Designing of an Electromagnet Producing Gradient MF and Its Effect on Water Properties

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1 Introduction

The molecular construction of water has been under inspection for almost a century and is persuaded by various factors. The features and duration of this region of 'structured' water have been a matter of debate. It has been provided with evidence that magnetic fields strengthen hydrogen bonds along with the basic properties of water. The MF impact on hydrogen bonds is also a source of discussion with much confirmation. However, Feng [1], has granted what appears to be strong support for the magnetic treatment of water. Amiri et al. [2] discovered that adjustments in surface pressure of water with time could be a crucial point in following debasements in water. Cai et al. [3] broke down the adjustment in the physicochemical properties of water when coursed at a consistent stream rate. Additionally, demonstrating a lessening of surface strain and the expansion of thickness over the treatment time; the two-stage model was built up. The outcomes prescribed that the normal size of water bunches become bigger by attractive medicines.

Holysz et al. [4] exhibited the dissipation measure of water expanded when presented to a static MF, and it reasoned that the MF caused variation in hydration framework of molecules. Chang et al. [5] studied the progression of subatomic elemental recreations depending upon the adaptable 3-focused model of the water system. The examination shows basic changes in the fluid by utilization of MF with a quality range (1–T). Guo et al. [6] examined the vanishing of water in MF of the

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high gradient (from utilizing the super magnet and reproduced gravity. Wang et al. [7] studied the impact of the attractive static field on the hydrogen holding in water utilizing a frictional examination. Gabrielli et al. [8] built a device to treat scales present in water using magnets (permanent). Wang et al. [9] investigated physical properties after MF exposer on various types of test water samples and concluded the results in affirmation. The ideal polarization MF strength was reduced to 300 mT. They examined the maximum evaporation and least B.P. at 300 mT. Until now, researches have studied the effect of static magnetic field on the water properties. However, a study on the effect of the gradient magnetic field is still in dew. In this work, the varying magnetic field by the tapered solenoid and its effect on the water properties is studied.

2 System Modelling

The actual model is represented schematically in Fig. 1.

The experimental set up designed for testing of the evaporation rate of water under the influence of the gradient magnetic field mainly consists of: Auto-Transformer, Tapered solenoid, Graduated cylinder, Resistance coil, NI cDAQ-9178, K-type thermocouple, and NI-9213 C Series Temperature Input Module.

The main part of the setup is the tapered solenoid which will be able to generate the gradient magnetic field along the axis of the solenoid. The tapered solenoid of length 150 mm having one end diameter of 50 mm and another end diameter of 100 mm is made of insulated copper wire is considered. Effect of copper wire diameter on the magnetic field is considered. Two sets of dia are considered, as mentioned in Table 1. Due to more diameters in the 2nd model number of layers of winding is increased as the length of the wire is constant for both cases. Design of the tapered solenoid in the first model and the second model is represented in Fig. 2a, b.

Because of linear change in diameter along the axis of the solenoid, the gradient magnetic field can be generated based on the concept of simple Biot–Savart's Law of electromagnetism. The actual set up of this model is shown in Fig. 2c.

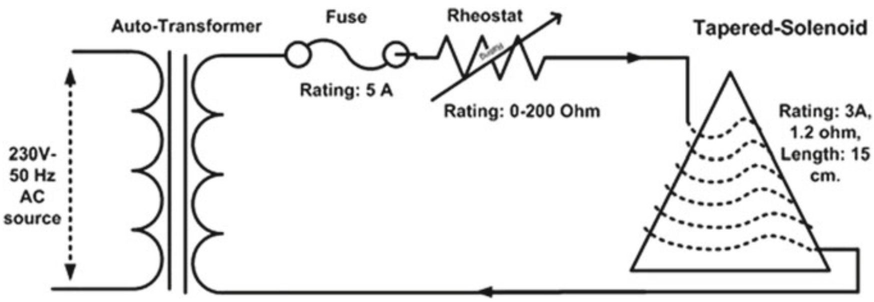

Fig. 1 Schematic representation of the actual model

Table 1 Detail description of the models

Description	1st model	2nd model
Diameter of copper wire	22 gauge	18 gauge
Length of copper wire	60 cm	60 cm
Number of turns	300	300
Number of layer winding	1	2
Winding connection	Series	Series

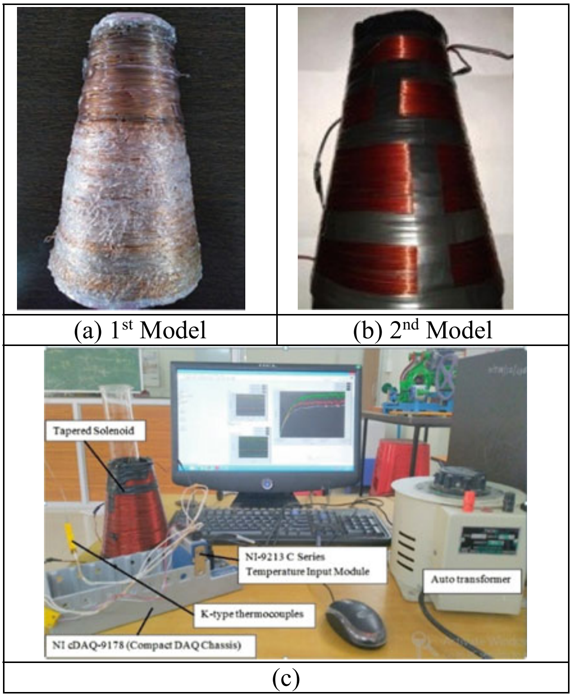

Fig. 2 **a**, **b** Design of tapered solenoid; **c** Actual set up of model

2.1 Derivation of the Magnetic Field Along the Axis of the Solenoid

The intrinsic magnetic moment of particles and currents (moving charges) are the main reasons for the generation of magnetic fields. In the present work, the relationship between current and magnetic field is evaluated. To study the effect of the magnetic field produced due to the element is determined by considering a point P at a distance of D along the solenoid axis. The point P is making an angle θ with the solenoid axis with the line joining the solenoid surface, as shown in Fig. 3c.

Z = radius of the ring which is at a distance x from the near edge

R_1 = radius of the near edge (smaller radius of the tapered solenoid)

R_2 = radius of the far edge (bigger radius of the tapered solenoid)

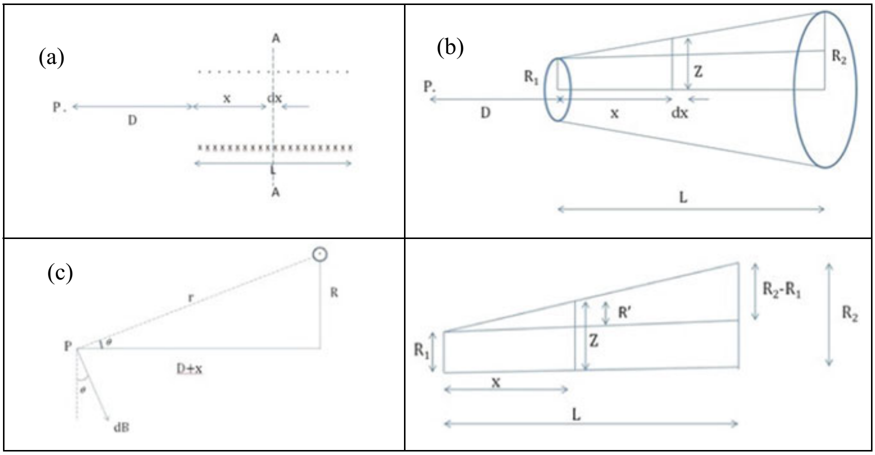

Fig. 3 Graphical representation of the tapered solenoid model

From the similar triangle rule,

$$x = \frac{LR'}{(R_2 - R_1)} \tag{1}$$

Then, the radius of the ring of the tapered solenoid at a distance x from the near edge

$$Z = R_1 + \frac{x}{L}(R_2 - R_1) \tag{2}$$

By differentiating the above the equation

$$dx = \frac{LdZ}{(R_2 - R_1)} \tag{3}$$

Then from Biot–Savart's law and Eq. (2), for a single loop at the distance x from the near edge of the tapered solenoid, the magnetic field will be,

$$dB = \frac{\mu_0 In}{4\pi} \frac{Z}{\left[(D + x)^2 + Z^2\right]^{3/2}} ds \tag{4}$$

Since, $s =$ the perimeter of the ring situated at a distance from the ear edge having radius Z, then

$$s = 2\pi Z$$
$$ds = 2\pi dZ \tag{5}$$

Then, by substituting the value of *ds* into Eq. (4), we get,

$$dB = \frac{\mu_0 In}{2} \frac{Z}{\left[(D+x)^2 + Z^2\right]^{3/2}} dZ \tag{6}$$

Differentiating equation 2,

$$dZ = \frac{(R_2 - R_1)}{L} dx \tag{7}$$

By substituting equation 2 and 7 in Eq. 6, the Gradient Magnetic Field at point ‘P’, the tapered solenoid of length ‘L’ the axis of the tapered solenoid at a distance $(D + x)$ from the near edge equals to:

$$\frac{dB}{dx} = \frac{\mu_0 In}{2} \frac{R_1 + \frac{x}{L}(R_2 - R_1)}{\left[(D+x)^2 + \{R_1 + \frac{x}{L}(R_2 - R_1)\}^2\right]^{3/2}} \frac{(R_2 - R_1)}{L} \tag{8}$$

2.2 Calculation of Gradient Magnetic Field for a Proposed Design

The experimental setup is expected to be kept in ideal condition. The working temperature is kept constant at 25 °C with a continuous flow of the current of 5 A. Prior to the experiments, the test structure was carefully observed for testing of the solenoid copper coil. The calculated gradient MF for both models is shown in Fig. 4. As the distance increases the magnetic field decreases. In the 2nd model, the magnetic field is very high at the near end. But the rate of decrease in the magnetic field is higher in the 2nd model.

3 Experimental Results

Initially, 100 ml of untreated water (13 °C) without the influence of the magnetic field is heated. Evaporation time and rate of the water has found as 24:40 min and 0.0675 ml/s, respectively. The boiling point of the water is 99.2 °C. It has performed the experiments for River water, RO water and Tap water under the GMF for both models. In the 1st model, with the effect of the magnetic field, the evaporate rate increases, and the boiling point of the water is decreased. Tap water is evaporating at a faster rate than river water and RO water. But the boiling point is the same for all the cases. The experimental results for the 1st model are mentioned in Table 2.

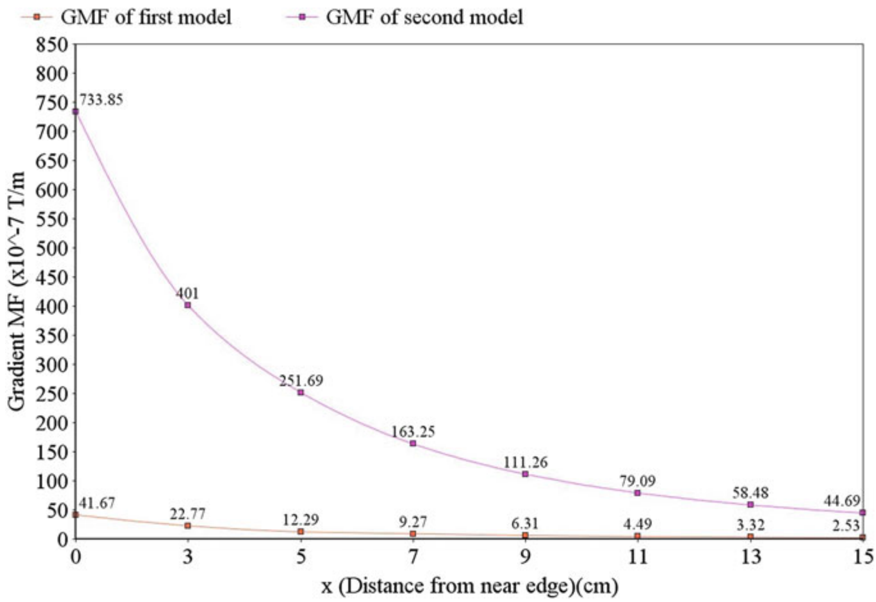

Fig. 4 Variation of the magnetic field in a new design

Table 2 Experimental results for water samples at various parameter for 1st model

Experimental parameter	River water	RO water	Tap water
Water initial temp. (°C)	12	13	13
Final temp. after GMF	32	30	31
Atm. temperature (°C)	13	13	12
GMF exposer time (min)	50	50	50
Evaporation time (min)	22:35	22:50	22:20
Sample amount (ml)	100	100	100
Evaporation rate (ml/sec)	0.0738	0.0729	0.0746
BP after GMF (°C)	96	96	96

In the 2nd model, also the evaporation rate is faster for the tap water than the river water and RO water. In RO water, due to the removal impurities, the magnetic particles will be separated. This causes a reduction in the evaporation rate. The boiling point of water is the same all cases but little higher than the 1st model. The experimental results for the 2nd model are mentioned in Table 3.

It shows that decreasing of insulated copper wire dia, for the same length, the magnetic field produced more. Fig. 5 represents the evaporation rate comparison for untreated test samples with treated (magnetized) water samples for both models. It shows that under the influence of the more magnetic field, the evaporation rate is high.

Table 3 Experimental results for water samples at various parameter for the 2nd model

Experimental parameter	River water	RO water	Tap water
Water initial temp. (°C)	12	13	13
Final temp. after GMF	40	38	39
Atm. temperature (°C)	15	15	14
GMF exposer time (min)	50	50	50
Evaporation time (min)	21:01	21:34	20.49
Sample amount (ml)	100	100	100
Evaporation rate (ml/sec)	0.0793	0.0781	0.0804
BP after GMF (°C)	96.5	96.5	96.5

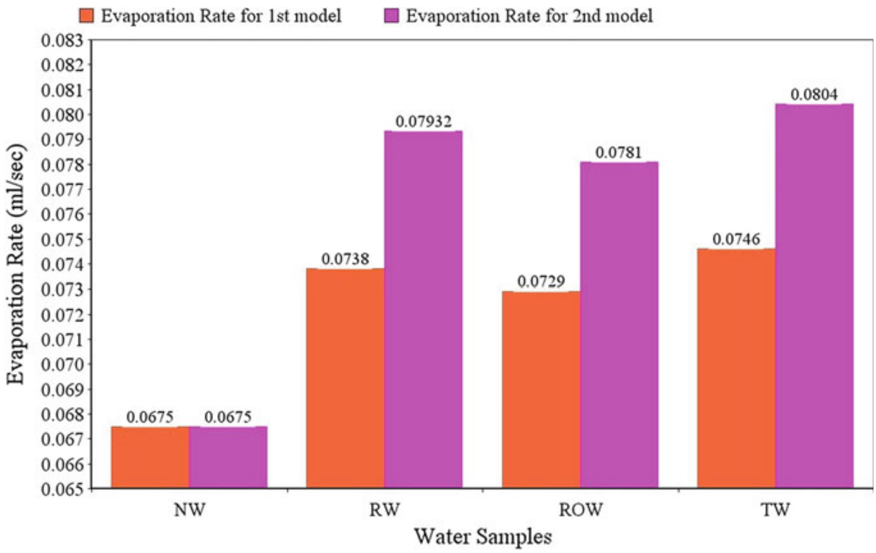

Fig. 5 Evaporation rate of normal water (untreated) with treated samples (RW, ROW and TW)

4 Results on Resistance and Conductivity Test of Water Samples under Gradient MF

Further, it has calculated the resistance and conductivity of the water samples with the designed 2nd model of the tapered solenoid. To calculate the resistance and conductivity of the water samples, it has kept them in the gradient MF for a total experimental time of 2 h 30 min. Figure 6 shows the change in the resistance of the water samples with respect to the time of exposing to the gradient MF. It can be observed that the resistance is continuously decreasing with the increase of time of gradient MF exposure. In the case of RW, the resistance is high as compared to TW and ROW. This is maybe due to more impurities in water samples. The

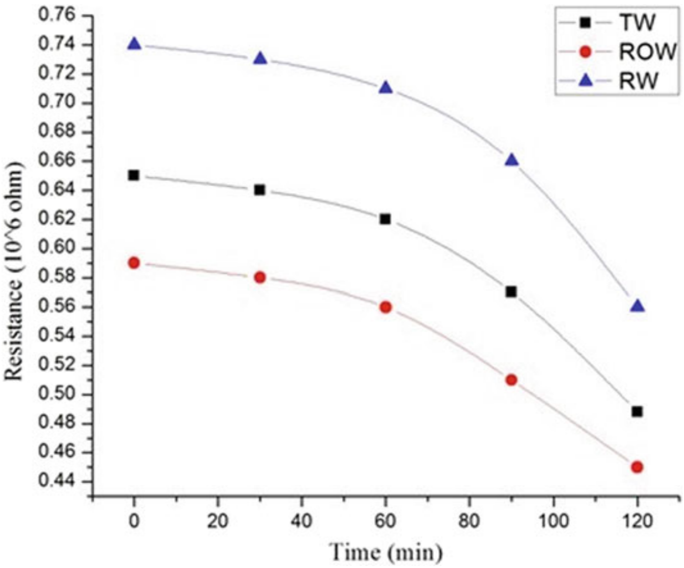

Fig. 6 The resistance of different water sample under GMF versus Time plot

resistivity/specific resistance of absolutely pure water is about 18.2 MΩ cm at 25 °C. But as the time of exposure of gradient MF increases, all samples experienced the flow of its movable charges and resulted in gives lowering electric resistance.

Conductivity is defined as the inverse of resistivity (SI units of Siemens per meter (S/m)). Fig. 7 shows the variation of conductivity of different water samples in the gradient MF with respect to the time. It shows that the conductivity of water is increasing continuously with time is due to more prolonged exposure to the gradient.

5 Conclusion

From the above experiments, certain conclusions were made. Detailed investigation shows that enhanced the properties of water. The designed setup gives a desirable continuous gradient magnetic field. When GMF was applied perpendicularly on the water surface, change in a property of water, e.g. change in boiling point, evaporation rate was observed. Under the exposure of MF, the boiling point of water is decreased from 99.2 to 96.5 °C. It also improved the evaporation rate of water samples. Experimental studies have been determined the changes in conductivity and resistance of water samples. As the time of exposure to gradient MF is increased, the flow of its movable charges enables water samples to improve the conductivities.

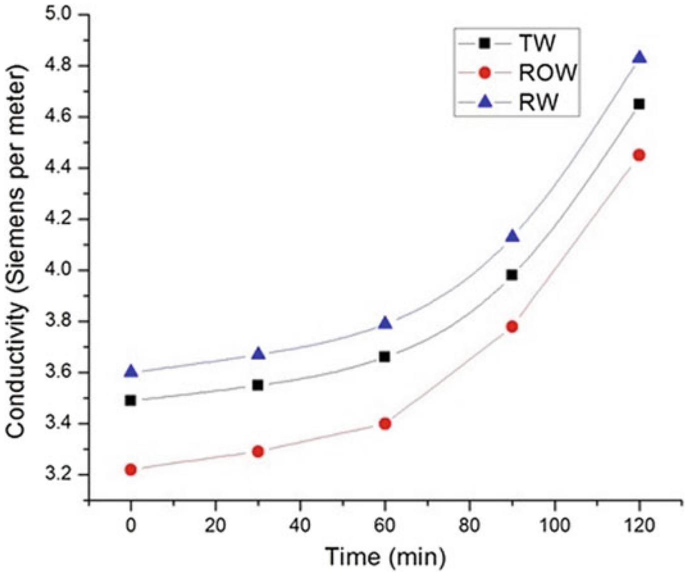

Fig. 7 Conductivity variation of magnetized water samples under GMF

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