4. Conclusion

In this study, the effects of the operating parameters such as pulse frequency, current density, pulse duty cycle, and energy consumption on the performance of hardness removal of electrochemical cooling water treatment for cooling tower of water-cooled chiller was evaluated. For the purpose of the quality of the cooling water after the treatment was obtained the required water quality of the water quality standards TCXD 232:1999 of Vietnam.

The results showed that the efficiency of total hardness removal is highest at the pulse frequency is 1.0 kHz, the pulse duty cycle is 0.7, and the current density is 80 A/m^2.

Acknowledgement

The authors would like to thanks for the support from Ho Chi Minh City University of Technology and Education, Ho Chi Minh City, Vietnam.

References

[1] W. Herbert, III. Stanford, HVAC water chillers and cooling towers: Fundamentals, Application, and Operation, Second ed, Taylor&Francis Group, 2012.

[2] C. Gabrielli, et al, "Electrochemical water softtening: principle and application", Desalination (2006). Vol. 201, pp. 150-163.

[3] A. Bannoud, "The electrochemical way of removing the hardness of water", Desalination (1993). Vol. 93, pp. 545-555.

[4] I.A.S. Hussein, "Electrochemical treatment of industrial cooling tower blowdown water using magnesium-rod electrode", Water Resources and Industry (2020). Vol. 92, 100121.

[5] X. Hao, et al ". Research and application progress of electrochemical water quality stabilization technology for recirculating cooling water in China: A short review", Journal of Water Process Engineering (2020). Vol. 37, 101443.

[6] H. A. Becker, J.J. Cohen and A.D.Zdunek "Electrochemical cooling water treatment*:* A new strategy for control of hardness, scale, sludge and reducing water usage", ASHRAE Transactions (2009), Vol. 115, Park 1. Pp. 384–392.

[7] V.T. Wagner, et al "A review on the removal of conditioning chemicals from cooling tower water in constructed wetlands", Critical Reviews in Environmental Science and Technology (2018). Vol. 48, pp. 1094-1125.

[8] P. Saha, et al "Cooling tower water treatment using a combination of electrochemical oxidation and constructed wetlands", Process Safety and Environmental Protection (2020). Vol. 144, pp. 42-51.

[9] O.M. Hafez and M.A, Shoeib "Removal of scale forming species from cooling tower blowdown water by electrocoagulation using different electrodes", Chemical Engineering Research and Design (2018). Vol. 136, pp. 347-357.

[10] P. Saha, et al "Removal of organic compounds from cooling tower blowdown by electrochemical oxidation: Role of electrodes and operational parameters", Chemosphere (2020). Vol. 259, 127491.

[11] Z. Liao, et al "Treatment of cooling tower blowdown water containing silica, calcium and magnesium by electrocoagulation", Water Science & Technology (2009). Vol. 23, pp. 2345-2352.

[12] M. Ren, et al "Treatment of berberine hydrochloride wastewater by using pulse electro-coagulation process with Fe electrode", Chemical Engineering Journal(2011). Vol. 169, pp. 84-90.

[13] M. Yao, et al "Effects of cathode pulse at high frequency on structure and composition of Al2TiO5 ceramic coatings on Ti alloy by plasma electrolytic oxidation", Materials Chemistry and Physics (2011). Vol. 126, pp. 227-231.

[14] J. Wei, X. Zhu and J, Ni "Electrochemical oxidation of phenol at boron-doped diamond electrode in pulse current mode", Electrochimica Acta (2011). Vol. 56, pp. 5310-5315.

[15] N.D. Mu'azu, et al "Specific energy consumption reduction pulsed electrochemical oxidation of phenol using graphite electrodes", *Journal of Environmental Chemical Engineering* (2016). Vol. 4, pp. 2477-2486.

[16] J. Wang, et al "Multivariate optimization of the pulse electrochemical oxidation for treating recalcitrant dye wastewater", Separation and Purification Technology (2020). Vol. 230, 115851.

[17] S. Karimi and F.R. Foulkes "Pulse electrodeposition of platinum catalyst using different pulse current waveforms", Electrochemistry Communications (2012). Vol. 19, pp. 17-20.

[18] F. Ye, et al "Effect of pulse electrodeposition parameters on electrocatalytic the activity of methanol oxidation and morphology of Pt/C catalyst for direct methanol fuel cells", Energy Conversion and Management (2018). Vol. 160, pp. 85-92.

[19] F. Ye, et al "Mechanism and kinetic study of pulse electrodeposition process of Pt/C catalysts for fuel cells", Renewable Energy (2020). Vol. 145, pp. 514-520.

[20] L. Jiani, et al "Pulse electrochemical oxidation of acid red G and crystal violet by PbO2 anode", Renewable Energy (2020). Vol. 8, 103773.

[21] A. Marlot, et al ". Pulse plating of Ni-Mo alloys from Ni-rich electrolytes", Electrochimica Acta(2002). Vol. 48, pp. 29-36.

[22] Y. Chen, et al "Electrosorption enhanced electrooxidation of a model organic pollutant at 3D SnO2-Sb electrode in superimpsed pulse current mode", Chemosphere (2018). Vol. 195, pp. 63-69.

[23] H. Jin, et al "Polarity reversal electrochemical process for water softening", Purification Technology (2019). Vol. 201, pp. 943-949.

[24] D. Hasson, et al "Development of the electrochemical scale removal technique for desalination applications", *Desalination* (2018). Vol. 230, pp. 329-342.

[25] O. Devos, et al "Nucleation-Growth process of scale electrodeposition influence of the supersaturation", Journal of The Electrochemical Society (2003). Vol. 150, pp. C494-C501.

[26] E.M.D. Pena and S. Roy "Electrodeposited copper using direct and pulse currents from electrolytes containing low concentration of additives", Surface & Coatings Technology (2018). Vol. 339, pp. 101-110.

[27] M.Y. Lin and L.M. Hourng "Effects of magnetic field and pulse potential on hydrogen production via water electrolysis", Int. J. Energy Research (2014). Vol. 38, pp. 106-116.

[28] J.S. Park, et al "Removal of hardness ions from tap water using electromembrane processes", *Desalination* (2007). Vol. 202, pp. 1-8.

[29] The water quality standards TCXD 232:1999 of Vietnam",