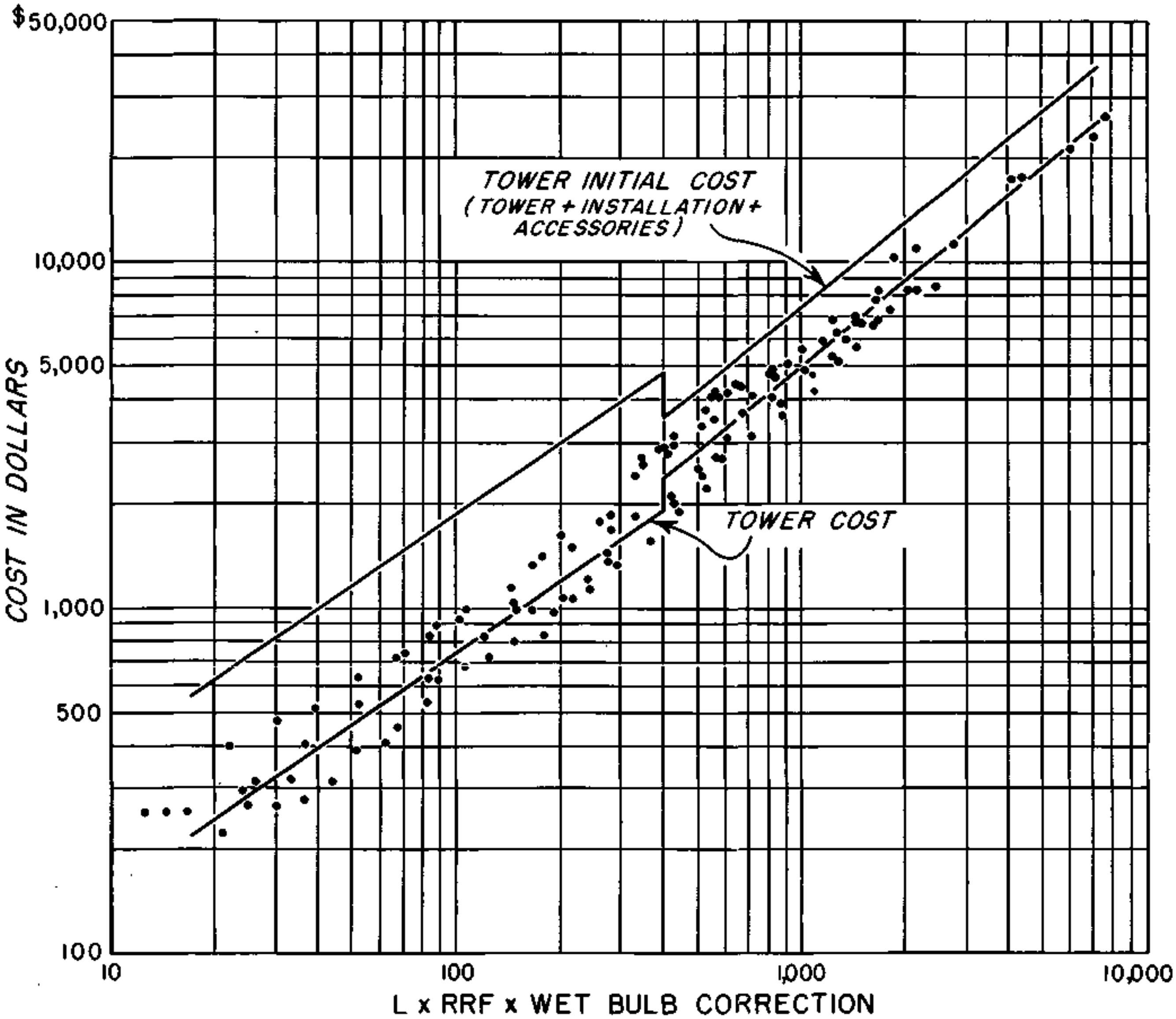

Figure 8. Point scatter of tower cost curve

by the discontinuity in the tower cost curve (figure 8). The installation costs (figures 2 and 8) have therefore been estimated as a rule-of-thumb to be 2-1/2 times the cost of the smaller (10-400 gpm) towers and 1-1/2 times the cost of the larger (400-10,000 gpm) towers, where circulation rates (L) are at 90F HWT, 80F CWT, and 70F WBT.

Chemical Treatment

Costs for only three common methods of water treatment were considered. These include costs of treatment for make-up water and supplementary treatment of circulating water. Cost derivations were made in a manner permitting all to be expressed in terms of cents per 1000 gallons of make-up water.

As shown in the table of nomenclature for water analysis, concentration of all ingredients used is expressed in equivalents of calcium carbonate except that for carbon dioxide. The cost of chemicals may vary depending on the source of supply and the quantity purchased. Usually these costs will be in the range indicated in table 5, which gives the costs of chemicals used in the formulas in the opposite column.

Table 5. Cost of Chemicals

	Cost used	Range*
Sulfuric acid, 66° Baume'	4¢/lb	3 to 5¢/lb
Scale and corrosion inhibitors	15¢/lb	15 to 25¢/lb
Salt	$2/100 lb	
Hydrated lime	$1.10/100 lb	

** Under circumstances where chemical costs include services in the form of periodic analyses or consultations, these may be as much as twice the range indicated.*

NOMENCLATURE, WATER ANALYSIS

A	Alkalinity (as $CaCO_3$), raw water
A'	Alkalinity (as $CaCO_3$), after lime treatment*
CO_2	Carbon Dioxide (as CO_2)
Ca	Calcium (as $CaCO_3$), raw water
Mg	Magnesium (as $CaCO_3$), raw water
H	Hardness (as $CaCO_3$), raw water
H'	Hardness (as $CaCO_3$), after lime treatment*

** Estimates from equipment manufacturer*

For the internal treatment by application of acid, the acid cost is based on 1 pound 66° Baume' acid (4¢/lb) per 1000 gallons make-up required to neutralize 120 ppm alkalinity. This cost, in cents per 1000 gallons, is 4 x (A/120), or 0.033A.

The scale inhibitor cost is based on an example where sodium polyphosphate is maintained at 6 ppm and sodium lignosulfonate at 18 ppm in the circulating water. This requires 0.05 pound of sodium tripolyphosphate (13¢/lb) and 0.15 pound of sodium lignosulfonate (15.6¢/lb) per 1000 gallons of circulating water. The cost of the make-up water requirements in cents per 1000 gallons is therefore

$$\frac{(0.05)\ (13)\ +(0.15)\ (15.6)}{C} = \frac{3}{C}$$

The corrosion inhibitor* cost is similarly based on maintaining 300 ppm CrO_4 in the circulating water, and is applied as $Na_2Cr_2O_7 \cdot 2H_2O$ (22¢/lb), or

$$\frac{300}{120} \times 1.28 \times \frac{22}{C} = \frac{71}{C}$$

The combined scale and corrosion inhibitor cost is then (3/C) + (71/C) or 74/C, in cents per 1000 gallons make-up, and the total treatment cost by this method is therefore 0.033A + (74/C).

With acid treatment, a simplified relationship for estimating maximum concentration of minerals in cooling water to avoid calcium sulfate scale is C = 2400/H. Using Denman's data[7] the maximum concentration was calculated for a number of representative Illinois waters treated with sulfuric acid, and the above equation provided comparable results for the 104F data.

The choice of internal versus external treatment depends on the many factors which should be studied by competent experts before reaching a decision based largely on economics. These factors are:

1) The water analysis, particularly the hardness and alkalinity
2) The availability and cost of water
3) The size of the system
4) The relative cleanliness of the system desired
5) The availability of space, capable operating personnel, and technical assistance.

External cold process softening by lime treatment generally reduces the hardness to about 80-100 ppm, and includes a subsequent acid application for stabilization and a corrosion inhibitor.

**Since chemicals of possible or definite toxicity are often used for corrosion inhibition in the water treatments, definite preventative measures shouldbe taken to insure that the cooling tower water can not be permitted to possibly mix with or be siphoned into the drinking water system. Make-up water should be introduced only at the tower basin and should be applied at least twice the effective pipe opening above the maximum possible water level or the overflow pipe in order to prevent back siphonage[6]. Disposal of wastes or blowdown should be in accordance with regulations of local health agencies and the State Public Health Department.*

For the external lime treatment process for the make-up water, the usual requirements are based onhydrated lime (1.1¢/lb) and on the formula, 0.007 (A + 50) + 0.015(CO_2) in pounds per 1000 gallons. Therefore the lime treatment cost is equal to

$$1.1 \times \left[0.007\ (A + 50) + 0.015(CO_2)\right]$$

Unusual waters with excessive non-carbonate hardness (H greater than A), require supplementary treatment.

To prevent the development of causticity in the circulating water, the acid requirements (4¢/lb) for the make-up following lime treatment are 0.033A'. The total treatment cost by this method, including the need for scale and corrosion inhibitors in the circulating water, will then be

$$0.0077(A + 50) + 0.0166(CO_2) + 0.033(A') + \frac{74}{C}$$

For estimating the maximum concentration of minerals when this treatment is used, the hardness of the treated water must be used in the permissible concentratton equation, p. 9, as follows: C = 2400/H'

Although external hardness removal by sodium zeolite softening maybe employed without application of a corrosion inhibitor, more complete inhibition is usually considered necessary.

For the external zeolite softening process the salt requirements (2¢/lb) are based on 1 pound salt required per 2000 grains hardness (H), where 1 grain-per-gallon hardness is 17 ppm. The salt cost then is equal to

$$\frac{H \times 1000 \times 2}{17 \times 2000 \times 1} = \frac{H}{17}$$

Therefore the total cost of zeolite treatment in cents per 1000 gallons make-up is the salt cost plus the inhibitor cost, or

$$\frac{H}{17} + \frac{71}{C}$$

In the case of zeolite softening, the maximum concentration is limited by the alkalinity of the circulating water. An arbitrary maximum limit of 1200 ppm is suggested; however lower values may be required to provide longer tower life by avoiding disintegration of wood by high alkalinity. The maximum concentration (C) is therefore 1200/A.

Figure 9 illustrates typical equipment costs for external treatment. The zeolite equipment cost is based on water hardness of 340 ppm and daily regeneration.

Make-up

Make-up (MU) water requirements (figure 5) were derived by assuming an evaporation loss in gallons per hour of 1 per cent per 10F range, or

$$60 \times 0.001 \times R \times L$$

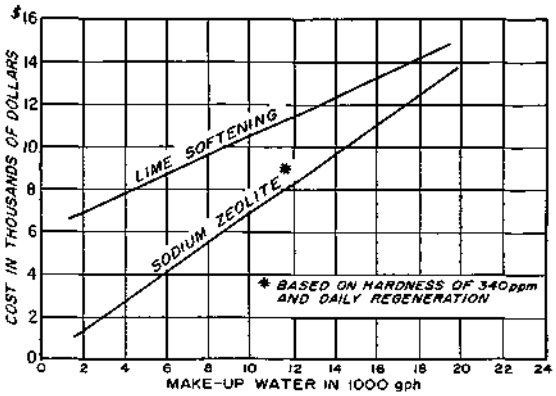

Figure 9. Water treatment equipment costs

The blowdown in gallons per hour required to satisfy a given concentration ratio maybe estimated as a fraction of the evaporation loss. In equation form,

$$\text{blowdown} = \frac{0.06 \times R \times L}{C - 1}$$

Summing both the evaporation loss and the blowdown, the make-up in gallons per hour is equal to

$$0.06\ R \times L\ (\frac{C}{C - 1})$$

Figure 5 is a nomograph of this equation. Drift or windage loss was assumed to be part of the blowdown and consequently does not appear in the equation. The general limit on drift loss is usually given as 0.1 per cent of the circulation rate with a maximum allowable of 0.2 per cent, but these limits are exceeded in some tower designs.

The make-up given in figure 5 is based on a constant heat load to the tower. This is generally not the case in air conditioning, as well as in some process work, and hence the make-up for a full season derived in the foregoing manner will be in error unless corrected by the equivalent full load method described in the first section.

The initial fill of water has been neglected in this calculation as it is generally a minor fraction of the operating cost if the system is drained and refilled only once a year.

Power

The power requirements (figure 3) were derived from the fan and pump power values cited by Pfeiffer.[8] These were assumed to be applicable at the conditions of 90F HWT, 80F CWT, and 70F WBT. Other conditions of approach, range, and wet bulb temperatures consequently require a different amount of power, which has been derived in the nomograph through incorporation of the wet bulb correction factor and the relative rating factor. The power requirements indicated by figure 3 are comparable (within 35 per cent) to those indicated by others.[4,9,10]

OTHER CONSIDERATIONS

Other cooling methods may be desirable for relatively small heat dissipation rates (less than 1,000,000 Btuh). For these rates refrigeration service or other similar condensing service, air-cooled condensers or evaporative condensers, can sometimes provide competitive cost advantages to cooling towers. The scope of this report has not permitted consideration of this type of equipment. Information is available from the ASHRAE Guide.[5]

Where land is available at reasonable cost, pond cooling can also be used for air conditioning as well as some process cooling purposes.

Other conservation methods may be considered also. Water used for cooling can be conserved by many different methods, either with or without the use of a cooling tower. The collection and storage of precipitation from roofs and parking areas can often provide an ample supply of low mineral content water for use as make-up for cooling towers. This method not only limits the cost of water to cost of storage, but also reduces the cost of water treatment.

Multiple reuse either within an industry or between industries is not an uncommon practice.

Side-channel or flood-water collection basins are also used for storage of necessary make-up water.

Sewage treatment plant effluents are available sources of low quality cooling water where potable water is at a premium.

These few examples suggest that the methods and practices of water conservation canbe adapted and expanded by positive efforts through evaluation and design. In each case, an element of "free" water is present which limits costs to storage and transportation.

SUMMARY

This report has been an evaluation of costs of water used for heat dissipation with particular emphasis on simplification of cooling tower estimates. Because of the complex nature of evaporative cooling methods, these simplifications should be used only for preliminary comparison of possible economic advantages in water conservation.

In the refrigeration industry, evaporative or air-cooled condensers are often economically competitive to cooling towers in the smaller sizes (10-100 tons).

For maximum economy, optimum size match is desired for the equipment to be cooled and the heat dissipation equipment. For this reason, specific cooling needs should be subjected to comprehensive study by a competent engineer.

If the costs of both once-through and conservation equipment are within about 30 per cent of each other, a thorough investigation should be advisable. The future availability of water is also a consideration that should not be overlooked.

Economical justification for conservation measures stimulates wise use of the water resource and avoids regulation and restriction.

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