

EFFECTS OF ELECTRICAL CURRENT FREQUENCY ON THE PHYSICOCHEMICAL CHARACTERISTICS OF WASTEWATER

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Abstract: Water plays a crucial role in the growth and development of species on Earth. Changes in the physicochemical properties of water have a large effect on human activities as well. Researchers have studied and evaluated the effects of electrical current frequency ($f = 0\div 2.000$ Hz) on the physicochemical properties (surface tension, dynamic viscosity, specific weight) of wastewater. The effect of electric fields on the physicochemical properties of water, allows it to identify the optimal treatment regimes that promote the intensification of various processes taking place in an aqueous medium or in the presence of water.

Keywords: Wastewater; Physicochemical; Hydrogen bonds; Frequency.

1. INTRODUCTION

Latimer and Rodebush first described hydrogen bonding in 1920. Water is the major constituent of cells and a remarkable solvent whose chemical and physical properties affect almost every aspect of life. Many of these properties are a direct reflection of the fact that most water molecules are in contact with their neighbors entirely through hydrogen bonds. Hydrogen bonds arise in the water where each partially positively-charged hydrogen atom is covalently attached to a partially negatively charged oxygen from a water molecule with a bond energy of about 492 kJ/mol and is also attracted, but much more weakly, to a neighboring partially negatively charged oxygen atom from another water molecule. In liquid water, the energy of attraction between water molecules is optimally about 23 kJ/mol and almost five times the average thermal collision fluctuation at 25 °C (figure 1). This is the energy required for breaking and completely separating the bond, and equals about half the enthalpy of vaporization (450 kJ/mol at 25 °C), as an average of just under two hydrogen bonds per molecule are broken when water evaporates [1].

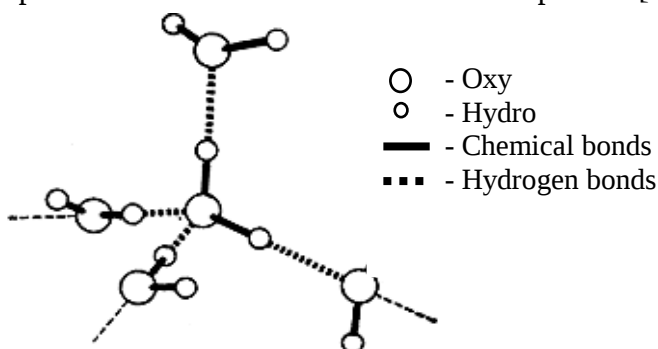


Figure 1. Hydro bonds between water molecules.

The Gibbs free energy change (ΔG) presents the balance between the increases in bond strength ($-\Delta H$) and consequent entropy loss ($-\Delta S$) on hydrogen bond formation (*i.e.* $\Delta G = \Delta H - T\Delta S$) and may be used to describe the balance between formed and broken hydrogen bonds. Several estimates give the equivalent Gibbs free energy change (ΔG) for the formation of water's hydrogen bonds at about 2 kJ/mol at 25 °C, the difference in value from that of the bond's attractive energy

being due to the loss in entropy (*i.e.* increased order) on forming the bonds. However, from the equilibrium concentration of hydrogen bonds in liquid water, ΔG is calculated to be more favorable at -5.7 kJ/mol [2].

Bond lengths and angles will change, due to polarization shifts in different hydrogen-bonded environments and when the water molecules are bound to solutes and ions. The oxygen atoms typically possess about 0.7e negative charge and the hydrogen atoms about 0.35e positive charge giving rise to both an important electrostatic bonding but also the favored trans arrangement of the hydrogen atoms as shown in Figure 1. Liquid water contains by far the densest hydrogen bonding of any solvent with almost as many hydrogen bonds as there are covalent bonds. These hydrogen bonds can rapidly rearrange in response to changing conditions and environments. In this paper, we will present the impacts of electrical current frequency ($f = 0 \div 2.000$ Hz) on the physicochemical properties of wastewater.

2. EXPERIMENT

2.1. Research equipment

In order to study the change in the physicochemical properties of wastewater, we used equipment TR (figure 2), researched and fabricated in Center of Industrial Environment, Institute of Mining – Metallurgy Science and Technology. The stimulation was applied at a range of frequencies ($0 \div 2000$ Hz), but in this paper, researchers were using current frequency $f = (25, 200, 500, 2000)$ Hz.



Figure 2. The layout of equipment TR-1 used to change the physicochemical properties of wastewater.

Treatment with an electromagnetic field, one of the potential techniques to increase scale deposition from wastewater, has the advantage of not requiring the addition of any chemicals.

2.2. Research Methods

a. Survey effects on the surface tension

Surface tension is the tendency of liquid surfaces to shrink into the minimum surface area possible. At liquid-air interfaces, surface tension results from the greater attraction of liquid molecules to each other (due to cohesion) than to the molecules in the air (due to adhesion). Let us consider a capillary tube of uniform bore dipped vertically in a beaker containing water. Due to surface tension, the water rises to a height h in the capillary tube as shown in figure 3.

To determine surface tension, we used equipment TR to change the physicochemical properties of wastewater in the period 15, 30, 45, and 60 minutes. Using standard burette stand to conduct experiments.

- *Step 1:* Use equipment TR to change physicochemical properties of 04 wastewater samples 500mL in the period 15, 30, 45, and 60 minutes;
- *Step 2:* Fix a needle near the capillary tube so that the needle touches the water surface;
- *Step 3:* The difference between the two readings of the vertical scale gives the height (h) of the liquid raised in the tube;
- *Step 4:* Evaluate the results achieved.

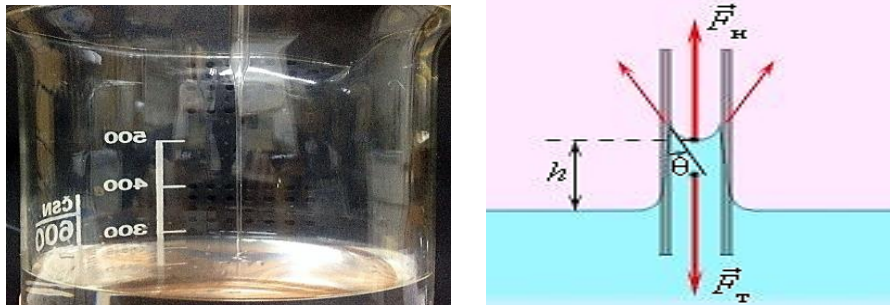


Figure 3. Survey effects on the surface tension.

Results of experiments are presented in table 1.

The surface tension of wastewater σ is calculated by equation (1):

$$h = \frac{2\sigma}{\rho \cdot g \cdot r} \text{ or } \sigma = \frac{h \cdot \rho \cdot g \cdot r}{2} \quad (1)$$

σ - Surface tension of the liquid (N.m^{-1}); h - Height of the liquid in the capillary tube (m); ρ - Density of water (kg.m^{-3}), $\rho = 997 \text{ kg.m}^{-3}$; g - Acceleration due to gravity ($g = 9.8 \text{ m.s}^{-2}$); r - Radius of the capillary tube (m), $r = 0,025 \cdot 10^{-2} \text{ m}$.

b. Survey effects on the dynamic viscosity of wastewater μ

The dynamic viscosity of water μ is the resistance inside the liquid. This resistance needs to overcome a force, which with such force, it can create the flow of liquid. Since the research carries out a survey to impacts of alternating current frequency to the dynamic viscosity of water by determining the time for a unit volume of water to flow out from the burette.

Use glass lock burette with volume 25 mL, respectively check time flowing out from burette of testing samples: wastewater, wastewater after using equipment TR in the period 15, 30, 45, and 60 minutes. The experimental steps are as follows:

- *Step 1:* Fix burette vertically in racks, for 25 mL wastewater into burette;
- *Step 2:* Open burette lock valve, as well as calculate time until water flows out from burette;
- *Step 3:* Calculate the dynamic viscosity and discuss.

The dynamic viscosity of water μ is calculated by equation Poiseuille (2):

$$\mu = \frac{\pi \cdot p \cdot \left(\frac{r_1}{r_2} \right)^4}{8 \cdot V \cdot l} \cdot t \quad (2)$$

in which: μ – The dynamic viscosity of wastewater, Pa.s; p – Liquid surface pressure, $p = 10383,6 \text{ kg/m}^2$; r_1 – Output radius of burette, $r_1 = 0,05 \cdot 10^{-2} \text{ m}$; r_2 – Radius of burette, $r_2 = 0,45 \cdot 10^{-2} \text{ m}$; t – Flowing out time of volume of wastewater, s; V – Volume of wastewater, $V = 0,25 \cdot 10^{-6} \text{ m}^3$; l – Measuring bar length of burette, $l = 39,8 \cdot 10^{-2} \text{ m}$. Results of experiments are presented in table 2.

c. Survey effects on the specific weight

To survey effect of electric current frequency to density of wastewater, the researchers use volumetric hydrometer 10 cm^3 , the steps are indicated in the document [3]. The experiment conducted in conditions of wastewater temperature is 25°C , density of wastewater is calculated by formula (3):

$$\rho = \frac{g_2 - g_0}{g_1 - g_0} \rho_{H_2O} \quad (3)$$

in which: ρ – The specific weight of wastewater after using equipment TR, kg/m^3 ; g_0 – The mass of the hydrometer, kg; g_1 – Hydrometer volume including wastewater not using equipment TR; g_2 – Hydrometer volume including wastewater using equipment TR; ρ_{H_2O} – The specific weight of wastewater in temperature 25°C , kg/m^3 , $\rho_{H_2O} = 997,32 \text{ kg/m}^3$ [4]. Results of experiments are presented in table 3.

3. RESULTS AND DISCUSSION

3.1. Effect of current frequency to physicochemical properties of wastewater

Survey results influence the frequency of the alternating current to physicochemical properties of water presented in table 1.

Via Table 1, Fig. 4 we see that surface tension of wastewater has an impact on electric current frequency (using equipment TR) smaller than wastewater not under the impact of electric current frequency (not using equipment TR). This can be explained that under the impact of electric current frequency elements of wastewater has the greater speed of movement and kinetic energy, it is easy to gain energy state to destroy hydrogen bonds from the open surface of the liquid. Hence, the surface tension of wastewater under the impact of electric current frequency is bigger.

Table 1. Impact of electric current frequency to the surface tension.

№	Time of experiments	Height of the liquid in the capillary tube, cm				Surface tension $\sigma \cdot 10^{-3}$, N/m			
		$\bar{h}_{25}$	$\bar{h}_{200}$	$\bar{h}_{500}$	$\bar{h}_{2000}$	σ_{25}	σ_{200}	σ_{500}	σ_{2000}
1	0	5,9	5,9	5,9	5,9	72,15	72,15	72,15	72,15
2	After 15 min	5,8	4,8	4,3	4,0	70,93	58,70	52,59	48,92
3	After 30 min	5,8	4,2	3,6	3,4	70,93	51,37	44,03	41,58
4	After 45 min	5,8	3,8	3,3	3,2	70,93	46,47	40,36	39,13
5	After 60 min	5,8	3,5	3,1	3,05	70,93	42,80	37,91	37,30

According to the results in table 1, we see that the surface tension of wastewater decreases with time which is affected by electric current frequency. When the time of experiments the surface tension down to 45,8% in the frequency from 25 to 2000 Hz.

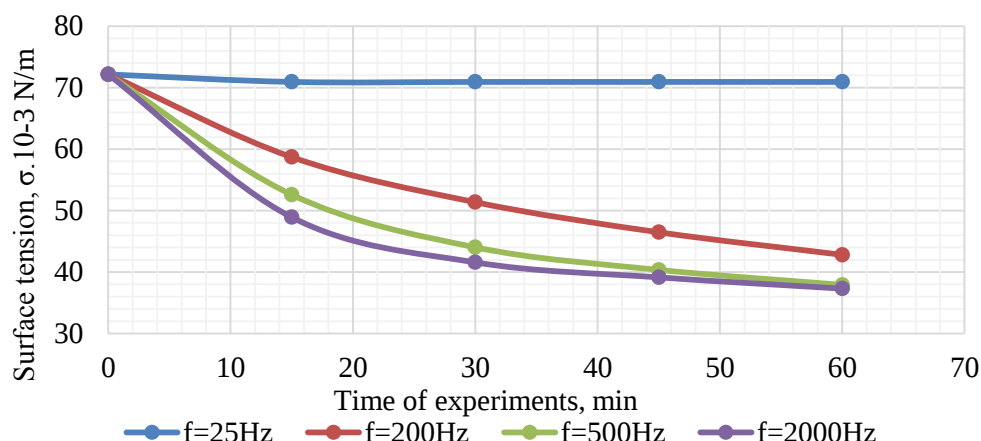


Figure 4. Impact of electric current frequency (TR) to surface tension.

Results of effects on the dynamic viscosity of wastewater by electric current frequency is shown in table 2. This can be explained that water sample under the impact of electric current frequency, links between elements become weaker, it is more easily destroyed than water sample without the impact of electric current frequency. Impacting time of electric current frequency is longer, dynamic (the velocity of the molecules) is bigger, it is easy to gain the status of the destruction of hydrogen bonds, and so that the number of hydrogen bonds reduces leading to the viscosity of liquid also reduces.

Table 2. Impact of electric current frequency to the dynamic viscosity of wastewater.

Wastewater	Dynamics viscosity of wastewater, $\mu \cdot 10^{-3}$, Pa.s			
	f=25 Hz	f=200 Hz	f=500 Hz	f=2000 Hz
0	0,924	0,923	0,923	0,924
After 15 min	0,919	0,910	0,903	0,900
After 30 min	0,918	0,902	0,896	0,893
After 45 min	0,916	0,897	0,892	0,890
After 60 min	0,916	0,896	0,890	0,890

Under the impact of the power line frequency, hydrogen bonds are broken by impacting time. Due to the increased number of elements, the liquid is also led to increase by time, and the special weight of the liquid is reduced by time. Results of the optimization process are presented in table 3.

Table 3. Physicochemical properties of wastewater with and without TR.

Frequency, Hz	Specific weight of wastewater ρ , kg/m ³				
	0	After 15 min	After 30 min	After 45 min	After 60 min
25	997,32	997,31	997,31	997,30	997,30
200	997,32	996,40	996,24	996,22	996,21
500	997,32	996,36	996,21	996,19	996,19
2000	997,32	996,34	996,20	996,18	996,18

As the results above shown, under the impact of the power line frequency,

hydrogen bridge links are weaker, water elements are easily converted into free and flexible, leading to penetration and impact to physicochemical properties of wastewater is faster.

3.2. Scaling mechanisms

Based on the literature review [6], we summarize into two fundamentally different approaches: (i) hydration effects, and (ii) magnetohydrodynamic under continuous flow conditions.

Hydration effects. Most of the observed electric current frequency effects can be elucidated in the light of magnetically induced changes in the hydration of ions, liquid interfaces, and hydrophobic solid surfaces, which also account for the impacts observed under the static or quiescent treatment conditions. The mechanisms involve changing the orientation of the proton spin, thereby disturbing hydration effects by hindering the transfer of the proton to a water molecule. Hence, the hydration effect is positively associated with the surface tension of water that determines the interfacial interactions between water molecules and scale-forming ions or solid surface. Some researchers noticed variations in the surface tension of water with the presence of MF, while others discovered negligible impact. Cho and Lee [5] used both permanent magnet and solenoid coil devices to investigate whether MF treatment can change the surface tension of hard water. They found that as the MF exposure time increased, the surface tension of the tested water decreased. Surface tension can be defined as the surface energy of a solid-liquid state is more than that of a liquid-liquid state. The presence of colloidal particles increases the surface energy at the water-colloid interface, thereby declining the surface energy at the water-reactor surface. It was also suggested that the results can be used to qualitatively evaluate the efficiency of MF for the prevention of scaling in heat exchangers [6, 7].

Magnetohydrodynamic phenomena. Magnetohydrodynamic phenomena exist only when both the treated fluid flows and the MF presents, such as in dynamic treatment conditions. The magnetohydrodynamic mechanisms can be used to explain a wide variety of MF effects, such as the effect of fluid velocity, magnetic induction on the quantity and crystal structure of the scale, and the main scale component.

Other mechanisms. Depending on the affected objects, the proposed MF mechanisms can also be broadly categorized under (even though the nature of mechanisms is identical): (i) intra-atomic effects, such as changes in electron configuration as discussed in hydration effects; (ii) inter-molecular/ionic effects, e.g., the hydration of ions alters by MF; (iii) interfacial effects, including alteration of liquid interfaces.

4. CONCLUSIONS

The result of the research shows the impact of the power line frequency to changes of physicochemical properties of water: reduce the surface tension, dynamic viscosity, and specific weight. When the time of experiments the surface tension down to 45,8% in the frequency from 25 to 2000 Hz.

The effect of electrical current frequency on the physicochemical properties of wastewater, which allows to identify the optimal treatment regimes that promote the

intensification of various processes taking place in an aqueous medium or in the presence of water. Next researches will be done on wastewater treatment systems, in order to evaluate optimizing impacts of physicochemical properties of water because of alternating current frequency.

REFERENCES

- [1]. P. L. Brezonik, "Chemical kinetics and process dynamics in aquatic systems", Boca Raton (1994).
- [2]. Mai Trong Ba, "Electro-physical treatment of irrigation water for priority to ensure the agricultural population emergency situations", VI scientific-technical conference young scientists, graduate students and students (with international participation) "Science Week – 2016", Conference on, pp. 232, (2016).
- [3]. K. P. Mishchenko, "Practical work on physical chemistry: The manual for high schools", St. Petersburg, Russia, (2002).
- [4]. A. A. Ravdel, "Quick reference physicochemical variables", St. Petersburg, Russia, (2002).
- [5]. Y. I. Cho, S. H. Lee, "Reduction in the surface tension of water due to physical water treatment for fouling control in heat exchangers", International Communications in Heat and Mass Transfer, **Vol. 32**, pp. 1-9 (2005).
- [6]. Pei Xu, Lu Lin, Wenbin Jiang, Xuesong Xu, "A critical review of the application of electromagnetic fields for scaling control in water systems: mechanisms, characterization, and operation", NPJ Clean Water, **Vol. 25** (2020).
- [7]. A. Alabi, M. Chiesa, C. Garlisi, G. Palmisano, "Advances in anti-scale magnetic water treatment", Environmental science water research and technology, **Vol. 1**, pp. 408-425 (2015).

TÓM TẮT

ẢNH HƯỞNG CỦA TẦN SỐ DÒNG ĐIỆN ĐẾN TÍNH CHẤT HÓA-LÝ CỦA NƯỚC THẢI

Nước đóng vai trò quan trọng trong sự sinh trưởng và phát triển của các loài sinh vật trên Trái Đất. Đồng thời, sự thay đổi tính chất hóa-lý của nước có tác động lớn đến các hoạt động của con người. Đã có nhiều nghiên cứu và đánh giá ảnh hưởng của tần số dòng điện ($f = 0 \div 2.000\text{Hz}$) đến các đặc tính hóa-lý (sức căng bề mặt, độ nhớt động học, trọng lượng riêng) của nước thải. Xác định ảnh hưởng của điện từ trường lên các đặc tính hóa-lý của nước là cơ sở xây dựng các chế độ xử lý tối ưu, thúc đẩy tăng cường các quá trình phản ứng khác nhau diễn ra trong môi trường nước hoặc khi có nước.

Từ khóa: Nước thải; Hóa lý; Liên kết hydro; Tần số.

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