INTERNATIONAL JOURNAL OF PLANT, ANIMAL AND ENVIRONMENTAL SCIENCES

IJPAES

Volume-4, Issue-2, April-June-2014

ISSN 2231-4490

Coden : IJPAES www.ijpaes.com

Received: 15th Feb-2014 *Revised: 15th March-2014* *Accepted: 20th March-2014*

Research article

COMPARISON STUDY OF CORROSION BEHAVIOR AND SEDIMENTATION OF TWO CONVENTIONAL AND OZONE METHODS IN WET COOLING TOWERS AT SEMI-INDUSTRIAL SCALE

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ABSTRACT: Wet cooling tower water is continuously exposed to airborne organic materials, and the buildup of bacteria, algae, fungi, and viruses presents hazards to the tower system. Corrosion occurrence is also probable due to steel-made equipment. Chlorine, as an oxidizer is generally used to inhibit the growth of bacteria and microorganisms and also used to annihilate them in the cooling towers. Chemical Inhibitors are used in order to decrease corrosion, sedimentation and microorganism activity difficulties. Ozone has a stronger oxidization capability than chlorine and destroys the organic materials and bio-films. A cooling tower in semi-industrial scale was built for investigations on corrosion and sedimentation issues in cooling towers. It was equipped with an industrial heat exchanger, a Corrater and a corrosion test rack. Important chemical and operational parameters in the pilot plant are monitored using HMI. In the first forty-five-day period, chlorine with a concentration of 0.5-1 mg/lit was used with conventional chemical inhibitors and in the second period, due to the stronger disinfecting quality of ozone, it was used with a concentration range of 0.05-0.15 mg/lit, While the concentration of chemical inhibitors was also reduced. Anti-corrosion and anti-sedimentation materials dosage was reduced down to 40 percents and biological distributor materials and non-oxidizing biocides were eliminated. Corrosion and sedimentation issues were investigated by means of coupon testing. Daily corrosion rate was also measured via Corrater device. Both ozone and chlorine are known as powerful oxidizers that may destroy the passive layer and cause cathode corrosion when in high concentration or when remaining in the system. In spite of being more powerful, ozone is more harmless due to the facts that its concentration ratio to chlorine was 0.1 and its residence time was only 10 minutes while chlorine remains in the system for 6 hours (Bach wise method). Hence, uniform and pit corrosion rates had been decreased for ozone disinfection. The daily corrosion results obtained using the instantaneous corrosion monitoring device Corrater was confirm using the results of coupon testing. The average corrosion rate for chlorination and ozone disinfection periods were calculated to be 0.028 mm/y and 0.012 mm/y, respectively. However, sedimentation did not demonstrate any differences.
Keywords: Cooling tower, Corrosion, Ozone disinfection, Chlorination

INTRODUCTION

The most conventional cooling system in industries is the open circulatory system of cooling towers. Cooling towers are known as heat exchangers in which evaporation of small amount of water (about 2 to 3 percent) causes rapid cooling of the remaining water. The American EPA prohibited using chromates inhibitor as anti-corrosion in 1989, due to its environmental problems. It offered of ozonation treatment in cooling towers, instead, as a more efficient disinfectant to eliminate impurities [1]. Mr. Gharaie, in their article presented in 2007 have researched .Mr. Gharaie has integrated ozone treatment with chemical inhibitors for water treatment in cooling tower his work resulted. In the reduction levels of bacterial and mineral substances in the waters discharged through blow-down decreases [2]. Water hardness was identified as the causative factor for the sedimentation in equipment and reduces the efficiency of heat transfer process. They defined corrosion as metal: the destruction of a metal or its properties by chemical or electrochemical reaction with its environment.

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There exists a high degree of Corrosion in wet cooling towers, occurrence is probable due to steel-made equipment which may cause several difficulties such as destruction of metallic parts of the cooling tower, deposition of corrosion products in heat exchangers, reduces the efficiency of exchangers, initiation and propagation of leakage in equipment, caused by corrosion, make the cooling tower mix the, process water of the exchangers and increase in water consumption and production costs. Open cooling towers are directly exposed to sunlight and air; cooling towers provide an appropriate growth medium for microorganisms. Microorganism's growth may bring about some problems like sedimentation and blockage, decay and destruction of wooden materials and corrosion caused by microbiological activities. These problems can in decrease the efficiency and consequently lead to higher economical expenses [3]. MR. Hertrampf, J. in1988, considering ozone unique specification, Ozone introduced it as a good alternative to chlorine in cooling water treatment [4]. Mr. Conner, A., in 2005, proposed the conjunction of ozone with other chemical inhibitors for corrosion resistance and scaling reduction has been reported [5]. M.R. Viera et al., in his studies in 2000, introduced chemical inhibitors and no oxidant biocides for elimination of bacteria and microorganisms. Using these chemicals could reduce corrosion and sedimentation effects. Using chemicals increases the operational costs in addition to creation of environmental issues. He considered Ozone, as a stronger oxidizing antiseptic than chlorine that possesses unique properties in addition to his study on high disinfecting qualities of ozone, in cooling towers, identified that dissolved in suitable concentration can cause the passive behavior of medium corrosion resistance in metals like carbon steel. However, corrosion resistance made in carbon steel, using ozone, is not high as that of stainless steel. The Reduction of water consumption, increase in energy efficiency and lowering the inhibitors are discussed in another article [6]. In this study, the passive behavior corrosion resistance in carbon steel in two methods of ozonation and conventional treatment was analyzed, using measuring equipment and software. Also, the effect of ozone and chlorine purification on depositional characteristics of water of cooling tower is experimentally studied in a semi-industrial scale. The amounts of anti-corrosion and anti-scaling substances were also compared in the two methods. The decline in the population of SRB anaerobic bacteria and the population of TBC aerobic bacteria, which could respectively make microbial corrosion and fouling, was studied, too. Purpose of making cooling tower plant pilot is measuring feasibility of using ozone gas in wet cooling towers. Practical evaluation of corrosion and sedimentation rate in ozone disinfection methods and conventional methods are discussed.

METHODOLOGY

Oxygen molecule consists of two oxygen atoms and ozone is produced out of dry air or pure oxygen separated from air through corona discharge process. Ozone is a molecule consisting of three oxygen atoms and is commonly referred to as O_3. Oxygen and ozone molecules are allotrope. Under ambient conditions, ozone is very unstable and there for has a relatively short half-life of usually less than 10 minutes. Ozone is a powerful oxidant biocide which could deactivate microorganisms and oxidize many organics. Conventional methods of cooling water treatment in pilot plant consist of pH control and chemical dispersant for scale prevention, addition of phosphate and polymer component for corrosion control, and chlorination by hypochlorite and non-oxidizer biocide for biofouling control. The new method (ozonation treatment) of cooling water treatment in pilot plant reduces the amount of chemical dispersant for scale prevention. Phosphate and polymer component are also decreased for corrosion control, and hypochlorite and non-oxidizer biocide are replaced by ozone for bio fouling control. Compared to the Conventional method, in the new one, the amount of chemical corrosion and scaling are decreased and ozone biocide is also replaced. This pilot plant and study were conducted in of the research and industrial in Iran.

Some operational and design parameters of the cooling tower pilot

Cooling tower type: wet tower, counter current with an induced fan, liquid mass flow to air ratio: 1.1, operational circulatory water: 2 cubic meters per hour, cooled temperature: 26 °C, return temperature: 42°C, wet temperature: 12 °C. Tower material: wooden structure with aluminum walls, filler (type): polypropylene (turbo splash) .Pipes and exchangers material: carbon steel, brass and stainless steel. A permanent 20-gram ozone device was purchased from Ozone Ab Co.

Design drawings using AutoCAD 2007 software is a pilot plant. A schematic of the pilot plant cooling tower with an automated software code 2007 is drawn, is shown in figure-1.

The cooling tower with the above -mentioned features, equipment with a heat exchanger and a Shelter of utility equipment is shown in figure 2.a. In this project, an ozone generator with the capability of producing 20 g/hr, fed by dry air, is used. In figure 2.b, the generator is shown with utility equipments including, high pressure pump, and contact vessel. In this pilot plant type of ozone generator is permanent work and silent corona discharge is used. In corona discharge, ozone is generated when an electrical discharge occurs between two conductors separated by discharge gap.

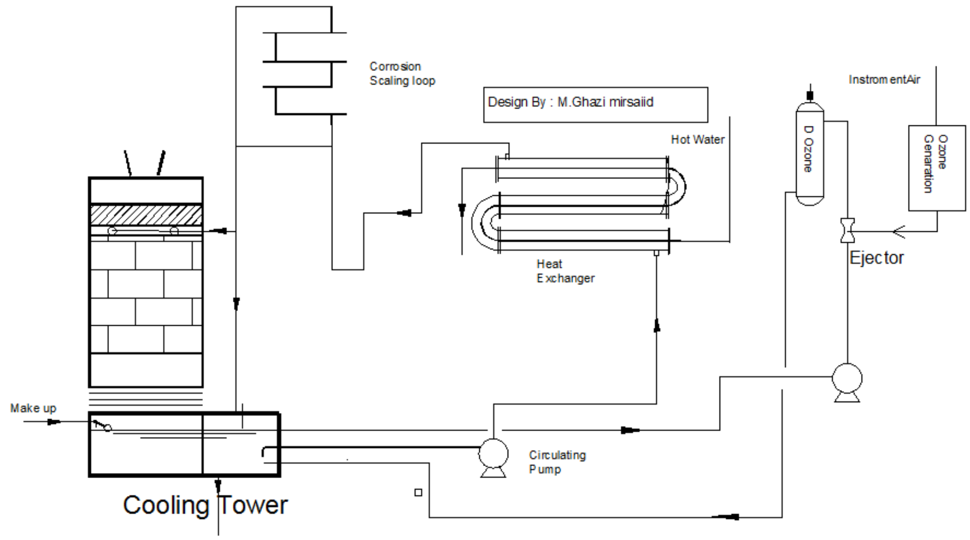

Figure-1.Block diagram for ozone treatment (pilot plant) of cooling tower water


Figure 2.a- Cooling tower pilot **Figure 2.b- Ozone-generator package**

A portion of the cooling water is entered to ejector using a high pressure pump. As a result of the vacuum in the ejector, ozone gas enters the ejector and is mixed with the cooling water stream that pumped by high pressure pump, then the ozone and cooling water stream mixture enters the contact vessel. The excess gas ozone is released from the contact vessel, and then water containing soluble ozone is diffused into the cooling tower bottom basin.

During Ozone Treatment, the concentration of the ozone diffused into cooling basin is 1.5to 2 mg/lit and concentration of the ozone into cooling water supply, justly before entering the heat exchanger is 0.05 to 0.15 mg/lit. Ozone concentration in exit pipe from basin (two meters after basin) is analyzed 3 days a week using the standard method of number Part 4500-O_3-B- Indigo method was done; [7]the same analysis is also done in a daily basis using KIT test method for its quick and approximate measurements.

In the conventional treatment, concentration of the free chlorine into cooling water supply, justly before entering the heat exchanger is 0.3 to 0.6 the free chlorine concentration in exit pipe from basin (two meters after basin) is analyzed 3 days a week using the standard method of number Part 4500-CL-G- DPD colorimetric method was done [7] the same analysis is also done in a daily basis using DPD KIT test method for its quick and approximate measurements. Also ozone concentration was continually and indirectly analyzed by ORP (Oxidation-Reduction potential) analyzer and the amount of ORP is shown on HMI (Human Machine Interface). Residual ozone concentration is controlled to remain between 0.05 to 0.15 mg/lit (500-600 mv) in this sample point. (Circulation cooling stream is 2 m^3/hr).

Pilot cooling tower tests

Pilot cooling tower tests were grouped in two stages. In stage one (45days) the conventional treatment is tested, and in stage two (45days) the ozonation treatment is tested. In order to, reach to the optimum consumption point of chemical inhibitors in the ozonation treatment, the process below were followed in a 45 day period.

1) Applying the expert's, guides in the supplier of chemical inhibitors.
2) Providing the same chemical condition and concentration cycle as in the chlorination treatment.
3) Corrosion and scaling rate monitoring.

All the above –mentioned stages resulted in the emergence of the optimum consumption point of chemical inhibitors or the elimination of the inhibitors. Safety factor was considered. A very significant point to be mentioned is that, microbial and chemical tests in this pilot plant are carried out based on the microbial and chemical tests done in main cooling towers, so that they could justify using ozone in the new method instead of chlorine in the conventional method. Other a very significant point to be mentioned is that, because stress corrosion is made by chloride, the amount of chloride in circulation water shouldn't be more than50 mg/li. The circulation cooling water was analyzed two times per day for pH, conductivity, calcium, magnesium, "M" alkalinity, "P" alkalinity, silica, and; chloride, sulfate. In addition to the water chemical analyses, total aerobic bacteria counts, sulfate reduction bacteria test were analyzed tree times per week. Pilot plant was equipped with a monitor, an on-line mild steel Corrater and corrosion test rack. The temperature and flow and some of chemical parameters are shown on HMI. The chemical and microbial quality of make-up water was measured at the beginning of each period. The average values are shown in table-1.

Table-1: Chemical and microbial results of make-up water

Parameter	Unit	Make-up water
pH	-	7.76
Conductivity	µs/cm	510
Total hardness	mg/l as $CaCO_3$	192
Calcium hardness	mg/l as $CaCO_3$	107
Mg hardness	mg/l as $CaCO_3$	85
M Alkalinity	mg/l as $CaCO_3$	165
Silica	mg/l as Silica	14.0
Chloride	mg/l as chloride	20
sulfate	mg/l as Sulfate	64
Turbidity	mg/l	Trace
Total Fe	mg/l	0.07
SRB	CFU/ml	0
TBC	CFU/ml	<10

Heat exchanger

In this pilot plant is used Double pipe heat exchanger. Single phase hot water with 80 °C temperature enters the internal pipe of the exchanger which is made of SS-304 and quits after heat exchanger. The cooling tower water with a temperature of 26°C enters the exchanger shell. Then, 43° C water enters the cooling tower after passing the corrosion loop. Double pipe heat exchanger is in the figure-3.

Corrosion test rack

Corrosion and sedimentation racks were used in order to investigate the corrosion and sedimentation in system. Carbon steel and brass coupons were applied for corrosion investigations and stainless steel coupons is also applied for investigating sedimentation. They were chosen according to the pipe material and the target tower heat exchangers. Coupons were placed via a device in accordance with ASTM D2688-05 Standards to make this, a glass tube corrosion loop is used (1 inch in diameter), two coupons for each kind (see figure 3.a). In this study, corrosion rate was measured by means of coupon placement test through a long-term period (45 days) and a daily measurement procedure via a Corrater device (9000 plus [8].



Figure 3- Double pipe heat exchanger Figure 3.a- Corrosion test rack Figure 3.b- Corrater device

This device evaluates the uniformed and pitting corrosion rates based on linear polarization potential measurements (see figure 3 b). Unit of the momentarily corrosion rate meter was mils inches per year. Table 2 shows specifications of coupons. Disinfections materials cause corrosion of the metallic body of water transfer pipes, heat exchangers and increase production costs (especially chlorine which is used highly concentrated and its residue is stable). Therefore, allowed corrosion rate is of great significance (see table-3).

Table-2: Specifications of applied coupons

Coupon type	Surface area (in^2)	Surface area(cm^2)
Bar-shape 3x0.5x1/16 in. (76x12.7x1.6 mm)	3.38	22.0
Metallurgies	Density ($g.cm^3$)	
Mild Steel(C1010)	7.86	
Stainless Steel (316)	7.98	
Admiralty Brass(CDA 443)	8.53	

Table-3: The allowed corrosion rate values of the applied metals [9].

Corrosion rate(mpy)		
Carbon steel	Copper based alloys	Description
<1	<0.1	Excellent
1 to 3	0.1 to 0.25	Very good
3 to 5	0.25 to 0.35	Good
5 to 8	0.35 to 0.5	Fair
8 to 10	0.5 to 1	Poor
>10	>1	Severe

Chemistry of cooling Water and Langelier saturation index calculation

Cooling tower water tendency for corrosion and sedimentation in two methods of ozonation and conventional treatment was studied using the results taken from corrosion and sedimentation indexes. The index used in this study is of LSI type. LSI has to plan in a way that the water achieves to the point of sedimentation. Chemical quality of makeup can affect on corrosion and scaling rate chemical and microbial quality of circulation cooling water tower was measured conventional method and ozone treatment in twice per every day by lab. Using chemical parameters of water and software was calculated Langelier saturation index every day.

Comparing the effectiveness of ozone and chlorine disinfections by microbial testing

Growth of microorganisms like bacteria, especially anaerobic ones may affect corrosion; therefore, microbial testing is discussed. A very significant point to be mentioned is that, microbial tests in this pilot plant are carried out based on the microbial tests done in main cooling towers , so that they could justify using ozone in the new method instead of chlorine in the conventional method. In main cooling towers, only SRB (Sulfate Bacterial Reduction), TBC (Total Bacterial Content) tests are conducted. TBC test is conducted using the standard method and standard Kit test. SRB test is conducted using the standard method. Based on the pervious experiences, no need is felt to other microbial tests. One of the problems, caused by bacteria is the accumulation of slime forming bacteria. Microbial testing is discussed. Initially, the population of aerobic (TBC) and anaerobic (SRB) bacteria were calculated according to ASTM D5465 and D4412, respectively. Total Bactria content (TBC) was measured 3 days a week using the standard method number D-5465.however ,due to its quickness and ease, test kit method with the standard B9215was used for the same process in a daily basis. Test results of TBC with using standard method confirm kit test method in following is brought general explanation for TBC standard method with number D-5465. These practices cover recommended procedures for counting colonies and reporting CFU (colony-forming units) on membrane filters and standard pour and spread plates. The grid lines help in counting the colonies. Some colonies will be in contact with the grid lines. Count the colonies in the squares indicated by the arrows. Count the colonies with a stereoscopic (dissecting) microscope that provides a magnification of at least 10 to 15x. Select the membrane with the number of CFU in the acceptable range and calculate the count/reporting volume from formula (1). Count the colonies with a stereoscopic (dissecting) microscope that provides a magnification of at least 10 to 15X. [10]

$$CFU/mL = \frac{colonies\ counted}{Volume\ of\ sample\ filtration\ in\ mL} \times 1 \quad (1)$$

Sulfate reduction Bactria (SRB) was measured microbial lab. In following is brought general explanation for SRB standard method with number D4412. Culture medium is prepared for SRB microbial test, and incubated at 20°C for 21 days. Positive reactions are indicated by the deposit of a black precipitate. Only absence or presence anaerobic bacteria SRB is important in main cooling tower in disinfection time. Its count isn't conventional in this project [11].

Corrosion

Table 4 gives the corrosion rates by days, obtained from coupons tests (Gravity test) during ozone disinfection and chlorination. Uniform corrosion diagrams are plotted in two ways in figure 4. Pitting corrosion diagrams are also pictured in two ways in figure -5.

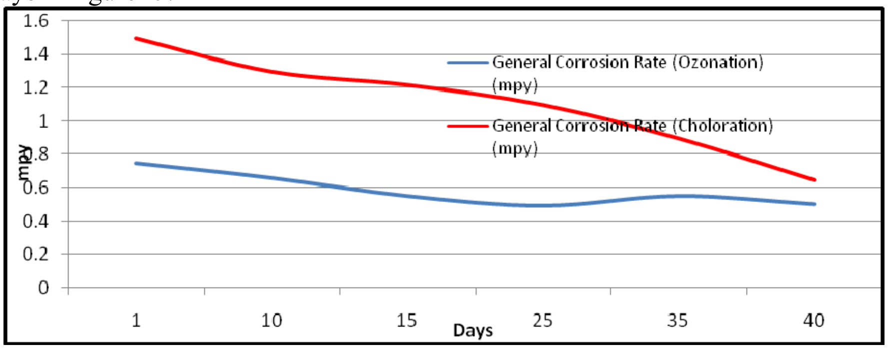

Figure-4: Uniform corrosion plot during ozone disinfection and chlorination

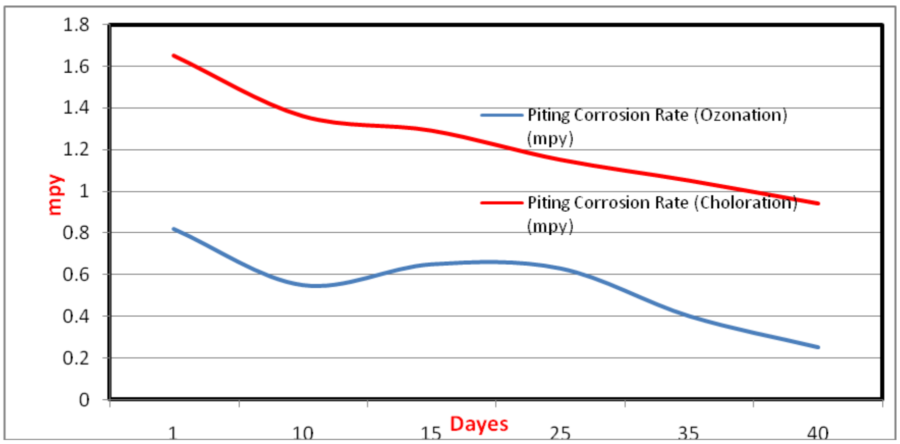

Figure-5: Pitting corrosion plot during ozone disinfection and chlorination

Table-4: The corrosion rates by days

	chlorination	ozone disinfection
Average weight loss of carbon steel coupons	54 mg	30 mg
Average weight loss of brass coupons	5mg	3 mg
Average weight increase of stainless steel coupons	15mg	14 mg

Calculating weight alterations of corrosion and sedimentation coupons

Uniform corrosion rate based on the standard method of weight loss using the equation (2). [9]

$$CR = \frac{W}{(A \times t \times d)} \times K \qquad (2)$$

Unit and description CR,W,A,t,d and K Is given in Appendix I.

Corrosion rate calculations for carbon steel during ozone disinfection

$$CR = \frac{W}{(A \times t \times d)} \times K = \frac{30}{3.38 \times 45 \times 7.86} \times 22.27 = 0.465 mpy = 0.012 mm/y$$

Corrosion rate calculations for carbon steel during chlorination

$$CR = \frac{W}{(A \times t \times d)} \times K = \frac{54}{3.38 \times 45 \times 7.86} \times 22.27 = 1.006 mpy = 0.025 mm/y$$

Corrosion rate calculations for brass during ozone disinfection

$$CR = \frac{W}{(A \times t \times d)} \times K = \frac{3}{3.38 \times 45 \times 8.53} \times 22.27 = 0.051 mpy = 1.3 \times 10^{-3} mm/y$$

Corrosion rate calculations for brass during chlorination

$$CR = \frac{W}{(A \times t \times d)} \times K = \frac{5}{3.38 \times 45 \times 8.53} \times 22.27 = 0.086 mpy = 2.2 \times 10^{-3} mm/y$$

Corrosion rate and sedimentation evaluations using the software

The software has the ability to calculate other indexes, but the index is Our Langelier index. The lingerie index is the accepted pattern in this article which its range and interpretations are available in table 6. In this research, the corrosion rate was mostly controlled by putting the chemical state of water in a relatively sedimentation situation (lingerie index was 1.9 to 2.3). Result: the software gives LSI equal to 2.2. (See figure 6)

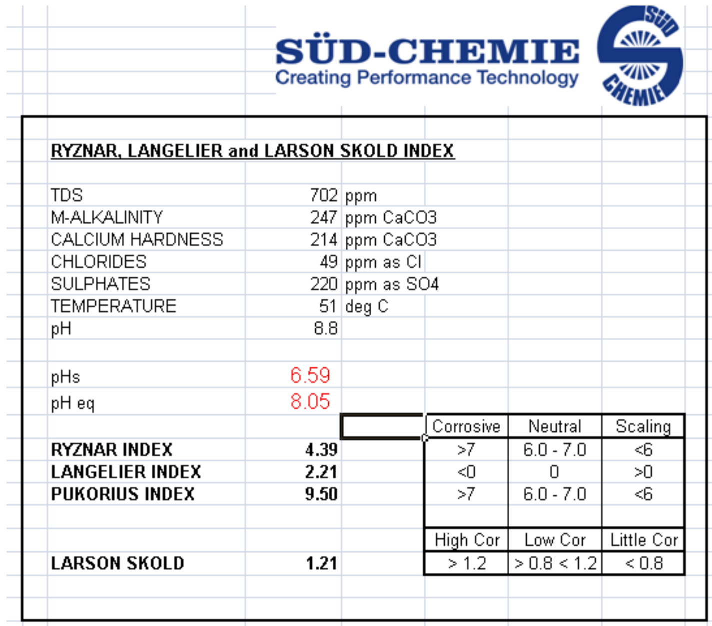

Figure-6: Calculating of the corrosion and sedimentation indices. [12]

Results of alterations in chemical injection program during ozone disinfection

Due to the powerful ability of ozone for disinfection and its other characteristics, the injection program of chemical inhibitors undergone some changes in ozonation and chlorination methods (as given in table 5) to control the biological species growth with no difficulties for corrosion and sedimentation conditions.

Table-5: Alterations in injection programme of chemicals and inhibitors for two 45-day periods

Row	Chemical inhibitors	Percent in the conventional injection (chlorination)	The injection of the ozonation method(Percent)
1	Anti-corrosion	100	40
2	Anti-sedimentation	100	40

Lower corrosion rate in ozone disinfection in comparison with chlorination and reduction of inhibitors and other chemicals may be totally explained by:

1- Both ozone and chlorine are known as powerful oxidizers which in case of high concentration or remaining in system may destroy the passive layer and cause cathodic corrosion. Ozone is more powerful than chlorine and is more harmless, due to the facts that its concentration ratio to chlorine was 0.1 and its residence time was only 10 minutes. While chlorine keeps its effects on system for 6 hours. Hence, uniform and pit corrosion rate have been decreased for ozone disinfection.

2- Inhibitors usage may be reduced because of decrease in corrosion. However, they cannot be eliminated to zero due to presence of other corrosive agents like oxygen. The optimum reduction level was determined to be one third of the chlorination level.

3- At high concentrations of inhibitors (anti-corrosive and anti-sedimentation) in chlorination method, cathodic protection is considered more in chlorination which shift anodic protection when a decrease occurs in concentration too, Soft sediment was precipitated in the pipe for protection and current anti-corrosive to anti-sedimentation ratio of 3 to 1 that is better to change 2 to 1.

4- The bio-dispersant is used to disperse biological and bio-film bulks of which chlorine is in need up to 0.5-1mg/lit and is more effective. Its dosage may be eliminated or reduced down to 2 mg/lit for ozone; since, ozone with high diffusivity may destroy the bio-films itself with a different mechanism.

5- The non-oxidizing biocides complete the disinfection process with chlorine; however, they may not be useful for ozone due to its powerful and different disinfection mechanism and continuous injection.
6- Most of inhibitors demonstrate high acid affinity except the solid chlorine; then, pH was reduced during ozone disinfection with decrease in chemicals usage. Hence, acid consumption percentage was raised up to 10%.

Due to discrete injection of chlorine and its higher concentration, more pit and local corrosion was observed. This information was collected at concentrations of 0.05-0.15 mg/lit and 0.5 to 1 mg/lit for ozone and chlorine, respectively. Mean values of chemical results of makeup water and circulatory water of the tower in forty-five-day period of chlorination and ozone disinfection are given in table 6. Notice given to the discussion of these results is not mentioned in this category.

Table-6: Comparing chemical results of circulation water and increasing cycle in two methods of chlorination and ozonation.

Parameter	Unit	Tower water by injecting ozone	Tower water by injecting Chlorine
pH	-	8.65	8.7
Conductivity	μs/cm	1250	1100
Total hardness	mg/l as $CaCO_3$	470	459
Calcium hardness	mg/l as $CaCO_3$	248	241
Mg hardness	mg/l as $CaCO_3$	222	218
M Alkalinity	mg/l as $CaCO_3$	265	285
Total phosphate	mg/l as phosphate	3.5	7.5
Silica	mg/l as Silica	40	30
Chloride	mg/l as chloride	44	51
Sulfate	mg/l as Sulfate	165	134
Turbidity	mg/l	0.7	2.9
Total Fe	mg/l	0.05	0.4
SRB	CFU/mL	0	0
TBC	CFU/mL	<100	<1000
Free CL_2	mg/l	0	0.5
O_3	mg/l	0.1	0

Sedimentation results and comparison

In addition to microbial pollutions and corrosion, hardness is an important parameter in cooling water. It shows sedimentation tendency of system; thus, the more hardness leads to more precipitation. Hardness is controlled by calcium and magnesium ions. Table 6 gives the associated concentrations of these ions during ozone disinfection and chlorination. As partial system tended sedimentation, corrosion mechanism turned cathodes in ozone disinfection due to reduction of inhibitors and partial increase in hardness. In general, no difference was observed in sedimentation on stainless steel for both cases. Coupon weighing and chemical results also proved the matter.

Microbial testing results

TBC test was conducted at a time when no disinfectant was injected into the system and the tower had started up five days the before. TBC before disinfection was $10^4\ CFU/mL$ Figure 7a-example of TBC test is illustrated before disinfection that was calculated according to ASTM D5465. Figure 8a-example of TBC test is illustrated before disinfection that was calculated according test kit method with the standard B9215. TBC test was performed when the tower was on the five day after the start up. Average TBC was $900\ CFU/mL$ in disinfection time with chlorine 0.5 mg/lit concentration that was calculated according to ASTM D5465 .(see Figure 7b)- Figure 8c-example of TBC test is illustrated in disinfection time with chlorine 0.5 mg/lit concentration that was calculated according test kit method with the standard B9215. TBC test was performed when the tower was on the five day after the start up. Average TBC was $200\ CFU/mL$ in disinfection time with ozone 0.1 mg/lit concentration that was calculated according to ASTM D5465 .(see Figure 7c)- Figure 8b-example of TBC test is illustrated in disinfection time with ozone 0.1 mg/lit concentration that was calculated according test kit method with the standard B9215.
The estimated population of bacteria on no-disinfection condition, ozone and chlorine disinfection was $>10^3$ CFU/ml, $<10^2$ CFU/ml and $<10^3$ CFU/ml, respectively. According to the standard method number D-5465, the bacteria population in cooling towers water has to be less than$<10^3$ CFU/ml; thus, it may be concluded that both cases are in range of acceptance.

However, the towering disinfection ability of ozone was revealed. Anaerobic sulfate reducing bacteria not found in the presence of ozone and chlorine with the mentioned concentration. Ozone is a powerful oxidizer with a standard electrode potential of 2.07 V vs. HSE which is approximately twice chlorine's. SRB test was conducted at a time when no disinfectant was injected into the system and the tower had started up five days the before, SRB test was positive. (See figure 9a). SRB test was performed when the tower was on the five day after the start up, When free chlorine concentration was less than 0.2 mg/lit, SRB test was positive(See figure 9b). When ozone concentration was amount of between 0.05to 0.15 mg/lit, and free chlorine concentration was amount of between 0.3to 0.6 mg/lit SRB that was negative. (See figure 10a, b), that was calculated according to D 4412–84
Only absence or presence anaerobic bacteria SRB is important in main cooling tower in disinfection time. Its count isn't conventional in this project.

a b c

Figure 7-a- TBC test is illustrated before disinfection that was calculated according to ASTM D5465
b-TBC test is illustrated, in disinfection time with chlorine 0.5 mg/lit concentration
c in disinfection time with ozone 0.1 mg/lit concentration that was calculated according to ASTM D5465.

a b c

Figure-8: Figures of TBC test, in the conditions of
a. lack of disinfection
b. ozone disinfection in 0.1 mg/lit concentration,
c. chorine in concentration lower than 0.2 mg/l that was calculated according test kit method with the standard B9215

a b

Figure-9: SRB test is illustrated before disinfection
b- SRB test is illustrated, chorine in concentration lower than 0.2 mg/lit.

a **b**

Figure 10-a-SRB test is illustrated, in disinfection time with chlorine 0.5 mg/lit concentration and b-in disinfection time with ozone 0.1 mg/lit concentration

ACKNOWLEDGEMENTS

The authors deeply appreciate Dr. B. Rasekhi, Dr .K.Ghaemipanah, the researchers' oil company research center, for their guides and encouragement.

CONCLUSIONS

Cooling tower water was studied with a tendency for corrosion and sedimentation in two methods of ozonation and conventional treatment by using the results taken from corrosion and sedimentation indexes and Corrater device and with coupon placement method. The index used in this study is of LSI type. LSI has to plan in a way that the water reaches to the point of sedimentation. Using a proper method and ozone with suitable concentration in cooling water, the following results are obtained.

1) The reduction of anti-corrosion amounts and anti-scaling substances and the elimination of biocides.
2) The dramatic reduction in the population of SRB anaerobic bacteria and the population of TBC aerobic bacteria, which could respectively make microbial corrosion and fouling
3) The dramatic reduction of chemical corrosion caused by the dramatic reduction of ozone disinfectant concentration compared to that of chlorine concentration.
4) Amore moderated passive behavior of corrosion resistance seems to be seen in ozone, having noticed the reduction of corrosion. Generally, efficiency in cooling water is affected by microorganism population, corrosion rate and sedimentation. The corrosion and sedimentation behavior causes by chlorination with addition of inhibitors which its dosage was controlled by a supplier that was studied in a month-and-half period. Sedimentation rate was acceptable and corrosion rate was obtained about 0.028 mm/y by means of a Corrater device and with coupon placement method. Inhibitors had been eliminated or reduced for the next period in which ozone disinfection was studied. It was found by means of same facilities that corrosion rate was reduced to 0.012 mm/y and sedimentation stayed in an acceptable range as well. It was proved by inspecting inside of tubes and coupon surface. Alkalinity, pH and corrosion and sedimentation indices kept in the following ranges, respectively: $240 \leq M$ Alkalinity ≤ 260 (mg/lit), $8.5 \leq pH \leq 8.6$ and $1.9 \leq LSI \leq 2.3$. If ozone disinfection is performed with a proportionate concentration and through a proper method (solution of ozone and releasing the excess) in cooling towers; corrosion rate in comparison to chlorination significantly improves.

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