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Adsorptive Behaviour, Isothermal and Kinetic Modeling Studies in Removal of Copper, Nickel, Zinc and Lead from Aqueous Solutions using *Carissa carandas* and *Syzygium aromaticum*: A Comparative Analysis

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The present study focused on the use of *Carissa carandas* leaves and *Syzygium aromaticum* (clove) powder as biosorbents for the removal of copper(II), nickel(II), zinc(II) and lead(II) from aqueous solutions. Results were investigated in batch mode and the observations were correlated with the pH variation, agitation time, dose of the adsorbent and initial metal ion concentration in the solution. Biosorbent *Carissa carandas* leaf powder showed higher sorption efficiency than that of biosorbent *Syzygium aromaticum* powder under identical experimental conditions. Langmuir isotherm models observed best equilibrium data in all four metals and both biosorbents and pseudo second order kinetics model perfectly matched in both biosorbents in all four metal ions.

Keywords: Biosorption, Ni(II), Cu(II), Zn(II), Pb(II), *Carissa carandas*, *Syzygium aromaticum*, Langmuir isotherm, Freundlich isotherm.

INTRODUCTION

Freshwater comprises 3 % of the total water on earth. Only a small percentage (0.01 %) of this freshwater is available for human use [1]. Heavy metals are natural components of the Earth's crust, unlike most organic pollutants, they are generally refractory and cannot be degraded or readily detoxified biologically [2]. The large amount utilization of heavy metal is a big source of heavy metal pollution in water and waste water. Zinc, copper, nickel and lead are the most common pollutant. Heavy metals are dangerous because they are non-degradable and tend to bio-accumulate. To a small extent they enter our bodies via food, drinking water and air. Higher concentration of heavy metal ions in drinking water cause many dangerous diseases [3], nausea and vomiting in children [4], anemia and cholesterol problems [5,6] encephalopathy, nephropathy, mental retardation, seizures and it forms complexes with oxo-groups in enzymes and affect the haemoglobin synthesis [7,8].

World Health Organization (WHO) recommends a maximum acceptable concentration for copper as 0.05 mg/L in drinking water, 0.002 mg/L for mercury, 0.003 mg/L for cadmium, 0.01 mg/L for arsenic, 0.05 mg/L for chromium and lead and 0.02 mg/L for nickel [9-16].

Green Chemistry has more effective and easy process for removal of heavy metals than other conventional methods. A

number of green techniques have been employed for removal of these metal(II) ions from water and waste water like biosorption [17], bioremediation [18], phytoremediation [19] and photocatalytic processes [20-22].

Many investigations have been accomplished to identify suitable and relatively low-cost biosorbents that are capable of removal of zinc(II), copper(II) nickel(II) and lead(II) ions. Several studies have been reported for biosorption of these heavy metal ions by using variety of biosorbents including *Trachyspermum copticum* (Ajwain) [23], modified chitosan nanofibers [24], *Farfantepenaeus aztecus* (shrimp) biomass [25], scots pine (*Pinus sylvestris* L.) biochar and silver birch (*Betula pendula*) biochar [26], rice bran [27], coir pith [28], *Eichhornia crassipes* [29], *Lycopersicum esculentum* (Tomato) [30] and *Spartium junceum* L. [31].

Biosorptive removal of divalent copper and nickel from aqueous solution by using *Carissa carandas* and *Syzygium aromaticum* was reported in previous studies [20,32]. These studies reported that the maximum adsorption capacities estimated for copper(II) were 54.2 and 76.61 mg/g for *Carissa carandas* and *Syzygium aromaticum* respectively and the maximum adsorption capacities for nickel(II) were estimated from Freundlich isotherm model are 3.76 and 2.96 mg/g for *Carissa carandas* and *Syzygium aromaticum*, respectively.

The efficiency of *Carissa carandas* and *Syzygium aromaticum* as biosorbent for removal of divalent metal ions e.g., zinc, copper, nickel and lead from aqueous solution are evaluated in present study. Maximum adsorption capacity of biosorbent, adsorption intensity of the adsorbate on biosorbent surface and biosorption potentials of biosorbent were estimated by Langmuir and Freundlich isotherms, respectively. In the present study *Carissa carandas* and *Syzygium aromaticum* leaves were used for biosorption of zinc(II), copper(II), nickel(II) and lead(II) from aqueous solutions. Batch adsorption experiments were carried out at ambient temperature (300 K) as a function of solution pH (2-12), biosorbent dosage (2-10 g/100 mL), contact time (60 min interval and up to 300 min) and initial metal ion concentration. Then, equilibrium isotherms and kinetic data parameters were evaluated.

EXPERIMENTAL

Analytical grades of $\text{Pb}(\text{NO}_3)_2$, $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, $\text{NiSO}_4 \cdot 7\text{H}_2\text{O}$, $\text{CuSO}_4 \cdot 7\text{H}_2\text{O}$, HCl and NaOH from Merck (India) were used in the present study. Aqueous solutions of metal ions were prepared by dissolving its corresponding salt in double distilled water. The pH of solutions was adjusted with 0.1 N HCl and NaOH. All the experiments were conducted three times and the average values have been reported. Also, blank experiments were conducted to ensure that no adsorption is taking place on the walls of the apparatus used.

Preparation of biosorbents: *Syzygium aromaticum* (cloves) buds were used as a biosorbent for the removal of heavy metal ions. Cloves were washed with double distilled water repeatedly to remove dust and solid impurities, dried in an oven for 24 h at 60 °C, ground and sieved. It was washed with double distilled water several times and dried in an air oven at 105 ± 5 °C for 6 h and cooled to room temperature in desiccators. It was grinded into fine powder in a mechanical grinder and sieved to a particle size of 0.3-0.5 mm. The adsorbent was stored in polypropylene jars for further experiments, which was used as adsorbent without any pre-treatment for nickel, copper, zinc and lead adsorption.

The leaves of *Carissa carandas* were taken from local vegetable market of Jaipur, Rajasthan. It was washed by double distilled water to remove dust and particulate materials from its surface. The substance was dried at room temperature in shade for 10 days and then in an air oven at 120 °C for 72 h. It was grinded into fine powder in a mechanical grinder and sieved to a particle size of 0.3-0.5 mm. The adsorbent was stored in polypropylene jars for further experiments.

Adsorption experiment: Batch adsorption studies were performed at room temperature. The adsorption equilibrium experiments for Zn(II), Cu(II), Ni(II) and Pb(II) solutions were carried out by taking 100 mL of metal solution in 250 mL conical flask. After a defined time interval of 60 min, samples were withdrawn from the shaker, filtered by Whatman filter paper No. 41 and the supernatant solutions were analyzed for Zn(II), Cu(II), Ni(II) and Pb(II) ion concentration using an atomic absorption spectrometer (Thermo scientific Solar S-series AA Spectrometer). The removal of heavy metals were calculated according to following expression:

$$\text{Metal removal (\%)} = \frac{(C_o - C_e)}{C_o} \times 100$$

where C_o and C_e are the initial and equilibrium concentrations (mg/L).

RESULTS AND DISCUSSION

Effect of pH: pH of solution is an important controlling and contributing factor in biosorption of heavy metal ions. The metal-binding capacity of biosorbent was highly pH dependent on pH value. Acidic or basic condition of aqueous solution could modify the surface properties of biosorbents and adsorption process by changing the ionization state of the functional groups present on the surface of the biosorbent. The experimental data shows the effect of pH on the batch adsorption of Zn(II), Cu(II), Ni(II) and Pb(II). The effect of pH was studied at 100 mg/L Ni(II) concentration, biosorbent dosage of 2 g/100 mL at the pH range 2-10. It was observed that biosorbent *Carissa carandas* shows higher metal ion removal efficiency at pH 4 for Pb(II), at pH 6 for Ni(II) and at pH 8 for Cu(II) and Zn(II) (Fig. 1). The biosorbent *Syzygium aromaticum* shows higher metal ion removal efficiency at pH 2 for Pb(II), at pH 6 for Ni(II) and Zn(II) and at pH 8 for Cu(II).

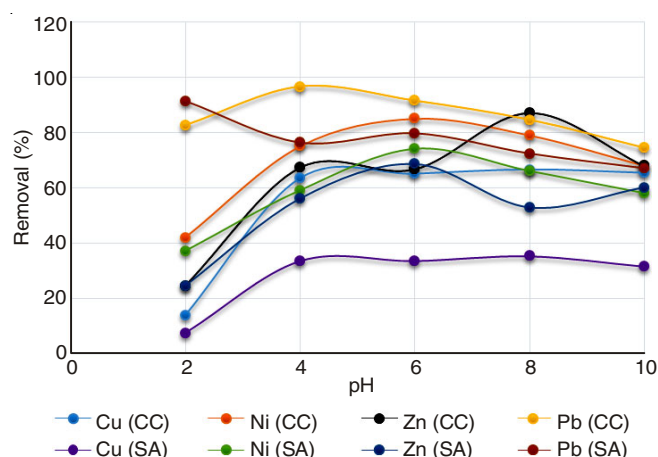


Fig. 1. Effect of pH: A comparative study ($C_o = 100$ ppm, dose = 2 g/100 mL, Contact time = 180 min) [*Carissa carandas* (CC) and *Syzygium aromaticum* (SA)]

Effect of biosorbent dose: The effect of adsorbent dosage is depicted in Fig. 2. *Carissa carandas* and *Syzygium aromaticum* adsorbents were used at dosage ranging from 2 g/100 mL to 10 g/100 mL in a batch adsorption technique. Increase in adsorbent dose resulted to an increase in percentage (%) removal of Cu(II), Pb(II), Ni(II) and Zn(II) ranging from 13.77 to 74.75 % and 38.14 to 77.89 % for copper, 72 to 95 % and 69 to 92 % for zinc, 85 to 99 % and 74 to 94 % for nickel and 94.43 to 97.31 % and 82.22 to 95.32 % for *Carissa carandas* and *Syzygium aromaticum* respectively.

Effect of metal ion concentration: The concentration of metal ions affects the adsorption process because of competition of various metal ions to occupy the limited adsorption sites on biosorbent. Increasing in metal ions concentration cause decrease in percentage of metal removal. Fig. 3 shows the effect of initial metal ion concentration of Zn(II), Cu(II), Ni(II) and Pb(II) on the adsorption of these ions using *Carissa*

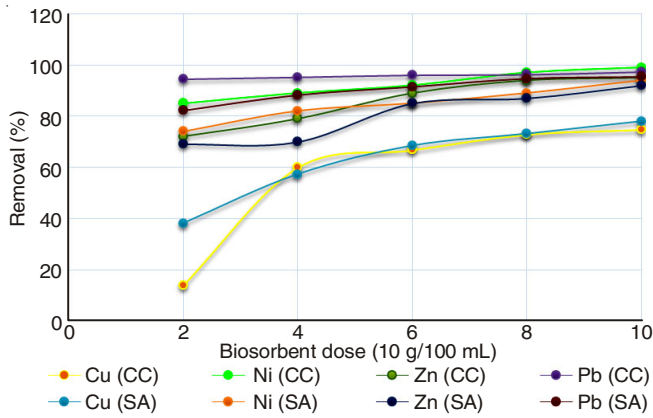


Fig. 2. Effect of biosorbent dose: A comparative study ($C_0 = 100$ ppm, Contact time = 180 min) [*Carissa carandas* (CC) and *Syzygium aromaticum* (SA)]

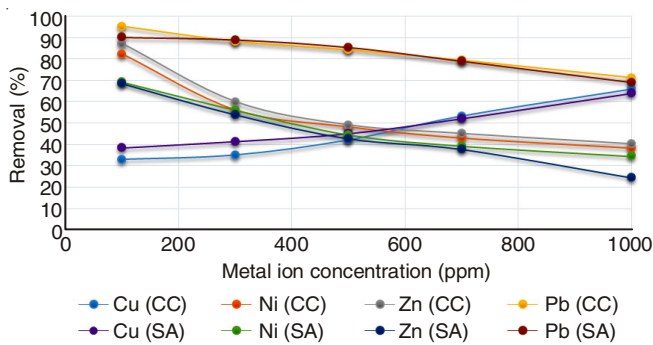


Fig. 3. Effect of metal ion concentration: A comparative study (Dose = 2 g/100 mL, Contact time = 180 min) [*Carissa carandas* (CC) and *Syzygium aromaticum* (SA)]

carandas and *Syzygium aromaticum* as adsorbents. It was observed that with increase in metal ion concentration from 100-1000 mg/L, there was an accompanying decrease in the percentage (%) removal of Zn(II), Cu(II), Ni(II) and Pb(II) for both adsorbents.

Effect of agitation time: The experimental runs measuring the effect of contact time on the batch adsorption of Zn(II), Cu(II), Ni(II) and Pb(II) are shown in Fig. 4. It was observed that, increase in contact time from 60 to 300 min significantly enhanced the percentage (%) removal of Zn(II), Cu(II), Ni(II) and Pb(II) using *Carissa carandas* and *Syzygium aromaticum* biosorbents. Fig. 4 showed that the initially rapid adsorption gradually gave way to adsorption at a slow rate; indicative of the fact that the process tended to approach equilibrium state between 180-300 min (for both adsorbents).

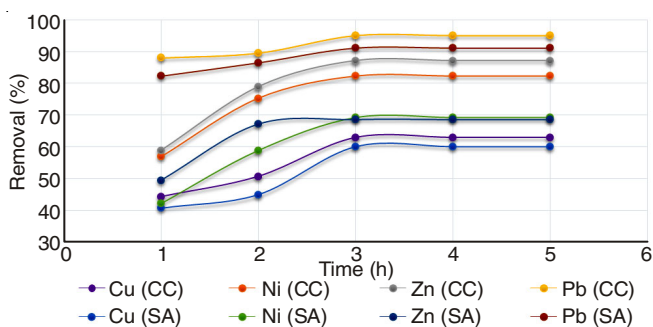


Fig. 4. Effect of agitation time: A comparative study ($C_0 = 100$ ppm, dose = 2 g/100 mL) [*Carissa carandas* (CC) and *Syzygium aromaticum* (SA)]

Effect of temperature: The effect of temperature on the batch adsorption of Zn(II), Cu(II), Ni(II) and Pb(II) is shown in Fig. 5. Higher removals were observed at 30 °C for Cu(II), Pb(II), Ni(II) and at 40 °C for Zn(II) for both biosorbents. Biosorption process was exothermic in nature and at the higher temperature the kinetic energies of Zn(II), Cu(II), Ni(II) and Pb(II) ions was higher. Therefore the biosorption of high energy metal ions is not easier compared with low energy ions.

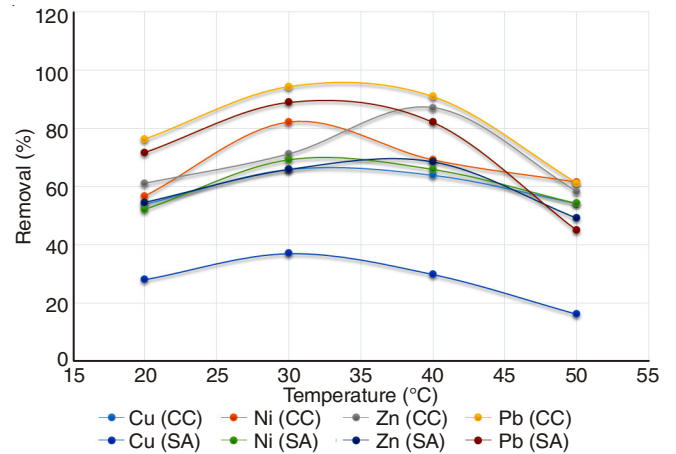


Fig. 5. Effect of temperature: A comparative study ($C_0 = 100$ ppm, dose = 2 g/100 mL, Contact time = 180 min) [*Carissa carandas* (CC) and *Syzygium aromaticum* (SA)]

Isotherm studies: Based on the relationship of adsorption capacity for Zn(II), Cu(II), Ni(II) and Pb(II) adsorption onto the *Carissa carandas* and *Syzygium aromaticum* adsorbents and the equilibrium concentrations, Langmuir and Freundlich adsorption isotherms were modelled and presented in Figs. 6 and 7, respectively. It was observed that Langmuir isotherm best fitted for both biosorbents. The maximum metal removal (q_{max}) was observed as 1.031, 0.821, 54.21, 76.61, 60.81, 57.02, 1.009 and 0.923 for *Carissa carandas* for zinc, *Syzygium aromaticum* for zinc, *Carissa carandas* for copper, *Syzygium aromaticum* for copper, *Carissa carandas* for nickel, *Syzygium aromaticum* for nickel, *Carissa carandas* for lead and *Syzygium aromaticum* for lead respectively (Table-1).

Kinetic studies: Kinetic studies are very important to determine the adsorption process to predict the capability of biosorbent to remove the metal ions. In batch adsorption system two types of kinetic models such as pseudo first order and

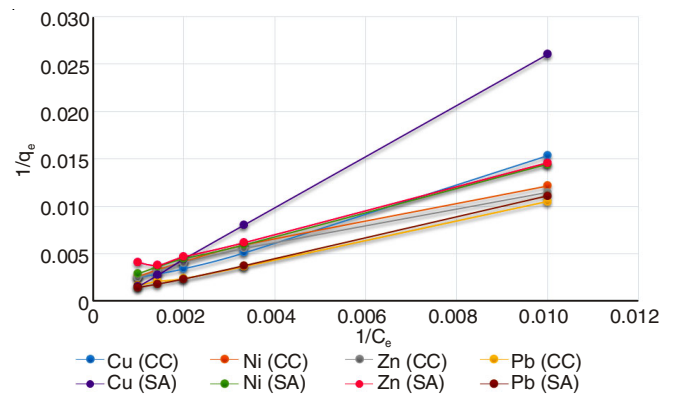


Fig. 6. Langmuir Isothermal study of *Carissa carandas* (CC) and *Syzygium aromaticum* (SA): A comparative study

TABLE-1
LANGMUIR AND FREUNDLICH ISOTHERM

Adsorbent	Metal ion	Langmuir isotherm			Freundlich isotherm		
		q _{max}	K _L	R ²	K _F	N	R ²
<i>Carissa carandas</i>	Zinc	1.031	969	0.99	0.614	1.51	0.99
	Copper	54.21	0.38	0.92	40.54	2.50	0.93
	Nickel	60.81	0.33	0.98	3.76	1.47	0.99
	Lead	1.009	2018	0.99	1.82	1.16	0.99
<i>Syzygium aromaticum</i>	Zinc	0.821	609	0.99	0.68	1.68	0.93
	Copper	76.61	0.68	0.97	67.32	1.50	0.97
	Nickel	57.02	0.30	0.97	2.96	1.44	0.99
	Lead	0.923	5414.18	0.99	1.50	1.11	0.99

TABLE-2
KINETICS STUDIES OF BIOSORPTION OF Zn(II), Cu(II) Ni(II) AND Pb(II) ON *Carissa carandas* AND *Syzygium aromaticum*

Biosorbent	Metal ion	Conc. (ppm)	Pseudo-first-order kinetic model			Pseudo-second-order kinetic model		
			q _{e,cal} (mg/g)	K ₁ (min ⁻¹)	R ²	q _{e,cal} (mg/g)	K ₂ (g mg ⁻¹ min ⁻¹)	R ²
<i>Carissa carandas</i>	Zinc	100	40.04	4.80 × 10 ⁻³	0.91	113.63	1.5 × 10 ⁻⁴	0.99
		300	90.01	3.60 × 10 ⁻³	0.95	212.76	1.1 × 10 ⁻⁴	0.99
		500	170.71	2.00 × 10 ⁻³	0.96	263.15	1.9 × 10 ⁻⁴	0.99
		700	252.14	1.10 × 10 ⁻³	0.92	322.58	2.6 × 10 ⁻⁴	0.99
		1000	290.03	1.84 × 10 ⁻³	0.96	434.78	1.3 × 10 ⁻⁴	0.99
	Copper	100	33.78	3.60 × 10 ⁻³	0.94	74.62	3.4 × 10 ⁻⁴	0.99
		300	76.70	1.80 × 10 ⁻³	0.98	112.35	5.3 × 10 ⁻⁴	0.99
		500	172.43	1.10 × 10 ⁻³	0.97	222.22	4.5 × 10 ⁻⁴	0.99
		700	327.01	0.60 × 10 ⁻³	0.94	384.61	4.0 × 10 ⁻⁴	0.99
		1000	482.99	1.80 × 10 ⁻³	0.99	714.28	8.0 × 10 ⁻⁵	0.99
	Nickel	100	36.96	4.60 × 10 ⁻³	0.92	105.26	1.6 × 10 ⁻⁴	0.99
		300	99.48	2.99 × 10 ⁻³	0.95	185.18	1.9 × 10 ⁻⁴	0.99
		500	177.68	1.84 × 10 ⁻³	0.96	256.41	2.5 × 10 ⁻⁴	0.99
		700	249.63	9.21 × 10 ⁻⁴	0.96	312.50	3.9 × 10 ⁻⁴	0.99
		1000	307.96	1.15 × 10 ⁻³	0.96	400.00	2.6 × 10 ⁻⁴	0.99
	Lead	100	62.27	2.50 × 10 ⁻³	0.95	106.38	3.7 × 10 ⁻⁴	0.99
		300	149.90	3.40 × 10 ⁻³	0.94	312.50	8.7 × 10 ⁻⁵	0.99
		500	275.88	2.30 × 10 ⁻³	0.95	476.19	8.2 × 10 ⁻⁵	0.99
		700	368.70	2.90 × 10 ⁻³	0.95	625.00	6.6 × 10 ⁻⁵	0.99
		1000	424.11	1.15 × 10 ⁻³	0.95	833.00	3.7 × 10 ⁻⁵	0.99
<i>Syzygium aromaticum</i>	Zinc	100	34.46	4.10 × 10 ⁻³	0.89	82.64	2.6 × 10 ⁻⁴	0.99
		300	108.85	2.50 × 10 ⁻³	0.86	181.81	2.5 × 10 ⁻⁴	0.99
		500	181.27	9.20 × 10 ⁻⁴	0.93	222.22	5.2 × 10 ⁻⁴	0.99
		700	225.87	9.21 × 10 ⁻⁴	0.95	277.77	4.4 × 10 ⁻⁴	0.99
		1000	196.36	1.30 × 10 ⁻³	0.95	256.41	3.2 × 10 ⁻⁴	0.99
	Copper	100	23.57	2.70 × 10 ⁻³	0.92	43.29	8.2 × 10 ⁻⁴	0.99
		300	77.47	2.70 × 10 ⁻³	0.98	140.84	2.4 × 10 ⁻⁴	0.99
		500	175.91	1.30 × 10 ⁻³	0.96	238.09	3.2 × 10 ⁻⁴	0.99
		700	323.75	0.60 × 10 ⁻³	0.95	370.37	4.6 × 10 ⁻⁴	0.99
		1000	487.84	1.60 × 10 ⁻³	0.97	666.66	1.0 × 10 ⁻⁵	0.99
	Nickel	100	36.96	3.68 × 10 ⁻³	0.91	83.33	3.0 × 10 ⁻⁴	0.99
		300	120.30	1.84 × 10 ⁻³	0.95	181.81	3.1 × 10 ⁻⁴	0.99
		500	169.01	1.38 × 10 ⁻³	0.95	232.58	3.3 × 10 ⁻⁴	0.99
		700	228.14	1.15 × 10 ⁻³	0.94	285.71	3.9 × 10 ⁻⁴	0.99
		1000	281.46	1.15 × 10 ⁻³	0.96	357.14	3.0 × 10 ⁻⁴	0.99
	Lead	100	38.09	5.00 × 10 ⁻³	0.92	121.95	1.2 × 10 ⁻⁴	0.99
		300	113.29	5.00 × 10 ⁻³	0.91	357.14	4.1 × 10 ⁻⁵	0.99
		500	210.60	4.30 × 10 ⁻³	0.91	526.31	3.9 × 10 ⁻⁵	0.99
		700	284.29	3.90 × 10 ⁻³	0.91	666.66	3.4 × 10 ⁻⁵	0.99
		1000	292.94	5.00 × 10 ⁻³	0.91	909.14	1.6 × 10 ⁻⁵	0.99

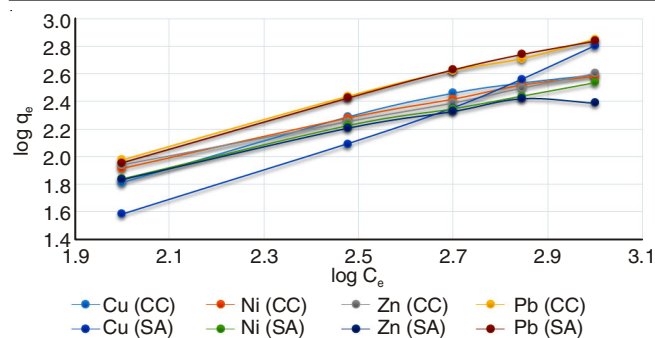


Fig. 7. Freundlich isothermal study of *Carissa carandas* (CC) and *Syzygium aromaticum* (SA): A comparative study

pseudo second order have been used. Pseudo-first-order kinetic model and pseudo-second-order kinetic model are examined and reported in Table-2. It was observed that pseudo-second-order kinetic model was best fitted for both biosorbents.

Conclusions

- The present study focused on the use of *Carissa carandas* leaves and *Syzygium aromaticum* (clove) powder as biosorbents for the removal of copper(II), zinc(II), nickel(II) and lead(II) from aqueous solutions. Biosorbent preparation, agitation, characterization and their uses for these metals removal at different operating conditions are reported well.

- Biosorbent *Carissa carandas* leaf powder showed higher sorption efficiency than that of biosorbent *Syzygium aromaticum* powder under identical experimental conditions.

- Agitation time and temperature also very important parameter for biosorption of heavy metals. The higher biosorption was observed at 180 min and 30 °C for lead(II), nickel(II) and copper(II) for *Carissa carandas*.

- Langmuir isotherm models observed best equilibrium data in case of all four metals and both biosorbents and pseudo second order kinetics model perfectly matched in both biosorbents in all four metal ions.

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REFERENCES

1. D. Hinrichsen and H. Tacio, The Coming Freshwater Crisis is Already Here. The Linkages Between Population and Water, Woodrow Wilson International Center for Scholars; Washington, DC (2002).
2. S. Mahiya, G. Lofrano and S.K. Sharma, *Int. J. Chem.*, **3**, 132 (2014).
3. F. Fu and Q. Wang, *J. Environ. Manage.*, **92**, 407 (2011).
4. L.M. Plum, L. Rink and H. Haase, *Int. J. Environ. Res. Public Health*, **7**, 1342 (2010).

5. R.K. Gautam, S.K. Sharma, S. Mahiya and M.C. Chattopadhyay, Contamination of Heavy Metals in Aquatic Media: Transport, Toxicity and Technologies for Remediation, Royal Society of Chemistry Publications, UK (2014).
6. C.K. Jain, D.C. Singhal and M.K. Sharma, *J. Hazard. Mater.*, **114**, 231 (2004).
7. C.M.A. Ademorati, Environmental Chemistry and Toxicology, Foludex Press Ltd., Ibadan (1996).
8. K. Schumann, *Z. Ernährungswiss.*, **29**, 54 (1990).
9. USEPA (United States Environmental Protection Agency), Mercury Study Report to Congress, Volume VII: Characterization of Human Health and Wildlife Risks from Mercury Exposure in the United States. p. 19; <http://www.epa.gov/ttn/oarpg/t3/reports/volume7.pdf> accessed 8 November (2006).
10. USEPA, Drinking Water Criteria Document for Copper, US Environmental Protection Agency, Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH, USA (1987).
11. WHO (World Health Organization), Guidelines for Drinking-Water Quality, Incorporating First addendum to third Edition, World Health Organization, Geneva, Switzerland, edn 3, vol. 1 (2006).
12. WHO (World Health Organization), Guidelines for Drinking-Water Quality, Recommendations, Geneva, Switzerland, Vol. 1, edn 2 (1993).
13. WHO Guidelines for Drinking-water Quality (GDWQ), edn 4 (2011); ISBN: 978 92 4 154815 1.
14. WHO, Environmental Health Criteria 108, Nickel, WHO, Geneva, Switzerland (1991).
15. JECFA, Evaluation of Certain Food Additives and Contaminants: Sixty-First Meeting of the Joint FAO/WHO Expert Committee on Food Additives, Geneva, World Health Organization (WHO Technical Report Series No. 922), (2004).
16. JECFA, Methylmercury, In: Safety Evaluation of Certain Food Additives and Contaminants, Report of the 61st Joint FAO/WHO Expert Committee on Food Additives. Geneva, World Health Organization, International Programme on Chemical Safety, WHO Technical Report Series, pp 132-139 (2004); http://whqlibdoc.who.int/trs/WHO_TRS_922.pdf.
17. P.S. Kumar, A. Saravanan and M. Yashwanthraj, *Textiles Clothing Sustain.*, **2:3**, 1 (2016).
18. M.A. Barakat, *Arabian J. Chem.*, **4**, 361 (2011).
19. M.A. Jayasri and K. Suthindhiran, *Appl. Water Sci.*, **1** (2016).
20. S. Mahiya, G. Lofrano and S.K. Sharma, *Chem. Sci. Transac.*, **3**, 1228 (2014).
21. D. Mani and C. Kumar, *Int. J. Environ. Sci. Technol.*, **11**, 843 (2014).
22. A. Fatehizadeh, S. Rahimi, M. Ahmadian, R. Barati, N. Yousefi, S.P. Moussavi, K. Rahimi, S. Reshadat, S.R. Ghasemi and N.R. Gilan, *Int. J. Environ. Health Eng.*, **3**, 31 (2014).
23. R.A.K. Rao and S. Ikram, *Int. J. Environ. Eng.*, **7**, 179 (2015).
24. A. Razzaz, S. Ghorban, L. Hosayni, M. Irani and M. Aliabadi, *J. Taiwan Institute Chem. Eng.*, **58**, 333 (2016).
25. A. Hernández-Estévez and E. Cristiani-Urbina, *Environ. Monit. Assess.*, **186**, 7987 (2014).
26. J. Komkiene and E. Baltreinaite, *Int. J. Environ. Sci. Technol.*, **13**, 471 (2016).
27. M.N. Zafar, I. Aslam, R. Nadeem, S. Munir, U.A. Rana and S.U.-D. Khan, *J. Taiwan Institute Chem. Eng.*, **46**, 82 (2015).
28. K. Swamalatha and S. Ayooob, *Int. J. Sustainable Eng.*, **1** (2016).
29. Q. Li, B. Chen, P. Lin, J. Zhou, J. Zhan, Q. Shen and X. Pan, *Int. J. Phytoremediation*, **18**, 103 (2016).
30. G. Yuvaraja, S.M. Venkata, M. Naushad and A. Krishnaiah, *Desalination Water Treat.*, **54**, 200 (2015).
31. T. Cerchiara, A. Chidichimo, A. Aloise and G. Chidichimo, *J. Nat. Fibers*, **13**, 77 (2016).
32. S.K. Sharma, S. Mahiya and G. Lofrano, *Appl. Water Sci.*, **1** (2015).