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Investigation of the Effects of Salt and Magnetic Field on Mass Transfer Coefficient of Water Evaporation under Different Conditions

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Abstract

Due to the importance of the evaporation process and the need to control it in many chemical and production processes, this study was conducted to investigate the effect of magnetic field and salt on changes in water evaporation values at forced convection. In this study, to investigate the effect of salt and magnetic field variables on air temperature, water temperature, velocity, and relative humidity of the air, A laboratory device designed and measured the amount of evaporated water by inducing different conditions. The results of the present study showed that the magnetic field has a direct effect on the rate of change of evaporated water concentration so that increasing the strength of the magnetic field directly increases the amount of evaporation and these changes in the control group and group N at the probability level. 5% is significant so that the lowest evaporation rate belonged to the group with 0.5 Tesla and the highest evaporation rate belonged to the 1.5 Tesla group. Also, the results of the salt group showed that the amount of salt decreased the Evaporation values of water. The results showed that the magnetic field increased evaporation and the salt decreased evaporation.

Keywords: Salt, Magnetic field, Water evaporation, Mass transfer coefficient;

1. Introduction

There are many applications of evaporating water, from industrial activities to climate control and even affecting Earth's weather. Chemical and industrial plants (that use water as a working fluid, like evaporative cooling, heat exchangers, or spent-fuel pools) use water as a working fluid. In chemical engineering industrial processes, it is necessary to change the concentration of substances involved in a reaction and to manufacture other products. In some of these isolates, we do not have chemical transformation (change), in some chemical reaction occurs [1]. When a transformation is only physical, in other words, we do the separation. There are various methods for this separation. For example, distillation is sometimes used for solutions. Any movement of particles is not called mass transfer material [2]. Increasing mass transfer and heat transfer are the most important engineering issues that reduce heat exchangers as well as reduce energy consumption. Applications to increase evaporation include the food industry (drying fruit pieces), the paper industry, and the textile industry. The use of volumetric airflow with high temperature and high speed are common methods in increasing the evaporation rate, which has low efficiency due to high energy consumption. Also, in many cases, rising temperatures reduce the quality of agricultural products [3, 4]. One of the new methods to control the amount of water evaporation is the use of a strong electric field that increases the rate of evaporation without the need to increase the temperature. Also, use salt to reduce this amount. Applying an electric potential difference between two wired and plate electrodes creates a strong electric field around the wired electrode. The intensity of the electric field causes air ionization and the formation of plasma around the wired electrode. And this phenomenon causes Aqa Yadan in the water inside the pool [5]. Evaporation can happen both inside and outside of a building. It is required to install an HVAC system to achieve the desired humidity; this system develops and manages the ideal indoor thermal comfort. The rate of evaporation is used to calculate the amount of water that has to be replaced, as well as the amount of vapor released into the air, which is measured by how much the humidity has increased. By molecular diffusion, the gas directly above the liquid's surface becomes saturated with moisture during evaporation; in the absence of gas movement, it spreads further in the bulk gas by diffusion. Diffusion occurs in five different ways, depending on the direction of heat and mass transfer processes [6]. The rate of evaporation is affected by the liquid's characteristics as well as ambient factors including temperature, humidity, velocity, and air turbulence. The correct estimation of the evaporation rate is a more challenging challenge due to the various changing and changeable factors [7]. In evaporation, due to the heating of the liquid, the mobility of the molecule/atoms of the material increases, so the distance between the molecules/atoms of the material increases; Therefore, the volume of the material also increases and it evaporates. The problem caused by water losses stored in lakes, dams, and reservoirs for irrigation and domestic consumption by evaporation during the summer months is significant and

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challenging. By identifying the factors affecting the rate of water evaporation from the free surface of water dams, ways to reduce evaporation can be reduced[8]. Water surface and finally suggested saving it [9]. Therefore, it can be said that due to the importance of evaporation in engineering processes, the need to study to find control methods shows its importance. The effect of magnetic field and salt on evaporation values. This study aims to investigate the effect of various factors such as dissolved salts such as sodium hydrochloride in water on the process of water evaporation, such as in air-cooling evaporators, or water desalination, as well as the use of a magnetic field to enhance evaporation by removing salt effects and reducing energy consumption during the process.

2. Materials and Measuring Device:

2.1 Measuring Device:

The laboratory device designed as a tunnel with cross-section area is square with dimensions of 24.8 × 24.8 cm and length of the tunnel is 165 cm and the body is made of acrylic glass (Perspex) with 8 mm thickness of Fig. 1, A pool water located at a distance of 120 cm from the beginning of the tunnel and 25 cm from the end the pool dimensions are 20×20 cm with 7 cm height that.

To investigate the effect of temperature, pressure, and relative humidity of air on evaporation. Two temperature and air pressure sensors (6) were used at the beginning and end of the designed tunnel and a hygrometer (3) sensor to measure environmental temperature and humidity and to control them. A fan (1) with an adjustable device (2) for controlling air velocity, was used at the inlet of the chamber. To prevent air turbulence inside the chamber, or more properly, smooth and non-turbulent movement, at the entrance of the chamber, by designing small cubes (4) with an of 4.8 cm by 4.8 cm, in 25 cm length. An anemometer (5) was also used to measure the speed of moving air which is measured with each rotation of the propeller, angular velocity, and finally wind speed. A laboratory balance of 0.0000 accuracies was used to measure the weight lost via the experiment.

2.2 Preparation of NaCl / H_2O concentration:

For this purpose, the desired concentrations of salt (NaCl 99.9%) are dissolved in water and according to the amount of salt in the water, the studied solutions are obtained. So, prepare 1.5, 3, and 4.5 grams of NaCl / Lit. Water concentration, soluble salts in 2.8 liters of water were 4.2, 8.4, and 12.6 g, respectively.

2.3 Generating a Magnetic Field:

For this purpose, a matrix of 5x5 rings of neodymium magnetic (20x5 mm and hole 4 mm) on a flat plate of acrylic glass under and above the air-water interface was centered to make the magnetic field lines perpendicular to the interface and different amounts of the magnetic field were produced on the surface of the water by changing the distance between two layers and adding more magnetic rings pieces.

2.4 Measuring Method:

The experiment started with adjusting the fan velocity and the environmental conditions (temperature and relative humidity) of air and water temperature for each various solution concentration with different values of the magnetic field.

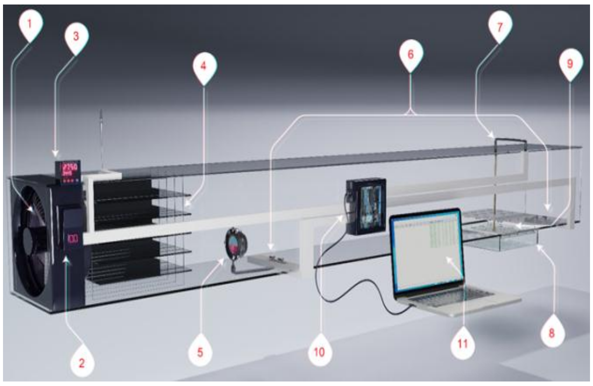

Fig.1: Schematic of an apparatus designed to investigate the water evaporation
1-Fan, 2-Dimmer (Voltage regulator), 3-Thermometer, 4-Air straightener,5- Anemometer, 6- Temperature/humidity sensors, 7-Thermocouple, 8-water pool.

All sensors are connected to an Arduino (electronic mini-board) that collects the data for 10 reads for each minute and the average of results saved in an Excel sheet is connected to a Computer (PC). The period of the experiment was 5 minutes after that amount of evaporation represent the water lost via experiment and measured from the difference in primary weight of water in pool minus secondary weight after 5 minutes, which will be in terms of grams.

3. Estimation Methods:

The experiment started with adjusting the fan velocity and the environmental conditions (temperature and relative humidity) of air and water temperature for each various solution concentration with different values of the magnetic field. All sensors are connected to an Arduino (electronic mini-board) that collects the data for 10 reads for each minute and the average of results saved in an Excel sheet is connected to a Computer (PC). The period of the experiment was 5 minutes after that amount of evaporation represent the water lost via experiment and measured from the difference in primary weight of water in pool minus secondary weight after 5 minutes, which will be in terms of grams.

Estimation Methods:

To calculate the mass transfer coefficient from the experiment data to explain the phenomenon of mass transfer:

Calculation of the theoretical mass transfer coefficient to estimate the mass transfer coefficient:

Through the evaporation process, water vapor diffuses into the air when it comes into direct contact with surface water, and the mass transfer coefficient can be calculated using the theoretical equation below:

$$E_{theo.} = h_{m,theo.} (\rho_{v,s} - Ø \rho_{v,\infty}) \quad (1)$$

$E_{theo.}$ is the evaporation rate (kg/m^2.s), h_m is the mass transfer coefficient (m/s), $\rho_{v,,s}$ and $\rho_{v,\infty}$ are the densities of water vapor at the surface of the water and the ambient conditions (kg/m^3) and Ø is the relative humidity of air [9].
In the experiment, water lost from the pool is represent the amount of water evaporated during the period time of the experiment and can express as follows [10]:

$$E_{theo.} = \frac{\Delta m_w}{\Delta t}\frac{1}{A} \quad (2)$$

4. Δm_w is the amount of water lost (evaporated) in term (kg), Δt is represented to the duration of experiment 5 minutes (300 second) and A is the water surface area is equal to 0.04m^2. Now by equal between equation (1) and (2) and rearrange it result [10]:

$$h_{m,theo.} = \frac{E_{theo.}}{(\rho v,s - \varnothing\ \rho v,\infty)} \quad (3)$$

The densities had been calculated by applying the following equations:

5. $$\rho_{v,i} = (3.484 - 1.317 \cdot x_{v,i})\frac{P_g}{T_i} \quad (4)$$

Where T_i is defined as the absolute temperature, K=°C+ 273.15, P_g is defined as the total pressure of the experiment in Kpa and $x_{v,i}$ is the mole fraction of the saturated water vapor at ideal gas assumption [9].

$$x_{v,i} = \varnothing\,\frac{P_{sat(Ti)}}{P_g} \quad (5)$$

Where, $_{(Ti)}$ is defined as the saturated water vapor at absolute air temperature in Kpa [9].

4. Results and Discussions:

4.1 Results for the control group (without salt and magnetic field):

Comparison of evaporation rate values in different groups:

The results showed that temperature values, both as air temperature and water temperature in the pool, have a direct effect on the rate of water evaporation, so that increasing the air temperature values, the rate of evaporation increases with increasing the water temperature inside the pool also rises. And this shows the synergistic effect of air temperature and water temperature inside the pool to increase the amount of water evaporation. However, the measured relative humidity of the air had the opposite effect on these values. Accordingly, the values of evaporation rate also change so that the increasing the air temperature, the temperature of the water inside the pool and the velocity of air movement, the evaporation rate increased and the increasing the relative humidity, the evaporation rates decreased (Fig.2,3 and 4). The results of this study agree with results of literatures [9-17].

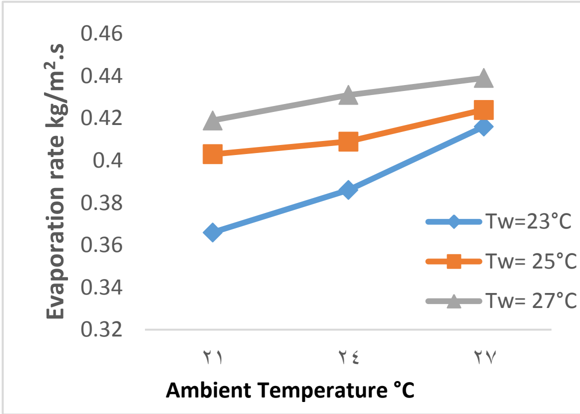

Fig.2: The interaction of air temperature and water temperature on the rate of water evaporation in the pool.

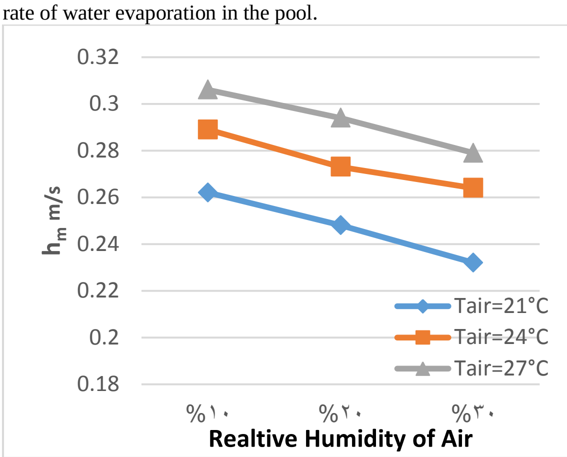

Fig.3: The effect of air humidity on the rate of water evaporation in the pool.

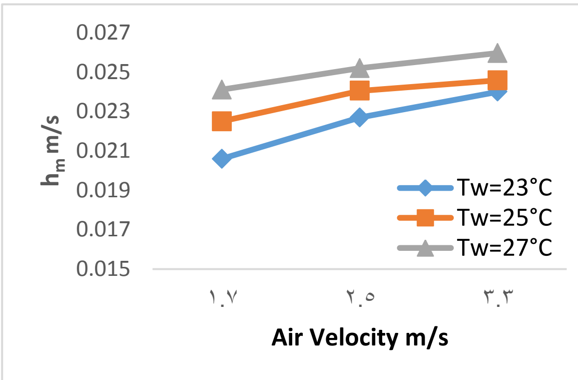

Fig.4: The effect of air velocity on the rate of water evaporation in the pool.

4.2 Results related to water with salt:

The results of the study of the effect of parameters on the rate of water evaporation in the pool containing different concentrations of salt showed that like the control group whose pure water in the pool (zero salt). Investigation of the interaction of salt concentrations It was observed that the presence of salt in water reduces the rate of water evaporation. So that at constant temperatures of pool water and air temperature also the same speed and humidity show that increasing the amount of salt reduces the rate of evaporation. Since the dissolved salt ions lower the free energy of the water molecules, i.e., decrease the water activity, and so reduce the saturation vapor pressure above saline water at a given water temperature, increasing water salinity reduces evaporation (Fig.5). These results were validated and agreed with the studies as [18-20] [22].

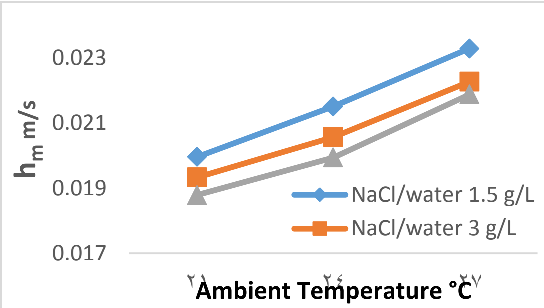

Fig.5: Comparison of the effect of different salt concentrations on mass transfer coefficient of water evaporation.

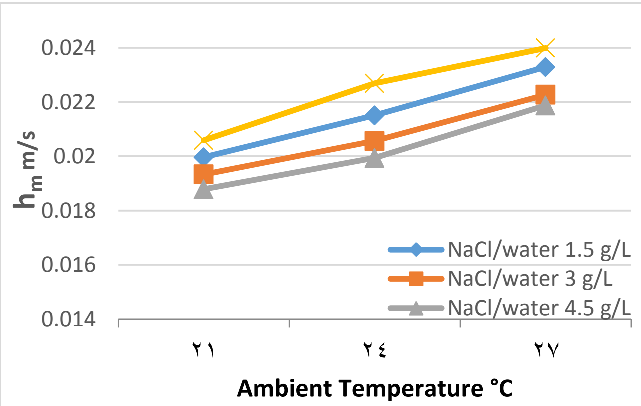

Fig. 6: Comparison of the effect of different salt concentrations on mass transfer coefficient of water evaporation with the control group.

Table 3: Results from SPSS statistical software and ANOVA statistical analysis to compare the effect of different concentrations of salt dissolved water evaporation.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.000	2	0.000	0.609	0.002
Within Groups	0.000	78	0.000		
Total	0.000	80			

Table 4
Results from SPSS statistical software and ANOVA statistical analysis to compare the effect of different concentrations of salt dissolved on water evaporation with the control group

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.001	3	0.000	0.163	0.002
Within Groups	0.002	8	0.000		
Total	0.003	11			

4.3 Results for water with magnetic field:

The results of the study of the effect of parameters on the rate of water evaporation in the pool with a magnetic field showed that like the control group that the pool water did not have a magnetic field, in this group the values of air temperature and water temperature in the pool have a direct effect on water evaporation. Because increasing the air temperature increases the rate of evaporation. This increase also increases with increasing water temperature inside the pool. And this shows the synergistic effect of air temperature and water temperature inside the pool to increase the rate of water evaporation. However, the measured air humidity had the opposite effect on these values. In contrast, air velocities, such as temperature, increased values. Therefore, in this group, it can be said that the higher the air temperature, the water temperature inside the pool and the speed of air movement, the more evaporation and the higher the humidity, the lower the evaporation values.

Investigation of the interaction of magnetic magnets with different strengths It was observed that the presence of a magnetic field centered at air/water interphase effectively increasing the rate of water evaporation when the strength of magnetic field increase (Fig.7). The results of this study agreement with various studies like [21-25]. So that at constant temperature of pool water and air temperature, also at the same speed and humidity shows that increasing the amount of magnetic field increases evaporation. This increase is significant in ANOVA analysis in SPSS software at 5% probability level (Table 7).
Also, the comparison of the present group with the control group and the salt group was observed, which showed higher evaporation values than both groups (Fig.8) (Table 8).

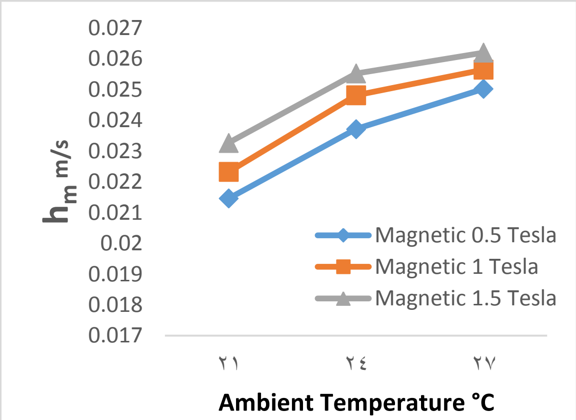

Fig. 7: Comparison of the effect of different values of magnetic field on mass transfer coefficient of water evaporation.

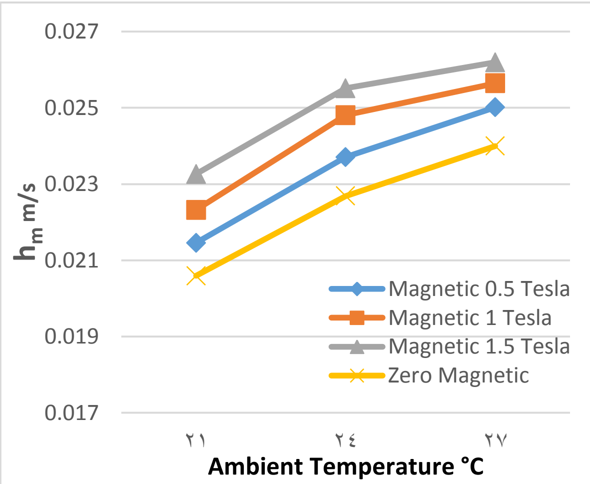

Fig.8: Comparison of the effect of different values of Magnetic field on mass transfer coefficient of water evaporation with the control group.

Table 7: Results from SPSS statistical software and ANOVA statistical analysis to compare the effect of different values of magnetic field on water evaporation.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.001	2	0.000	0.677	0.003
Within Groups	0.003	6	0.000		
Total	0.004	8			

Table 8
Results from SPSS statistical software and ANOVA statistical analysis to compare the effect of different concentrations of salt dissolved on water evaporation with the control group.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.010	3	0.003	8.050	0.008
Within Groups	0.003	8	0.000		
Total	0.014	11			

The calculation of h_m values is influenced by different concentrations of mixed salt in water:
Comparison of the available parameters with the amount of h_m showed that increasing the values of air temperature, water temperature, air speed and even increasing the amount of humidity has an increasing effect on the amount of h_m. In contrast, the presence of salt reduces the calculated hm values so that as the amount of salt increases, the calculated hm values decrease (Fig.9).
Calculation of h_m values under the influence of different amounts of magnetic field around the pool water:

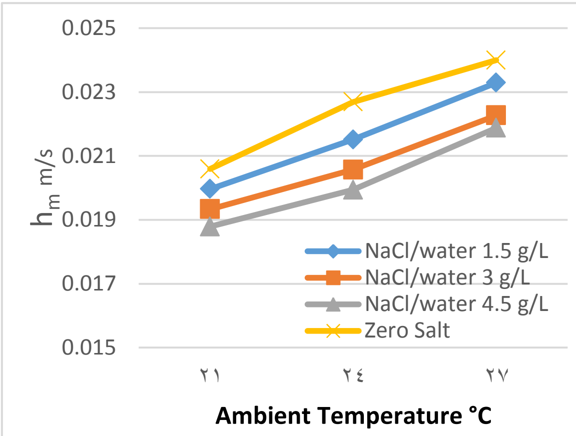

Fig.9: Comparison of the results of calculating the h_m results obtained from groups containing different amounts of salt and comparison with the control group.

Comparison of the available parameters with the amount of h_m showed that increasing the values of air temperature, water temperature, air speed and even increasing the amount of humidity has an increasing effect on the amount of h_m. In contrast, the presence of different values of magnetic field increases the calculated h_m values so that by increasing the amount of magnetic field created around the pool, the calculated h_m values are degraded. Also, comparing the results with the control group also shows an increase in values. Finds hm relative to the control group (Fig.10).

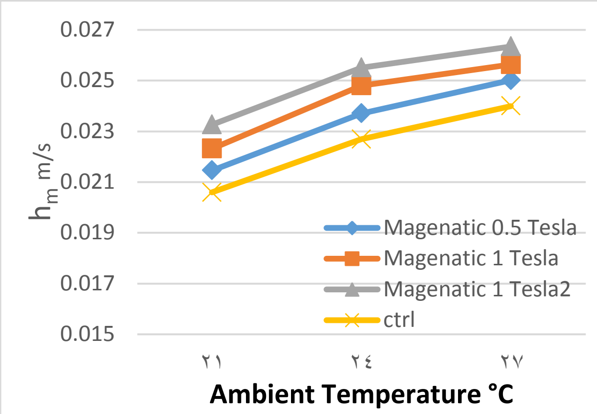

Fig.10: Comparison of the results of calculating the h_m results obtained from groups containing different amounts of salt and comparison with the control group.

5. Discussion:

The results of the present study showed that the magnetic field has a direct effect on the rate of change of evaporated water concentration, so that increasing the strength of the magnetic field directly increases the amount of evaporation and these changes in the control group and salt group in the level of probability. 5% is significant, so that the lowest evaporation rate belonged to the group with 0.5 Tesla and the highest evaporation rate belonged to the 1.5 Tesla group. It was also observed in our study that salt reduces the amount of water evaporation. In other studies, the results of our study are almost confirmed. Guo et al research's found that Evaporation of pure water at simulated gravity points (0 gravity levels (ab. G), 1 g, 1.56 g, and 1.96 g) in a superconducting magnet was examined in the absence of a magnetic field in 2012 to study the rate of water evaporation as a function of the magnetic field and the gradient of the field. The findings revealed that water evaporates faster in the presence of a magnetic field than in the absence of one. Furthermore, the rate of water evaporation is affected by the sample's position in the magnetic field. Evaporation at 0 g, in particular, was significantly faster than in other conditions [26]. Due to variances in the magnetic sensitivity of the surrounding climate vapor, the results are analyzed from the perspective of climate surface evaporation and magnetic force convection [10, 27]. Also, in a study by Dueñas in 2021 to investigate the magnetic effect of water evaporation: A three-dimensional experimental model stated that when an external polar field is applied to it, the bonding forces change. In many studies, water evaporation, an essential process in nature, has been targeted. Static magnetic fields ranging from 30 to 200 mT were utilized to circulate treated water in this study to see how the evaporation rate changed under various environmental circumstances. The importance of the magnetic induction effect was assessed using a statistical method. Our findings indicated that introducing a static magnetic field to water enhances the rate of evaporation at low temperatures and increases the rate of evaporation for magnetic water up to 6 ° C. We also discovered that water circulation had no effect on the rate of evaporation. To link the applied magnetic field with ambient temperature and humidity factors, we developed a triple experimental model [28, 29]. In a study conducted by Chibowski et al. in 2018, the researchers utilized neodymium ring magnets (0.5-0.65 T) and zinc tests to evaluate the effect of magnetic field on evaporation rate and surface tension of water (MF). At room temperature, water evaporation and surface tension were measured (22-24 ^{o}C). In trials conducted over several days or weeks, a rise in evaporation was seen, according to the literature. However, in other trials, the amount of water evaporation (maximum 440 mg in 150 minutes) fluctuates. The evaporation values are influenced by the ring magnet's pole. The rather strong MF (0.65 T) induced a 60-minute-long reduction in surface tension (11 2.11 mN / m), and the memory effect gradually faded. The literature has documented reduced surface tension data as a result of MF technique, although there are also contradicting results. Data from molecular simulation literature and the theory that MF alters hydrogen bonds within and within clusters of water molecules, possibly causing some to fail, can explain the observed results. The effect of Lorentz force is also considered. Lorentz force is also taken into account. The rise in water evaporation in the magnetic field, on the other hand, has received less attention. Previous research has looked into the basic mechanics of his phenomenon. We describe a study of water evaporation in a large-gradient magnetic field in this publication. In the absence of a magnetic field, the evaporation of pure water at simulated gravity points (0 gravity levels (ab. G), 1 g, 1.56 g, and 1.96 g) in a superconducting magnet was compared. The findings revealed that water evaporates faster in the presence of a magnetic field than in the absence of one. Furthermore, the rate of water evaporation is affected by the sample's position in the magnetic field. Evaporation at 0 g, in particular, was significantly faster than in other conditions. Due to variances in the magnetic sensitivity of the surrounding climate vapor, the results are analyzed from the perspective of climate surface evaporation and magnetic force convection. Many investigations have been conducted on the influence of magnetic fields on water since the mid-nineteenth century, but the results have sometimes been conflicting. When "water conditioning" was sold as a unit employing permanent magnets in the early 1950s, this issue arose [21, 28]. According to a 2017 study by Ben Amor et al., which aimed to test the influence of a magnetic field on the surface tension of water, water supply is a major concern in Tunisia for agriculture, drinking water, and industry. It's worth noting that agriculture is the most popular pastime. However, one of the key constraints restricting Tunisia's agricultural development is the lack of water resources, both quantitatively and qualitatively, as well as its geographical distribution. The magnetic device clearly has an impact on the characteristics of limestone. Water, on the other hand, has a wide range of physical and chemical qualities, which boosts productivity and production. The performance of magnetic water irrigation is superior than that of raw water irrigation. In this context, we look into the effects of magnetic treatment on surface tension and evaporation in irrigation water. As a result, four devices were used, each with its own set of features. The employment of a magnetic field changes the properties of water, lowering its surface tension by up to 24% and causing its volume to evaporate as compared to raw water. Our experimental results were statistically significant, according to statistical analysis [21, 30].

6. Conclusion:

The results of the present study showed that the magnetic field has a direct effect on the rate of change of evaporated water concentration, so that increasing the strength of the magnetic field directly increases the amount of evaporation and these changes in the control group and group N at the probability level. 5% is significant, so that the lowest evaporation rate belonged to the group with 0.5 Tesla and the highest evaporation rate belonged to the 1.5 Tesla group. Also, the results of the salt group showed that the amount of salt decreased Evaporation values become water.

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