Influence of Microbes in Cooling Tower: A Review

Ranjana Tewari, S K Mehta, Pujan Vaishnav

Gujarat state fertilizers and chemicals limited, Vadodara, India

---

Abstract - *Cooling towers are the most crucial system in industrial process. Most of the industries like fertilizer, oil, power use cooling towers to decrease the temperature of process water. Cooling towers are heat rejection devices used to transfer process waste heat to atmosphere. The continuous flow of water in cooling tower makes it susceptible to microbial growth. The growth of microbes in cooling water system decreases the efficiency of cooling tower, causes microbial induced corrosion and deteriorates the wooden structures of cooling tower. To overcome the microbial growth the cooling tower systems are continuously dosed with chlorination and biocides are added whenever required. This review covers how microbes influence the cooling tower and how the monitoring of the cooling tower for microbial growth is to be done. This review gives a brief description of standard followed in India to before procurement of cooling tower wood also it covers the new approaches to control the microbial growth in cooling towers.*

***Key Words*: Total viable count, Sulphate reducing bacteria, microbially influenced corrosion (MIC), Cooling towers.**

1. INTRODUCTION

Industrial processes and machines generate such large amounts of heat and its continuous dissipation is necessary for efficient operation. The cooling towers used in various industries cool down the process water so that it can be reused. Cooling Tower is susceptible to microbial contamination because of its optimum conditions of pH, temperature, dissolved oxygen and nutrients in cooling water that encourages the growth of microorganisms. The numbers and species of microorganisms in circulating cooling water directly depend on the quality of the makeup water. When makeup of cooling water is done by groundwater or tap water, fewer microorganisms would grow. However, when recycled water is used to make up the system, more microorganisms will grow. There are various species of Bacteria, Fungus and Algae that grow in the cooling tower. An inappropriate control of these microorganisms may lead to damage of expensive equipment, cause loss of production, increase in maintenance cost, and reduce heat transfer efficiency and waste energy. In GSFC we are having 14 cooling towers and microbial monitoring of these cooling towers is done fortnightly. Based on the results of microbial count the dosage of biocides is decided, along with biocides other chemicals like corrosion inhibitors, antiscalants are added routinely to maintain the health of cooling tower.

1.1 Cooling Tower: Function and Types

The primary task of a cooling tower is to reject heat into the atmosphere. Most of the cooling towers work on the principle of evaporative cooling. Evaporative cooling is the process where warm water from an industrial process is pumped up to the top of the cooling tower and then it is distributed by cooling water distribution system. The water gets distributed by cooling tower nozzles to the wet deck. At the same time, air is being drawn through the air-inlet forcing water to evaporate. The Functioning of cooling Tower is shown in Figure 1.

Types of cooling towers:-

Cooling towers fall into two main categories:

a. Natural draft
b. Mechanical draft.

Natural draft towers use very large concrete chimneys to introduce air through the media. Mechanical draft towers utilize large fans to force or suck air through circulated water. The water falls downward over fill surfaces, which help increase the contact time between the water and the air this helps in maximizing heat transfer between the two. The mechanical draft cooling towers are more widely used than natural draft.

Mechanical draft towers

Mechanical draft towers are available in the following airflow arrangements:

1. Counter flow induced draft.
2. Counter flow forced draft.
3. Cross flow induced draft.

In the counter flow induced draft design, hot water enters at the top, while the air is introduced at the bottom and exits at the top. Both forced and induced draft fans are used. In cross flow induced draft towers, the water enters at the top and passes over the fill. The air, however, is introduced at the side either on one side (single-flow tower) or opposite sides (double-flow tower). An induced draft fan draws the air across the wetted fill and expels it through the top of the structure.

1.2 Microbes in cooling tower

Microorganisms are omnipresent. They propagate wherever they find optimum conditions for their growth. Cooling water systems due to their optimum conditions like pH, temperature, are the location for prosperous growth of microorganisms. Growth of microbes adversely affects the

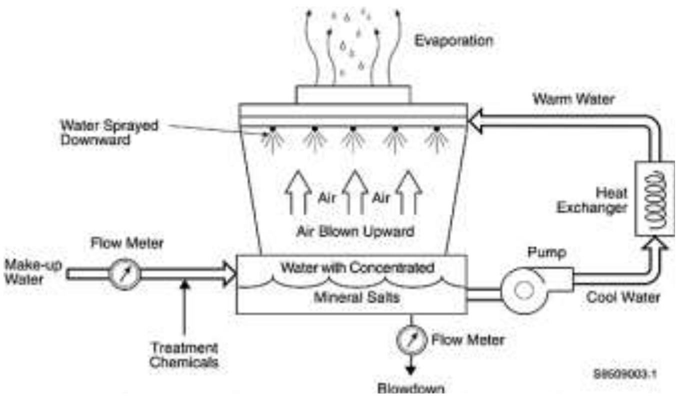

Figure 1: Function of cooling tower

Performance of cooling tower. Types of microbes found in cooling tower and their effects are described in table 1. Details of microbes found in cooling tower are explained below-

a. Bacteria- Bacteria mostly grow in heat exchangers where they restrict water flow; they form an insulating layer on heat transfer surfaces causing reduction in heat transfer, also presence of bacteria increases the corrosion rate of metal equipment. Types of bacteria present in cooling tower and their effects are explained below-

i. Sulphate reducing bacteria- SRB are the anaerobic bacteria (eg. Desulfovibrio) that reduce sulphur compounds like sulphate, sulphite, thiosulphate to H_2S. They are the major cause of corrosion in cooling tower. SRB mostly survives under anaerobic conditions but some SRB can also adjust to survive in aerobic conditions. It was reported that SRB can bear Oxygen concentration of up to 1.5mM using several defense strategies (1). The mechanisms by which they cause corrosion include Cathodic depolarization, anodic depolarization, production of corrosive iron sulphides, sulphide induced stress corrosion cracking and local corrosion. Indications of SRB include reddish or yellowish nodule on metal surfaces that when broken exhibits black corrosion by-products. If hydrochloric acid is added to the black deposit, hydrogen sulfide will be released giving off a "rotten" egg odor (2). SRB mostly grows underneath the aerobic bacteria; this is the ideal place for them to grow as the aerobic biofilm prevents the supply of oxygen below its surface (3).

ii. Metal reducing bacteria- This type of bacteria causes corrosion by dissolving the corrosion resistant oxide film on metal surfaces. They along with the SRB enhance the corrosion process of metals. It includes the bacteria Pseudomonas and Shewanella spp.

iii. Metal depositing Bacteria- This group of bacteria inclides Leptothrix and Gallionella. They convert soluble iron to iron oxide and produce voluminous deposits. They also convert manganous ion to manganic ion with deposition of manganese di oxide. These deposits of ferric and manganese oxides promotes corrosion by cathodic depolarization.

iv. Legionella – Legionella pneumophila is a pathogenic Gram negative bacterium that produces symptoms like Pneumonia. It is aerobic bacteria and if it grows in the cooling tower it causes the health hazard to the persons nearby.

v. Pesudomonas – Pseudomonas spp. have been reported to from biofilms in the cooling towers. It produces extracellular polysaccharide that promotes the formation of biofilms. These biofilms reduce the heat transfer in heat exchangers and give the suitable environment to anaerobic bacteria to grow.

vi. Acid Producing bacteria -These include Thiobacillus, Thiothrix etc. They have ability to produce acids like Nitric acid, Sulphuric acid, Acetic acid, Lactic acid etc. The production of these acids lowers the pH, dissolves the protective layers like Calcium carbonate formed on the surface.

b. Algae- Algae grow only in the sunlight exposed areas of cooling tower. The presence of algae does not necessarily indicate a problem but, if growth is heavy, distribution holes can become plugged resulting in poor water distribution through the fill. Also when the algal biomass sloughs off, there is a possibility that it will get into the piping and restrict system water flow.

c. Fungus- Fungus often attack cooling tower wood and cause deterioration in the wooden parts of the cooling tower. Following types of fungus attack the wooden structure of cooling towers (4)-

i. Brown rot fungi- It breaks down the cellulose and hemicelluloses component of wood. These fungi are the most important cause of decay of softwood species. Cellulose is broken down by Hydrogen peroxide (H_2O_2) that is produced during the breakdown of hemicelluloses. Hydrogen peroxide being a small molecule can diffuse rapidly through the wood, leading to a decay that is not confined to the direct surroundings of the fungas. Decay due to this type of fungus causes the wood to shrink, shows brown discoloration, and cracks into roughly cubical pieces, a phenomenon termed cubical fracture. The species of fungus include Serpula lacrymans, Fibroporia vaillantii etc.

ii. Soft rot fungi- This type of fungi secrete Cellulase enzyme that leads to degradation of cellulose in the wood. This leads to the formation of microscopic cavities inside the wood. The damage caused by this type of fungus looks like brown rot fungi. The fungus of this group includes Chaetomium, Ceratocystis, Kretzschmaria deusta etc.

iii. White rot fungi- It breaks down the lignin and cellulose in the wood and have bleaching effect. It causes the wood to changes texture, becoming moist, soft, spongy, or stringy and its colour becomes white or yellow. White rot fungus include Pleurotus ostreatus, Oyster mushrooms etc.

iv. Acid Producing Fungus- Some fungus also produces organic acids like Acetic acid, Carbonic acid that lowers the pH and dissolves the protective layer formed on surface like Calcium carbonate. The fungus involved in this category include Penicillium spp, Fusarium Spp., Aspergillus spp etc.

Microbe	Effected part	Effect
Sulphate Reducing Bacteria	Heat exchangers, Deck, Basin	Convert Sulphate to H_2S, Causes Corrosion
Shewanella	Heat exchangers	Dissolves Fe/Mn oxide protective layer
Gallionella	Heat exchangers, Deck, Basin	Converts soluble iron salts to iron oxide; can form voluminous deposits
Leptothrix	Heat exchangers, Deck, Basin	Converts soluble iron salts to iron oxide; can form voluminous deposits
Thiobacillus	Heat exchangers, wood	Converts Sulfur or Sulfides to Sulfuric acid
Pseudomonas	Heat exchangers	Produces exo-polysaccrides that promotes biofilm formation.
Legionella	Human being	Produces Pneumonia like symphtoms
Brown rot Fungus	Wooden structure	Biodegradation of wood
White rot fungus	Wooden structure	Biodegradation of wood
Soft rot fungus	Wooden structure	Biodegradation of wood
Blue green algae	Heat exchangers, Deck, Basin	Reduces heat transfer in heat exchangers

Table 1: Types of microbes effecting cooling towers

2. IDENTIFICATION AND MONITORING OF MICROBES IN COOLING TOWER

The presence of microbes in cooling towers can be done by analytical methods and physical methods. The methods of identification are given below. Excess of algae and bacteria in the cooling tower may be indicated by these symptoms-

a. Increasing emperature of process water in the heat exchanger.
b. Decrease in Delta T across a heat exchanger or cooling tower.
c. Increase in the value of Total Viable Count (TVC) and Sulphate Reducing Bacteria (SRB) above the threshold value.

Fungal contamination in the cooling tower system is indicated by these symptoms:

a. Darkness in colour and softening of wood in the flooded portions of cooling tower. A cross-checked surface is always the result of fungal attack. Loss of dimension is also result of deterioration.
b. Non flooded areas are mostly attacked by internal rots. The internal rots (white and brown) are insidious because there is no outward indication of decay. Internal rot can be detected by:-

i. Thumping the wood with a mallet or hammer. If the sound is a dull thud, the next step is to probe the wood with a screw driver or similar tool to check for internal damage. Sometimes, such decay is evidenced by abnormal sagging or settling of the tower wood.
ii. Unexpected softness in an apparently healthy wood beam is also a sign of decay.

2.1 Analytical methods of cooling tower monitoring

a. Total viable count (TVC) - The measurement of total viable count in cooling tower is an important tool to know the no of microbes present in cooling water. This test is done by using serial dilution method and organisms are grown in Nutrient agar. The routine testing of TVC is necessary to decide the treatment of biocides to be given to Cooling tower (5). The maximum limit for TVC is $1X10^5$CFU/ml.

b. Sulphate reducing bacteria (SRB) - The testing of sulphate reducing bacteria is done by most probable number (MPN) method. The sample is grown in Sulphate API Broth. Anaerobic condition in test tube is created by using paraffin oil. The tubes are incubated for 5 days before taking the final results. This is done by using Mac Cardy's table (5). The maximum limit for SRB is 100MPN/100ml.

c. Iron bacteria- Iron bacteria are measured by growing in their respective medium and counting the numbers of colonies.

d. Azide spot test – This test is used to confirm the presence of SRB on metal surface. This test is done on the spot of the corrosion site. A solution of this reagent is placed onto the metal surface for testing. Using a concentrated light and a magnifying lens, nitrogen bubbles are seen to evolve when sulphides are present. The rate of bubble evolution is indicative of the degree of sulphide contamination (6) (Figure 2).

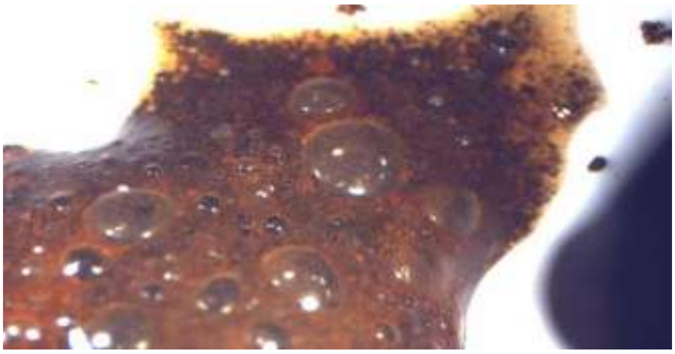

Figure 2: Azide spot test showing high rate of nitrogen bubble evolution, indicating positive indication of SRB

2.2 Factors enhance decay risk in cooling tower

a. Any Cooling tower which has experienced internal biological decay earlier has the chances of spreading the fungus to nearby wood.
b. Non-maintenance of the microbial count (TVC, SRB) as per the prescribed limit increases the decay risk.
c. Alternate drying and wetting cycles of operations.
d. Use the wood not prescribed in as per IS standard.
e. Treatment of preservatives on the wood is not done as per the prescribed process in Indian standard (IS).

3. MICROBIALLY INFLUENCED CORROSION

Corrosion of metals and alloys induced by the activities of microorganisms is defined as Microbially-influenced corrosion (MIC). In literature it is seen that MIC is not caused by the interaction of micro-organism with the material but by the action of the medium materializing in the area of the biofilm, especially from the metabolism of the participating organisms (7). MIC is observed wherever an influx of organic substances and wherever suitable surfaces are available for the colonizing of micro-organisms that form biofilm. The temperatures of the media play more of a secondary role as the relevant micro-organisms are active within a temperature range of approx. – 20°C and +120 °C. The ideal temperature, however, is at +10 °C to below +40 °C. Hence, the operation temperature of cooling water pumps lies within the ideal range that makes it prone to MIC (8). The activity of the micro-organisms in the biofilm causes the electrochemical open circuit potential (OCP) of the metal to increase. This increase is called potential ennoblement that increases the risk of crevice corrosion or pitting.

Biofouling refers to adhesion of microbes onto the surfaces in marine, fresh water and soil environments leading to formation of fouled layers. Initial surface adhesion is due to microorganisms including bacteria, followed by macro organisms. The initial event of bacterial attachment is more important since it paves the foundation for a heterogeneous biofilm build-up (9). Steps involved in biofim formation are shown in figure 3.

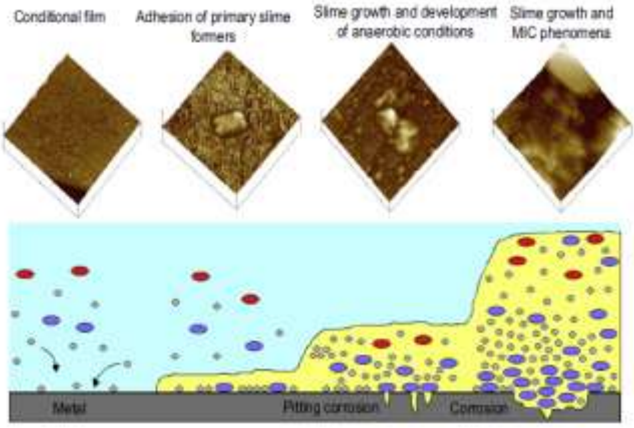

Figure 3: Biofilm formation step by Step

4. COOLING TOWER WOOD

Most of the industries use wood for the construction of cooling towers. Species selection, strength properties and preservation aspects are important criteria for selection of cooling tower wood. Damage of wood can collapse the entire cooling tower (Fig 3). The quality of wood is of paramount importance in maintaining the life span of cooling tower. In India Quality of wood to be used in cooling tower is to be checked as per IS 2372:2004. Various varieties of wood are approved under this standard for use in cooling tower. Following are the important points to be considered before selection of wood for cooling tower:-

i. Wood to be used should be from the plants as given in IS 2372:2004.
ii. Minimum safe permissible stress is 8.5N/mm^2, hence those species which does not match this requirement should be avoided in load bearing sections.
iii. The depth of penetration of preservative in different species should be according to IS 2372:2004.
iv. Quality of preservative shall be checked as per IS 10013 (Part II, III) -1981. As per the standard Copper-Chrome-Arsenic Composition (CCA) and Copper-Chrome-Boron Composition (CCB) are the two preservatives that are used in cooling tower timber.
Testing of wood preservatives against fungus and penetration and retention of preservatives in treated wood can be checked at Forest Research Institute (FRI) Dehradun India.

5. ROUTINE MAINTENANCE TO PREVENT MICROBIAL GROWTH

Cooling towers are to be routinely inspected for microbial growth. Following routine is to be followed to prevent microbial growth in cooling tower

a. Routine chlorination is to be done to prevent the microbial growth and bio-film formation. To prevent chemical and biological attack on wood, free residual chlorine shall be less than 1 ppm preferably to a range of 0.3-0.7 ppm. Chlorine should be supplemented by non-oxidizing antimicrobials to control biological attack.

b. Biocides, anti-scalants, bio-fouling inhibitors and corrosion inhibitors are to be regularly dosed as per the requirement of the cooling water plant and based on microbial and chemical analysis.

c. Cooling tower decks shall be cleaned regularly to reduce algae growth.

d. Inspect the tower framework visually for any deterioration. Flooded portions of a cooling tower must be inspected for fungal attack. A cross-checked surface is always the result of fungal attack. Infected wood may be replaced by new wood or can be treated with antifungal spray depending on the penetration of fungal attack.

e. Non flooded areas are mostly attacked by internal rots. Unexpected softness in an apparently healthy wood beam is also a sign of decay. Any wood with such softness must be replaced with new one. As the infection can be spread to the nearby woods, all the woods near to the infected wood must be inspected and replaced to prevent the spread of infection.

f. Manual spraying of antifungal compound with pneumatic sprayer is an effective method of treating cooling tower wood. A concentrated antifungal with EPA (Environment protection agency) registration can be applied directly to the wood. Spray application of 5% or better solution of tri-butyltin oxide or other suitable wood preservative is recommended once in every year in non water flooded area and fan deck top.

6. CHEMICALS USED IN COOLING WATER TREATMENT

The chemicals used in treatment of cooling water can be divided into three categories-

a. Oxidizing Biocides - Oxidizing biocides include those chemicals that have the ability to kill microorganisms through an electrochemical process of oxidation. These include Chlorine, Bromine, Iodine, and Chlorine di oxide, Ozone, and Hydrogen per oxide. Out of these chlorine is most widely used in cooling tower treatment.

b. Non- Oxidizing biocides - This class of chemicals works through various poisoning processes such as interfering with reproduction, stopping respiration, or lysing the cell wall. They include Isothiazolines, Carbamates, Methylene bisthiocyanate (MBT), Polyquaternary amines, Tetrehydro-3,5, dimethyl-2H-1,3,5 thiadiazine-2-thione. Selection of a nonoxidizing biocide depends upon water pH, available retention time, efficacy against various bacteria, fungus, and algae, biodegradability, toxicity, and compatibility with the other chemistry.

c. Bio dispersant- Chemicals that can penetrate and loosen the complex matrix of biofilms allow biocides to reach the organisms for more effective kill and control. These chemicals are typically shot fed at dosages that break down polysaccharides, emulsify oils, release minerals and foulants, or disperse the biopolymers.

Figure 4: Image showing damaged cooling tower

Source: National Fertilizer Limited Case Study

7. NEW APPROACHES TREAT MICROBIAL GROWTH IN COOLING WATER

a. Ozone treatment-– Ozone has the bactericidal properties that are utilized to treat the microbes in cooling towers. Ozone works as an oxidizing biocide. It works as a strong biocide in very small quantity and it eliminates all the microbes. Ozone therapy is also used to treat inflammation and infections of certain internal organs, especially when antibiotic therapy has failed to control multidrug-resistant bacteria (10, 11). Ozone treatment of cooling water is not practical under ambient circumstances as Ozone is very unstable and has a relatively short half-life of usually less than 10 minutes. Huth et al. [12] studied the effect of gaseous ozone and ozonated water on biofilms formed by bacteria that can colonize root canals. Exposure to a 5 μg/mL ozone solution for 1 minute led to complete elimination of planktonic cells of Enterococcus faecalis and Candida albicans. Gaseous ozone having concentration of 32 g/L eliminated microorganisms completely in just after 1 minute of exposure. Bialoszewski et_al have reported the eradication of S. aureus biofilms after 30 seconds of exposure to ozonated water at lower ozone concentrations of 1.2–3.6 μg/mL. However, Ozone treatment should be done only after ensuring high safety at cooling tower as it is a large scale operation. Any leakage of ozone can be harmful to the persons working nearby.

b. Ultrasound treatment -High power ultrasound at frequencies around 20 kHz is capable of killing bacteria and for many years has been standard technique in microbiology for the disruption of living cells. Specific ultrasound waves can be utilised to directly target biofilms. Benefits of the ultrasonic treatment are (a) Prevent bacteria from settling on a surface in the primary stages of biofilm formation (b) Alter the structure of an existing biofilm, eventually breaking it down (c) Control potential algae attaching to a biofilm. Wang et_al have studies the effect of the ultrasound treatment in biofilm formation in catheter tubes and have found that it is effective in preventing biofilm formation of Pseudomonas aeruginosa. The most of the biofilm formed in cooling tower is also due to P. aeruginosa so this treatment can also be explored for cooling tower treatment (13).

c. Ultravoilet light treatment- UV light has been traditionally used in pharmaceutical and food industries where no microbial contamination is required. This approach of decontamination can also be used in cooling water treatment. Advantages of using UV are low operating cost and no chemicals to handle or store. Disadvantages are cost of installation can be very high, need system to monitor UV light operation and ineffective if water has even low levels of total suspended solids. Sorensen et_al have found that in comparison to treating cooling water with chemicals, UV disinfection combined with H_2O_2 offers an alternative in many ways. It was also found advantageous solution by providing a more efficient and environmentally safer cooling tower operation (14).

d. HVCB Technology- High Voltage Capacitance based technology is effective method to prevent biofilm formation in Heat exchangers. In this treatment, a cylindrical capacitor is created by inserting an insulated and sealed electrode into a metal pipe or vessel to produce electrostatic dispersion. The system functions by inducing a time transient alteration of the particle surface charge over the natural state. The effect is expressed on dielectric colloidal particles, as well as on the wetted surfaces of the pipe or vessel. Romo et_al have done experiments on the prevention of biofouling by using HVCB technology and have found encouraging results (15).

8. STUDIES AND EXPERIMENTS ON MIC IN COOLING TOWER

MIC accounts for 20% of the corrosion in building material and metals (16). Several researchers have studied and done experiments on various aspects of MIC. Most of the studies on MIC are done in oil, petroleum and fertilizer industries as they are handling various transport pipelines, huge vessels and cooling towers that often encounter the problems of MIC. Legionella sp .are the most studied bacteria in cooling tower system as it causes Pneumonia like symptoms. Different types of bacteria cause MIC in the industries but sulphate reducing bacteria is the most studied and experimented because it is the reason for crevice and pitting corrosion on metal by microbes. Other groups of bacteria are like acid producing bacteria, nitrate reducing bacteria (17), methanogenic archaea [18], Slime forming bacteria, Iron reducing bacteria [19] are also responsible for MIC in many instances. The microbes responsible for MIC have been identified and studied by many researchers Like Magot et_al have studied the different types of microbes present in petroleum oil reservoirs and found different variety that are responsible for biocorrosion in petroleum reservoirs and pipelines(20). Tingyue Gu have done the theoretical modelling of corrosion caused by sulphate reducing and acid producing bacteria. Acid producing bacteria can cause severe pitting corrosion in pipelines if water wetting is an operation condition (21). Ali Abd Sharad et_al have found the 59 Shewanella species in crude oil that are responsible for the biocorrosion in carbon steel. Shewanella chilikensis and Shewanella algae are an Iron reducing bacterium that forms the biofilm on the carbon steel and causes MIC. Rajasekar et_al have studied the corrosive microbial community in cooling water and they have found a new genus Massilia that causes corrosion in cooling tower, also they have found that bronopol as the effective biocide on copper metal surfaces (22). As mentioned above, the microbiology of the cooling tower has been studies by many researchers. This often include the isolation and molecular identification of microbes present in the cooling tower, but the pragmatic approach to solve the problems related to MIC in industries is still at its infancy. Some of the researchers have been successful in establishing the mechanism of MIC in industrial plants. Enning et_al have done experiments on the effect of Desulfovibrio ferrophilus on iron corrosion. It was found that this bacterium degraded the iron coupon with a very high corrosion rate of 0.7mm Fe per year in five months. This data shows that SRB can cause very severe corrosion in iron (23). Gavrila et_al have studied the cooling water system of different industries and have found that Ammonia and Urea plant having high concentration of nitrogen contains more population of nitrifying bacteria. They have also found that the plants using Sulphuric acid to maintain the pH have high population of SRB due to the presence of high sulphate content (24) . Material of Construction (MOC) of the heat exchangers is also very important for MIC to occur. If the MOC is of carbon steel or mild Steel, the chances of pitting corrosion and crevice corrosion increases. Xiao et_al have found that Mild steel is more susceptible to MIC as compared to Copper metal in cooling water system (25). The immersion of any metal in water induces the development of a microbial film called biofilm which is established after 1-3 weeks. Stainless steel is more resistant to MIC as compared to other metals. Copper is found to be more resistant to MIC as compared to galvanized steel (26).

9. CONCLUSIONS

Cooling towers are mostly handled by plant engineers and they are unaware of microbial aspects of cooling water. They mostly focus on the damages caused by scaling and use the corrosion inhibitor and biocides to save their plants. The direct economic loss by MIC is about 300 to 500 billion dollars. Microbes not only cause damage to the cooling water system but also to the other equipments and machines of the plant. Studies have been done on microbiology of the cooling towers but to solve the problems of MIC in industrial plants still much work has to be done on the identification of MIC and development of method to differentiate between MIC and chemical corrosion. MIC problems in cooling tower can be solved by creating awareness regarding the damage caused by microbes. The review is drafted especially to understand and indentify the problems of MIC and also the precaution to be taken to prevent MIC to occur. This review also summarizes the problems with current approaches of solving MIC and how new approaches can be adopted to prevent the MIC. The review also highlights points to be considered before the procurement of cooling water wood material. Some examples of MIC in metals are added in the review to know the practical problems of MIC. This review will help the plant engineers to understand and solve the problems caused by microbes in cooling tower system.

REFRENCES

[1] P. Sigalevich, Y. Cohen. "Oxygen-Dependent Growth of the Sulfate-Reducing Bacterium Desulfovibrio oxyclinae in Coculture with Marinobacter sp. Strain MB in an Aerated Sulfate-Depleted Chemostat". Appl. Environ Microbiology. 2000 pp. 5019- 5023.

[2] International Chemtex Corporation. Technical Topics, Sulphate Reducing bacteria.

[3] Iwona beech, Alain bergel, Alfonso mollica, hans-curt flemming,vittoria scotto, wolfgang snad. "Microbial influenced corrosion of industrial material" Biofilm publications September 2000.

[4] G. Thomasson, J. Capizzi, F. Dost, J. Morrell, and D. Miller. "Wood Preservation and Wood Products Treatment" Training Manual EM 8403 • Revised August 2006G.

[5] American Public Health Association. 1989. Estimation of bacterial density, p. 977–980. In Standard methods for the examination of water and wastewater, 17th ed. American Public Health Association, Washington, D.C.

[6] Ameer K Ibraheem "Microbiologically Induced Corrosion" Research Gate, Conference paper 2011.

[7] Heitz, E.; Flemming, H.-C.; Sand, W.: Microbially Influenced Corrosion of Materials; Springer Verlag, Berlin 1996.

[8] Erika Nowak, Simone Bartels, Tobias Richter. "Microbially Influenced Corrosion in Cooling Water Systems – Development of a New Protection Concept for System Components Conveying Brackish Water" 20th International Conference on Structural Mechanics in Reactor Technology (SMiRT 20) Espoo, Finland, August 9-14, 2009 SMiRT 20-Division 8, Paper 1815.

[9] K.A. Natarajan, Biofouling and microbially influenced corrosion of stainless steels, Advanced Materials Research Online: 2013-09-04 ISSN: 1662-8985, Vol. 794, pp 539-551

[10] De Souza YM, Fontes B, Martins JO et al. Evaluation of the effects of ozone therapy in the treatment of intra-abdominal infection in rats. Clinics, 2010; 65(2): 195–202

[11]. Nogales CG, Ferrari PH, Kantorovich EO, Marques J L.Ozone therapy in medicine and dentistry. J Contemp Dent Pract, 2008; 9(4): 75–84.

[12] D. Bialoszewski, A P Padzik, A Kalicinska, E Bocian, M Czajkowska, B Bukowska, S Tyski. Activity of ozonated water and ozone against Staphylococcus aureus and Pseudomonas aeruginosa biofilms. Med Sci Monit, 2011; 17(11): BR339-344.

[13] Huanlei Wang, Fengmeng Teng, Xin Yang, Xiasheng Guo, Juan Tu, Chunbing Zhang & Dong Zhang, Preventing microbial biofilms on catheter tubes using ultrasonic guided waves. www.nature.com/scientific reports. Published online 04 April 2017

[14]. Martin Sörensen and Christian Gurrath UV-Disinfection of cooling towers Water treatment. Wastewater Report.

[15] R. Romo, M. M Pitts and N. B. Handagama Biofouling control in heat exchangers using high voltage capacitance based technology. ECI Symposium Series, Volume RP5: Proceedings of 7th International Conference on Heat Exchanger Fouling and Cleaning - Challenges and Opportunities, Editors Hans Müller-Steinhagen, M. Reza Malayeri, and A. Paul Watkinson, Engineering Conferences International, Tomar, Portugal, July 1 - 6, 2007

[16] H.-C. Flemming, "Economical and Technical Overview," In: E. Heitz, H.-C. Flemming and W. Sand, Eds., Micro-bially Influenced Corrosion of Materials, Springer-Verlag, Heidelberg, 1996.

[17] Xu D, Li Y, Song F, Gu T. 2013. "Laboratory investigation of microbiologically influenced corrosion of C1018 carbon steel by nitrate reducing bacterium Bacillus licheniformis". Corros. Sci. 77:385–390.

[18] Dinh HT, Kuever J, Mußmann M, Hassel AW, Stratmann M, Widdel F. 2004. Iron corrosion by novel anaerobic microorganisms. Nature 427: 829–832.

[19] Ali Abd Sharad, Orooba Meteab Faja, Khansa Mohammed Younis, Merriam Ghadhanfar Alwan, Ashraf Abbas Drais, Anmar Hammeed Bloh, Gires Usup, Fathul Karim Sahrani, Asmat Ahmad, Isolation and Identification of anaerobic cultivable iron reducing bacteria from crude oil and detection of biofilms formation on carbon steel surfaces American-Eurasian journal od sustainable agriculture volume 10 issue 2 Pages 55-64 (2016).

[20] M. Magot, ''Indigenous microbial communities in oil fields'', in: B. Ollivier, M. Magot (Eds.), Petroleum Microbiology, ASM Press, Washington, DC, 2005, pp. 21-33.

[21] Tingyue Gu "Theoretical Modeling of the Possibility of Acid Producing Bacteria Causing Fast Pitting Biocorrosion'', Journal of Microbial & Biochemical Technology 2014, 6:2.

[22] Rajasekar Aruliah, and Yen-Peng Ting "Characterization of Corrosive Bacterial Consortia Isolated from Water in a Cooling Tower''. Hindawi Publishing Corporation ISRN Corrosion Volume 2014, Article ID 803219.

[23] Enning D, Venzlaff H, Garrelfs J, Dinh HT, Meyer V, Mayrhofer K, Hassel AW, Stratmann M, Widdel F. 2012. Marine sulfate-reducing bacteria cause serious corrosion of iron under electroconductive biogenic mineral crust. Environ. Microbiol. 14:1772–1787.

[24] Lucian Gavrila , Daniela Gavrila , Andrei-Ionuţ Simion Microbiologically induced corrosion and it's mitigation in cooling cycles. Scientific study & research,vol. iv (1-2) ,2003 issn 1582-540x.

[25] Xiao Lei Li,Jayaraman Narenkumar, Aruliah Rajasekar, Yen Peng Ting. Biocorrosion of mild steel and copper used in cooling tower water and its control Springer-Verlag GmbH Germany, part of Springer Nature 2018, 3 Biotech (2018) 8:178.

[26] Dogruoz nihal, Minnos Bihter, Esra Ilhan-sungur, aysm cotuk. Viofilm formation on copper and galvanized steel surfaces in a cooling water system.IUFS Journal of biology 2009, 68(2):105-111.