Water Conditioning for Cooling Towers, Spray Ponds, etc.

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Water conditioning is often necessary where heat transfer operations are involved, such as, in cooling towers, condensers, air-conditioning plants, etc. If water quality is not properly controlled it may lead to any one of the following problems :

Scale formation
Corrosion
Organic growths (slime)

Water Circulation System

If plentiful supply of water is available the water may be used on a "once-through" basis (Fig. 1). Generally, the water has to be recirculated in order to conserve the limited supplies available
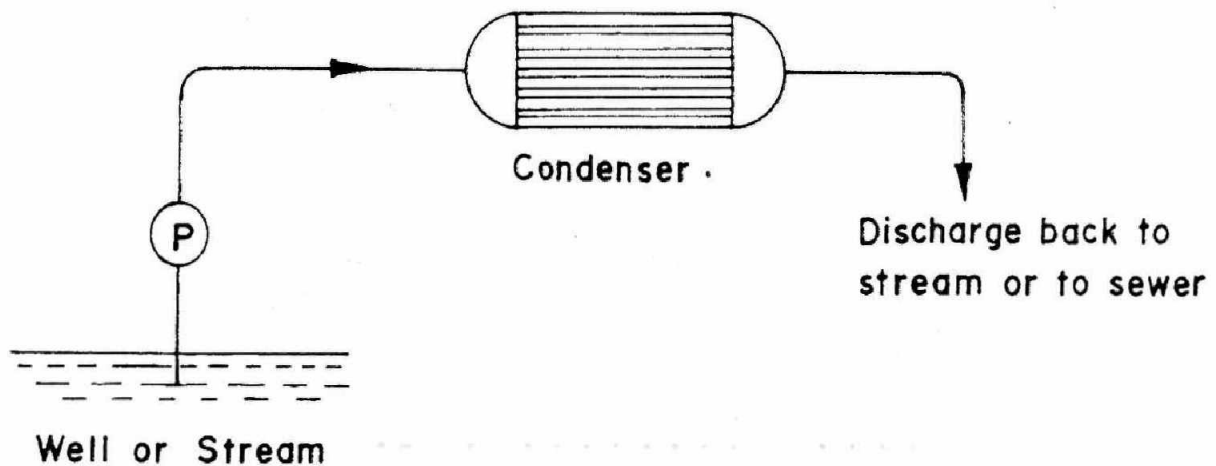

Condenser .

Discharge back to stream or to sewer

P

Well or Stream

FIG. 1.

to an industry. The open recirculating system as shown in Fig. 2 is often used requiring the provision of a cooling tower or spray pond.

Water Losses in Recirculation

Some make-up water is necessary in recirculation systems to make-up for the losses occurring from the following :

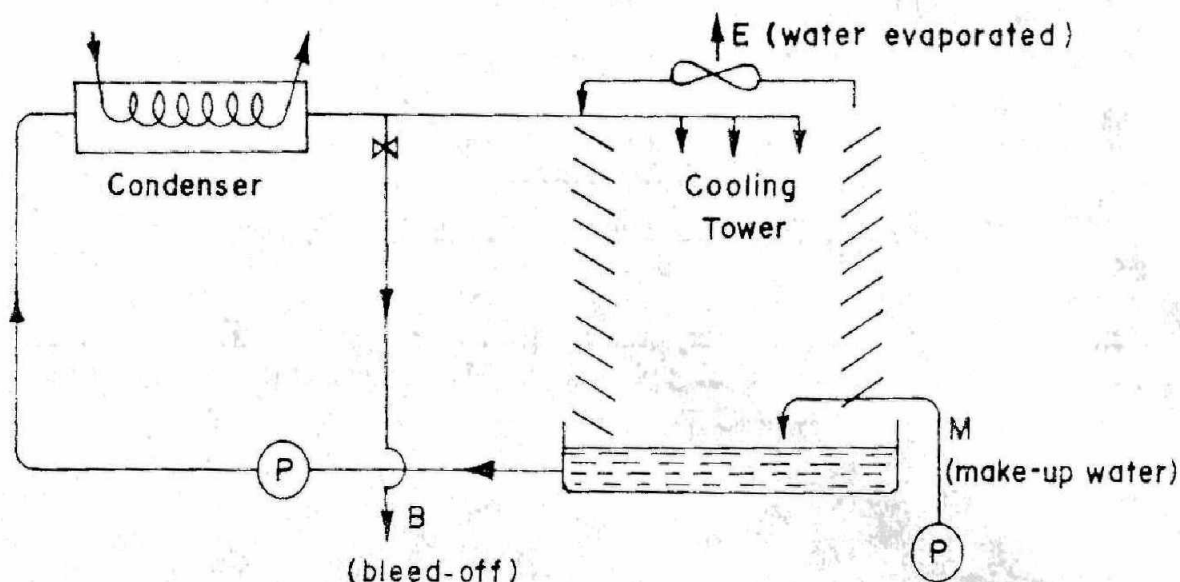1. Evaporation
2. Windage
3. Bleed-off

FIG. 2. OPEN RECIRCULATING SYSTEM

Evaporation loss (E) in a cooling tower or spray pond is approximately 1% of the water being recirculated per 10°F drop in water temperature through the unit. Compression refrigeration machines in normal air conditioning evaporate, in cooling towers, 0.03 gpm per ton of refrigeration capacity. A 1000 ton plant would thus entail evaporation losses of 30 gpm or 43,200 gallons per day for 24 hour working of the plant. When water evaporates off, it leaves behind all the salts and hence the total dissolved solids in the system increase with time. This is the major cause for change in quality of recirculating waters.

Windage loss (W) is due to small droplets of water being carried away by the wind. Fortunately, windage does not change the quality of the recirculating water, as evaporation does, since dissolved salts are also lost with the spray. The windage loss can be estimated as follows :

Heat Exchange Equipment	Windage loss as percent of recirculating water
Spray pond	1.0-5.0
Cooling tower (atmospheric)	0.3-1.0
Cooling tower (Mech. draught)	0.1-0.3

Bleed-off (B) is necessary to help control the maximum concentration of salts in the recirculating water. In bleed-off, the salts dissolved in the water are also removed and hence bleed-off is similar to windage in its effect on water quality. In fact, where windage losses are high no Head-off may be necessary to control the water quality as discussed latter. Bleed-off is controlled by the operator or supervisor and it is necessary for him to know how it affects the quality of the recirculating water.

Cycles of Concentration

Depending upon the relative proportions of water loss by E, S and B above, a certain amount of "build-up" of solids occurs in the system. This can be stated as "Cycles of Concentration".

$$\text{Cycles of Concentration} = \frac{\text{Concentration of substance in recirculation water}}{\text{Concentration of substance in make-up water}}$$

Chlorides are often determined in the recirculation water as well as in the make-up water and their ratio gives the cycles of concentration. Instead of chlorides other substances can be determined if desired, such as hardness, dissolved solids, methyl orange alkalinity, etc. For example, if dissolved solids in recirculation water are 600 mg/1 and in the make-up water only 200 mg/1, the cycles of concentration $= \frac{600}{200} = 3$.

When a new tower is being designed the cycles of concentration have to be estimated by the designer. This can be estimated as follows :

$$C = \frac{\% \text{ E}}{\% \text{ W} + \% \text{ B}} + 1$$

where all losses are expressed as a percentage of the recirculating water.

Fig. 3 gives a graphical solution of the above equation which can be conveniently used in practice to determine either the cycles of concentration actually occurring in a case or the bleed-off percentage necessary to hold the cycles of concentration below a desired value.
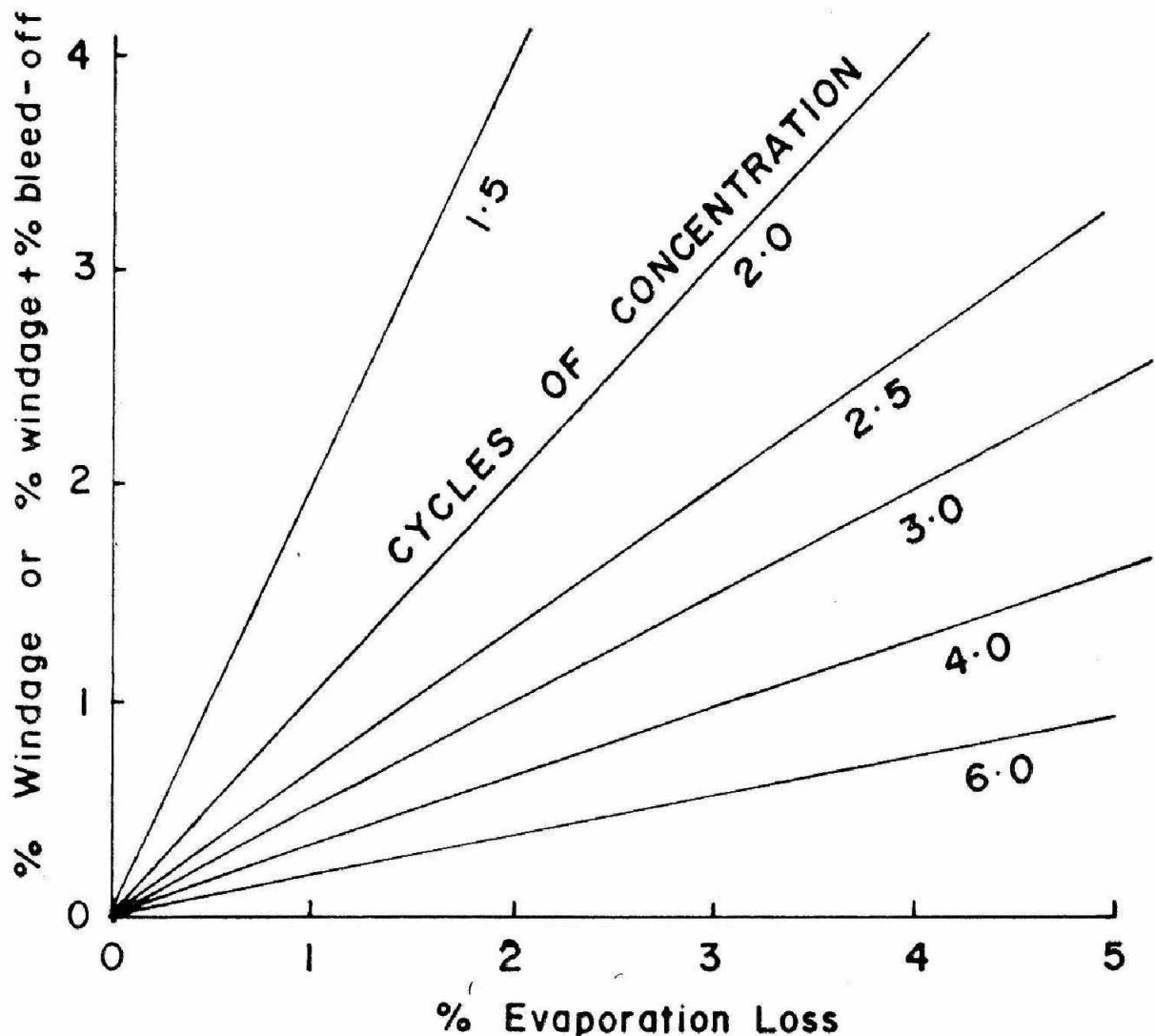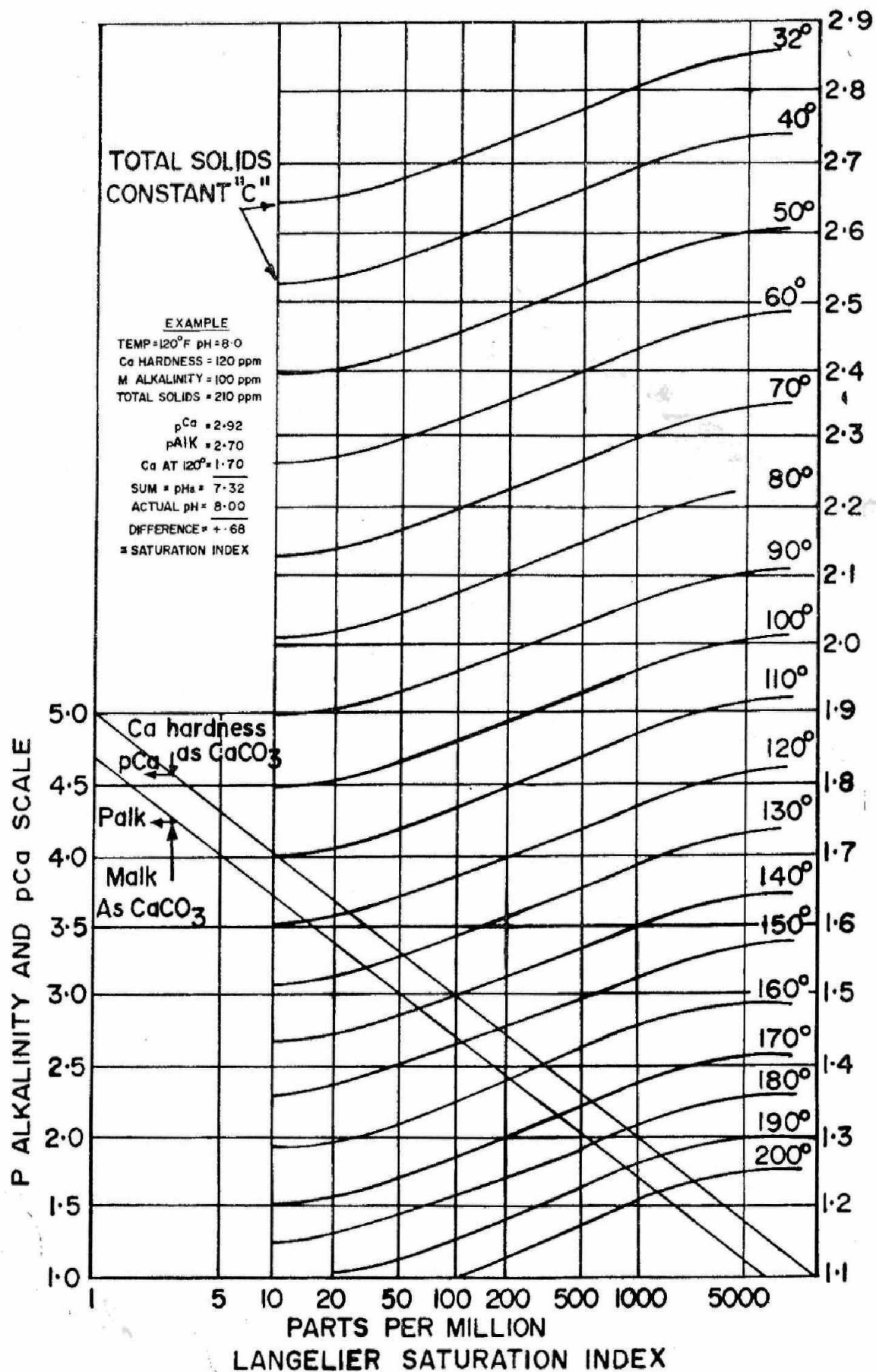

Fig. 3

TOTAL SOLIDS CONSTANT "C"

EXAMPLE
TEMP = 120°F pH = 8·0
Ca HARDNESS = 120 ppm
M ALKALINITY = 100 ppm
TOTAL SOLIDS = 210 ppm

p^{Ca} = 2·92
p^{Alk} = 2·70
Ca AT 120° = 1·70

SUM = pHa = 7·32
ACTUAL pH = 8·00

DIFFERENCE = + ·68
= SATURATION INDEX

Ca hardness
pCa as CaCO₃

Palk

Malk
As CaCO₃

P ALKALINITY AND pCa SCALE

PARTS PER MILLION

LANGELIER SATURATION INDEX

Fig. 4

For example, if a $10°F$ drop of temperature of water occurs in a tower or spray pond, it corresponds to an evaporation loss of 1% of the recirculating water. If a spray pond is used and windage losses are assumed as 2% and if the bleed-off is nil, then from Fig. 3, the cycles of concentration would be 1.5. If cooling tower was used instead of spray pond and windage loss 0.6% only, the cycles of concentration would be 2.7. For a mechanical draught tower with windage loss of 0.2% only, the cycles of concentration would be 6.0. In this case if the cycles of concentration have to be restricted to say 3 only, the sum total of windage and bleed-off should be 0.5%. Generally, the cycles of concentration should not be so high as to give dissolved solids in excess of 2500 ppm in the recirculating water. Ca^{++} and alkalinity have also to be kept within limits or else the pHs will be very different from the pH as described below and the water may either tend to be highly scale-forming or highly corrosive.

The Langelier & Ryznar Indices

The langelier saturation value (pHs) can be readily determined from the chart (Fig. 4) if the values of actual pH, Ca^{++}, alkalinity and total dissolved solids are known.

Langelier Index = pH-pHs
Ryznar Index = 2pHs-pH

Tendency of water	Ryznar Index	Langelier Index
Heavy scale	4.0-5.0	+2.0 & higher
Light scale	5.0-6.0	+2.0
Light scale or corrosion	6.0-7.0	+0.5
Corrosion significant	7.0-7.5	−1.0
Heavy corrosion	7.5-9.0	−2.0
Corrosion intolerable	9.0 & higher	−2.0 & higher

These indices only show a tendency of a water to scale or corrode but are *not* a measure of the capacity to corrode or scale. A water having high hardness and positive index will definitely give a $CaCO_3$ scale; whereas low hardness with the same positive index may not form any appreciable scale. These indices are for waters *without* addition of scale inhibitors. A water with a scale inhibitor gives the *same* index as untreated water but may not give scale trouble. For example, with 1.7 ppm polyphosphate little scale may be formed even with a Ryznar Index of 4.0.

Prediction of pH for various Cycles of Concentration

When water recirculates through a heat exchanger or cooling tower or other aeration device, the pH is usually different from the pH of the make-up water because atmospheric "concentration" with CO_2, SO_2 and other gases, influence pH and alkalinity. Generally, aeration tends to lower pH and alkalinity. In some industrial areas, there may be enough SO_2 and CO_2 to neutralise alkalinity in make-up water and give a pH of 4 to 5. (This is particularly true if M. O. alkalinity of make-up water is less than 50 ppm). Corrosion may then be a problem. The pH for a cooling water or for an evaporative condenser in the majority of systems falls within the shaded area (Fig. 5). (The dotted line can be used as an average).
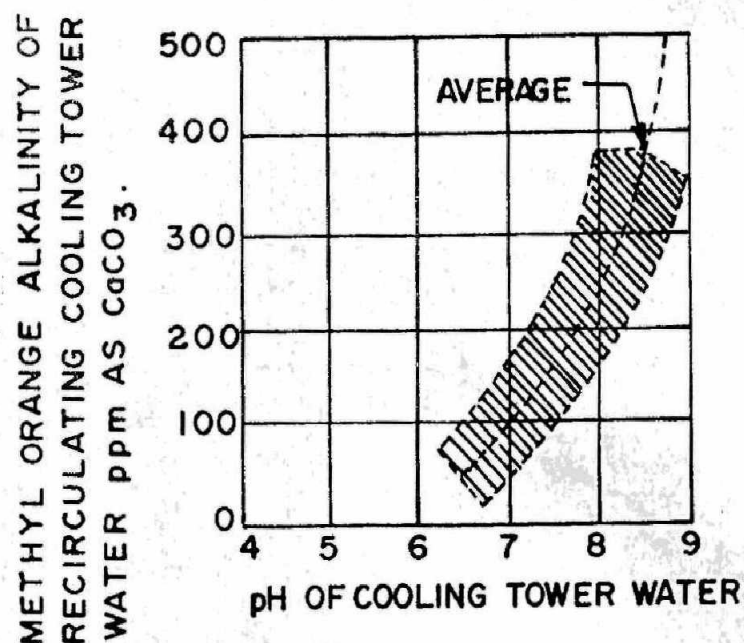
FIG. 5. EXPECTED pH OF COOLING TOWER WATER

(NORMALLY pH FOR 90% OF TOWERS IS WITHIN SHADED AREA.)

The usefulness of the above discussions can now be best illustrated by an example :

Example

Determine the scaling tendency of a cooling tower system for 1, 1.5, 2 and 3 cycles of concentration assuming the following analysis of the make-up water :

M.O. alkalinity of make-up water	=	94 ppm as $CaCO_3$
Ca^{++} hardness	=	85 ,, ,,
Total solids	=	128 ,, ,,
Total hardness	=	109 ,, ,,
pH	=	7.8
Recirculating water temperature	=	115°F

Cycles of concentration	1	1.5	2	3
M.O. alkalinity	94	141	188	282
Ca^{++} hardness	85	128	170	255
Total solids	128	192	256	384
Total hardness	109	163	218	327
pH	7.8			

Cycles of Concentration	1	1.5	2	3
Results :				
pH (using average line)	7.0	7.4	7.7	8.1
pHs	7.54	7.22	6.97	6.63
Langelier Index (pH-pHs)	−.54	+.18 (slight scale)	+.73 (scale forming)	+1.47 (definitely scale forming)
Ryznar Index (2pHs-pH)	8.08	7.04 (very little scale or corrosion)	6.24 (little scale or corrosion)	5.16 (scale forming)
Remarks	corrosion inhibitor desirable	corrosion inhibitor desirable	slight scale deposit may take place	scale control by adding 2.5 ppm of polyphosphate

Scale Deposit Prevention

Factors affecting $CaCO_3$ scale formation are :

   (i)   High alkalinity
  (ii)   High calcium content
 (iii)   High pH
 (iv)   High temperature (deposition is most noticeable in the high temperature areas)
  (v)   High dissolved solids

Some of the corrective steps that can be taken are :

1. Adjust bleed-off rate accompanied by additional make-up water.
2. Use polyphosphates which inhibit crystal growth.
3. Use acid + polyphosphates.

These surface active agents increase solubility of scale-forming salts and permit an over-saturated condition to exist, (others are tannins, lignins, starches) and heance, bleed-off and make-up water rates can be reduced. Approximate graphs are given in Fig. 6 based on :

1. condensing temperature of 100-120°F
2. M.O. alkalinity=100 ppm maximum without polyphosphates
3. M.O. alkalinity=400 ppm maximum with 2.5 ppm of polyphosphates

When M.O. alkalinity of make-up water does not exceed 100 ppm as $CaCO_3$, bleed-off alone may be satisfactory. Use of polyphosphates is recommended when alkalinity is greater than 100 ppm in make-up water. Satisfactory scale control can be achieved with polyphosphates if make-up water alkalinity is not greater than 150 ppm. If alkalinity is in the range of 150-250 ppm some scale may
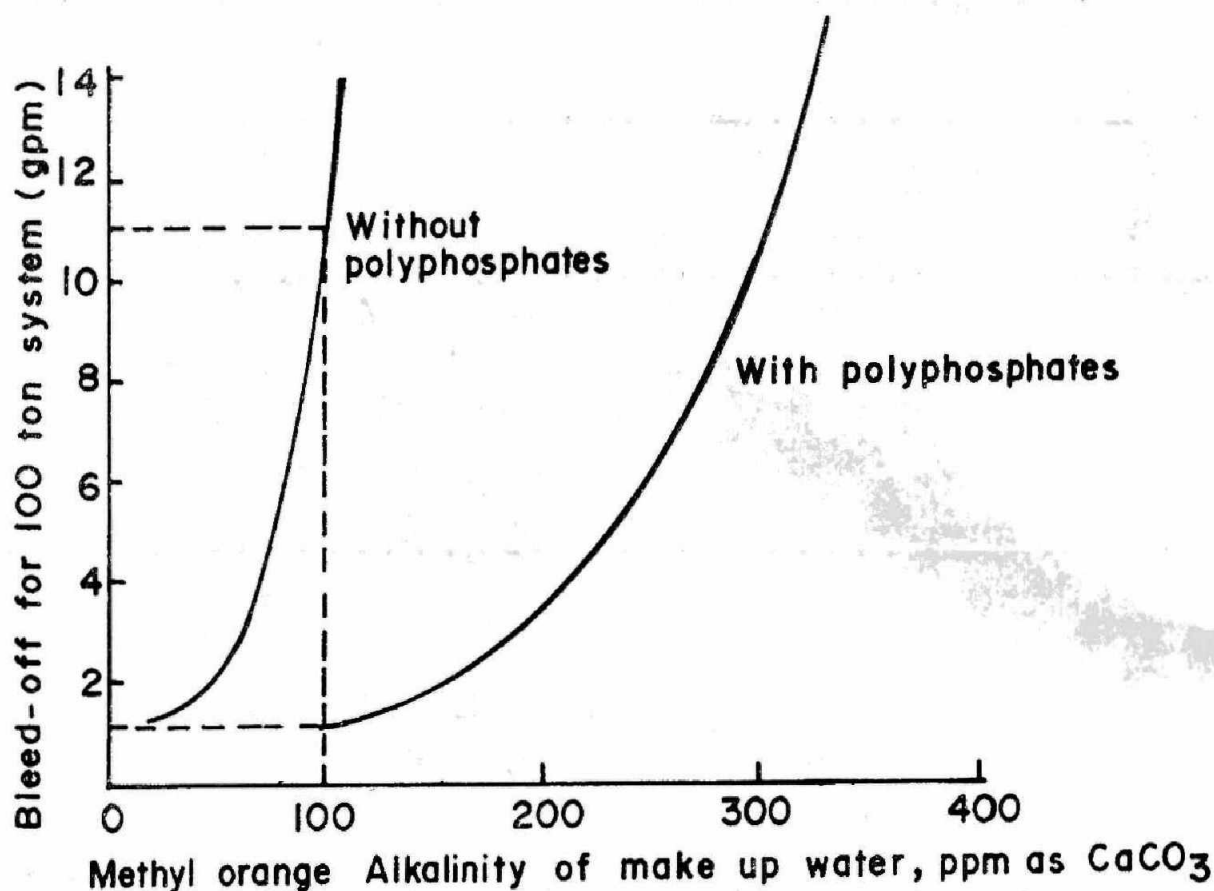
FIG. 6.

be expected (acid cleaning once a year or so). If alkalinity is greater than 250 ppm more scale can be expected thus requiring increased rate of bleed-off and chemical feed. Polyphosphates should be stored in dry form. Polyphosphates which are molecularly dehydrated phosphates revert to the ineffective ortho-phosphates, in the recirculation water system. This can give deposition of Ca-orthophosphate sludge. The ortho-phosphate content should be limited to 2 to 3 times the polyphosphate content by use of bleed-off.

Use of acid+polyphosphates enables to carry still more solids in the system.

$$Ca(HCO_3)_2 + H_2SO_4 \longrightarrow CaSO_4 + 2CO_2 \uparrow + 2H_2O$$
(less soluble)   (more soluble)
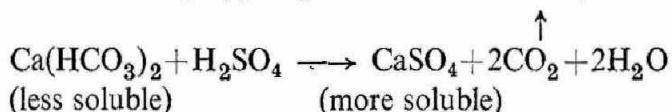
1 ppm of H_2SO_4 is needed to neutralise 1 ppm of M.O. alkalinity as $CaCO_3$. In open recirculation system, the acid is introduced down-stream of condenser.

Non-carbonate hardness is actually not as serious a problem because its solubility is many times greater than the carbonate hardness. In many cases, water may contain as much as 1200 ppm as $CaCO_3$ (or 1630 as $CaSO_4$) of non carbonate hardness and yet not deposit a $CaSO_4$ scale. Bleed-off is used to control this concentration. Addition of H_2SO_4, to stabilise from $CaCO_3$ scale point of view, can increase SO_4 in make-up water and give sulphate scale (Fig. 7).

In respect of carbonate hardness, $CaCO_3$ has decreasing solubility as temperature rises and pH has a marked effect on solubility of $CaCO_3$ (Fig. 8). The lesser the pH the better it is. Hence the use of acid in make-up water.
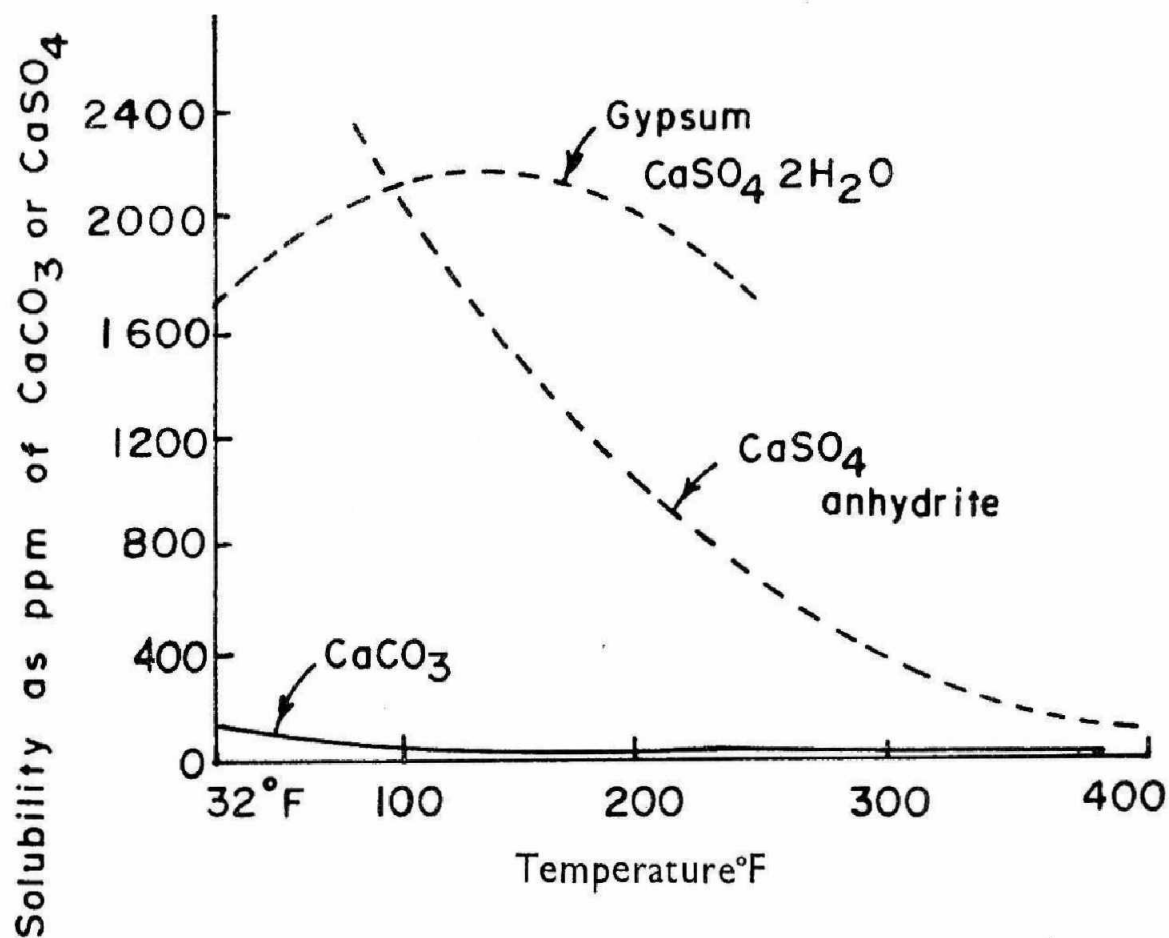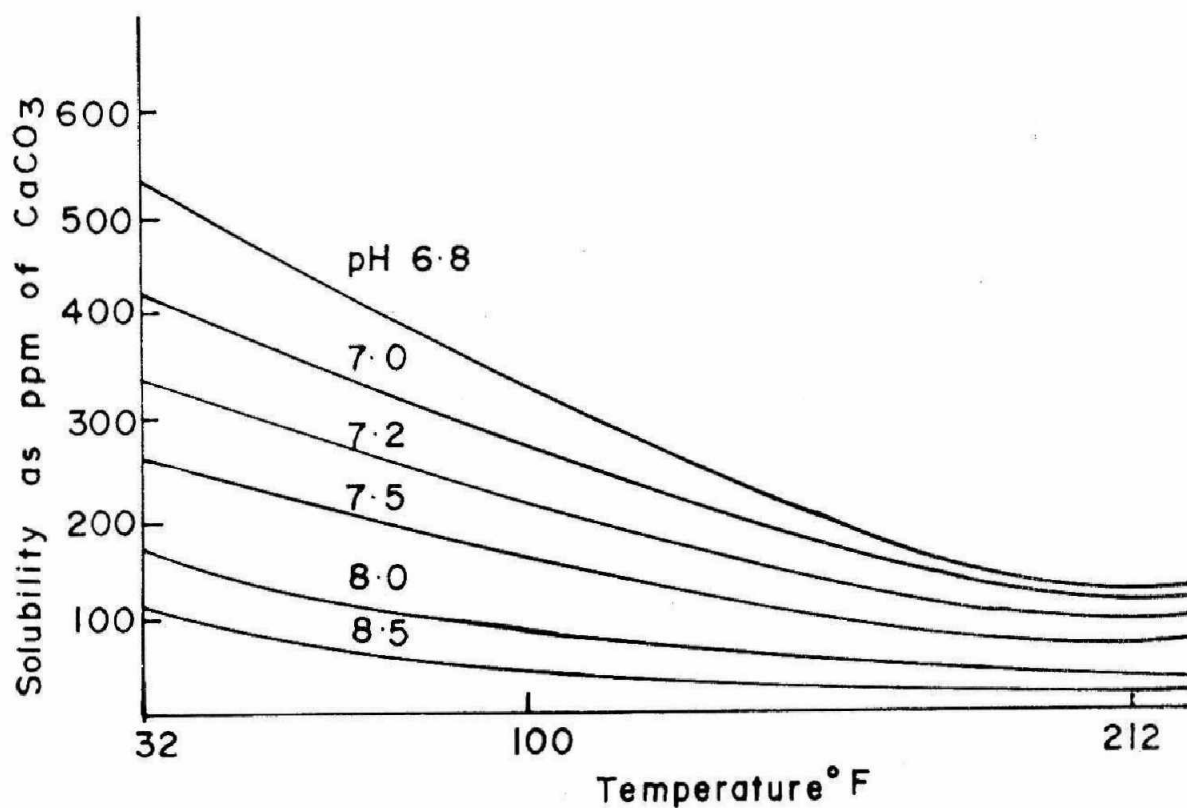
FIG. 7.

FIG. 8.

A desirable practice in cooling water conditioning is to control the chemistry to be slightly on the corrosive side and then add corrosion inhibitors such as :

Sodium dichromate—$Na_2Cr_2O_7, 2H_2O$

Sodium chromate   —Na_2CrO_4

Dichromate is acidic (pH less than 5.0) and hence to neutralise 100 kg of dichromate, 36 kg of soda ash or 27 kg of caustic soda (resulting compound is sodium chromate with pH 8.0) is required. Lower chromate concentration can be used if supplemented with polyphosphates. Main objection to the use of chromates is stains by yellow colour and there is difficulty in the disposal of bleed-off.

Slime & Algae Control

Problem of slime and algae control is in cooling systems, not in heating systems as in the latter it would be too hot for bacteria to be active. The growths may be due to algae or fungi or bacteria. Examples of iron bacteria are Crenothrix, Leptothrix and Gallionella. Examples of other bacteria are Filamentous slime bacteria, Sphaerotilus, Leptomitus, Beggiatoa, Zoogleal slime bacteria. One may also find Protozoa in closed systems, Sponges, Hydra, Insects and Worms.

Use of Chemicals

1. *Sod. penta chlorophenate :* Easy and safe to use. 200 ppm concentration is enough for shock feeding. Use 20-40 ppm. Very toxic even at high pH (only for recirculating systems).

2. *Copper Sulphate :* 0.5 ppm kills most of the common forms of organism. Higher dose upto 10 mg/l may be required in some cases. Does not kill many types of bacteria. $CuSO_4$ is, however, corrosive to steel.

3. *$KMnO_4$:* Quite effective, but chemical consumption is high as it reacts with dead as well as living organic matter.

4. *Chlorine :* Residual (after satisfying other demands) of 0.5 to 1.0 ppm is enough (will not discourage sponges and mussels). Use Ca or Na-hypochlorite. If continuous use, 0.3 to 0.5 ppm is enough. For intermittent use, 1.0 ppm is required for several hours. (Maximum 1.0 ppm to minimise attack on cooling tower wood). It is desirable to hold pH between 6.0 and 7.0 but definitely not greater than 8.0 and also to measure chlorine residual *before* water falls through the tower.

Conclusion

Water conditioning for cooling water is necessary in some form or another for most cases. The type of conditioning or control measure has to be decided after careful consideration of various factors enumerated above. This subject has unfortunately often suffered from 'rules of thumb' solutions and magic takes of cures, although the chemistry of water is sufficiently well-known to be able to provide tailor-made solutions. The problem must be correctly diagnosed before the appropriate remedy can be adopted. What is good in one case may be totally ineffective in another case.