Turkish Journal of Computer and Mathematics Education Vol.12 No.9 (2021), 3123-3128

Research Article

The Effect Of Electromagnetic Field On Hard Water Treatment And Scale Formation Using Variable Flow Rate

Amrit Anand Dosar[1] and Vivek Srivastava[2]

[1] Research Scholar, BBD University, Lucknow, India
[2]Professor, DIT University, Dehradun, India
amritdosar@bbdu.ac.in

Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 20 April 2021

Abstract : Scale deposition in water pipe due to hard water circulation often leads to various technical and economical problems. The conventional chemical treatment methods uses hazardous chemical which affects human health as well as water chemistry. This study shows the effect of physical water treatment method like pulsating electromagnetic field on water characteristics and scale reduction under different turbulent flow conditions and pipe materials. The scale removal rate was analyzed by the formation of aragonite crystal in water pipes in place of calcite crystals after electromagnetic treatment. The morphology of aragonite and calcite crystals was analyzed by field emission scanning electron microscope on different pipe materials. The water flow rate was maintained at 3, 5 and 7 L/min. After electromagnetic treatment result shows that the scale removal rate increases from pipe wall and reduces the total dissolved solids (TDS), electrical conductivity (EC), hardness and alkalinity of water. These water characteristics are further decreases on increasing the flow rate from 3 to 7 L/min. The reduction rate of these water characteristics was higher for the first 15 hours of circulation time than the remaining 15 hours. On investigating the effect of electromagnetic treatment on pipe material, it was obtained that the polyvinyl chloride (PVC) pipe is much effective than galvanized iron (GI) and copper pipes.

Keywords: *Electromagnetic water treatment; Pulsating magnetic field; Scaling, Hard water, Pipe material, Flow rate.*

I. Introduction

Scale deposition due to hard water in various household and industrial equipments causes significant economical and technical losses [1]. Scale reduces the heat transfer from pipes in heat exchangers and blocking the water flow in pipes [2]. For scale removal various conventional methods are generally used like, the application of chemical product, the pre precipitation of the scale with soda ash or lime and by ion-exchange process. All these conventional methods are very efficient, but they can change the water chemistry and are much costly. So to avoid the chemical use physical methods were developed, pulsating electromagnetic treatment device method is the example of such method to prevent scale formation and water treatment [3]. Chemical products used in conventional methods were harmful to the atmosphere as well as human health [5]. Electromagnetic treatment device helps in reducing the scale formation on the walls of various domestic and industrial equipments. In water system electromagnetic water treatment (EMWT) has been used for several years as a preventing and controlling tool for scale deposition [5].

The alternating electromagnetic field hindered the precipitation of $CaCO_3$ and formed aragonite and veterite crystals as $CaCO_3$ precipitate [6]. Piyadasa et al. [7] observed that the pulsed electromagnetic field treatment is efficient in scale removal and biofouling in reverse osmosis membrane. They also found that the treatment is also helpful in increasing the efficiency of heat exchanger.

The efficiency of MWT depends on the material of pipe, used for water circulation. Alimi et al. [8] investigated the effect of magnetic treatment on different pipe material (PTFE, Tygon, Copper, PVC and Stainless Steel) by circulating hard water at 0.16 Tesla magnetic field. They found that the increase in total precipitation ratio was obtained when the magnetic field was applied through pipes of non-conductive material.

The rate of flow of water affects the scale formation and water characteristics due to the Lorentz force. Latva et al. [9] examined using a pilot project that MWT gives the best result at 2.3 m/s flow velocity of water and found that the magnetic field reduced calcium scaling by 15% from the pipe.

Magnetic field effects the water characteristics by changing its hardness, alkalinity, pH, TDS, electrical conductivity, etc. Mghaiouini et al. [10] investigated using experimental study that in a closed loop system at low speed of 0.18 m/s the electromagnetic treatment changes the conductivity, TDS, salinity and temperature by 3.66%, 4.0%, 4.4%, and 0.76% respectively. Helal et al. [11] analyzed the effect of magnetic treatment at 1500 ^{0}C at 6480 Gauss magnetic field. They analyzed that the magnetic field reduces scale formation and changes the electrical

conductivity of $CaCO_3$. The application of a magnetic field decreases the surface tension of water and increases its volume evaporated [12].
Electromagnetic field treatment method is also effective on biofouling. It reduces the bacterial count and diversities in biofilm. It also minimizes the mineral precipitates, carbonate and silicate content in biofilm [13]. Othman et al. [14] studied the effect of magnetic water treatment under various conditions. They observed that MWT controls the growth rate of scale; hence improve the life of water pipeline and its performance.
Out of all the above research, very few literatures are available on the effect of the electromagnetic treatment on scale formation and Physico-chemical characteristics of water flow through different pipe materials. The effect of flow rate and circulation time on the percentage change in water characteristics also needed to be explained.
The objective of this research was to experimentally analyze the effect of pulsating electromagnetic treatment on the formation of aragonite crystal in different materials of pipe and to analyze the change in water characteristics on increasing the flow rate and circulation time. The effect of pipe material on water characteristics also needed to be examined.

II. Experimental Procedures

The experimental electromagnetic treatment device (EMTD) is shown in Fig. 1. It consists of a solenoid coil by which magnetic field was generated in all the three pipe materials like PVC, GI and copper one after another. The coil is further connected to the relay switch to provide pulsating current to the solenoid coil. The water that has to be treated passed through the solenoid coil arranged at one end of the pipe fitting. The magnetic field generated by the coil was perpendicular to the flow of water. The hard water to be treated was circulated in pipe through solenoid coil by the centrifugal pump. The water was circulated in pipes at three different flow rates in a turbulent range (3, 5, and 7 L/min).
The solenoid coil with relay switch was used to generate pulsating electromagnetic field. Hardened water was circulated in the different materials of pipe-like copper, GI, and PVC under magnetic and non magnetic condition (magnetized sample and un-magnetized sample) and different flow rates. Further the analysis was done to obtain the effect of scale formation on different pipe materials. The total dissolved solids, electrical conductivity, hardness, and alkalinity in the water samples were measured for all flow rate conditions.

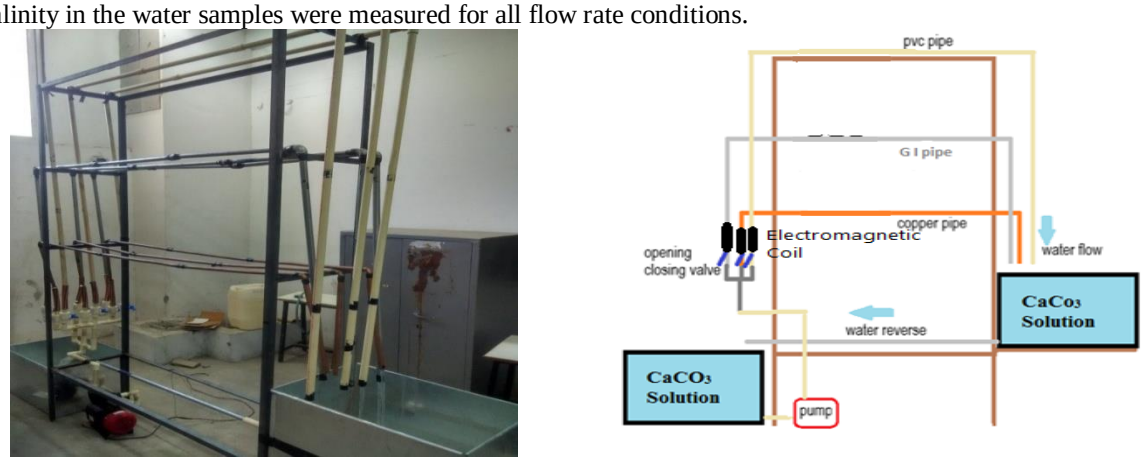

Fig. 1 Experimental Setup and its corresponding layout

The field emission scanning electron microscope (FESEM); model Gemini Zeiss Supra 35 VP is used to analyze the morphology of crystal $CaCO_3$ on pipe walls. The magnifications of this test were at 10000 X zoom for all materials of pipe and in both magnetic and non-magnetic case.
The TDS, EC, hardness, and alkalinity of water were checked with a 1-liter sample of magnetized and non-magnetized water for all flow rates and different materials of pipes.

III. Results and discussions

Effect of magnetic field on scale removal

A small number of deposited scales were formed on the inner surface of the pipe walls after magnetized and non-magnetized treatment of water pipes of different materials which was analyzed by FESEM method. Fig.2 shows the size and morphology of the scale.

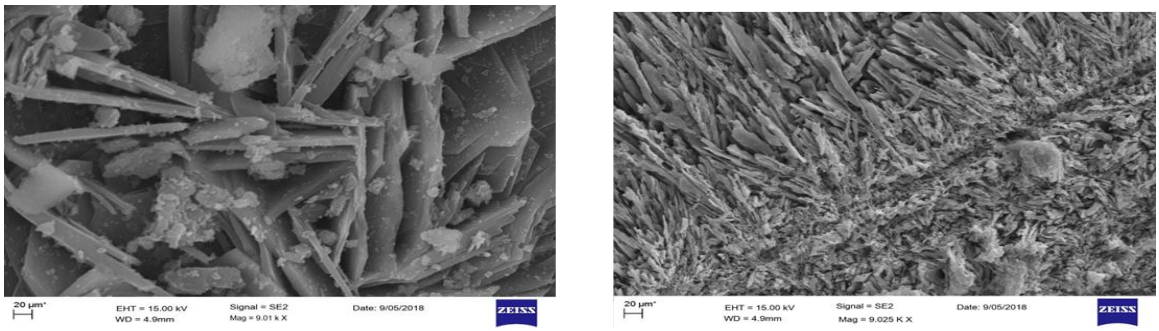

Fig. 2 FESEM image of untreated and treated PVC pipe

These FESEM images show that the crystal structure on the inner surfaces of pipes of treated water is of orthorhombic or needle crystal, which means after magnetic treatment aragonite crystals are formed which have low adhesive calcium crystal phase and can easily remove by the turbulent flow of water, while on untreated water pipes surface trigonal-rhombohedral shaped calcite crystals are formed which are usually associated with a hard scale and are difficult to remove.

After electromagnetic treatment, FESEM images show that due to the formation of aragonite crystals the scale removal from pipe increases and less scale formed on the surface of pipes. The results are confirmed with an earlier study in which the experiment claimed that the aragonite crystals are formed due to the magnetization of the solution [15]. Lipus et al. [16] investigated the effect of scale formation in industrial water processing system with high (0.1 T to 0.2 T) magnetic field. They found that electromagnetic field reduces the scale formation on at least 10 times less cost than the ion exchange process.

Hence by the formation of aragonite crystals after electromagnetic treatment, the scale formation in pipes can be reduced and enhances the life of the pipe.

Influence of pipe material

For analyzing, the effect of pipe material the electromagnetic water treatment was done on three different materials of pipe-like PVC, GI, and Copper pipe. The water was circulated for 30 hours and different water characteristics are analyzed.

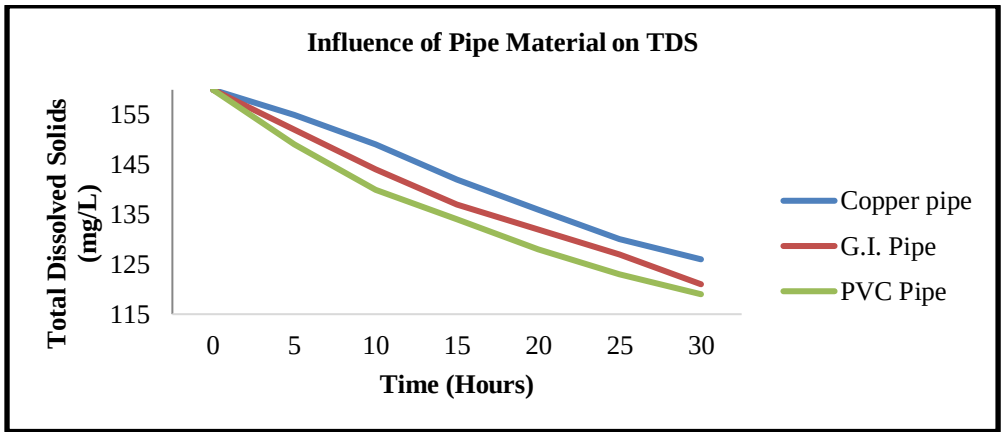

Fig. 3 Influence of pipe material on TDS of water

Figure 3 shows the influence of pipe material on the TDS of water under the effect of the electromagnetic field. For the above study, the flow rate was fixed at 7 L/min and the only TDS of water was measured because after study we analyze that best result of water treatment was obtained at 7 L/min flow rate and average percentage change was observed for TDS. The result shows that after magnetic treatment maximum reduction in TDS was observed for PVC pipe 25.63%, while in GI and copper pipes less reduction was observed 24.37% and 21.25% respectively. This shows that the efficiency of the magnetic field is different in different materials of pipe and it is maximum for the pipe whose conductivity is less. As we know that the PVC pipe is nonconductive so the treatment effect is maximum for this pipe material while for conductive copper pipe treatment effect is minimum. Alimi et al. [8] who experimentally analyzed the effect of MF treatment on various pipe materials also verify the above results. They exposed the water to the magnetic field (0.16 T) with different flow rates (0.54- 0.94 L/min) for 15 min and found that non-conductive pipe materials are much effective than others in respect to the homogeneous and total precipitation ratios. The type of material of pipe plays an important role in the formation of scale also [17].

The rate of TDS reduction is different for different materials of pipe. In PVC and GI pipes the maximum reduction is obtained in the first 15 hours while for copper pipe maximum reduction is obtained in the last 15 hours because magnetic field effectiveness is higher for non-conductive and less for conductive material.

Influence of magnetic field on the characteristic of water

The electromagnetic field affects the total dissolved solids (TDS), electrical conductivity (EC), hardness, and alkalinity of water under different flow rates in turbulent ranges for PVC pipe. Water circulation time for the study was taken 30 hours.

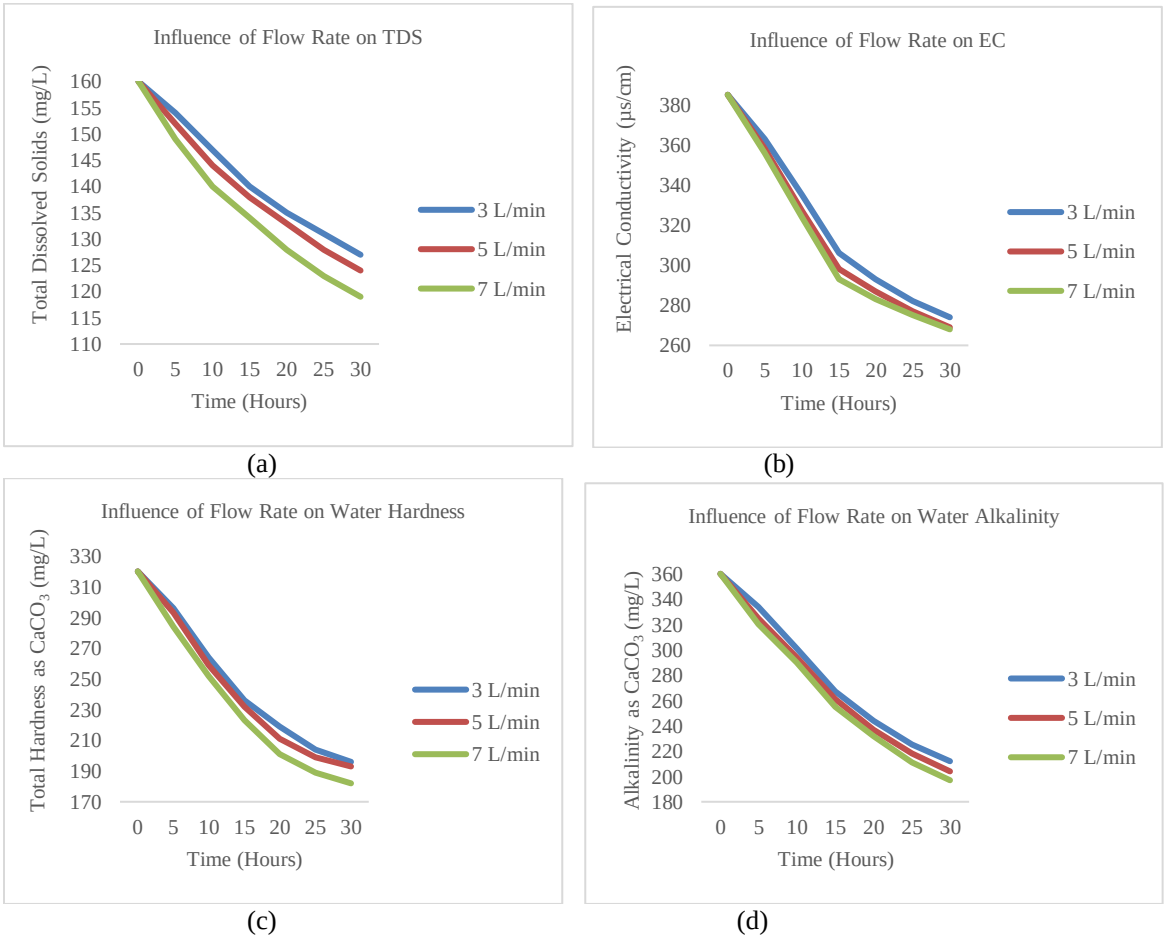

Fig. 4 Influence of flow rate on (a) total dissolved solids (TDS), (b) electrical conductivity (EC), (c) total hardness as $CaCO_3$, (d) alkalinity as $CaCO_3$

Figure 4 (a) - 4 (d) shows the effect of flow rate on TDS, EC, total hardness, and alkalinity of water after magnetic treatment. For the above study, PVC pipe material is used in all cases because PVC pipe is much efficient for magnetic water treatment than other pipe materials. The graphs are plotted between the characteristics of water and the magnetic circulation time. All the four figures show that on increasing the circulation time the above characteristics of water goes on decreasing due to the magneto-hydrodynamic (MHD) effect. In the magnetic water treatment process the magneto-hydrodynamic (MHD) mechanism are involved [18].

Hence, the magnetic field reduces the TDS, EC, hardness, and alkalinity of treated water. The results are consistent with an earlier study in which Zhang et al. [19] experimentally analyzed the effect of the electromagnetic field on circulated water at constant flow rate. They found that after treatment physic-chemical characteristics of water like TDS, turbidity, conductance, and hardness of water by 9.64%, 84.8%, 9.57% and 17.11% respectively. Mghaiouini et al. [10] also examined the effects of the magnetic treatment on water purification. Water was exposed to the weak magnetic field. They found that the magnetic field decreases the conductivity and alkalinity of water.

Influence of flow rate

Figure 4 (a) - 4 (d) is plotted between water characteristics and magnetic circulation time for different flow rates (3, 5 & 7 L/min). The figure shows that the flow rate is inversely proportional to the above water characteristics. The

average reduction in TDS, EC, hardness, and alkalinity of water on increasing the flow rates are 22.91%, 29.78%, 40.52%, and 43.24% respectively while at 7 L/min flow rate the change in above water characteristics are 25.62%, 30.38%, 43.12%, and 45.27% respectively. These changes are occurring due to the Lorentz force. The Lorentz force can be defined as:

$|F_L| = q\ |v \times B| = qvB \sin \Theta$

The experiment shows that the flow is perpendicular to the magnetic field and q & B are fixed. So on increasing the velocity of particles the Lorentz force increases, which increases the magnetic field effect. The above statement can be justified by, Saksono et al. [20] who related the effect of flow rate with Lorentz force. They stated that the increase of Lorentz force directly proportional to the increase of velocity of moving particles. Therefore, on increasing the flow rate the magnetization effect also increases.

IV. Conclusion

In the present study, the hard water is circulated in different materials of pipe (PVC, GI and copper) and at different flow rates (3, 5, and 7 L/min). After 30 hours of circulation, it is concluded that:

1) The magnetic treatment enhances the aragonite crystals formation, which is less adhesive than calcite crystals.
2) Magnetic field reduces the TDS, EC, hardness, and alkalinity of the water and it goes on decreasing on increasing the circulation time of water.
3) Flow rate is inversely proportional to the water characteristics (TDS, EC, Hardness and Alkalinity), means on increasing the flow rate from 3 L/min to 7 L/min the TDS, EC, hardness, and alkalinity decreases at a faster rate.
4) At 7 L/min the TDS reduction rate in PVC pipe (25.63%) is higher than GI (24.37%) and copper (21.25%) pipe.
5) For magnetic treatment, the PVC pipe is much effective than GI and copper pipe.

References

1. Hui, F. and Lédion, J., (2002). Evaluation methods for the scaling power of water. JOURNAL EUROPEEN D HYDROLOGIE, 33(1), pp.55-74.
2. Gabrielli, C., Jaouhari, R., Maurin, G. and Keddam, M., (2001). Magnetic water treatment for scale prevention. Water Research, 35(13), pp.3249-3259.
3. Lin, L., Jiang, W., Xu, X., & Xu, P. (2020). A critical review of the application of electromagnetic fields for scaling control in water systems: mechanisms, characterization, and operation. npj Clean Water, 3(1), 1-19.
4. Joshy, N. and Meera, V., (2020). Scale Control on Pipe Materials: A Review. In GreenBuildings and Sustainable Engineering (pp. 421-429). Springer, Singapore.
5. Georgiou, D., Bendos, D., Kalis, M., & Koutis, C. (2018). Removal and/or prevention of limescale in plumbing tubes by a radio-frequency alternating electric field inductance device. Journal of water process engineering, 22, 34-40.
6. Han, Y., Zhang, C., Zhu, L., Gao, Q., Wu, L., Zhang, Q., & Zhao, R. (2019). Effect of alternating electromagnetic field and ultrasonic on CaCO3 scale inhibitive performance of EDTMPS. Journal of the Taiwan Institute of Chemical Engineers, 99, 104-112.
7. Piyadasa, C., Ridgway, H. F., Yeager, T. R., Stewart, M. B., Pelekani, C., Gray, S. R., & Orbell, J. D. (2017). The application of electromagnetic fields to the control of the scaling and biofouling of reverse osmosis membranes-A review. Desalination, 418, 19-34.
8. Alimi, F., Tlili, M.M., Amor, M.B., Maurin, G. and Gabrielli, C., (2009). Effect of magnetic water treatment on calcium carbonate precipitation: Influence of the pipe material. Chemical Engineering and Processing: Process Intensification, 48(8), pp.1327-1332.
9. Latva, M., Inkinen, J., Rämö, J., Kaunisto, T., Mäkinen, R., Ahonen, M., Matilainen, J. and Pehkonen, S., (2016). Studies on the magnetic water treatment in new pilot scale drinking water system and in old existing real-life water system. Journal of Water Process Engineering, 9, pp.215-224.
10. Mghaiouini, R., Elaoud, A., Garmim, T., Belghiti, M. E., Valette, E., Faure, C. H., ... & El Bouari, A. (2020). The electromagnetic memory of water at kinetic condition. International Journal of Current Engineering and Technology, 10.
11. Al Helal, A., Soames, A., Gubner, R., Iglauer, S. and Barifcani, A., (2018). Influence of magnetic fields on calcium carbonate scaling in aqueous solutions at 150° C and 1 bar. Journal of colloid and interface science, 509, pp.472-484.
12. Amor, H.B., Elaoud, A., Salah, N.B. and Elmoueddeb, K., (2017). Effect of magnetic treatment on surface tension and water evaporation. International Journal of Advance Industrial Engineering, 5, pp.119-24.

13. Xiao, Y., Seo, Y., Lin, Y., Li, L., Muhammad, T., Ma, C., & Li, Y. (2020). Electromagnetic fields for biofouling mitigation in reclaimed water distribution systems. Water research, 173, 115562.
14. Othman, A., Sohaili, J. and Supian, N.S., (2019). A Review: Methodologies Review of Magnetic Water Treatment As Green Approach of Water Pipeline System. Pertanika Journal of Science & Technology, 27(1).
15. Tai, C.Y., Chang, M.C., Shieh, R.J. and Chen, T.G., (2008). Magnetic effects on crystal growth rate of calcite in a constant-composition environment. Journal of Crystal Growth, 310(15), pp.3690-3697.
16. Lipus, L. C., Ačko, B., & Hamler, A. (2011). Electromagnets for high-flow water processing. Chemical Engineering and Processing: Process Intensification, 50(9), 952-958.
17. MacAdam, J. and Parsons, S.A., (2004). Calcium carbonate scale formation and control. Re/Views in Environmental Science & Bio/Technology, 3(2), pp.159-169.
18. Johan, S., Fadil, O. and Zularisham, A., (2004). Effect of magnetic fields on suspended particles in sewage. Malay. J. Sci, 23, pp.141-148.
19. Zhang, P., Cheng, S., & Guo, B. (2009). Effect of rotating-electromagnetic field on scaling in hard water. In 2009 International Conference on Energy and Environment Technology (Vol. 1, pp. 614-617). IEEE.
20. Saksono, N., Yuliusman, Y., Bismo, S., Soemantojo, R. and Manaf, A., (2010). Effects of pH on calcium carbonate precipitation under magnetic field. Makara Jyournal of Technology, 13(2), pp.79-85.