Design, construction and performance evaluation of a magnetic water treatment

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Abstract: Magnetic water treatment (MWT) techniques have shown promising potentials in different areas especially in agriculture. This report deals with the design and manufacturing of a magnetic water treatment apparatus. A positive effect on irrigation water was found by using this apparatus. The device was capable of adjusting the magnetic field strength up to 500 mT and also was equipped with a magnetic water circulation system and a cooling system. In this study, the effects of magnetized water were investigated on the germination rate of cotton seeds in order to evaluate the apparatus.

Keywords: magnetic water, seed, germination, magnetic water apparatus.

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1 Introduction

Water is a crucial source for life on earth. Any living creature needs water to hydrate every cell. Long term and frequent droughts and competing water demands in most parts of the world have caused severe pressure on water resources. In addition, high costs of irrigation in the most countries are the main problem of agricultural development. Annually, large quantities of water are used in agriculture. Therefore, emerging new strategies to reduce water consumption is of significant importance. One of these strategies is magnetic water technology. The effect of magnetism on water was first observed by Russian scientists (Bruns et al., 1966; Klassen, 1978). Since then, many studies have been carried out in various fields, most of which have focused on the issue of magnetic water purification and manufacturing devices for this purpose (Zúñiga et al., 2016).

Electromagnetic fields (EMFs) have shown great potentials in medical, industrial and environmental applications (Yadollahpour and Jalilifar, 2014; Massah et al., 2019). Because of the electrical origin of the live and existence of all cells and living creatures, EMFs can interact with all living cells so that can modulate their functions (Lee and Kang, 2013). These modulations in appropriate conditions can have useful outcomes such as treatment or inducing the desire characteristics in different compounds. Various studies have revealed that magnetic treatment of irrigation water can improve the productivity of water (Duarte Diaz et al., 1997; Gholizadeh et al., 2008). Magnetic water treatment (MWT) has shown promising potential in saving water resources that will be of significant importance in near future. MWT has shown various potentials in environmental and agricultural applications (Yadollahpour et al., 2014). Some of these

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applications are therapeutic effects of MW, preventing scale deposition, improving irrigation water quality and crop yield, scale elimination, soil improvement, corrosion control and wastewater treatment (Amaya et al., 1996; Podleśny et al., 2004; Flórez et al., 2007).

Previous studies have shown several beneficial effects of EMF treatment on the growth of plants (Ayesha et al., 2023; Phirke et al., 1996; Abe et al., 1997; Volpe, 2003). It was demonstrated that an optimal external EMF can increase the rate of the plant growth, especially the percentage of seed germination (Amaya et al., 1996). Podleśny et al. (2004) reported that exposing the broad bean seeds to variable magnetic strengths before sowing imposes significant effects on seed germination and seed yield. In addition, they showed that applying EMF to broad bean during the growing season can increase the number of pods per plant and reduce the plant losses per unit area. Several studies have demonstrated the effectiveness of EMFs on the root growth of various plants (Belyavskaya, 2004). Muraji et al. (1992) observed that EMF treatment increases the root growth of maize. Turker et al. (2007) reported that static EMF has an inhibitory effect on the root dry weight of maize plants, but had a beneficial effect on root dry weight of sunflower plants. Different studies have shown the inhibitory effect of weak EMF on the growth rate of primary roots during early growth (Belyavskaya, 2004). It was demonstrated that EMF can decrease the proliferative activity and cell reproduction in meristem cells in plant roots.

The previous studies have shown that the effects of magnetic treatment varied with plant type and the type of irrigation water used, and there were significant increases in plant yield and water productivity (kg of fresh or dry produce per 1 m^3 of water used) (Maheshwari and Grewal, 2009; Surendran et al., 2016). In particular, the magnetic treatment of recycled water and 3000 ppm saline water respectively increased celery yield by 12% and 23% and water productivity by 12% and 24%. For snow peas, there were 7.8%, 5.9% and 6.0% increases in pod yield with magnetically treated potable water, recycled water and 1000 ppm saline water, respectively. Several studies have revealed beneficial effects of MF treatment in fruit yield and plant growth. Lin and Yotvat (1990) explained that applying magnetically treated water increases productivity of water in both crop and livestock production. Similarly, several studies have shown that EMF treatments enhance the flowers and total fruit yield of strawberry and tomatoes (Danilov et al., 1993; Eşitken and Turan, 2004). Duarte Diaz et al. (1997) observed that magnetic treatment increases the nutrients absorption in tomato. Some of the main effects of magnetic treatment of seeds or irrigation with MW in plants include plant growth rate, transplant dry weight, transplant leaf area, and seed germination.

The objective of this study was the design and manufacturing a magnetic water apparatus which equipped with a magnetic water circulation system and a cooling system. In this device, the number of instances which a certain amount of water passes through the magnetic field can be determined. Then, to evaluate the performance of the apparatus, experiments were conducted on the effect of magnetized water on the germination rate of cotton seed.

2 Materials and methods

2.1 Design and development of the apparatus

The design of the device is derived from a combination of two magnetic water devices, that water passes through a spiral tube, and the device with a variable horizontal magnetic field intensity with a direct current supply (Vashisth and Nagarajan, 2009). Also, the scheme proposed by LaVerne and Brocklehurst (1996) was used for the rotational part of the water; the manufactured device is shown in Figure 1. The device includes a water circulation duct through the magnetic field, power supply and magnetic field strength regulator, flow meter, magnetic field coil cooling system, and Tesla meter. The main components of the devise are shown in

Figure 2 which contains three substrates.

Part 1, the chassis of the machine, which contains three substrates, is made of St 37 steel, and 8 mm thick. In two vertical pieces of chassis, two holes are created with a diameter of 42 mm, where the magnetic cores are mounted.

Figure 1 Magnetic water treatment devices

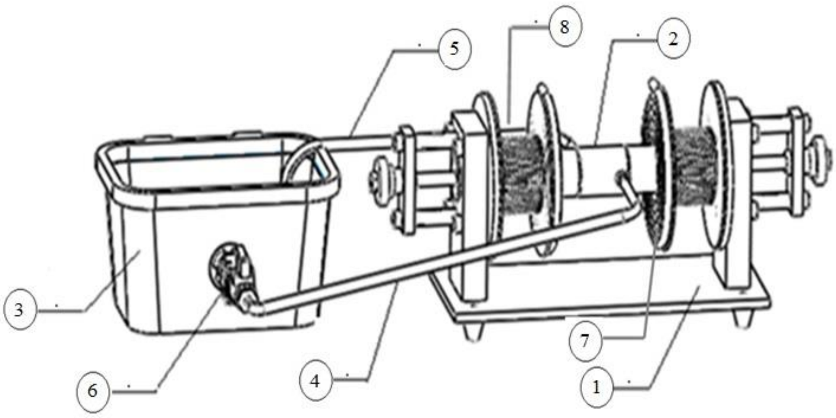


Figure 2 Schematic drawing of magnetic water generating apparatus

Part 2, the fluid circulation chamber in the magnetic field has spiral grooves for crossing the water flow. This part is made of hard PVC (PVC-U) and it is positioned between the cores.

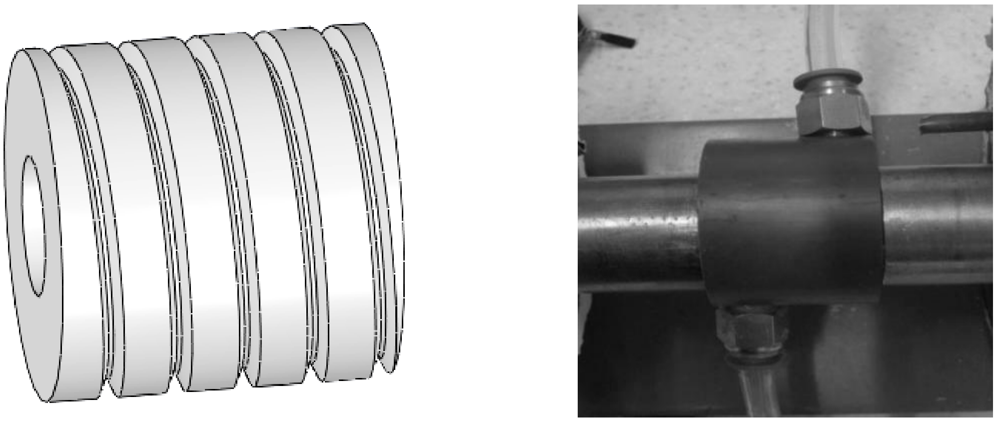
The water circulation system includes a 220 V electric pump for generating water circulation in the magnetic field, flow meter, valve which connects the water flow with the corresponding connections, water tank with volume of two liters, hose and a water circulation chamber. One of the important factors in choosing the diameter size of the hose was the velocity of water passing through the magnetic field. The manufacturer of magnetic water purifiers (Polar International) has determined the optimum water velocity of 1.5 to 3 m s^{-1} (Baker and Judd, 1996). Also, according to some manufacturers of CEPI (conditionnement électromagnétique par induction) devices, the minimum water velocity in this system is recommended to be 1.2 m s^{-1} (McMahon, 2009). If the water velocity passing through the chamber is lower than this, the water velocity can be increased by reducing the diameter of the selected hose. Water velocity is calculated using Equation 1:

$$V = \frac{Q}{15\times10^3\times\pi\times d^2} \quad (1)$$

Where, V is water velocity in the pipe (m s^{-1}), Q is the water flow rate (L min^{-1}), and d is the inner diameter of the water pipe (m).

In this equation, by placing the water pump discharge of the device, which was 13.2 L min^{-1}, and the inner diameter of the hose, which was 10 mm, the velocity of water moving in the chamber is obtained 2.8 m s^{-1}, which was appropriate considering the recommended amount (McMahon, 2009).

The water circulation path was created as a spiral on the PVC pipes. The water was pumped out of the tank, then passed through the space between two magnetic field cores and returned to the tank again. A flow meter was located in the direction of the water flow to measure the amount of water displaced volume. As shown in Figure 3, water was passed through the spiral PVC chamber so that the velocity vector of water is perpendicular to the direction of the magnetic field, which in this case, the Lorentz force is maximized on the water particles.



(a) Water circulation duct (b) water circulation chamber between two magnetic field cores

Figure 3 Water flow path in Magnetic water devices

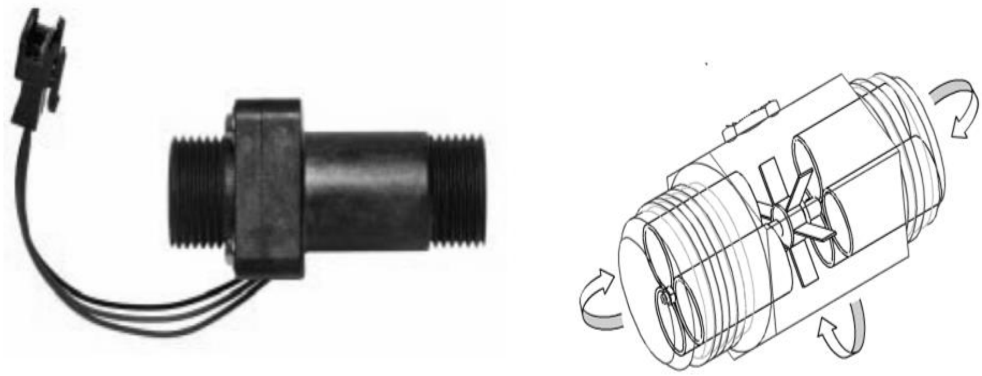


Figure 4 Volumetric flow meter used in this study

Part 3, magnetic water tank, piece, the volume of the tank was 2 L and made of plastic.

Parts 4 and 5, water passage hoses, water enters the water recirculation system from tank No. 5 through these plastic hoses. Their inner and outer diameter was 10 and 12 mm, respectively.

Part 6, flow meter and water flow control valve, the flow meter sensor (FS-4400H, Savant Electronics Inc., Taiwan) was used in this study (Figure 4), which consists of a tube-shaped housing with a propeller inside. The propeller rotation speed varies with the fluid velocity (discharge). Its accuracy is about 1%, output data is digital, and is suitable for liquids up to 100 cSt viscosity. Also, the amount of water displacement can be visualized by the digital display.

Part 7, the cooling system for magnetic field generator coils, it consisted of a pump, a 10-liter water tank, a hose and a copper pipe (Figure 5). Copper tubes with an inner diameter of 4 mm were used to cool the magnetic field generating coils (Figure 6). These tubes were spirally attached to the side plates of the magnetic field generating coils. Silicate adhesive was used as a conductive material between copper tubes and side plates of magnetic field generating coils. The water was pumped out of the tank and then passed through the plastic hoses to the copper pipes and returned to the tank again.

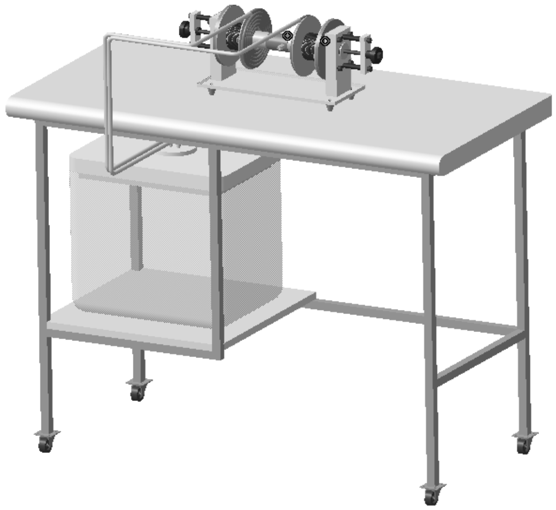


Figure 5 Magnetic water treatment cooling system circuit

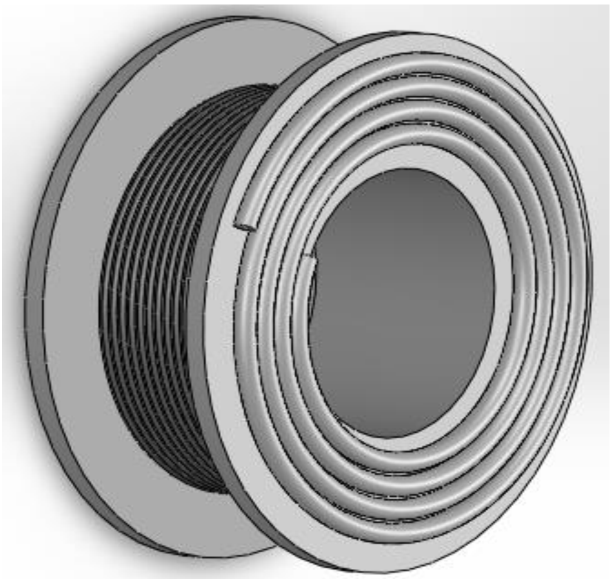


Figure 6 Schematic drawing of one of the copper pipe's coils of the cooling system

Part 8, magnetic field generator coils, the diameter and length of the magnetic cores were 40 mm and 135 mm, respectively, as recommended by research papers and manufacturer (Vashisth and Nagarajan, 2009). According to Helmholtz's law, in order to reduce the magnetic driving force in the air gap and to create a more uniform field with a smaller edge effect, the air gap size should be considered less than half the average diameter of the coil, which was 88 mm by mechanical design. Therefore, the air gap size was set at 40 mm. The reluctance or resistance of the magnetic circuit can be calculated using Equation 2:

$$\mathcal{R} = \frac{l}{\mu A} \quad (2)$$

Where, l is the length of the magnetic circuit (m); A is the effective cross-section of the magnetic circuit (m^2); μ is the magnetic permeability(TmA^{-1}).

According to this equation and core length (l_{core}) value of 135 mm, core cross section (A_{core}) of 1257 mm^2, magnetic permeability of the core (μ_{core}) of 3.125×10^{-3} TmA^{-1}, the core reluctance ($\mathcal{R}_{core}$) value was 34368 AT^{-1} m^{-2}. Also, according to these values, of 40 mm air gap length and 40 mm air gap width, the air gap cross section area (A_g) in the air gap was 6400 mm^2, thus, with respect to the magnetic permeability of air $\mu_0 = \pi^4 \times 10^{-7}$ TmA^{-1}, the air gap reluctance ($\mathcal{R}_g$) was 4973592 AT m^{-2}.

Flux density (B) is the amount of magnetic flux that crosses a cross-section with the area of A perpendicular to the flux (Equation 3).

$$B = \frac{\Phi}{A} \quad (3)$$

Where, Φ is magnetic flux (Wb); Now, if we want the flux density to be 500 mT in the air gap, considering Equation 3, the magnetic flux in the core (Φ_{core}) and in the air gap (Φ_g) equals 6.28×10^{-4} Weber and 32×10^{-4} Weber, respectively. According to the obtained quantities, the amount of magnetomotive force required to create a strength of 500 mT can be determined using Equation 4.

$$MMF = N \times I = \mathcal{R}_g \Phi_g + 2\mathcal{R}_{core}\Phi_{core} \quad (4)$$

Where, *MMF* is the magnetomotive force; *N* is the number of turns of the magnetic excitation circuit winding;

I is the ampere applied to the coil of the magnetic excitation circuit (A); $\mathcal{R}_g$ is the air gap reluctance (AT^{-1} m^{-2}); Φ_g is the magnetic flux in the air gap (Wb); $\mathcal{R}_{core}$ is the magnetic core reluctance (AT^{-1} m^{-2}) and Φ_{core} is the magnetic flux in the core (Wb).

By placing the values obtained using Equation 4, the required magnetomotive force will be 15958.6 A-turn. The insulated wire cross-section is obtained from Equation 5 (Abe et al., 1997):

$$q = \frac{l_m \, . \, MMF}{k \, . \, V} \quad (5)$$

where q is the cross-sectional area of the insulated wire (mm^2), l_m is the average ring length (m), k is the coefficient of thermal conduction (for the coil), V is the voltage applied to the coil, and *MMF* is the magnetomotive force or required ampere turn for the desired magnetic field. The average length of the ring (l_m) is obtained by multiplying the average diameter of the coil by 88 mm in π. Thermal conductivity coefficient (K) for copper wire (coil specification) was 60, so the *MMF* was equal to 15958.6.

The applied voltage to the coil was considered 40 V. As a result of placing the above values in Equation 6, q was calculated to be 1.8 mm^2. Depending on q, the diameter of the insulated wire is obtained. To obtain the diameter of the copper wire with lacquer insulation, a 0.1 mm diameter was added to the uninsulated wire diameter. Thus, the diameter of the copper wire for the coil was 1.6 mm, but the copper wire diameter of 2 mm was selected for greater assurance. According to the calculations, a power supply that was capable of supplying the desired voltage was designed and constructed. The power supply of the device included a voltage supply circuit, magnetic field coils and flow meter circuit, ampere meter, and a voltmeter.

2.2 Performance evaluation of the apparatus

In this study, in order to evaluate the apparatus, the produced magnetic water was used to study its effects on the germination rate of wheat seeds. In this experiment, drinking water was treated by a magnetic field with different field strengths, which was measured by a magnetometer (HT201, Hengtong Magnetoelectricity Co., China). At each stage of the experiment, half a liter of water was exposed to the magnetic field for 30 min. The water was then used for seed irrigation in a standard germination experiment. Effects of magnetic strengths (400, 500 and 600 mT) and one type of water were studied on the speed of germination. The factorial experiment was conducted as a randomized complete design with three replications. In each replication, 20 cotton seeds were used in the experiments. These experiments were conducted at 25℃/15℃ (day/night), 65% RH, and a photoperiod of 16:8 (light: dark) h in a greenhouse.

Tests were performed according to the instructions issued by the International Seed Testing Association (ISTA, 2004). The seeds were disinfected with 1% NaOCl, washed thoroughly under tap water and finally with distilled water. The seeds were germinated on top of moist papers (Whatman Grade 181) and placed in 9 cm Petri dishes. The Petri dishes were placed in an incubator maintained at the recommended temperature of 25℃. After 7 days, germinated seeds were grouped as normal, abnormal, fresh un-germinated and dead seeds. The germination rate was calculated based on the normal seedlings as described by ISTA (ISTA, 2004) using Equation 6,

$$GR = \Sigma Ni/Ti \quad (6)$$

where Ni is the number of seeds germinated on the ith day, and Ti is the number of days after sowing.

3 Results and discussion

In this study, the effects of magnetic field on the germination rate of cotton seeds were evaluated. The results were obtained from comparing the mean magnetic field levels for the highest *GR* value, to the highest observed value which belonged to the field of 400 MT with a germination rate of 41.65% (Table 1).

Table 1 Comparison of mean magnetic field main levels on cotton seeds

Magnetic field strength (mT)	Germination rate (%)
0	39.51
400	41.65
500	40.50
600	38.47

Similar to the results, using MW for irrigation of squashes increases the weight of the squash. Bio-magnetic water is more solvent and has a lower surface tension; nutrients are absorbed greater in the water (Eşitken and Turan, 2004; Grewal and Maheshwari, 2011; Mohamed and Ebead, 2013). Similarly, other field studies have indicated a significant role of MW irrigation of seeds in improving the growth of seedlings (Maheshwari and Grewal, 2009). Furthermore, MW improves quantity and quality of bean crops and germination, fresh weight, and shoot length of maize (Aladjadjiyan, 2002). Magnetic treatment can accelerate the plant emergence to 2–3 days, in comparison to the control plants. Abou El-Yazied et al. (2011) and Aladjadjiyan (2002) showed that EMF dose and the duration of exposure can affect the *GR* of different seeds including tomato and broad been. They demonstrated that the strength of EMF plays a significant role on germination percentages. These results are in agreement with the results obtained from this study. It should be noted that in all experiments, the magnetic field had a significant effect on *GR*.

4 Conclusions

The results from the evaluation of the apparatus on the cotton seeds showed the positive effect of water treated by magnetic field. The results showed that the highest value of *GR* was observed at 400 mT field. The magnetic field induces stress on the plants that are directly or indirectly exposed to the magnetic field. Plant species vary in their sensitivity and respond to the stress because they have different abilities for stress perception, signaling, and response (Bohnert et al., 1995). There are many reports about the positive effects of magnetic water and magnetic field on seeds. These effects cause physiological changes in the seed which results in faster water uptake therefore increasing the viability of the seed.

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