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Examining Adsorbent Charge Effect on Metal Removal from Contaminated Water

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Abstract: Heavy metal contaminated water sources can cause serious health problems for humans, animals, and plants. Heavy metals can lead to the decrease or loss of liver, kidney, and brain function. Objective: The aim of this research is to examine the effect of charge on adsorbents in the removal of metal cations. Study Design & Methods: Standard solutions of Ca, Cu, Pb, and Zn with concentrations of 1,000 ppm were treated with sodium carbonate and sodium phosphate with various charges. Then, the solutions were placed on a shaker for 24 h, centrifuged, and the supernatant was analyzed using ICP-AES (Inductively Coupled Plasma-Atomic Emission Spectrometry). Results: The order of average metal removal by sodium phosphates is: dibasic (99.3%) > monobasic (96.5%) > tribasic (95.4%). The average metal removal by sodium carbonate and bicarbonate is 98.5% and 96.4% respectively. Conclusion: The adsorbent removability depends on the relationship between the charge present on the metal and the charge on the adsorbent. Thus, metal cations in this study with a +2 charge had a greater affinity for the adsorbent with -2 charged ligands, dibasic sodium phosphate and sodium carbonate.

Key words: Charge effect, environmental chemistry, ion exchange, metals, solubility, contaminated water.

1. Background

Many water sources around the world have been polluted by various toxic metals. It has become such a widespread problem because metal pollution can result from a variety of activities. Metals, especially heavy metals, are distributed in the environment through natural, industrialization and anthropogenic activities. They are not degradable; thus, they persist in the environment [1]. The metals accumulate in the environment, and their concentrations increase over time. Although zinc, copper, and calcium are micronutrients required in small concentrations for the human body, however, in higher concentrations they are toxic for living organisms and also for the environment [2]. High concentrations of metals in the body can cause a multitude of health conditions and diseases. Excess copper in the body can cause neurotoxicity, liver toxicity, and jaundice, liver failure, lung cancer and many other adverse ailments [3-9]. Excess zinc can have harmful and fatal effects on human health [10-12]. Excessive calcium in water sources can cause kidney stone formation, skin irritation, hypercalcemia, hair loss, etc. Lead exposure can lead to severe brain and kidney damage [13].

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2. Material and Methods

Standard solutions of 1,000 ppm of Ca(II), Cu(II), Pb(II), and Zn(II) ions were prepared with the corresponding salts for each. Equivalent amounts of each salt were dissolved in 1,000 mL of solution. Duplicate samples of about 40 mL for each metal contaminated solution were put into centrifuge tubes. The duplicate samples were treated with about 5 g of each of the adsorbent substrates (NaH_2PO_4, Na_2HPO_4, Na_3PO_4, $NaHCO_3$, and Na_2CO_3). The samples were vortexed to mix and placed into a shaker for 24 h at room temperature. Then, all the samples were centrifuged at 3,000 rpm for 10 min. The supernatant of each sample was decanted into a new centrifuge tube. The resulting samples were analyzed for residual metal ion concentration using the EPA Method 6010 (ICPAES (Inductively Coupled Plasma-Atomic Emission Spectrometry)).

3. Results

Fig. 1 displays the percentages of metal removed from the various aqueous solutions treated with three different sodium phosphate adsorbents. Calcium, copper, zinc, and lead were tested for residual metal concentrations and compared. All of the metal contaminated solutions were treated with either monobasic, dibasic, or tribasic sodium phosphate. Lead had the highest percentage of metal removed across all adsorbents. The order of average percent metal removal is: lead (98.5%) > copper (98%) > zinc (96.9%) > calcium (94.7%). Although calcium has the lowest average percent removal, it had the highest percentage of metal removed by Na_2HPO_4 (100%). Calcium also reported the lowest percentage of metal removed by Na_3PO_4 (87.6%). The dibasic sodium phosphate, Na_2HPO_4, was the most efficient adsorbent across all metals. The order of average percent metal removed by adsorbent is: Na_2HPO_4 > NaH_2PO_4 > Na_3PO_4, especially for calcium and lead.

Fig. 2 presents percentages of metal removed by sodium carbonate and sodium bicarbonate. The same four metals were treated with either sodium carbonate, or sodium bicarbonate. The percentages of metal removed were compared. The sodium bicarbonate was a more efficient adsorbent for removing metals than sodium carbonate, except for calcium. The average percentage of metal removal for $NaHCO_3$ is 98.5% while the average percentage of removal for Na_2CO_3 was approximately 96.4%. The order of percent

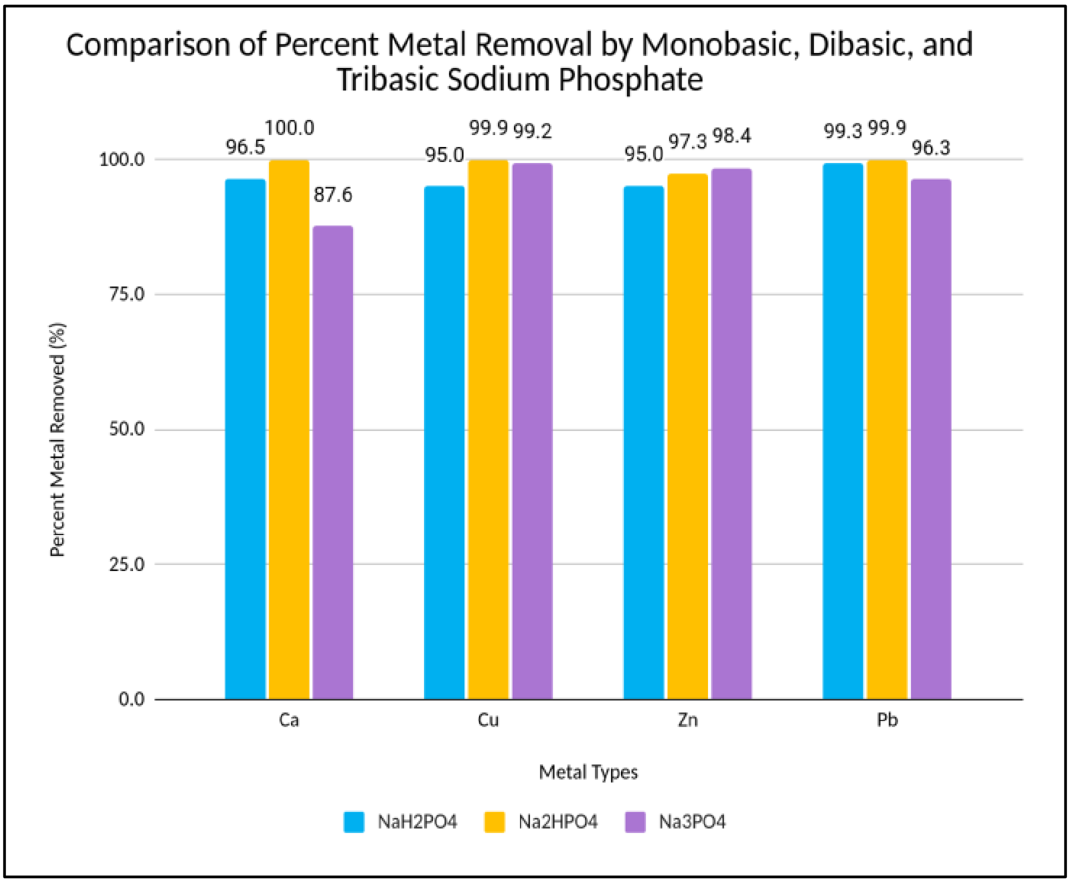

Fig. 1 Comparison of percent metal removal by monobasic, dibasic, and tribasic sodium phosphate.

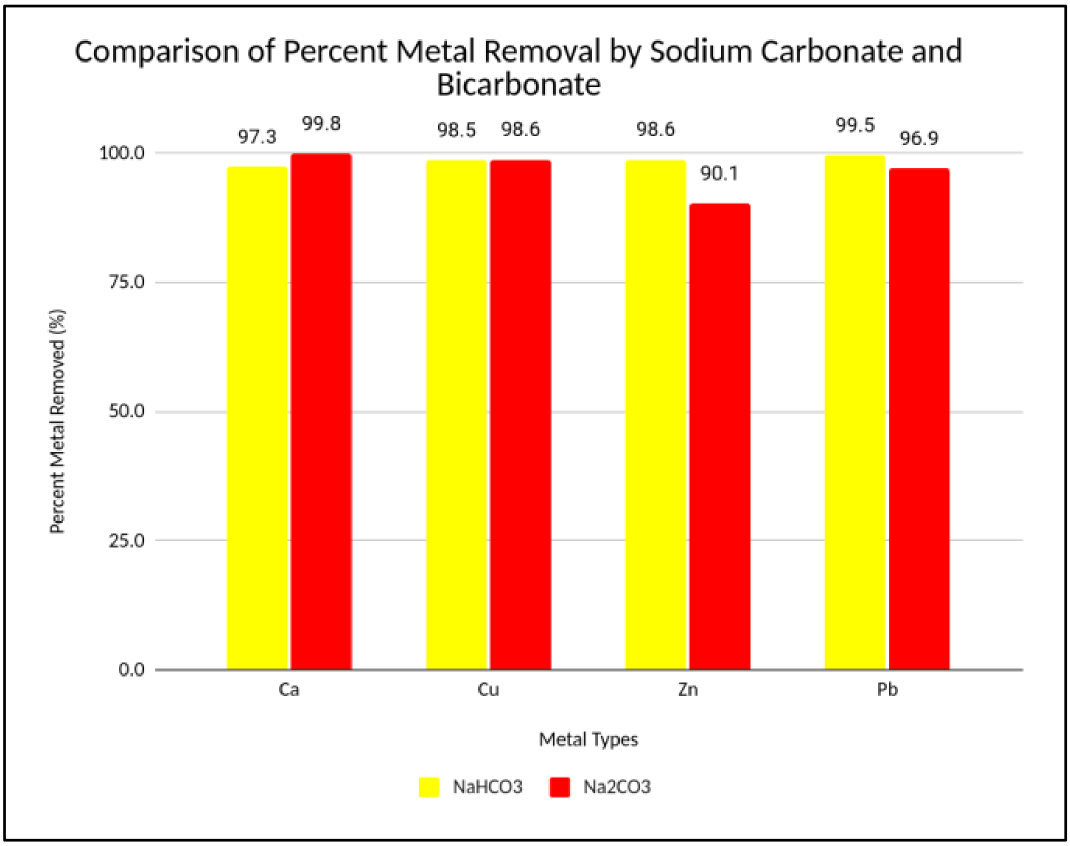

Fig. 2 Comparison of percent metal removal by sodium carbonate and bicarbonate.

removal of metal for sodium bicarbonate is: lead (99.5%) > zinc (98.6%) > copper (98.5%) > calcium (97.3%). Lead presented the highest percentage of metal removed when treated with the bicarbonate. Calcium had the highest percentage of metal removed by the carbonate. The order of percent removal by metal for sodium carbonate is: calcium (99.8%) > copper (98.6%) > lead (96.9%) > zinc (90.1%).

Fig. 3 shows the comparison of percent metal removal by $NaHCO_3$ and NaH_2PO_4. Overall, the sodium bicarbonate adsorbent was more efficient than the monobasic sodium phosphate adsorbent on all four metals. The order of percent metal removal by sodium bicarbonate is: lead (99.5%) > zinc (98.6%) > copper (98.5%) > calcium (97.3%). The average percentage of metal removed by sodium bicarbonate was approximately 98.48%. The order of percent metal removed by monobasic sodium phosphate is: lead (99.3%) > calcium (96.5%) > copper and zinc (95%). The average percentage of metal removed by monobasic sodium phosphate is about 96.45%. It is worthy to note that both adsorbents removed at least 95% of contaminants across all metals tested. Therefore, both adsorbents are efficient in removing toxic metals from aqueous solutions.

Fig. 4 illustrates the comparison of percent metal removal by sodium carbonate and dibasic sodium phosphate. The dibasic sodium phosphate proved to be an impressive adsorbent for removing toxic metals. The order of percent removal by dibasic sodium phosphate is as follows: calcium (100%) > copper ~ lead (99.9%) > zinc (97.3%). The average percentage of metal removed by dibasic sodium phosphate is approximately 99.3%. The sodium carbonate adsorbent order of percent removal is: calcium (99.8%) > copper (98.6%) > lead (96.9%) > zinc (90.1%). The average percentage of metal removed by sodium carbonate is about 96.4%. It is still worthy to note that both adsorbents removed at least 90% of all contaminants across all aqueous solutions.

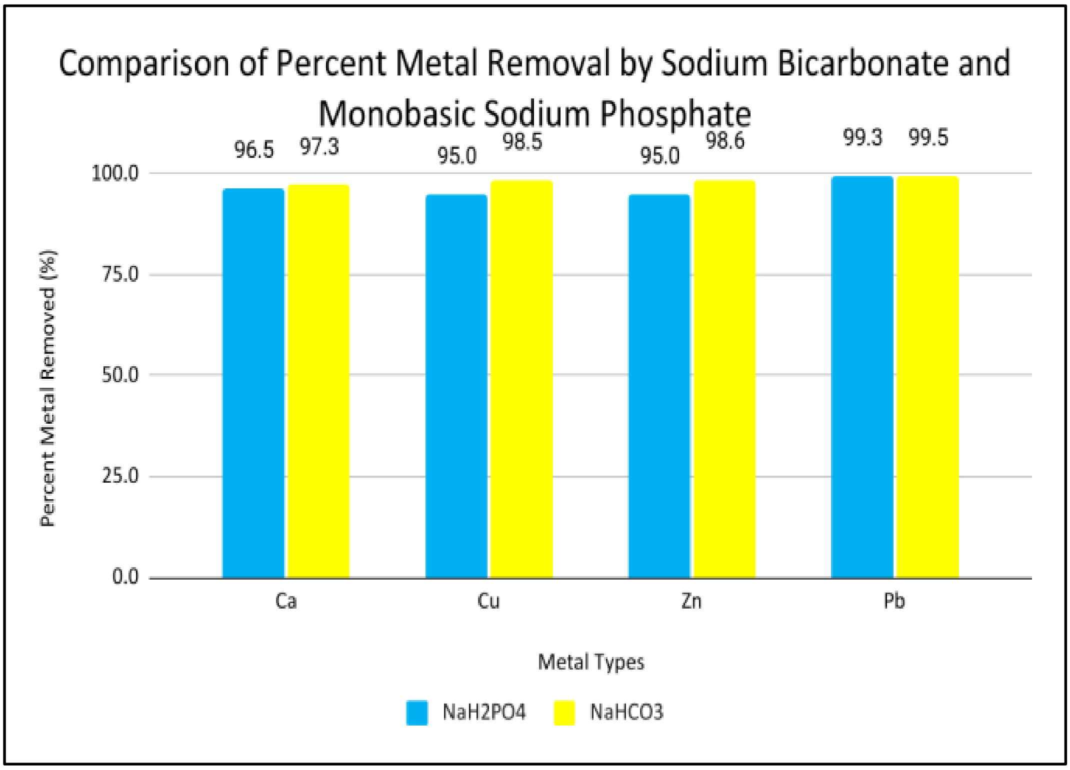

Fig. 3 Comparison of percent metal removal by sodium bicarbonate and monobasic sodium phosphate.

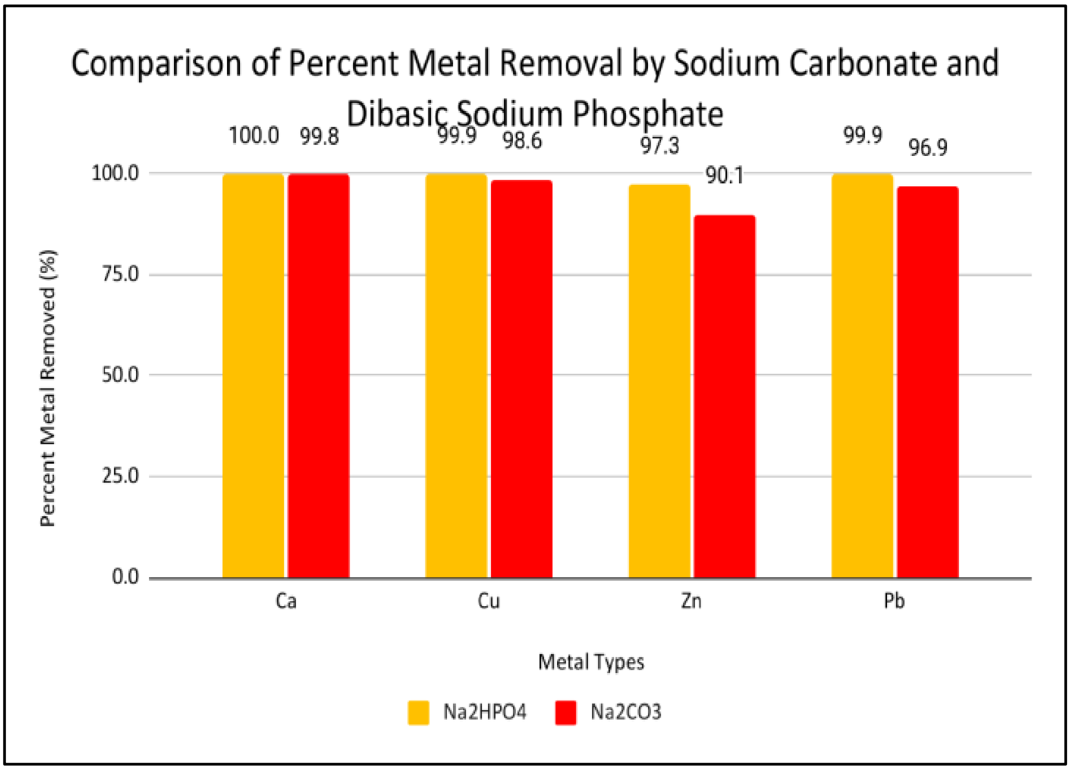

Fig. 4 Comparison of percent metal removal by sodium carbonate and dibasic sodium phosphate.

4. Discussion

The results in Fig. 1 clearly demonstrate the effect of charge on sodium phosphate on metal removal. Charge clearly plays a part in affecting the efficiency of the adsorbent because dibasic > monobasic > tribasic. Since all of the cations used to prepare the standards were from metals with a +2 charge, the dibasic adsorbent was the most efficient. The -2 ligands had a higher affinity than the +2 metals. Thus, for the phosphate based adsorbents, Na_2HPO_4 with a -2 charge performed the best. There are several factors that can influence the observed results such as adduct structure, solubility, cation-anion ratio, and pH.

5. Conclusion

Sodium phosphate and sodium carbonate are efficient adsorbents for the removal of heavy metals from contaminated water sources. All adsorbents, regardless of charge, removed at least 87% of all metals tested. Although the use of sodium phosphate and sodium carbonate in heavy metal remediation has been tested, the significance of charge has not been reported. Based on the results presented in this research, it can be concluded that the efficacy of metal removal of an adsorbent depends, in part, on the composition and charge of the targeted metal. Furthermore, a 1:1 metal cation to ligand anion ratio appeared to be the most effective in metal removal.

Declare of Interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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References

[1] Kapahi, M., and Sachdeva, S. 2019. “Bioremediation Options for Heavy Metal Pollution.” *Journal of Health and Pollution* 9 (24): 191203.

[2] Singh, R. G., Mishra, N. A., and Gupta, R. 2011. “Heavy Metals and Living Systems: An Overview.” *Journal of Pharmacology* 43: 246-53.

[3] Barnum, S. J. 1982. *Introduction to Organic and Biological Chemistry*, 3rd ed. New York: MacMillan.

[4] Agwaramgbo, L., Magee, N., Nunez, S., and Mitt, K. 2013. “Biosorption and Chemical Precipitation of Lead Using Biomaterial, Molecular Sieves, and Chlorides, Carbonates, and Sulfates of Na & Ca.” *Journal of Environmental Protection* 4 (11): 1251-7.

[5] Manzoor, Q., Nadeem, R., Iqbal, M., Saeed, R., and Ansari, T. M. 2013. “Organic Acids Pre-treatment Effect on *Rosa bourbonia* Phyto-Biomass for Removal of Pb(II) and Cu(II) from Aqueous Media.” *Bioresource Technology* 132: 446-52.

[6] Uriu-Adams, J. Y., and Keen, C. L. 2005. “Copper, Oxidative Stress and Human Health.” *Molecular Aspects of Medicine* 26: 268-98.

[7] Pandit, A., and Bhave, S. 1996. “Present Interpretation of the Role of Copper in Indian Childhood Cirrhosis.” *American Journal of Clinical Nutrition* 63: 830-85.

[8] Muller, T., Feichtinger, H., Berger, H., and Muller, W. 1996. “Endemic Tyrolean Cirrhosis: An Ecogenetic Disorder.” *Lancet* 347: 877-80.

[9] Scheinberg, I. H., and Sterlieb, I. 1994. “Is Non-Indian Childhood Cirrhosis Caused by Excess Dietary Copper?” *Lancet* 344: 1002-4.

[10] Plum, L. M., Rink, L., and Haase, H. L. 2010. “The Essential Toxin: Impact of Zinc on Human Health.” *International Journal of Environmental Research and Public Health* 7: 1342-65.

[11] Brown, M. A., Thom, J. V., Orth, G. L., Cova, P., and Juarez, J. 1964. “Food Poisoning Involving Zinc Contamination.” *Archives of Environmental Health* 8: 657-60.

[12] Cummings, J. E., and Kovacic, J. P. 2009. “The Ubiquitous Role of Zinc in Health and Disease.” *Journal of Veterinary Emergency and Critical Care* 19: 215-40.

[13] Agwaramgbo, L. O. E., Cardoso, R. F., and Matos, T. S. 2016. “Copper and Zinc Removal from Contaminated Water Using Coffee Waste.” *Journal of Scientific Research and Reports* 12: 1-9.