

# **ECONOMICAL CALCULATIONS FOR THE USE OF OZONE IN COOLING TOWERS**

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## **Abstract**

Ozone has been successfully applied to industrial cooling water systems with the resultant improvement in operational efficiency due to increased heat transfer, reduced system corrosion, improved environmental impact and reduced on-going chemical expenditure. The aim of this paper is to provide practical advice on the options available for the application of ozone and the potential benefits which can be realised.

## **Introduction**

Open evaporative cooling systems are used extensively throughout industry to remove heat from process systems and modern buildings for the purpose of air conditioning. Heat is dissipated to atmosphere by the evaporation of water and energy removed due to the latent heat of vaporisation of water, achieved by bringing the cooling water into direct contact with the surrounding air. As a result, open type evaporative cooling systems are subject to potential biofouling problems as a result of micro-organisms from the surrounding environment. They are also prone to corrosion due to the establishment of corrosion cells within the system fabric in contact with the aqueous medium and to scale formation due to the increasing concentration of scale forming hardness salts as a result of the cycling of mineral salts present in the system make up water due to the evaporation of “pure” water from the cooling circuit.

For optimum performance the above problems must be minimised, heat transfer surfaces maintained in a clean condition, corrosion controlled to maintain system integrity and to avoid unexpected outages and microbial activity controlled to prevent the build-up of biofilm and the proliferation of legionella bacterium. Traditional methods utilise a chemical programme incorporating chemical inhibitors and biocides which, in themselves, also present particular problems of storage and handling and potential environmental impact issues.

## **Practical Ozone Scaling Index ( POSI)**

The normal convention used to determine the degree of scale forming potential of a cooling water at differing cycles of concentration is the Langelier saturation Index (LSI). The LSI uses the calcium concentration (ppm  $\text{CaCO}_3$ ), alkalinity concentration (ppm  $\text{CaCO}_3$ ), TDS and temperature of the cycled-up cooling water to determine the maximum pH at which calcium carbonate will be stabilised. This is then compared to the actual pH of the cooling system which, if greater, will exhibit scale forming potential. Scale inhibitors are then dosed to retain calcium carbonate in solution at positive LSI and typically a maximum LSI of say +3 can be achieved and is controlled by system bleed to achieve the maximum cycles of concentration possible under the chemical treatment programme.

This is to be compared to virtually zero blow-down systems using ozone, where the cooling water is cycled up many more times, realising calcium loss within the cooling system but also without the deposition of hardness scale on heat transfer surfaces. “Sandy” calcium carbonate precipitates can be found in cooling tower sumps rather than on heat exchanger surfaces indicating the involvement of surface-active biopolymers.

Several mechanisms have been proposed to explain the observed scale reduction in ozonated water including chelation of scale forming cations by oxidation products of biofilm and organic compounds to liberate bio-polymers, carboxylic acids and other organic compounds. Alginates, polysaccharides and other bio-polymers released are known to be surface active and may function as dispersants for suspended solids, including small crystalline scale particles and corrosion products.

This approach also gives excellent corrosion inhibition within the cooling system probably due to the cathodic protection afforded by calcium carbonate. Thus the water conditions establish a non-corrosive environment.

In order to quantify the parameters for ozone to operate at high cycles of concentration without scale deposition the POSI index was developed which gives the maximum conductivity at which the tower can operate without scale deposition. As calcium is lost from solution this also leads to a reduction in the conductivity (TDS) of the cooling water – this is expected and allowed for in this index. This maximum conductivity can then be compared to the conductivity of the cooling tower make-up water to then determine the actual maximum concentration factor.

As this mechanism also provides corrosion protection it is important that the cycles of concentration are not allowed to go too low.

Maximum cooling water conductivity =  $10^{(1/\log((Ca \times Mg)/(Na + Cl))/\log(Alk/10))}$  x conductivity of make up water

Ca = Calcium hardness of make-up, ppm CaCO<sub>3</sub>

Mg = Magnesium Hardness of make-up, ppm CaCO<sub>3</sub>

ALK = Total alkalinity of make-up, ppm CaCO<sub>3</sub>

Cl = Chlorides in make-up, ppm Cl

Na = Sodium in make-up, ppm Na

For example, with a make-up water quality with the following parameters:

pH	8.4	
Conductivity	130	µS
Calcium hardness	30	ppm CaCO <sub>3</sub>
Magnesium hardness	10	ppm CaCO <sub>3</sub>
Sodium	10	ppm Na
Chloride	7	ppm Cl
Total alkalinity	39	ppm CaCO <sub>3</sub>
Temperature	55	deg. F

The maximum conductivity using POSI =  $10^{(1/\log((30 \times 10)/(7 + 10))/\log(39/10))}$  x 130 = 2964 µS

□ maximum concentration factor = 2964 ÷ 130 = 22.8 cycles

This would compare to a chemical treatment programme maximum cycles of concentration for this water of some 10 cycles.

The water is supersaturated with calcium therefore any chemical species entering the cooling system which would react with calcium to form a very insoluble salt would cause significant scaling. Such species are phosphate and borate and could be present in a chemical water treatment programme. The guidance note recommends a maximum of 1 ppm total phosphate in the make-up water to the cooling system.

### **Minimum cycles of concentration**

To establish the minimum cycles of concentration needed to afford corrosion protection the alkalinity and silica concentrations within the make-up water are used:

Theoretical silica concentration should exceed 150mg/l SiO<sub>2</sub>

Theoretical alkalinity should exceed 450mg/l CaCO<sub>3</sub>

For example:

Make-up water silica = 20mg/l

Make-up water alkalinity = 60 mg/l

Minimum cycles of concentration required based on chloride analysis = 7.5

SiO<sub>2</sub>, 20 x 7.5 = 150 mg/l SiO<sub>2</sub>

Alkalinity, 60 x 7.5 = 450 mg/l CaCO<sub>3</sub>

### **Recommended ozone concentrations**

There is general agreement in the literature as to the recommended residual ozone concentrations required. These range from:

Cooling tower basin	0.025	to	0.250	ppm
Recirculating pump inlet	0.075	to	0.150	ppm
Heat exchanger inlet	0.040	to	0.080	ppm
Return line to tower	0.010	to	0.040	ppm

We calculate the size of the ozone generator based upon a dose rate of 0.2 ppm with respect to the recirculation rate of the system. The recommended residuals should be achieved at this dose rate, as we have found from actual applications. For small systems (less than 20 minute turnover time) an application dose rate of 0.1 ppm based upon the recirculation rate is likely to be sufficient.

Using an injector system we can achieve 95% mass transfer in a pressurised side stream strong water line which can be used to provide multi-point dosing around the tower system to ensure that the recommended reserves are achieved. The main dosage point being after the recirculation pumps.

When corrosion has occurred it is typically linked to higher ozone concentrations so care should be taken to ensure that the maximum recommended residual ozone concentrations are not exceeded.

### Use of ozone with chemicals

Under some circumstances it may be required to utilise chemical treatment in addition to ozone. In these conditions care should be taken not to compromise the treatment programme integrity.

Many modern programmes utilise inhibitors which are stable to the typical ozone application rates given above, however, the system parameters, such as the concentration factor, must be operated in line with the requirements of the chemicals utilised.

In this instance ozone is used as a complimentary product to control microbiological fouling and to achieve low planktonic counts.

Whilst the water treatment specialist should be consulted with respect to the compatibility of his product with ozone, the following actives have been evaluated and found to be compatible:

PBTC	Phosphonate scale and corrosion inhibitor to protect against hardness scale deposition. (HEDP and AMP are unstable to oxidising compounds including ozone)
Molybdate	Corrosion inhibitor for soft waters
Silicate	Corrosion inhibitor at system calcium concentrations < 200 ppm.
TTA / BTA	Yellow metal inhibitors can be effectively used due to their relatively slow oxidation by ozone (72h to completion), copper and brass alloy protection.
Zinc based	Corrosion inhibitor.
Phosphate	Used in "di-anodic" application with dispersant and acid dosing ozone stable dispersants.

### Ozone compatible materials

The following materials are considered suitable for use with ozone:

Pipe work:	316 Stainless steel Teflon/PTFE Kynar/PVDF
Vessels:	316 stainless steel (welds to be ground smooth internally)
Gaskets:	Teflon/PTFE FPM/Viton

### Off-Gas Venting

Off-gas venting can be achieved by either using a contacting vessel or by installing a degassing valve at the highest point in the recirculation system near the injection point.

A VOD may be utilised in either case or alternatively it is feasible to take the off gas into the area of the cooling tower sump to make use of any small traces of ozone which may be present to provide additional protection for the cooling tower sump.

### Economic comparison

Each case must be evaluated individually and will depend upon the chemical programme utilised and the reasons for utilising ozone from an improved performance and possibly an improved environmental perspective.

Some indication can however be given:

Cooling Tower:

System volume	4 000 m <sup>3</sup>
Recirculation rate	21 000 m <sup>3</sup> /h
Temperature differential	10 ° F
Evaporation rate	210 m <sup>3</sup> /h

<u>Programme Type</u>	<u>Chemicals</u>	<u>Ozone only</u>
Concentration factor	3	10
Bleed rate (m <sup>3</sup> /h)	105	23
Water usage (m <sup>3</sup> /h)	315	238

Savings:

Water cost savings	- Make-up (\$0.06 m <sup>3</sup> )	\$40 471.00 / year
	- Discharge (\$0.1 m <sup>3</sup> )	\$67 452.00 / year
Chemical programme cost savings	- Inhibitor at 25ppm	\$115 000.00 / year
	- Biocides	\$100 000.00 / year
	- Dispersant	\$50 000.00 / year
Maintenance savings		\$20 000.00 / year
<b>Total on-going savings</b>		<b>\$342 923.00 / year</b>

### Unquantified cost savings

Energy savings as a result of improved operational efficiencies due to the increased heat transfer resulting from biofilm removal from heat exchange surfaces. These savings could realise the greatest benefit from the use of ozone for cooling water treatment as typically approach temperature performance improves dramatically. A reduction of 3°C in cooling water temperature would give an associated energy saving of approximately 1%.

Administrative cost savings resulting from eliminating the need for chemical inventory management.

### **Ozone treatment costs**

A complete ozone solution incorporates the following equipment:

- Feedgas supply equipment -in this case air fed with a compressor and air dryer.
- Ozone generator proper
- Contacting system - consisting of side stream injector and motive water pump.
- The equipment would be installed in a suitable room/enclosure fitted with appropriate health and safety devices.
- An off-gas venting degassing valve would be installed in a suitable location.

Total cost of the equipment for the above example is estimated at \$ 370 000.00 including monitoring and control equipment.

The total electrical running cost at \$0.06 / kWh would be \$ 59 524.00 per year.

In addition to the above costs allowance must be made for installation.

For many cooling water systems ozone provides an efficient treatment solution which is easier to manage, provides on-going cost savings and supports environmental improvement objectives.

### **Keywords**

Ozone, Cooling Water, Cooling Towers, Inhibitors, Chemical treatment, Biocide

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