Development of Electromagnet for Laboratory Water Treatment Experiments

*[1]Aye T. Ajiboye, [1]Abdulrahman O. Yusuf, [2]Kamorudeen O. Yusuf and [2]Ayodele O. Ogunlela

[1]Department of Computer Engineering, University of Ilorin, Ilorin, Nigeria
[2]Department of Agricultural & Biosystems Engineering, University of Ilorin, Ilorin, Nigeria
{ajiboye.at | yusuf.oa}@unilorin.edu.ng | {kamaru.yusuf | aogunlela}@yahoo.com

Submitted: 29-JAN-2020; Reviewed: 27-FEB-2019; Accepted: 04-MAR-2020

Abstract- Water is said to be magnetized when it flows across the magnetic field and magnetized water finds its application in many areas of life. Despite the numerous benefits of magnetized water, very little works have been reported on the development of magnet for water magnetizer application. In most of the reported works, the detailed theoretical analysis and design procedure required for the development of the magnet was not accounted for; hence the need for the present study. Electromagnetic means of producing flux density is considered in this study due to its advantage of flux density variation, which is not achievable with the use of its permanent magnet counterparts. The design equation of short electromagnet was derived from the existing equations of coil magnetic flux density and then used for the air core electromagnet design. The variation of the magnetic flux density with the distance between two electromagnets was empirically investigated. The performance of the developed electromagnet is satisfactory, as the flux density varies between 814.6 and 510G corresponding to the gap (0 - 4cm) between the coils (i.e., water pipe diameter).

Keywords- Air core, Coils, Iron core, Magnetic flux density, Magnetized water

1 Introduction

Water is said to be magnetized when it has been passed across a magnetic field. The results obtained by Khater & Ibraheim (2015) showed that the magnetic field has great effects on Physico-chemical parameters of water. According to Tyari, Jamshidi, & Neisy (2014), both the chemical and physical properties of water change when it is magnetized. These changes alter both the chemical and physical properties of magnetized water, which make it behave differently from the ordinary water (Nasher, 2008). Therefore, the process can be considered as one of the environmentally friendly means of overcoming the negative effects of water pollution (Ibraheim & Khater, 2013). Recently magnetic water has been used in different fields like agriculture, healthcare, constructions, dairy production, environmental and oil industries (Karam & Al-Shamali, 2012). Special attention has been drawn to this method of water purification due to the numerous advantages (ecological, purity, safety, simplicity and reduced operating cost) associated with it compared to other methods of water and wastewater treatments (Ibraheim & Khater, 2013).

Experiments have shown that magnetic field affects the quality of water and has the ability to reduce water hardness (Banejad & Abdosalehi, 2009). Water magnetization reduces water-borne diseases by increasing the water oxygen content per litre and kills bacteria in the water (Tyari, Jamshidi, & Neisy, 2014). The process, if properly done is capable of activating water and consequently leads to the reduction in the molecule group size, accumulation of hard scale, lime and similar deposits in the water and also improve the taste of the water (Ajitkumar, 2014). When water is magnetized its PH level increases (Kotb, 2013). Application of magnetic field for water purification may be likened to a simple simulation of a natural scenario; for instance, water becomes more biologically active when it is subjected to a magnetic field.

*Corresponding Author

It is glaring that the role of magnetism in solving water pollution problem cannot be overemphasis (Khater &Ibrahoim, 2015). All the negative effects associated with stagnant water can be overcome by treating it magnetically because magnetic flux density increases the values of physical, chemical and bacteriological properties of water (Ibraheim & Khater, 2013). According to Nasher (2008), irrigating of Chick-Pea seeds with magnetized water enabled the seeds to acquire more nutrients from the soil, increase soil salts which in turn lead to enhancement of photosynthesized property of plants and finally increase the crop production and plant physical size. The explanation of these results can be based on the ability of magnetized water to improve soil water holding and salt distribution (Zlotopolski, 2017). Ajitkumar (2014) observed improvement in the germination, plant growth, flowers, fruit, average yield, quality, general appearance and non-formation of white salty deposits near the plant per plant in a plot treated with magnetic water. Increase in the growth rate and yield of the tomato irrigated with magnetized water compared to that of non-magnetized water was also reported in Yusuf (2017).

The performance of plants and animals become more effective when magnetic water is used due to increase in the solubility of minerals which in turn improves nutrients transport to all parts of the body (Tyari, Jamshidi, & Neisy, 2014). Ebrahim & Azab (2017) concluded that prevention of harmful effects of drugs, toxins, and environmental pollutant on human and animals can be achieved through the usage of magnetic water because it improves their blood picture, biochemical parameters, semen quality, and antioxidant status. Consumption of magnetic water or its product by livestock improves the health, yield and their nutritional values (Tyari, Jamshidi, & Neisy, 2014). Investigation on effects of drinking magnetic water on the growth and quality improvement of poultry was also conducted by Gholizadeh *et al.*, (2008) and it was revealed that meat-to-fat ratio, livability and European production efficiency were increased, while a decrease in mortality, sick case and feed rate were recorded. The results of the study by Al-Hilali (2018) revealed that magnetized water could help to improve poultry productivity because it improved all biochemical and physiological properties of Japanese quail. Reproduction efficiency of bulls can be improved by using magnetized water for the development of artificial insemination for Holstein bulls between the ages 17 and 18 months because it can increase the dimensions and circumferences of their testis and scrotal respectively (Al-Nuemi *et al.*, 2015). The investigation carried out by Karam & Al-Shamali (2012); Reddy, Ghorpade, & Rao (2013, 2014) on concrete produced using magnetic water shows an increase in workability, density, compressive strength, tensile strength and flexural strength of the concrete.

Despite all the numerous benefits of magnetized or magnetic water in every aspect of life, very little works have been reported on the development of electromagnet which is the backbone of the electromagnetic-based water magnetizer. Busch & Busch (1997) used an electromagnetic coil with the provision of a cooling device to preserve the temperature of the magnetizing water. A device containing seven U-shaped magnets, with North and South poles that have consoled in form of the same axis with a magnetic field length of 25cm was used by Banejad & Abdosalehi (2009) to produce magnetic water. Krzemieniewski *et al.* (2004) used magnetic pile made of permanent magnets that generate a constant magnetic field of intensity between 0.4 and 0.6T for the treatment of wastewater. Stack of magnets with a flux density of 18 G was used in Khater & Ibraheim (2015) to magnetize and purify water circulated at a constant flow rate across the field. A round magnet radiating magnetic flux density of 985 G was used in Reddy, Ghorpade & Rao 2013 (2014) to produce-magnetic water by placing a beaker filled with the water on the magnets for a 24hours period.

In all the aforementioned methods of realizing water magnetizer the theory and the design procedure, which is the backbone, required in the development of electromagnet for electromagnetic-based water magnetizer were not presented, therefore the need for this study. The use of a permanent magnet to produce the magnetic field is not only economical but also environmentally friendly (Zaidi *et al.*, 2014). The major drawback is that the flux produced by the permanent magnet cannot be varied. To achieve flux density variation using a permanent magnet, at least one of the magnet's geometry, size, orientation or its arrangements in the system must be a variable parameter. This is not both economically and technically viable when a variation of magnetic flux density is required. Therefore, application of permanent magnet is not feasible in research that involves a dynamic variation of magnetic flux density. An electromagnet is a suitable candidate in such a situation, since the flux density is a function of magnetizing current, therefore the former can be varied by varying the latter depending on the applied voltage. In this study, an electromagnet is developed for electromagnetic water magnetizer for laboratory applications, which requires a dynamic variation of flux density.

2 System Design

2.1 Design Theory

Short coils are required in the construction of electromagnet for water treatment as they are arranged in the water treatment chamber. The coils can be connected in series, parallel or parallel-series depending on the power supply current and voltage ratings. Therefore, the common equations for long solenoids cannot be used for designing these coils. Instead, the model equation developed by Misakian (2000) for rectangular loop of wire and used for square coil by Herceg, Juhas, & Milutinov (2009) was modified in calculating the value of magnetic flux density produced at arbitrary point P along z-axis of a square coil whose geometry is shown in Fig. 1. The coordinates are defined by the values of x, y and z.

The magnitude of the magnetic flux density, B_T at point P is the resultant of the magnetic flux densities, B_x , B_y and B_z produced along the x, y and z directions, respectively. As can be seen in equations (1) - (4), B_T is a function of the electric current, I flowing through the coil, number of wire turns in the coil, N, permeability of the medium, μ, coil dimensions, "a by a", and the coordinates of point P (x, y and z); that is,
$B_T = f(I, N, \mu, a, \mathrm{P})$.

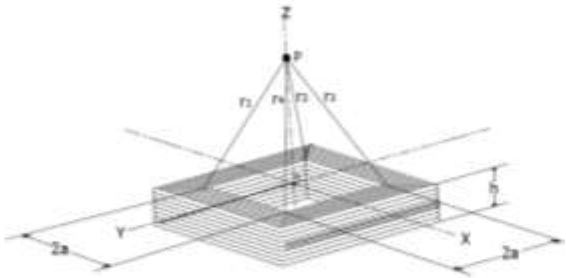

Fig. 1: Geometry of Square Coil

$$B_T = NI\sqrt{{B_x}^2 + {B_y}^2 + {B_z}^2} \quad (1)$$

where:

$$B_x = \frac{\mu}{4\pi}\sum_{n=1}^{4}\left[\frac{(-1)^{n+1}(z-z_k)}{r_n[r_n+d_n]}\right] \quad (2)$$

$$B_y = \frac{\mu}{4\pi}\sum_{n=1}^{4}\left[\frac{(-1)^{n+1}(z-z_k)}{r_n[r_n+(-1)^{n+1}C_n]}\right] \quad (3)$$

$$B_z = \frac{\mu}{4\pi}\sum_{n=1}^{4}\left[\frac{(-1)^{n}d_n}{r_n[r_n+(-1)^{n+1}C_n]} - \cdots \quad \cdots\frac{C_n}{r_n[r_n+d_n]}\right] \quad (4)$$

where:
z = coil distance from point P along z-axis in meter
k = coil index number
r = coil corner distance from point P in meter
n = coil corner index number
$C_1 = -C_4 = a + x$
$C_2 = -C_3 = a - x$
$d_1 = d_2 = y + a$
$d_3 = d_4 = y - a$
$r_1 = \sqrt{(a+x)^2 + (y+a)^2 + (z-z_i)^2}$
$r_2 = \sqrt{(a-x)^2 + (y+a)^2 + (z-z_i)^2}$
$r_3 = \sqrt{(a-x)^2 + (y-a)^2 + (z-z_i)^2}$
$r_4 = \sqrt{(a+x)^2 + (y-a)^2 + (z-z_i)^2}$

The required magnetomotive force, $\mathrm{F} = NI$ (Ampere-turns) for the production of the flux density is obtained from equation (1) as follows:

$$NI = \frac{B_T}{\sqrt{B_x{}^2 + B_y{}^2 + B_z{}^2}} \qquad (5)$$

Depending on the designer's choice either of N or I can be selected and then used to determine the other.

2.2 Coil Design

The design specifications of the proposed square coil are as given in Table 1.

Table 1. Design Specifications of the Proposed Square Coil

Parameters	Value
Flux density in between 2 coils	≥ 400 G
Maximum water pipe diameter	4cm
Core length	6cm
Core breadth	6cm

The permeability of air was used so as to ensure that the variation of flux density with the current is a linear relationship. The number of coil turns was randomly selected as 200 for the design so that the expected flux density produced by a single coil should be at least 200G, based on the design specifications shown in Table 1. For better results when air-gap is introduced in-between the two coils 400G was used for the design. Since the gauge of wire that corresponds to the calculated current value, $I = 10A$ is 11 (according to the American Wire Gauge, AWG), which is readily available and can easily be handled during coil winding process.

2.3 Computation of the Axial Flux Density Between Two Coils

Computation of axial magnetic flux density at midpoint P along the z-axis for the two coils arrangement shown in Fig. 2 is presented.

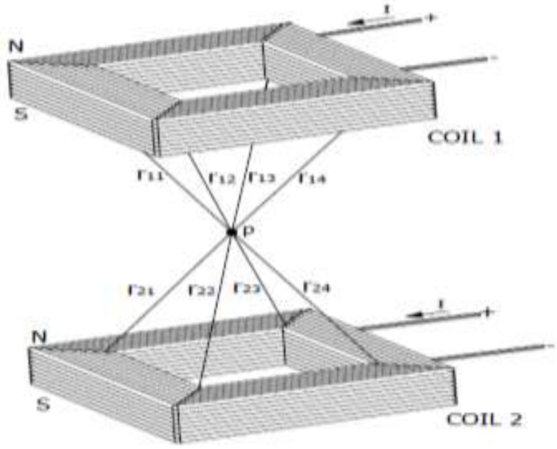

Fig. 2: Two Coils Arrangement

The water magnetizer pipe was installed in such a way that at point P, water cuts the magnetic flux density in-between the two coils at right angles as it flows through the pipe in order to yield maximum effect. The resultant magnetic flux density generated by the two coils at point P, B_R is the algebraic sum of the flux densities generated by each of the coils, as follows:

$$B_R = B_{T1} + B_{T2} \qquad (6)$$

$$B_{T1} = NI\sqrt{B_{x1}{}^2 + B_{y1}{}^2 + B_{z1}{}^2} \qquad (7)$$

$$B_{T2} = NI\sqrt{B_{x2}{}^2 + B_{y2}{}^2 + B_{z2}{}^2} \qquad (8)$$

where B_{x1}, B_{y1} and B_{z1} are the magnetic flux densities produced along the x, y and z directions for coil 1, respectively, while B_{x2},$B_{y2}B_{z2}$ are the corresponding values for coil 2.

2.4 Experimental Determination of Magnetic Flux Density

The experimental set up is as shown in Fig. 3. The setup consists of two coils, power supply unit (PSU), AVO-meter, clamp meter and gaussmeter for voltage; current and power; and flux density measurements respectively. The coils were arranged on a flat platform that has been graduated in centimetre and firmly secured at both sides with aluminium bar to prevent coil movement due to magnetic force of attraction. The magnetic flux density at the midpoint between the two coils was experimentally determined with the opposite poles facing each other.

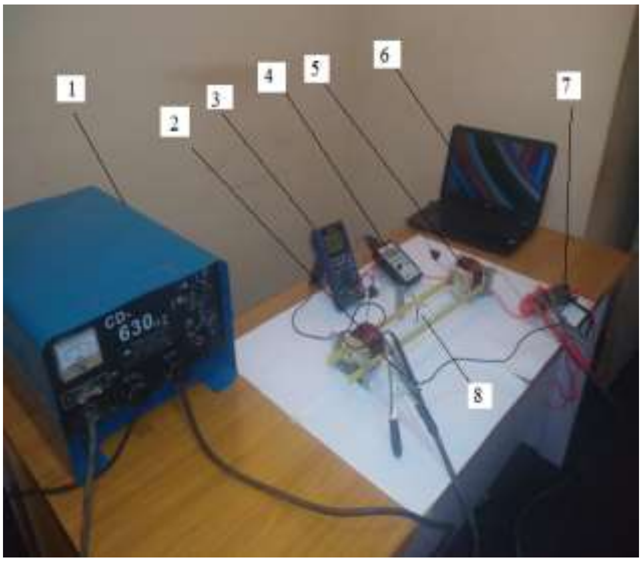

Fig. 3: Experimental Setup for Determination of Magnetic Flux Density at the Midpoint between the two Coils; where 1-Power supply unit; 2-Coil 1; 3-AVO meter; 4-Gauss meter; 5-Coil 2; 6-Lap-top; 7-Clamp meter; 8-Gauss meter sensor

In the experiment the value of the voltage across the two coils, the current through the two coils and power drawn by the coils was fixed at 12V DC, 10A and 70W respectively. The distance between the 2 coils was varied between 0 and 42cm in step of 2cm (each of the two coils was shifted away from point P simultaneously in step of 1cm). Using 0cm as a reference, for every shift in the coils position the value of the resulting flux density at point P was measured and recorded.

3 Results and Discussion

Using the results of the experiment, the comparison between the calculated and measured flux densities at the midpoint between the two coils at different separation distances is shown in Fig. 4. As can be seen from the Figure, the flux density decreases exponentially with increasing separation distance. The minimum and maximum calculated values of flux densities are 3.226 and 814.6G respectively, while the corresponding measured values are 5 and 808G respectively.

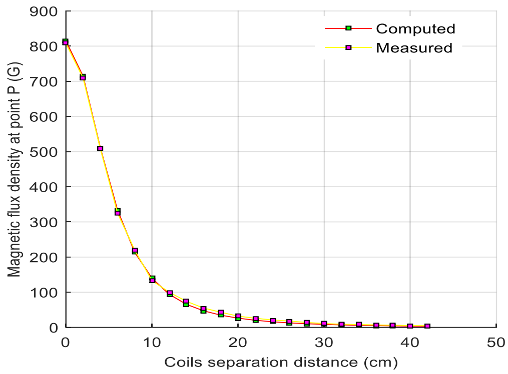

Fig. 4: Computed and Measured Magnetic Flux Density at point P versus Coils separation Distance

To determine the deviation between the measured and calculated magnetic flux densities, the absolute error was calculated at various distances and plotted, as shown in Fig. 5. From the Figure, the absolute errors are 6.587 and 2.107G at 0 and 4cm respectively. The maximum and minimum absolute errors are 8.483and 1.28G, corresponding to 14 and 40cm, respectively. It can be seen from Fig. 4 that water pipe with a maximum diameter of 5cm is appropriate for the designed coils because at a distance of 5cm the flux density is 400G which is the minimum required flux density. Whereas at a distance of 4cm the flux density is 510G, this is greater than the minimum required flux density which is better. The designed electromagnet is appropriate for any water pipe between 0 and 5cm diameter; because for this pipe size, the magnetic flux density will range between 400 and 814G.

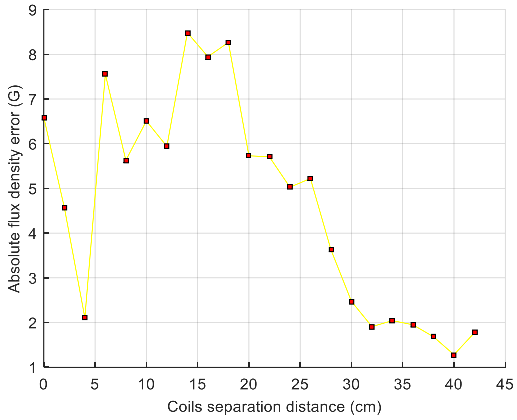

Fig. 5: Absolute Magnetic Flux Density Error versus Coils separation Distance

4 Conclusion

Air core electromagnetic coil was designed. The responses of magnetic flux density to changes in separation distance between two coils were investigated. The maximum absolute error between the distances of interest (0 and 4cm) was 0.8086G, thereby confirming the satisfactory performance of the developed electromagnet. The flux density varies between 510 and 814.6G when the distance was varied between 0 and 4cm. Hence, the proposed electromagnet has satisfied the design specifications as this is the range of distance of interest (i.e., the pipe diameter).

References

Ajitkumar, G. P. (2014). Device for magnetic treatment of irrigation water and its effects on quality and yield of banana plants. *International Journal of Biological Sciences and Applications, 1*(4), 152-156.

Al-Hilali, A. H. (2018). Effect of Magnetically Treated Water on Physiological and Biochemical Blood Parameters of Japanese Quail. *Poultry Science, 17*(2), 78-84.

Al-Nuemi, S., Al-Badry, K., Atteyh, A., Al-Sabeea, W. S., Ibrahim, F., & Rajab, B. (2015). Effect of magnetic water drinking on testis dimension, scrotal circumference and blood parameters of holstein bulls born in Iraq. *Adv. Anim. Vet. Sci, 3*(7), 413-417.

Banejad, H., & Abdosalehi, E. (2009). *The effect of magnetic field on water hardness reducing.* Paper presented at the Thirteenth International Water Technology Conference, IWTC.

Busch, K. W., & Busch, M. A. (1997). Laboratory studies on magnetic water treatment and their relationship to a possible mechanism for scale reduction. *Desalination, 109*(2), 131-148.

Ebrahim, S. A., & Azab, A. E. (2017). Biological effects of magnetic water on human and animals. *Biomed Sci, 3*, 78-85.

Gholizadeh, M., Arabshahi, H., Saeidi, M., & Mahdavi, B. (2008). The effect of magnetic water on growth and quality improvement of poultry. *Middle-East Journal of Scientific Research, 3*(3), 140-144.

Herceg, D., Juhas, A., & Milutinov, M. (2009). Design of a four-square coil system for a biomagnetic experiment. *Facta Universitatis-series: Electronics and Energetics, 22*(3), 285-292.

Ibraheim, M. H., & Khater, Z. Z. (2013). The Effect of electromagnetic field on water and fish Clarias garpienus, Zagazig, Egypt. *Life Science Journal, 10*(4), 3310-3324.

Karam, H., & Al-Shamali, O. (2012). *Effect of Using Magnetized Water on Concrete Properties.* Paper presented at the Third International conference on sustainable construction materials and technologies.

Khater, Z. Z., & Ibraheim, M. H. (2015). Ecological studies on the effect of magnetic field on water. *Int. J. Curr. Res. Aca. Rev, 3*(8), 262-279.

Kotb, A. (2013). Magnetized water and memory meter. *Energy and Power Engineering, 5*(6), 422-426.

Krzemieniewski, M., Debowski, M., Janczukowicz, W., & Pesta, J. (2004). Effect of the Constant Magnetic Field on the Composition of Dairy Wastewater and W Domestic Sewage. *Polish Journal of Environmental Studies, 13*(1), 45-53.

Misakian, M. (2000). Equations for the magnetic field produced by one or more rectangular loops of wire in the same plane. *Journal of research of the National Institute of Standards and Technology, 105*(4), 557.

Nasher, S. H. (2008). The effect of magnetic water on the growth of chickpea seeds. *Engineering and Technology Journal, 26*(9), 1125-1130.

Reddy, B. S. K., Ghorpade, V. G., & Rao, H. S. (2013). Effect of magnetic field exposure time on workability and compressive strength of magnetic water concrete. *International Journal of Advanced Engineering Technology, 4*(3), 120-122.

Reddy, B. S. K., Ghorpade, V. G., & Rao, H. S. (2014). Influence of magnetic water on strength properties of concrete. *Indian Journal of Science and Technology, 7*(1), 14-18.

Tyari, E., Jamshidi, A., & Neisy, A. (2014). Magnetic water and its benefit in cattle breeding, pisciculture and poultry. *Advances in Environmental Biology*, 1031-1037.

Yusuf, K. O. (2017). Effects of magnetized water on the vegetative growth and yield of tomato. *Agricultural Engineering International: CIGR Journal, 19*(1), 1-8.

Zaidi, N. S., Sohaili, J., Muda, K., & Sillanpää, M. (2014). Magnetic field application and it's potential in water and wastewater treatment systems. *Separation & Purification Reviews, 43*(3), 206-240.

Zlotopolski, V. (2017). The Impact of magnetic water treatment on salt distribution in a large unsaturated soil column. *International Soil and Water Conservation Research, 5*(4), 253-257.