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Optimal Treatment Methods for Anti-Tartar Management in Circulating Water Systems

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Abstract

Utilizing seawater in industrial water systems leads to scale formation on heat exchange surfaces, reducing efficiency significantly. Even a 1 mm deposit causes a 30% decrease in effectiveness, raising cooling or condensation temperatures by 6°C and increasing electrical power consumption by 18%. Preventive measures include chemical treatments, which require careful balancing to avoid corrosion risks, and physical treatments like magnetic or electronic conditioners, which vary in efficacy. Water softening replaces metals with sodium ions but may increase mineral content, exacerbating scale buildup. Corrosion control is essential to counter metal degradation. Balancing prevention strategies is crucial. Research explores using Mediterranean seawater in cyclic systems to conserve freshwater and enhance coastal water availability. The aim is to find economically viable methods to stabilize cooling systems for both soft and saline water.

Keywords: corrosion control, heat exchangers, seawater, tartar formation, water industry.

1 Introduction

Water scarcity is a global concern exacerbated by increasing demand, particularly in industrial sectors. The demand for water is projected to double in the next two decades, underscoring the urgency of addressing water availability challenges [1, 2]. In Algeria, where water access remains a critical issue, water resources play a pivotal role in supporting economic and social development [3]. The industrial water supply is essential for maintaining the functionality and product quality of industrial facilities [4, 5]. However, utilizing seawater in industrial processes poses significant challenges due to its chemical composition, which leads to scale formation and corrosion on equipment surfaces [6, 7]. To address these challenges, various methods have been developed to improve seawater's technological characteristics and mitigate scale formation and corrosion [6, 7].

Water scarcity also impacts industrial water consumption globally, necessitating the adoption of water recycling practices [8, 9]. However, water recycling often exacerbates scale formation on equipment surfaces, reducing thermal efficiency and operational performance [10, 11]. To mitigate scale formation, water treatment agents particularly synthetic phosphorus-free scale

inhibitors have gained popularity for their effectiveness and stability [12, 13]. Traditional water treatment agents, such as inorganic salts and synthetic phosphine organic compounds, are limited by environmental concerns [14, 15]. While natural polymers are affordable, they require large quantities and lack stability at high temperatures [16]. Consequently, synthetic phosphorus-free scale inhibitors represent a promising alternative for effective scale inhibition in industrial water recycling systems [13, 16].
This article investigates various methods for stabilizing cooling water, whether soft or saline (Table 1), to identify a simple and efficient approach. Experimental studies were conducted to evaluate these methods and assess the feasibility of using seawater in industrial water distribution systems.

Table 1: Salinity and chemical composition in % comparison [17]

Designation	Salinity (g/l)	Chloride (Cl^-)	Sodium (Na^+)	Magnesium (Mg++)	Sulfate (SO_4^{2-})	Calcium (Ca^{++})	Potassium (K^+)	Bicarbonate (HCO_3^{--})
Sea Mediterranean	37.0	55.1	0.2	7.9	0.2	30.6	1.1	1.2
Soft water	1.5	25.1	-	25.1	-	5.01	-	10

2 Methods

2.1 Methods to combat tartar formation

Typically, two methods are employed for stabilizing water circulated within industrial systems:
- Chemical methods,
- Physical methods.

Chemical methods include acidification, decarbonation, phosphatation, the use of surfactant agents, and combined methods (such as phosphatation with acidification, etc.). However, there is a current trend towards methods that don't involve chemical agents, such as physical methods like ultrasonic treatment, and the application of magnetic and electric fields.
Among these chemical methods, acidification is commonly employed, with the principle as follows:

2.1.1 Acidification

To prevent the formation of tartar on heat exchange surfaces, sulfuric acid (H2SO4) or hydrochloric acid (Hcl) is utilized. During the acidification of circulating water, a portion of the bicarbonate salts converts into an equal quantity of non-bicarbonate salts that are easily soluble. This process involves the following reactions:
- The reduction of bicarbonate concentration in water leads to a decrease in the required level of carbon dioxide.
- The release of carbon dioxide during chemical reactions aids in stabilizing remaining bicarbonates in the water after acidification.

The acidification method is applicable to all types of natural waters.
According to Koutcherenko, acidification allows for the reduction of soft water quantity (balance water). During cyclic water treatment, determining the optimal dosage of acid is

crucial, and it depends on the alkalinity of the water. Specifically, the concentration of acid will be adjusted based on the reduction in water alkalinity and stabilization conditions.
Currently, acidification is a common method, but it comes with certain drawbacks such as difficulty in dosing under natural conditions and the potential for acid-induced metal corrosion. The dosage of acid (mg/l) can be calculated using the Koutcherenko [18] formula (1):

$$D_a = e\left(A_{ap} - \frac{A_{cir}}{K_{cs}}\right)\frac{100}{C_a} \quad (1)$$

Where:
Da: the concentration of acid in the technical acids of it %;
e: represents the equivalent mass of the acid (in mg/meq), for sulfuric acid e = 49;
Aap: denotes the alkalinity of the balance water (in meq/l);
Acir: signifies the alkalinity of the circulation water (in meq/l);
Kcs: stands for the coefficient of salt concentration

2.2 Objectives and applied study focus

The applied studies aim to assess the rate of tartar formation on heat exchange surfaces and the balance water dosage. The specific goals of these studies include:

- Investigating the influence of temperature within the cyclic system on tartar formation speed,
- Analyzing the impact of hydraulic regime variations on tartar formation speed,
- Evaluating the effect of pH levels in acidified seawater solutions on tartar formation speed when using the acidification method.

2.3 Factors influencing scaling processes in cooling systems

The process of scaling is influenced by various complex physicochemical phenomena occurring within the cyclic system. Factors affecting both qualitative and quantitative aspects of scaling include:

- Chemical composition of Mediterranean seawater,
- Turbidity of the water,
- Temperature variations,
- Carbon dioxide (anhydride) content in the water and its loss during the cooling process,
- Hydraulic and thermal regime of the cooling water system operation,
- Quantity of balance water used.

For a comprehensive understanding of scaling processes, it is essential to consider all these factors. However, practical limitations in laboratory settings often necessitate simplification of the methodology in applied studies.

2.4 Description of the Experimental Setup

The schematic diagram of the laboratory setup, as illustrated in Figure. 1, is designed as follows: An electric thermostat (1) is utilized to maintain the temperature within the range of 40 to 45°C, simulating typical industrial cooling temperatures. Water is drawn from the feeding reservoir (2) using a pump and circulated back into the same reservoir to maintain a closed-loop cyclic system. Within this reservoir, another vessel (3), constructed of organic glass, contains test

samples made of steel (5) to mimic materials used in industrial settings. Temperature regulation is monitored by a contact thermometer (4).
For acidification treatment, a valve-equipped vessel facilitates two modes of operation: continuous and discontinuous addition of balance water. The quantity of balance water, representing a percentage of seawater, varies between 1.24 % and 1.96 % of the total balance of seawater used.

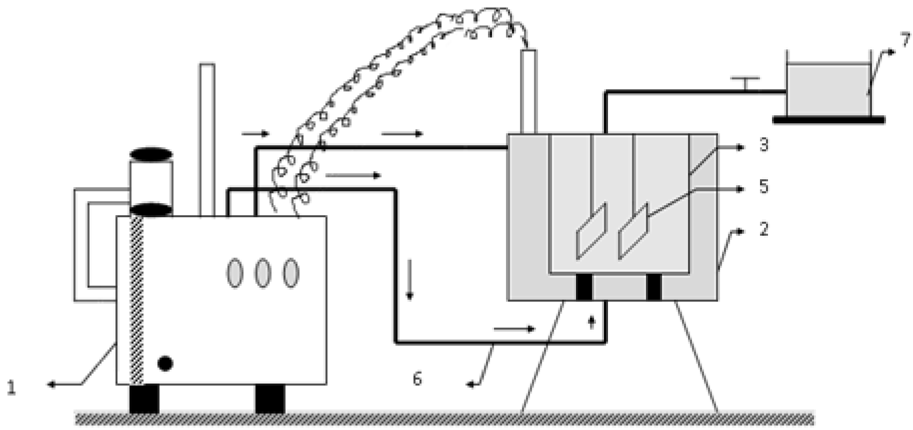

Figure 1: Experimental setup diagram

Legend:
1. Electric thermostat; 2. Reservoir for maintaining the temperature of seawater desalination; 3. Seawater accumulation reservoir; 4. Contact thermometer; 5. Testing samples; 6. Circulation system for the heat exchange agent; 7. Balanced water accumulation reservoir.

3 Results and discussion

3.1 Influence of temperature on tartar formation intensity

Experiments were conducted at temperatures of 40°C and 45°C under continuous and discontinuous regimes of balance water addition. The rate of tartar formation was determined using gravimetric methods, with test plates dried in an electric oven at 105°C until reaching a constant weight. The following table illustrates the tartar formation speed for the discontinuous regime at various temperatures (Tables 2 and 3):

Table 2: Influence of temperature on tartar formation intensity

Temperature (°C)	Time of operation (hours)	Intensity of Tartar Formation (mg/cm².year)	Alkalinity (meq/l)	HCO_3 Concentration (mg/l)
35	27	337.6	3.5	212.2
40	27	460.5	3.0	183.0
45	27	567.9	2.5	152.5

The results indicate that increasing the temperature in the cyclic system leads to a corresponding increase in tartar formation intensity (Figure 2). Additionally, as shown in the table, the concentration of bicarbonate ions (HCO_3) decreases with rising temperatures, explaining the observed increase in tartar formation speed due to decreased alkalinity of the seawater.

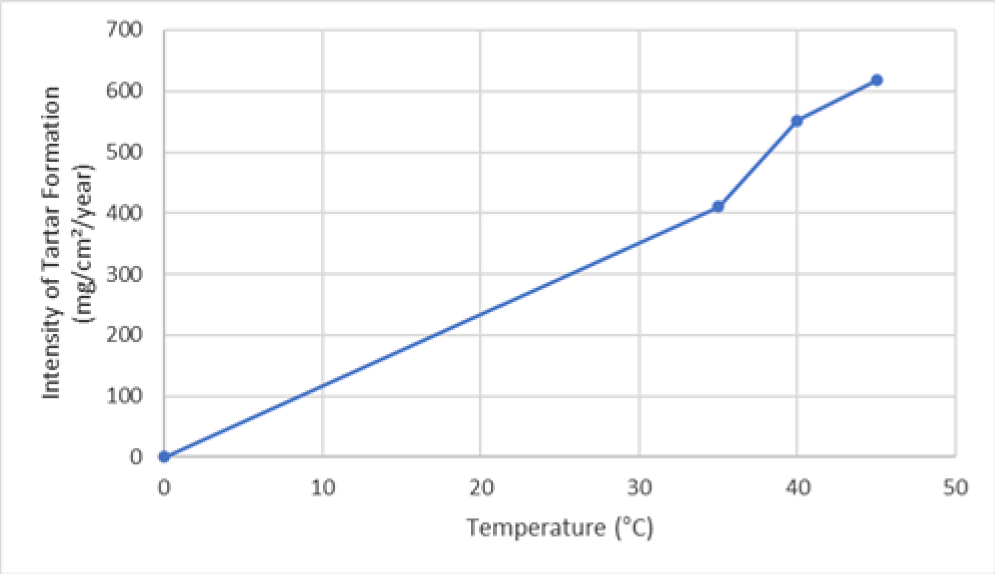

Figure 2: Influence of temperature on the intensity of tartar formation

3.2 Influence of hydraulic regime on tartar formation

Experiments were conducted under continuous and discontinuous regimes of balance water addition. The continuous regime involves a steady addition of balance water, while the discontinuous regime entails periodic addition every 6 hours. The following table (Table. 3) illustrates the variation in tartar formation speed at temperatures of 40°C and 45°C under the continuous regime:

Table 3: Influence of hydraulic regime on tartar formation

Temperature (°C)	Time of operation (hours)	Intensity of tartar formation (mg/cm²/year)	Alkalinity (meq/l	HCO3 Concentration (mg/l)	Final pH
35	27	490.7	3.2	172.6	5.2
40	27	551.8	3.0	183.0	4.8
45	27	617.6	2.7	195.2	4.5

The results (Figure 3) indicate that increasing the temperature of the circulating water enhances the intensity of tartar formation under both balance water addition regimes. However, the rate of tartar formation is more gradual under the continuous regime compared to the discontinuous regime. This can be explained by the continuous increase in salt concentration under the continuous regime, leading to reduced alkalinity as temperature rises.

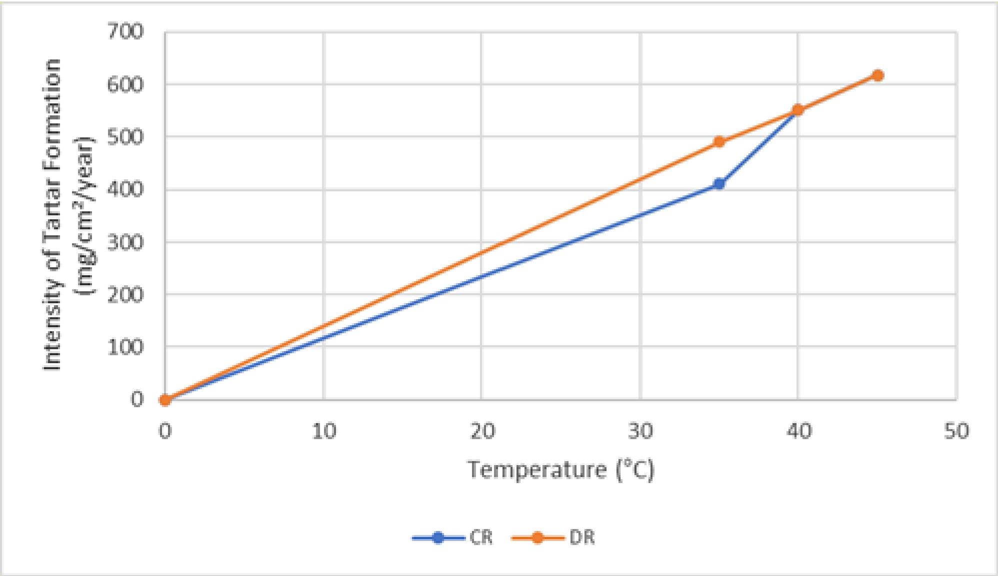

Figure 3: Influence of hydraulic regime on tartar formation

3.3 Influence of pH of circulating water

Experiments were conducted under continuous regime conditions using varying doses of sulfuric acid. Table 4 below illustrates the results:

Table 4: Influence of pH on Circulating Water in Scaling Processes

T (°C)	pH of Balance Water	Time (h)	Intensity of Tartar Formation (mg/cm²/year)	Intensity of Corrosion (mg/cm²/year)	pH of Circulating Water	Alkalinity (meq/l)	HCO_3 Concentration (mg/l
40	4.0	19	91.5	578.0	8.3	1.5	91.6
	5.2	19	122.6	402.9	9.2	2.8	170.8
	6.0	19	242.0	198.7	9.3	2.6	156.6
	7.9	27	551.8	-	4.8	2.7	195.2
45	3.0	19	166.4	631.2	6.8	2.0	122.0
	6.0	19	268.6	335.8	9.2	3.0	183.0
	7.9	27	617.6	297.8	4.5	2.7	195.0

The analysis (Figure 4) reveals that increasing the acid dose in the balance water reduces the intensity of tartar formation but concurrently accelerates corrosion speed. To counteract corrosion, corrosion inhibitors are introduced. At a balance water pH of 4 and a circulating water temperature of 40°C, the tartar formation intensity is minimal, measuring 0.1 mg/cm²/year.

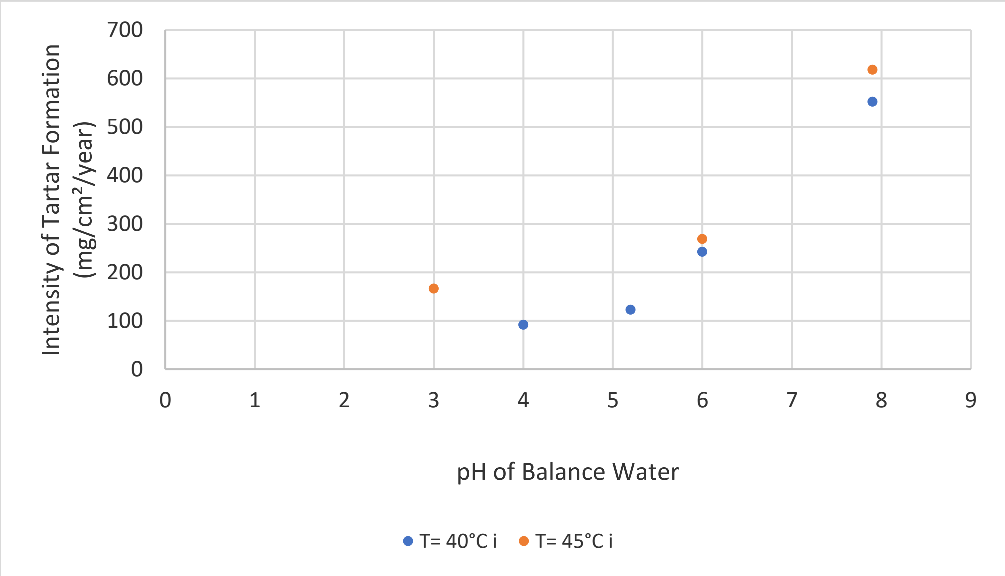

Figure 4: Influence of pH on circulating water and tartar formation

Increasing the acid dose indeed accelerates corrosion speed. However, a dose corresponding to a pH of 5.5 effectively controls corrosion for both temperatures. To practically address this issue, corrosion inhibitors are added (Figure 5).

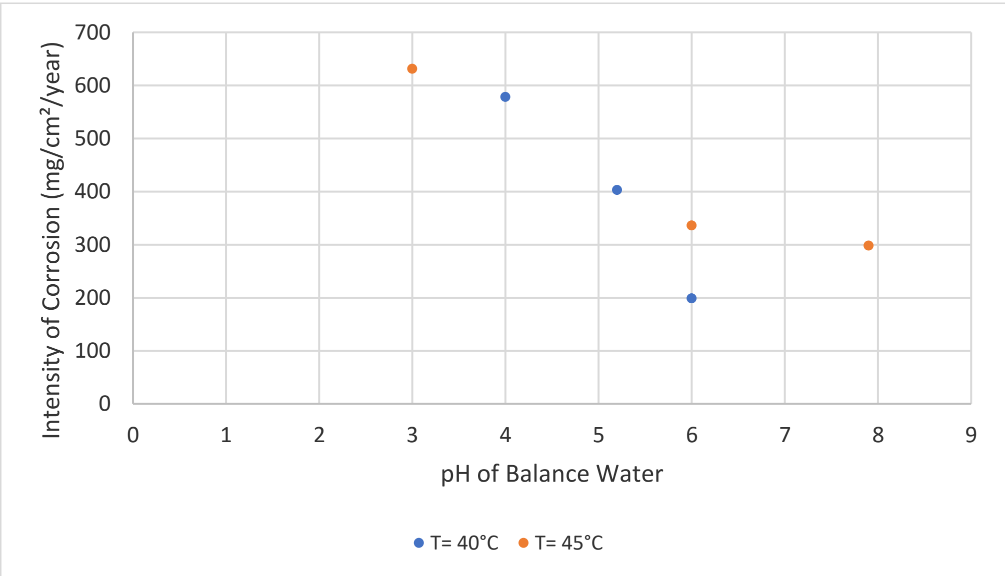

Figure 5: Influence of pH on circulating water and corrosion intensity

4 Conclusion

In conclusion, the findings of this study suggest that seawater could serve as a viable alternative to soft water in industrial and network circuits. However, its effective utilization requires

comprehensive anti-scaling and anti-corrosion treatments. Various techniques can achieve these desired results, but they must be evaluated not only based on their efficacy but also on cost-effectiveness and environmental impact.
Experimental results demonstrate that employing an acid dose corresponding to a pH of 4 for balanced water significantly reduces scaling by a factor of six compared to untreated water. The acidification method proves effective due to its use of inexpensive reagents, minimal equipment requirements, straightforward implementation, ease of treatment control, and minimal additional pollution.
However, this method does have drawbacks. Treated water tends to become corrosive due to its lowered pH, the liberation of CO_2, and increased salt content at elevated temperatures. Consequently, anti-corrosion treatment, coupled with decarbonation, becomes imperative, albeit at an increased cost. Careful dosing of strong acids is essential to mitigate potential adverse effects.
Comparatively, physical methods such as ultrasonic treatment show promise in reducing scaling. However, the mechanisms underlying their effectiveness remain poorly understood. Additionally, they pose potential health risks to personnel due to the operation of ultrasonic generators.
Overall, this investigation demonstrates that seawater can be integrated into industrial water distribution systems, particularly when adequate technical expertise is available for water treatment. The choice of treatment method ultimately depends on the specific characteristics of the water and the proficiency of the personnel managing the system. Therefore, the selection of a suitable process should be based on a thorough evaluation of all relevant factors.

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