

3.4 Sodium Hypochlorite Requirement

In Table 9, C_{NaOCl} = NaOCl mass concentration = 565.122 kg/m³ or 565122 mg/L while in Table 6, Q_{A} = 2360.363 m³/h = 56.6487 MLD. If plugged into Equation (1), DCC will be equal to 32013.4266 kg/day. Hence daily consumption of NaOCl by the treatment plant is approximately 32 000 kg. The equation helped in knowing the daily feed requirement of NaOCl to the plant to be charged in subsequent plant run instead of relying on the initial guessed amount of 50 kg. It also avoids overfeeding the reservoir tank with chlorine, as the computed value is within the acceptable range.

3.5 Hardness Computation and Removal Rate

This research goal was to remove a total of 3423.2 mg Calcium/L and 5134.8 mg Magnesium/L equivalent to 8558 mg CaCO₃/L hardness concentrations initially present in the RAWH2O-A feed stream of the plant. Successfully, the entire CaCO₃ concentration in the water was removed as no amount was detected in the outlet stream. This is because 8715 mg/L of CaCO₃ got discarded via the SLUDGE stream. Hence, hardness concentration after treatment ($C_{\text{after softening}}$) = 0 mg/L) obtained herein corresponds with 100% removal in this simulation. In reality, this removal rate will be difficult to achieve, but CaCO₃ concentration of as low as 200 mg/L still present in the purified stream for instance, is still okay and within WHO standard. Such outcome matched a removal rate of 97.66% which is still desirable.

4. CONCLUSION

Hard water containing 8558 mg CaCO₃/L and made of 33% sand was successfully modelled using Aspen Plus V8.8 by choosing the ENRTL-SR and Pitzer reference property model. A 41.667 m³/h feedstock containing 50% water was treated using Al₂(SO₄)₃, Ca(OH)₂ and NaOCl. Using different unit operations arranged successively starting from aerator, mixer, decanter, filter and lastly storage tank, 3.053 m³/h of purified water stream was generated. It was discovered that the removal of MIXER-2 and the need for service water supply will still enable the achievement of the desired goal, since Ca(OH)₂ can be fed in liquid form. Analysis has shown that increasing the feed flow will prompt a corresponding need to raise the amount of treatment chemicals required for the operation. Block properties such as temperature, pressure and temperature-estimate play insignificant role in enhancing production, as they are best suited if kept at ambient conditions. Notwithstanding the scope covered in this study, some observable limitations should be addressed in future works:

1. In this study, Ca(HCO₃)₂ and Mg(HCO₃)₂ were not defined and tracked in Aspen Plus, but are assumed present, since they can easily be formed along the process stages and at the same time decompose back to the original reactant.
2. Effect of block conditions on the treated water should be tested in future studies, as the results of this work's sensitivity studies did not point to any optimal value in which the process may be kept.
3. In the decanter, coagulation and flocculation are assumed a joint process in which sand and other solid metallic compounds are expected to settle. Sticks and other debris or heavier impurities wasn't modelled.
4. Concentration of H⁺ and OH⁻ ions in the streams are too low to compute the streams pH using all the property methods enumerated in the methodology. Therefore, the effect of pH cannot be stated.

Setting up a water treatment facility to remove hard water alone is not an advisable venture since hard water poses no serious health challenge if present in low amount, which is often the case. However, setting up an objective to generate soft water, right from the beginning, from contaminated/raw water (say, river, lake or stream water) may be desired for specific industrial application. Since the above drawbacks, as many as they are, expose the weaknesses of Aspen Plus in simulating water treatment plant operations, several other software with complete capabilities should be targeted. This research still achieves a 100% removal of CaCO₃ using Aspen Plus above the requirement to always ensure that the hardness chemical must not exceed 200 mg/L WHO standard for drinking water.

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REFERENCES

- 3MC. 2021. Nanofiltration and membrane degassing successfully reduce water hardness and excess CO₂ from drinking water. 3M Science Applied to Life (3M Company): 3M Separation and Purification Sciences Division. <http://3m.com/liwuid-cel>
- Abdul Aziz, N.I., Othman, N., Altowayti, W.A.H., Yunus, Z.M., Fitriani, N., Md Din, M.F., & Fikri, F.M., 2021. Hardness removal of groundwater through sand, zeolite and rice husk activated carbon. *Malaysian Journal of Analytical Sciences (MJAS)*, 25 (4), Pp. 605–621. https://mjas.analis.com.my/mjas/v25_n4/pdf/lzzah_25_4_6.pdf
- Abdulrazzaq, G.H., 2016. Reducing the water hardness by using electromagnetic polarization method. *Al-Khwarizmi Engineering Journal*, 12 (4), Pp. 111–116. <https://doi.org/10.22153/kej.2016.07.002>
- Abeliotis, K., Candan, C., Amberg, C., Ferri, A., Osset, M., Owens, J., and Stamminger, R., 2015. Impact of water hardness on consumers' perception of laundry washing result in five European countries. *International Journal of Consumer Studies*, 39, Pp. 60–66. <https://doi.org/10.1111/ijces.12149>
- Abera, W.A., 2021. Dynamic simulation and modelling of methane production process for Habesha Beer water treatment process using Aspen Plus software. *American Journal of Chemical Engineering*, 9 (4), Pp. 91–100. <https://doi.org/10.11648/j.ajche.20210904.13>
- Abubakar, A.M., Mazawaje, Y.A., Olayinka, M.B., Itamah, E.I., Francis, O.C., and Bukar, U.Y., 2022. Water treatment operations: Case study of Mada Water Works. *World Academics Journal of Engineering Sciences (WAJES)*, 9 (3), Pp. 21–37. <https://doi.org/10.5281/zenodo.7158718>
- Agostinho, L.C.L., Nascimento, L., and Cavalcanti, B.F., 2012. Water hardness removal for industrial use: Application of the electrolysis process. *Open Access Scientific Reports*, 1 (9), Pp. 1–5. <https://doi.org/10.4172/scientificreports.460>
- Ahn, M.K., Chilakala, R., Han, C., and Thenepalli, T., 2018. Removal of hardness from water samples by a carbonation process with a closed pressure reactor. *Water*, 10 (54), Pp. 1–10. <https://doi.org/10.3390/w10010054>
- Akram, S., and Fazal-ur-Rehman. 2018. Hardness in drinking-water, its sources, its effects on humans and its household treatment. *Journal of Chemistry and Applications*, 8 (1), Pp. 1–4. <https://www.researchgate.net/publication/325781174>
- Al-Dosary, S., Galal, M.M., and Abdel-Halim, H., 2015. Environmental impact assessment of wastewater treatment plant-(Zenien and 6th of October WWTP). *International Journal of Current Microbiology and Applied Sciences (IJCMAS)*, 4 (1), Pp. 953–964. <http://www.ijcmas.com>
- Al-Malah, K.I.M., 2016. Introducing Aspen Plus. In *Aspen Plus: Chemical Engineering Applications* (1st ed., p. 47). John Wiley & Sons, Inc. <https://doi.org/10.1002/9781119293644.ch1>
- Amrutha, M.C.V., and Haseena, P.V., 2020. Wastewater treatment plant analysis and simulation using computational tools: A review. *International Conference on Green Energy for Environmental Sustainability [ICGEES-13th and 14th March 2020, NIT Calicut]*, Pp. 1–7.
- Anwar, H.M.I., 2011. Simulation of solid processes by Aspen Plus (R. Tuunila & M. Louhi-Kultanen (eds.)) [Faculty of Technology, Lappeenranta University of Technology]. <https://www.scribd.com/doc/232451033/aspen-plus-simulation-solid>
- Aragaw, T.A., and Ayalew, A.A., 2019. Removal of water hardness using zeolite synthesized from Ethiopian kaolin by hydrothermal method. *Water Practice & Technology*, 14 (1), Pp. 145–159. <https://doi.org/10.2166/wpt.2018.116>
- Aziz, S.Q., and Mustafa, J.S., 2019. Step-by-step design and calculations for

- water treatment plant units. *Advances in Environmental Biology (AEB)*, 13 (8), Pp. 1–16. <https://doi.org/10.22587/aeb.2019.13.8.1>
- Boyd, C.E., 2000. Total hardness. In *Water Quality-An Introduction* (pp. 123–128). Springer, Boston, MA. <https://doi.org/10.1007/978-1-4615-4485-2-8>
- Bulta, A.L., and Michael, G.A.W., 2019. Evaluation of the efficiency of ceramic filters for water treatment in Kambata Tabaro zone, southern Ethiopia. *Environmental Systems Research*, 8 (1), Pp. 1–15. <https://doi.org/10.1186/s40068-018-0129-6>
- Caratar, J.F., Cano, R.E., and Garcia, J.I., 2020. Model of a drinking water treatment process and the variables involved using coloured perti nets. *Ingeniare. Revista Chilena de Ingenieria*, 28 (3), Pp. 424–433. <https://doi.org/10.4067/S0718-33052020000300424>
- Chandraseager, S., Abdulrazik, A.H., Abdulrahman, S.N., and Abdaziz, M.A., 2019. Aspen Plus simulation and optimization of industrial spent caustic wastewater treatment by wet oxidation method. 1st Process Symposium 2019-IOP Conference Series: Materials Science and Engineering, 702 (012011), Pp. 1–7. <https://doi.org/10.1088/1757-899X/702/1/012011>
- Chandu, E., Rahaman, A., Venkatesh, G., Sai, K.P., and Dey, S., 2021. Removal of chlorides and hardness from synthetic water using biosorbents. *International Research Journal of Modernization in Engineering Technology and Science (IRJMETS)*, 3 (7), Pp. 979–981. www.irjmets.com
- Chemil, M., Zizi, Z., Droviche, N., Khodja, M., and Hadji, M., 2021. Water treatment technology performance for chemical enhanced oil recovery: Modeling, simulation and optimization. *Applied Water Science*, 11 (145), Pp. 1–8. <https://doi.org/10.1007/s13201-021-01476-4>
- Czekala, J., Jezierska, A., and Krzywosadzki, A., 2011. Calcium and magnesium content in treated waters and their total hardness. *Journal of Elementary Science*, Pp. 169–176. <https://doi.org/10.5601/jelem.2011.16.2.01>
- Deshpande, L., 2010. Water quality analysis laboratory methods. In *National Environmental Research Institute (NEERI), Nagpur* (pp. 1–68). Council of Scientific & Industrial Research, New Delhi, Govt. of India. <https://www.mpcb.gov.in/sites/default/files/water-quality/reports/LSD-NEERI>
- Dey, D., Herzog, A., and Srinivasan, V., 2007. Chemical precipitation: Water softening (S. A. Hashsham & J. Nguyen (eds.)) [Michigan State University]. <https://www.egr.msu.edu/~hashsham/courses/ene806/docs/Water Softening 1.pdf>
- Dubey, A., 2022. A study on effects of hard water on human health. *Research Ambition: An International Multidisciplinary e-Journal*, 6 (IV), Pp. 15–21. <https://doi.org/10.53724/ambition/v6n4.06Received10thFeb.2022>
- Faudot, E.K., 2021. Investigation of sustainable methods to reduce water hardness in drinking water treatment plants (C. Paul (ed.)) [Lund University]. <https://lup.lub.lu.se/student-papers/record/9037741/file/9037742.pdf>
- FSI. 1999. Standard methods for the examination of water and wastewater (Part 1000) (22nd ed.). Fisher Scientific International (FSI), Inc.: American Public Health Association (APHA), American Water Works Association, Water Environment Federation. https://beta-static.fishersci.com/content/dam/fishersci/en_US/documents/programs/scientific/technical-documents/white-papers/apha_water-testing-standard-methods-introduction-white-paper.pdf
- Greenleaf, J.E., and Sengupta, A.K., 2006. Environmentally benign hardness removal using ion-exchange fibers and snowmelt. *Environmental Science & Technology*, 40 (1), Pp. 370–376. <https://doi.org/10.1021/es051702x>
- Hettiarachchi, E., Kottegodra, N., and Perera, A.D.L.C., 2017. Activated coconut coir for removal of water hardness. *Desalination and Water Treatment*, 66, Pp. 103–110. <https://doi.org/10.5004/dwt.2016.0339>
- Ibrahim, A.A., 1988. Steady-state simulation of waste-water treatment plants using ASPEN [Office of Scientific and Technical Information (OSTI)]. <https://www.osti.gov/biblio/7255773>
- Issa, H.M., 2019. Optimization of wastewater treatment plant design using process dynamic simulation: A case study from Kurdistan, Iraq. *ARO-The Scientific Journal of Koya University*, 7 (1), Pp. 59–66. <https://doi.org/10.14500/aro.10488>
- Jadhav, A., Chalak, R., Gholap, V., Ige, V., and Deshmukh, A., 2022. Removal of water hardness by zeolite process. *International Journal of Innovative Research in Technology (IJIRT)*, 9 (1), Pp. 1038–1040. https://ijirt.org/master/publishedpaper/IJIRT155506_PAPER.pdf
- Juntunen, P., Liukkonen, M., Pelo, M., Lehtola, M.J., and Hiltunen, Y., 2012. Modelling of water quality: An application to a water treatment process. *Applied Computational Intelligence and Soft Computing*, (846321), Pp. 1–9. <https://doi.org/10.1155/2012/846321>
- Kalash, K.R., Ghazi, I.N., and Abdul-Majeed, M.A., 2015. Hardness removal from drinking water using electrochemical cell. *Engineering and Technology Journal*, 33 (1), Pp. 78–89. [https://www.uotechnology.edu.iq/tec_magaz/2015/volum332015/No.01.A.2015/Text\(6\).pdf](https://www.uotechnology.edu.iq/tec_magaz/2015/volum332015/No.01.A.2015/Text(6).pdf)
- Kaleta, J., and Puszkawicz, A., 2019. Influence of water hardness on the effectiveness of coagulation of humic compounds. *Journal of Ecological Engineering (JEE)*, 20 (6), Pp. 126–134. <https://doi.org/10.12911/22998993/108650>
- Karimi, A.R., Mehrdadi, N., Hashemian, G.R., Bidhendi, G.R.N., and Moghaddam, T., 2011. Selection of wastewater treatment process based on the analytical hierarchy process and fuzzy analytical hierarchy process methods. *International Journal of Environmental Science & Technology*, 8, Pp. 267–280. <https://doi.org/10.1007/BF03326215>
- Komesli, O.T., and Gokcay, C.F., 2014. Investigation of sludge viscosity and its effects on the performance of a vacuum rotation membrane bioreactor. *Environmental Technology*, 35 (5–8), Pp. 645–652. <https://doi.org/10.1080/09593330.2013.840655>
- Komulainen, T.M., and Johansen, H., 2021. Possible concepts for digital twin simulator for WWTP. *Proceedings of SIMS EUROSIM 2021 [Virtual, Finland, 21-23 September 2021]*, Pp. 398–404. <https://doi.org/10.3384/ecp21185398>
- Koskela, T., 2016. Removal of hardness from groundwater with nanofiltration-Case study: Meri-Lapin Vesi Oy (L. Vanska & E. Toukoniitty (eds.)) [Helsinki Metropolia University of Applied Sciences]. <https://urn.fi/URN:NBN:fi:amk-2016091214202>
- Kularathne, K.A.M., Weerasooriya, R., Kumarasinghe, A.R., and Attanayake, A.N.B., 2018. Hardness removal using graphite-based nano materials. *Proceedings of the 2nd International Research Symposium, Uva Wellasa University, Badulla 90000, Sri Lanka [1st-2nd February 2018]*, Pp. 240–240.
- Lestari, A.Y.D., Malik, A., Sukirman, Ili, M.I., and Sidiq, M., 2018. Removal of calcium and magnesium ions from hard water using modified Amorphophallus campanulatus skin as a low cost adsorbent. *MATEC Web of Conferences [ICET4SD 2017]*, 154(01020), Pp. 1–4. <https://doi.org/10.1051/mateconf/201815401020>
- Limphitakphong, N., Pharino, C., and Kanchanapiya, P., 2016. Environmental impact assessment of centralized municipal wastewater management in Thailand. *The International Journal of Life Cycle Assessment*, 21 (12), Pp. 1789–1798. <https://doi.org/10.1007/s11367-016-1130-9>
- Malakootian, M., and Yousefi, N., 2009. The efficiency of electrocoagulation process using aluminum electrodes in removal of hardness from water. *Iranian Journal of Environmental Health Science and Engineering*, 6 (2), Pp. 131–136. <http://www.bioline.org.br/pdf/se09020>
- Matino, I., Alcamisi, E., Porzio, G.F., and Colla, V., 2014. Evaluation and monitoring of physico-chemical properties of water streams through unconventional techniques. *2014 UKSim_AMSS 8th European Modelling Symposium*, Pp. 281–285. <https://doi.org/10.1109/EMS.2014.23>

- Meramo-Hurtado, S.I., Moreno-Sader, K.A., and Gonzalez-Delgado, A.D., 2020. Design, simulation, and environmental assessment of an adsorption-based treatment process for the removal of polycyclic aromatic hydrocarbons (PAHs) from seawater and sediments in North Colombia. *ACS Omega*, 5 (21), Pp. 12126–12135. <https://doi.org/10.1021/acsomega.0c00394>
- Nabgan, B., Abdullah, T.A.T., Nabgan, W., Ahmad, A., Saeh, I., and Moghadamian, K., 2016. Process simulation for removing impurities from wastewater using sour water 2-strippers system via Aspen Hysys. *Chemical Product and Process Modeling*, 11 (4). <https://doi.org/10.1515/cppm-2016-0020>
- Nabulsi, R., and Al-Abbadi, M., 2014. Review of the impact of water quality on reliable laboratory testing and correlation with purification techniques. *Lab Med Fall*, 45 (4), Pp. 159–165. <https://doi.org/10.1309/LMLXND0WNRJ6U7X>
- NEC. 2018. Water quality standards. National Environment Commission (NEC); Food and Agriculture Organisation (FAO). <https://faolex.fao.org/docs/pdf/bhu202080.pdf>
- Padarev, N., and Peneva, P., 2018. Study on water intended for sanitary decontamination. *International Scientific Journals of Scientific Technical Union of Mechanical Engineering "Science. Business. Society,"* 3 (4), Pp. 163–164. <https://stumejournals.com/journals/sbs/2018/4/163>
- Perez, K., 2014. Implementing electrolyte simulation in a water treatment process simulator. OLI Simulation Conference [October 22, 2014], Pp. 1–19. <https://downloads.olisystems.com/OLISimulationConferences/SIM00NF14/Presentations/11120-Perez-Presentation.pdf>
- Pooja, K., and Salkar, V.D., 2017. Review of studies on hardness removal by electrocoagulation. *International Journal of Engineering Research and Technology*, 40 (1), Pp. 309–313. <http://www.irphouse.com>
- Ranganathan, K., and Suresh, S., 2011. Water quality assessment and wastewater management in thermal power plants (pp. 1–23). Central Pollution Control Board (CPCB) Zonal Office (South). <https://cpcb.nic.in/displaypdf.php?id=em9iZW5nYWx1cnUvQ1BSS55wZGY=>
- Roy, R., 2019. An introduction to water quality analysis. *International Research Journal of Engineering and Technology (IRJET)*, 6 (1), Pp. 201–205. <https://doi.org/10.31786/09756272.18.9.2.214>
- Saeed, A.M., and Hamzah, M.J., 2013. New approach for removal of total hardness (Ca²⁺, Mg²⁺) from water using commercial polycyclic acid hydrogel beads, study and application. *International Journal of Advanced Biological and Biomedical Research (IJABBR)*, 1 (9), Pp. 1142–1156. <http://www.ijabbr.com>
- Sajjad, M., and Rasul, M.G., 2015. Simulation and optimization of solar desalination plant using Aspen Plus simulation software. 6th BSME International Conference On Thermal Engineering (ICTE 2014), 105, Pp. 739–750. <https://doi.org/10.1016/j.proeng.2015.05.065>
- Sakib, F.S., 2022. Designing and modeling of a municipal wastewater treatment plant with GPS-X. In B. Kumar, A. Razzaq, & S. Ali (Eds.), *ResearchSquare* (pp. 1–28). <https://doi.org/10.21203/rs.3.rs-1209601/v1>
- Saltelli, A., 2002. Sensitivity analysis for importance assessment. In *Risk Analysis* (pp. 1–21). Joint Research Centre of the European Communities in Ispra (I). <https://doi.org/10.1111/0272-4332.00040>
- Shareef, M., Kamdod, A.S.M., and Mohammed, A., 2015. Hardness removal by freezing with a dry gas. *International Advanced Research Journal in Science, Engineering and Technology (IARJSET)*, 2 (12), Pp. 83–84. <https://doi.org/10.17148/IARJSET.2015.21214>
- Shemeera, K.H., Indubhavani, N., Hemalatha, B., and Laksmivijayadurga, B., 2019. Removal of hardness using coconut shell carbon. *International Journal of Recent Technology and Engineering (IJRTE)*, 8 (258), Pp. 1252–1254. <https://doi.org/10.35940/ijrte.B1048.08825819>
- Sowgath, M.T., and Mujtaba, I.M., 2017. Design of reverse osmosis process for the purification of river water in the Southern Belt of Bangladesh. *Chemical Engineering Transactions (CET)*, 61, Pp. 1159–1164. <https://doi.org/10.3303/CET1761191>
- Spellman, F.R., 2013. *Handbook of water and wastewater treatment plant operations* (3rd ed.). CRC Press. <https://doi.org/10.1201/b15579>
- Tang, C., Rygaard, M., Rosshaug, P.S., Kristensen, J.B., and Albrechtsen, H.J., 2021. Evaluation and comparison of centralized drinking water softening technologies: Effects on water quality indicators. *Water Research*, 203 (117439), Pp. 1–11. <https://doi.org/10.1016/j.watres.2021.117439>
- Thermo-012. 2012. Use of a decanter to recover solvent and cross distillation boundaries in Aspen Plus V8.0. Aspen Technology, Incorporation. <https://lms.nchu.edu.tw/sysdata/doc/f/16a849314475e8a/pdf>
- Tian, W., Cui, Z., Qin, H., and Li, L., 2017. Conceptual design of the Eastman organic wastewater treatment process. *Chemical Engineering Transactions (CET)*, 61, Pp. 109–114. <https://doi.org/10.3303/CET1761016>
- Usman, I.U., Abubakar, A.M., Askira, B.I., Arowo, M.N., Lawan, A.S., and Saka, T., 2023. Artificial water hardness removal-Modelling and simulation in ASPEN Plus. *DS Journal of Modeling and Simulation (DSMS)*, 1 (1), Pp. 1–8. <https://dsjournals.com/ms/MS-V111P101>
- WHO. 2022. Guidelines for drinking-water quality: Incorporating the first addendum (F. Ahmed, I. Chorus, J. Cotruvo, D. Cunliffe, A. M. de R. Husman, T. Endo, J. K. Fawell, M. Giddings, G. Howards, P. Jackson, S. Kumar, S. Kunikane, Y. Magara, A. V. F. Ngowi, E. Ohanian, C. N. Ong, O. Schmoll, & M. Sobsey (eds.); 4th ed.). World Health Organization (WHO). <https://apps.who.int/iris/bitstream/handle/10665/254637/9789241549950-eng.pdf>
- Wickramasuriya, A.I.R., Arachchige, R.C.W., and Kottegoda, I.R.M., 2021. Characterization and modification of clay for removal of drinking water hardness. *Material Science Research India (MSRI)*, 18 (3), Pp. 318–331. <https://doi.org/10.13005/msri/180307>
- Wolski, P., 2021. Analysis of rheological properties of thickened sewage sludge. *Desalination and Water Treatment*, 232, Pp. 331–338. <https://doi.org/10.5004/dwt.2021.27517>
- Wurts, W.A., 1993. Understanding water hardness. *World Aquaculture*, Pp. 1–2. <https://www.researchgate.net/publication/307122312>
- Zeng, Y., Ma, L., and Bai, P., 2022. Study of organic acid pollutant removal efficient in treatment of industrial wastewater with HDH process using ASPEN modelling. *Water*, 14(22), 1–11. <https://doi.org/10.3390/w14223681>

