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Article

Treating Scale Deposits in Pipes Using Ultrasonic

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Abstract: One of the most important technical and economic problems is the calcification of scales on the surface of the transport pipes and heat exchanger due to the flow of tough water. Combining ultrasound with other techniques leads to highly efficient results in treating calcification. This study combines two techniques to treat calcification: the first is physical, represented by ultrasound using an ultrasonic device with a frequency of 25 kHz, and the second is chemical, represented by adding weak acids (citric acid, salicylic acid, and ethylenediaminetetraacetic acid). We immersed the samples in the system tank containing hard water for three months, until a layer of calcifications formed on the surface. Afterwards, we treated the samples using ultrasound technology, applying concentrations of (1%, 2%, 3%, 4%, 5%, 6%) of the used acids at a temperature of 40 °C. That using ultrasonic technology in conjunction with weak acids leads to positive results in removing limescale deposits in transport pipes. Specifically, citric acid proved to be the most effective in removing limescale deposits, as it showed a long period of effectiveness. The best concentration of citric acid was applied to a sample of heat exchanger pipes that had previously been exposed to limescale deposits, which prevents the metal from corrosion.

Keywords: ultrasonics, weak natural acids, pipe, heat exchanger, calcifications

1. Introduction

Removing scale from heat exchangers is a well-known challenge for non-petroleum, chemical, and agricultural maintenance and operation [1]. Despite the primary responsibility of cleaning the dirt from the equipment, it is also necessary to calcify the exchanger, and then the exchanger unit, to achieve the required performance level [2, 3]. Scales can significantly impact the performance and life of the product, energy consumption. They can also render the equipment unusable and unclean, leading to service fees, basic equipment maintenance, and potentially up to 25% energy consumption [4], as illustrated in Figure (1).

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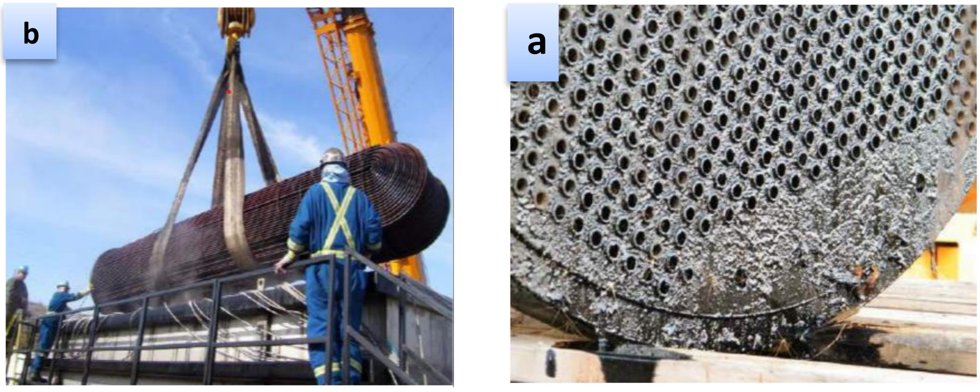

Figure 1. (a) (b) The heat exchanger bundle contains scale calcination

Chemical inhibitors for removing limescale are currently the most efficient means of preventing limescale growth. However, the chemical treatment process is expensive and may have negative environmental consequences. Therefore, researchers have investigated more cost-effective and environmentally friendly techniques [5, 6]. Such as natural chemical agents, surface coating treatments, and magnetic and electrical devices. Table 1 shows the varying levels of effectiveness of these alternatives.

Table 1. Efficiency of different size treatments [6, 7]

Scaling therapy	Efficiency (percentage decrease)
Ion exchange technology	100
Technology for the administration of acid	100
Chemical inhibitors technology	100
Metal ions technology	80
Magnetic technology	80
Electronic technology	80
Electrolytic technology	40
Ultrasound technology	30

It has long been an effective alternative for descaling [8]. During the past decades, ultrasonic transport has been applied as one of the mechanical improvements to improve the overall descaling efficiency required [9, 10]. Ultrasonic cavitation occurs when an ultrasonic device oscillates, creating pressure differences. As the longitudinal pressure waves propagate through the fluid, they create compressions (regions of high pressure) and rarefactions (regions of low pressure). If the oscillations are large enough, the pressure in the rarefaction region may drop below the vapor pressure of the fluid. Cavitation occurs when the vapor phase creates bubbles or flow structures that expand and collapse rapidly [11, 12].

Cavitation is a physical phenomenon that results from a series of dynamic processes, including pulsation, oscillation, growth, contraction, or collapse of bubbles [13]. Under certain conditions, the formation of tiny vacuum bubbles, invisible to the naked eye and partially filled with vapour, gas, or a combination of both, explodes in a liquid. The internal explosion releases energy, which displaces the calcifications from the object's surface [14]. Numerous factors contribute to the effectiveness of calcification removal, such as the tank's size and shape, the materials used in its construction, the energy converters, and the type and size of the inhibitors used [15]. The frequency and pH of these factors play an important and effective role in ultrasonic treatment efficiency [16]. Naude and Ellis (1961) [17] observed that the fine bubbles typically face the adjacent surface. Also, the cavitation bubbles quickly collapse, creating a high transient pressure (>2μs) and pressure (10^{22} PMa) inside the bubble during collapse, which helps remove deposits from the heat exchanger surface [18]. The high frequencies of ultrasound and the duration required to treat calcifications have an impact on the metal properties of the materials used. Therefore, in this research paper, we have utilized a synergistic effect between ultrasound and chemical agents, specifically weak acids, which are environmentally friendly, inexpensive, readily available, and do not damage the metal, to improve the efficiency and speed of ultrasound technology.

2. Materials and Methods

Sample preparation

The alloys used in this investigation are stainless steel alloys (specifically carbon steel N-80), provided by the Southern Oil Company. These alloys have measurements of 4.9 units in length, 1.38 units in breadth, and 0.4 units in height.

Table 2. The alloy components used

C	*0.3*	**Mo**	0.026	**Ni**	*0.024*
P	0.05	*S*	0.06	**Cu**	*0.018*
Mn	*1.2*	*Al*	0.062	**Fe**	*98.242*

Figure 2. Shape of the N-80 carbon steel oil pipe samples used

Prior to commencing the research, the samples underwent a smoothing process using silicon carbide sheets with different levels of fineness (ranging from 120 to 600) before being used. We measured the weight of each sample and took individual photographs. We immersed the samples in a basin of hard water from the Shatt al-Arab River for 180 days to allow natural scales to calcify on their surfaces, confirming that the samples used in the laboratory tests contained constant or similar levels of deposited scales.

Solution preparation

In this experiment, we used three acids (citric acid, salicylic acid, and EDTA) from 1% to 6%.

Ultrasonic device

The DW-5200D ultrasonic device is responsible for the generation of ultrasonic waves. The ultrasonic waves have 250 watts of power. The heater generates 320 watts of power. Drawwell International Technology Co., Ltd.

Figure 3. Ultrasonic device used during treatment

After adhering the scales to the samples' surface, usually at a rate of 0.42 to 0.45 grammes, we dry them in an oven at a precise temperature of 60 degrees Celsius. Before starting the treatment, we measure the weight of the sample with a high-precision electronic analytical balance Next, we immerse the sample in a constant concentration of one of the acids. We then place the sample in the ultrasonic device and expose it to ultrasound waves at precise time intervals. We carry out this process to identify the acid that is most efficient in removing the deposits and to determine the optimal duration of treatment.

3. Discussion and Production

We analyzed the scales using Field Emission Scanning Electron Microscopy (FESEM) techniques to determine their type and shape. Additionally, we examined the surface of the sample using FESEM to obtain a morphological image of the samples. The laboratory of Day Petronic Company conducted this analysis using a ZEISS SIGMA VP device from Carl Zeiss Microscopy Germany. We found the deposits on the surface to be calcite crystals with a rhombic geometric shape.

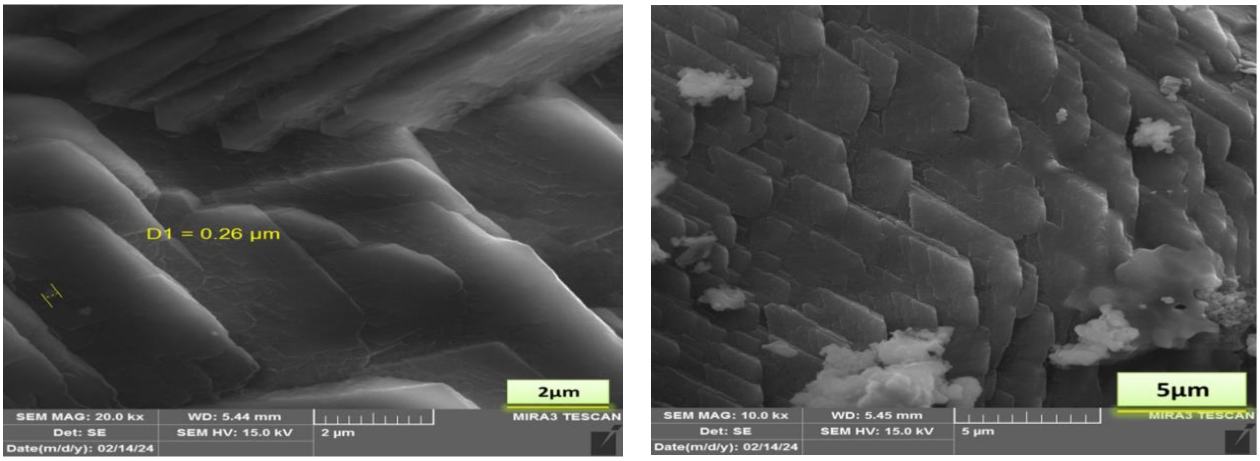

Figure 4. Technical image (SEM) of PVC pipes according to the selection

Ultrasound technology

Ultrasonic technology refers to the use of high-frequency sound waves to perform various tasks or functions. Ultrasound technology is highly efficient in removing scale and deposits from pipes [19]. This is because ultrasound generates cavitation, which leads to the formation of reactive free radicals and vibration waves [11, 20]. Combining ultrasound with other technologies yields even better results than using ultrasound alone. Organic solvents may not be as effective in certain applications without the application of additional mechanical energy to achieve the desired level of removal. Thus, in this experiment, we merged the two methods to guarantee a very efficient descaling effect that is both faster and cheaper while also being ecologically friendly.

Salicylic acid

Is an aromatic carboxylic acid that is naturally extracted from plants such as white willow and rosemary, and can also be manufactured in the laboratory [21]. acid content directly affects the removal of calcification, the higher the concentration, the greater the amount of calcification removed in a shorter period of time as in Table (3). Figure (7)(8) also shows that the use of salicylic acid at concentrations of (1%, 2%, 3%, 4%, 5%, 6%) took approximately (14, 14, 10, 8, 8, 6) minutes, respectively, to remove all calculi.

Table 3. Illustrates how salicylic acid influences the rate of calcification over time

sample	Salicylic	Original weight	Weight after treatment							
			Weight with sediment	2 mint	4 mint	6 mint	8 mint	10 mint	12 mint	14 mint
1s	1 %	38.0153	38.4436	38.3696	38.297	38.2256	38.1606	38.1082	38.0517	38.0205
2s	2%	38.0274	38.4273	38.341	38.236	38.177	38.116	38.079	38.038	38.012
3s	3%	38.0153	38.4268	38.292	38.2082	38.1248	38.0488	38.030	38.018	37.982
4s	4%	38.0114	38.4417	38.3112	38.2171	38.1137	38.054	38.027	37.9932	37.9735
5s	5%	38.0529	38.455	38.292	38.182	38.096	38.031	37.9861	37.976	37.962
6s	6%	38.023	38.473	38.294	38.146	38.065	38.015	37.981	37.964	37.942

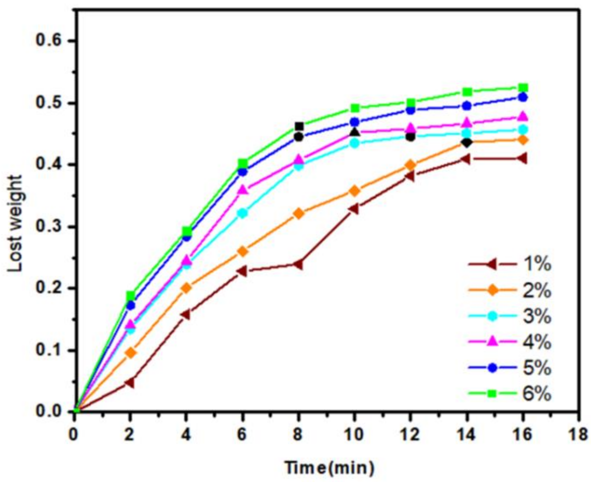

Figure 6. Weight loss over time for each concentration of salicylic acid

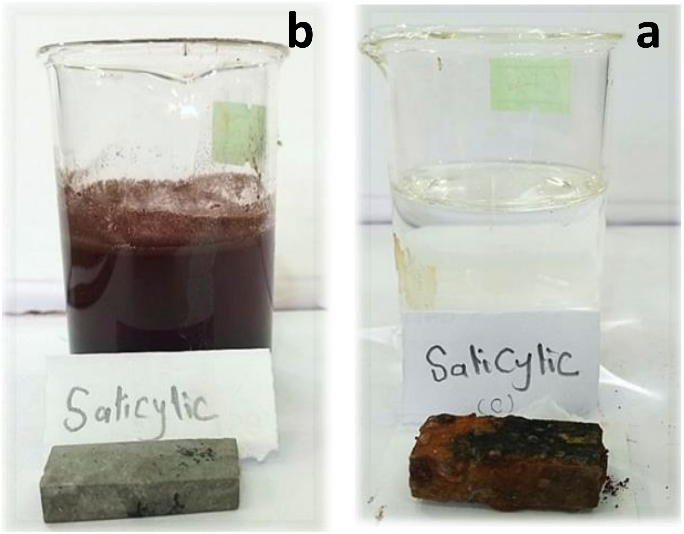

Figure 7. (a) Sample of carbon steel pipe for testing before treatment. (b) Sample after treatment with salicylic acid

A 4% acid concentration effectively removes the scales within a reasonable timeframe, unlike concentrations of 1%, 2%, and 3%, when comparing the time required to remove scales with the impact of acid concentration on the metal after removal. Furthermore, a 4% acid concentration has the least detrimental effect on the metal after scale removal, in comparison to concentrations of 5% and 6%, as depicted in Figure (8).

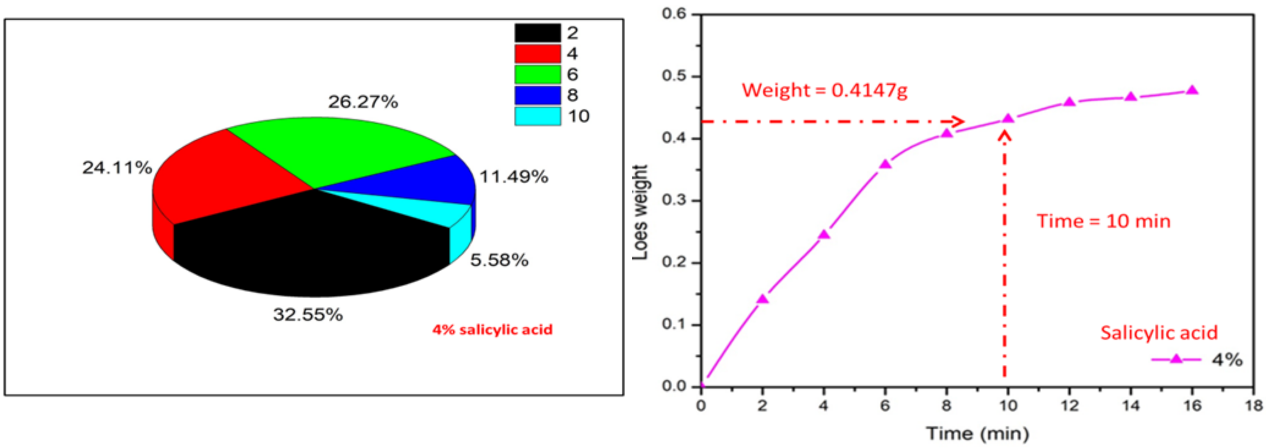

Figure 8. The descaling efficiency of 4% salicylic acid

EDTA

EDTA, short for ethylene diamine tetra acetate, is a polyamine carboxylic acid molecule. We refer to the ethylenediamine tetraacetate as the conjugate base. EDTA is a transparent, readily dissolvable solid in water. The next category pertains to the mitigation of salt accumulations. Table 4 illustrates the correlation between the acid concentration and the amount of descaling, showcasing the impact of increasing acid concentrations on the descaling process at various concentrations.

Table 4. Illustrates how EDTA influences the rate of calcification over time

sample	EDTA	Original weight	Weight with sediment	Weight after treatment						
				2 mint	4 mint	6 mint	8 mint	10 mint	12 mint	14 mint
1s	1 %	38.0153	38.4096	38.3432	38.3001	38.23502	38.1642	38.1179	38.0566	38.0021
2s	2%	38.0274	38.413	38.3213	38.2323	38.1443	38.0683	38.0523	38.025	37.997
3s	3%	38.0253	38.419	38.2865	38.1577	38.0887	38.0317	38.023	38.018	37.996
4s	4%	38.014	38.4488	38.2428	38.1407	38.0938	38.073	38.039	37.9798	37.9745
5s	5%	38.0129	38.4688	38.2662	38.1542	38.067	38.012	37.9946	37.9887	37.9694
6s	6%	38.013	38.4727	38.2601	38.1378	38.0388	37.991	37.9624	37.9545	37.9468

Figure (9)(10) demonstrates that higher concentrations of EDTA result in a more rapid and pronounced rise in descaling. Specifically, when employing EDTA concentrations of (1%, 2%, 3%, 4%, 5%, 6%), the time required to completely remove all accumulated scales was approximately (14, 12, 10, 10, 8, 8) minutes on the right side.

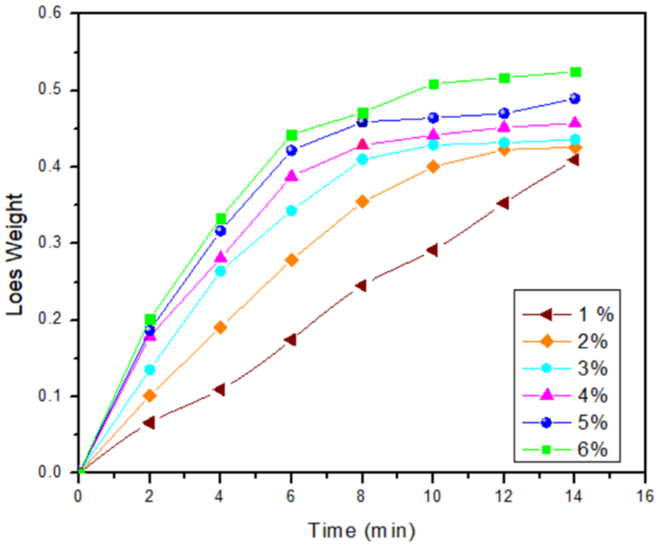

Figure 9. Weight loss over time for each concentration of EDTA

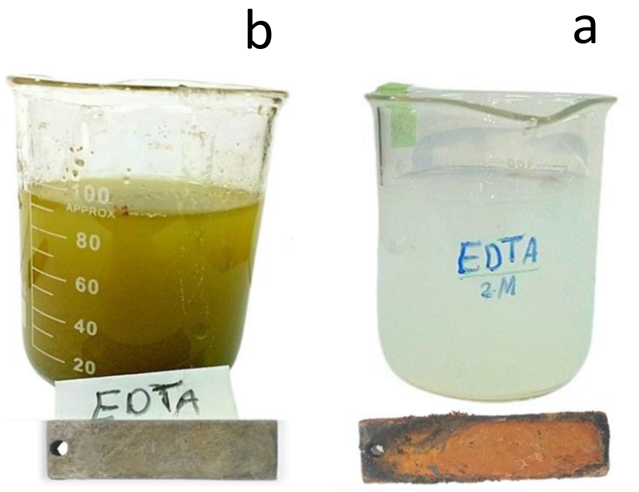

Figure 10. (a) Sample of carbon steel pipe for testing before treatment. (b) Sample after treatment with EDTA

When comparing the time it takes to remove calcifications with the effect of different concentrations of EDTA on the metal after removal, we observe that a 4% concentration of EDTA is more efficient at quickly removing calcifications than lower concentrations (1%, 2%, and 3%). Additionally, Figure 11 shows that the 4% concentration has a lesser impact on the metal after calcification removal compared to higher concentrations (5%, 6%).

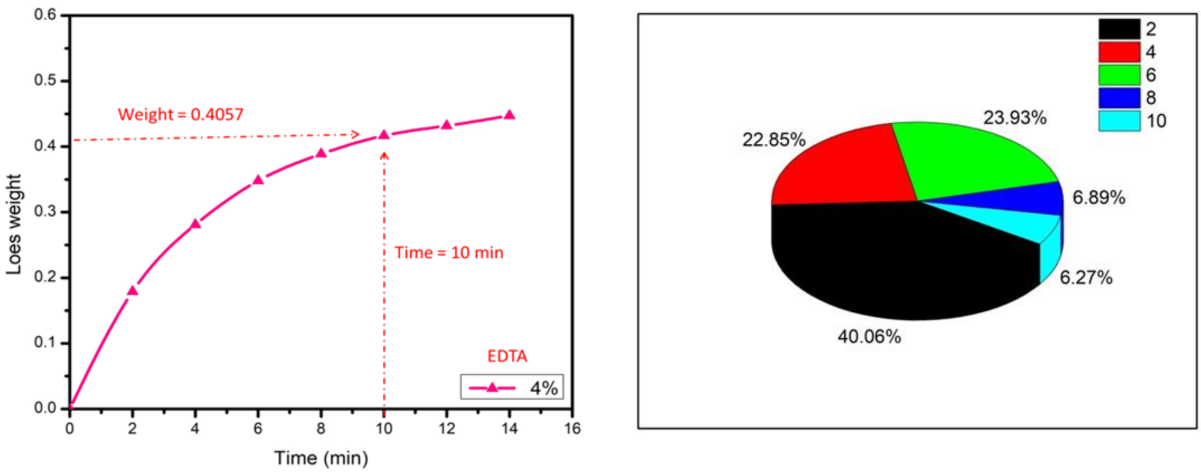

Figure 11. The descaling efficiency of 4% EDTA

Citric acid

Citric acid is a relatively low-strength organic acid that is naturally present in citrus fruits. It is an organic compound. It acts as an antioxidant and functions as a defensive agent. Table 5 demonstrates a positive correlation between acid concentration and the extent of calcification removal. Specifically, higher acid concentrations result in greater amounts of calcification removal within a shorter time frame. As shown in Figure (12 and 13).

Table 5. Illustrates how salicylic acid influences the rate of calcification over time

sampl e	Citric acid	Original weight	Weight with sediment	Weight after treatment						
				2 mint	4 mint	6 mint	8 mint	10 mint	12 mint	14 mint
1s	1 %	38.0153	38.4308	38.3003	38.1998	38.1288	38.0658	38.0368	38.015	37.9953
2s	2%	38.0274	38.4811	38.322	38.2255	38.125	38.0747	38.0337	38.002	37.9901
3s	3%	38.0153	38.5059	38.338	38.2284	38.0113	38.058	38.0255	38.013	38.007
4s	4%	38.0514	38.5921	38.3678	38.2528	38.1378	38.0637	38.0136	37.9956	37.945
5s	5%	38.0429	38.542	38.3051	38.166	38.058	38.021	37.934	37.8637	37.7937
6s	6%	38.073	38.594	38.322	38.154	38.074	38.026	37.898	37.791	37.631

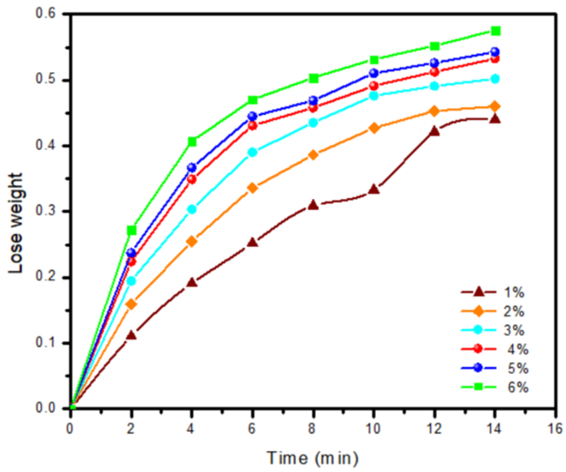

Figure 12. Weight loss over time for each concentration of Citric acid

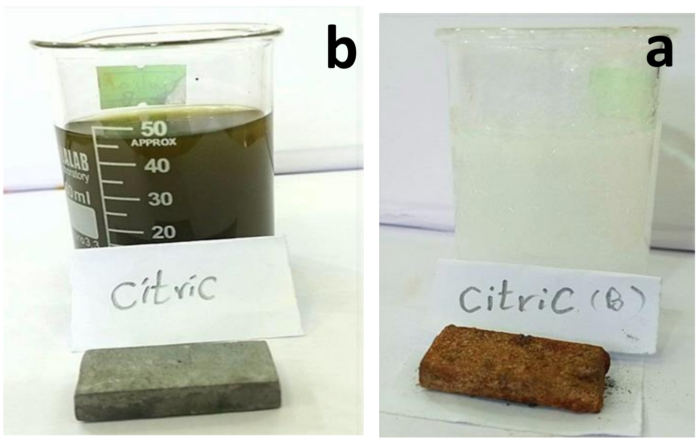

Figure 13. (a) Sample of carbon steel pipe for testing before treatment. (b) Sample after treatment with Citric acid

Concentration on the metal after removal, it is evident that a 3% concentration is the most effective. This concentration removes scales in a relatively short period of time, compared to concentrations of 1% and 2%. Additionally, compared to concentrations of 4%, 5%, and 6%, it has the least detrimental effect on the metal after scale removal, as illustrated in Figure (14).

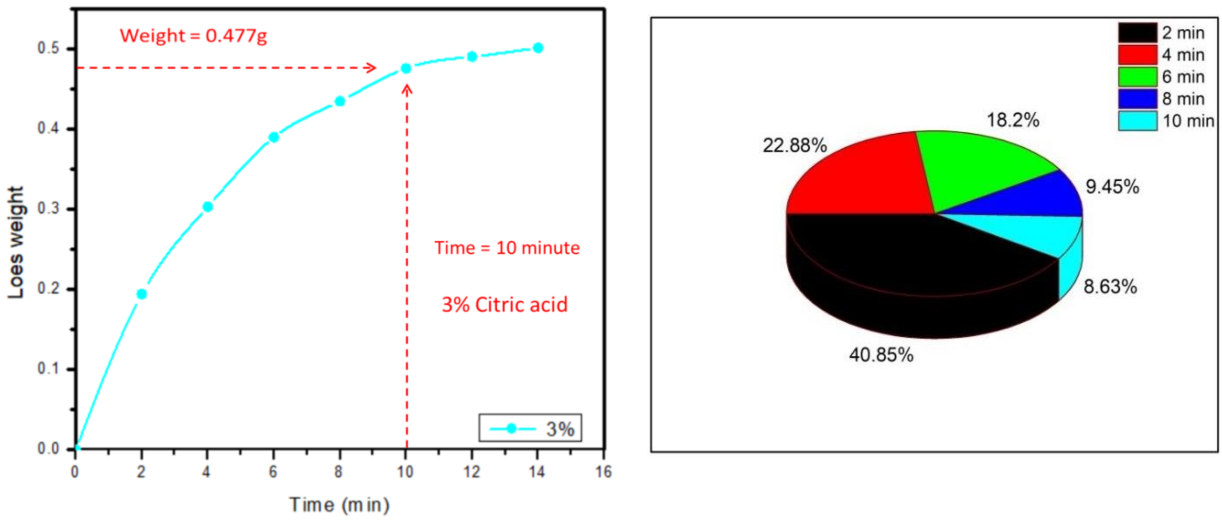

Figure 14. The descaling efficiency of 3% Citric acid

Application

The results proved that using ultrasonic technology in conjunction with weak acids leads to positive results in removing limescale deposits in transport pipes. Specifically, citric acid proved to be the most effective in removing limescale deposits, as it showed a long period of effectiveness. The best concentration of citric acid was applied to a sample of heat exchanger pipes that had previously been exposed to limescale deposits, as shown in Figure (15).

Figure 15. Sample of defective heat exchanger pipe before treatment

The table (6) illustrates the effectiveness of citric acid, at a concentration of 3M, in removing scale from a heat exchanger pipe sample using ultrasonic technology. The experiment proved highly efficacious, achieving remarkable speed in eliminating the deposit.

Table 6. How citric acid affects the rate of scaling of the pipe over time

Sample	Citric acid	the weight	Weight after treatment						
			2 mint	4 mint	6 mint	8 mint	10 mint	12 mint	14 mint
heat exchanger pipe	3%	32.1991g	31.582	30.9903	30.776	30.595	30.507	30.368	30.323

Figure 16. A sample of the heat exchanger pipe after treatment

4. Conclusion

1. Combining ultrasound with other techniques leads to high efficiency in removing limescale deposits on the surface of pipes.
2. The amount of limescale deposits removed varies according to the type of acid, its concentration and the level of ultrasonic frequency power.
3. The acids used are natural, which makes them a safe, environmentally friendly and economical treatment method.
4. Citric acid is more efficient than salicylic acid and EDTA in treating deposits.
5. The concentration of the acid used has an effect on the amount of deposits removed and the time taken, i.e. increasing the concentration causes corrosion.
6. Citric acid at a concentration of 3M gives the best and highest efficiency in removing deposits on the heat exchanger tube sample compared to the remaining concentrations.

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