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Application of Cockle (*Anadara granosa*) Shell Waste as an Adsorbent of Heavy Metal Cadmium (Cd), Copper (Cu), and Lead (Pb)

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Abstract

Heavy metal is one of the water pollutants that are harmful to the environment and humans. Cockle (*Anadara granosa*) is only used for meat so that the shells become waste that pollutes the environment. This study examines the ability of cockle shell powder as an adsorbent in the process of adsorption of heavy metals cadmium (Cd), copper (Cu), and lead (Pb). The ability of the adsorbent was tested through the batch method, using a glass beaker (100 ml) at a speed of 90 rpm; initial metal concentration 20 ppm; adsorbent weighing 0.1 – 0.5 grams; contact time of 20 minutes and 30 minutes. The results showed that the adsorbent weighing 0.5 grams can reduce > 75% concentration of cadmium (Cd), copper (Cu), and lead (Pb). Freundlich and Langmuir adsorption isotherms of cadmium (Cd), copper (Cu), and lead (Pb) had R^2 > 0.9.

INTRODUCTION

Water pollution by heavy metals has significantly increased over the last decades. Heavy metals in the water environment mostly come from anthropogenic activities such as smelting, mining, and electronic manufacturing. The toxicity of heavy metals constitutes a great risk to the environment and human health. Today, about 80% of the global wastewater has untreated. Once water is contaminated, it is difficult, costly, and often impossible to remove the pollutants. The nature and amount of pollutants in water determines the suitability of water for many human uses such as drinking, bathing, and agriculture (United Nations Environment Programme (UNEP), 2021). United Nations (UN) (2021) reported that 1 in 3 people live without safe drinking water, and approximately 5.7 billion people in 2050 could be living in areas where water is scarce for at least one month a year. Therefore, the removal of heavy metal pollutants from contaminated water and wastewater has received increasing attention among the scientific community.

Indonesia as a maritime country with a coastline of 81.000 km, has the potential for abundant shellfish. Cockle (*Anadara granosa*) has a delicious taste, easy to find in the market, has high and complete nutritional content, and is an affordable price. Cockle meat contains:

crude protein (15.95 %), carbohydrates (1.33 %), crude fat (1.6 %), water (78.69 %) and ash (2.44 %) (Bhara *et al*., 2018). Financially, the cockle farming industry has considerably boosted the Indonesian economy. However, the disposal of cockle shell waste has led to environmental problems, namely blocks access roads, reduces the aesthetics of an area, and causes bad odor. Therefore, the recycling of cockle shell waste has become an issue of concern. To date, a portion of cockle shell waste has been recycled for use as souvenirs, fertilizers, and animal feed. Hence, alternative approaches are required for the recycling of cockle shell waste.

Several studies have been conducted in Indonesia to evaluate possible means of reusing bivalve shell waste material for heavy metals removal from contaminated water. Anugerah dan Iriany (2015) used cockle (*Anadara antiquata*) shell waste to remove cadmium (Cd) and lead (Pb) from an aqueous solution. Pridyanti *et al*. (2018) used blue mussel (*Corbula Faba*) shell waste to remove chromium (Cr) from batik liquid waste. While Matondang (2019) used windowpane oyster (*Placuna placenta*) shell to remove lead (Pb) from electroplating liquid waste. Therefore, in this study, we examined the use of cockle shell waste as an adsorbent of heavy metal cadmium (Cd), copper (Cu), and lead (Pb) from an aqueous solution.

METHODOLOGY

Place and Time

The research was conducted from January to October 2020 at Laboratory of Multipurpose I, Faculty of Pharmacy, Airlangga University, Surabaya.

Research Materials

The materials used in this research were cockle (*A. granosa*) shell waste from a traditional market in Surabaya, East Java;$(CH_3COO)_2Cd.2H_2O$ 99 % p.a (Merck, Germany); $CuSO_4$ 99 % p.a (Merck, Germany); $(CH_3COO)_2Pb.3H_2O$ 99,5 % p.a (Merck, Germany), HNO_3 65 % p.a (Merck, Germany); and aquadest p.a.

The main equipment was magnetic plate (IKA C-MAG HS 10), atomic absorption spectrophotometry (Shimadzu AA-7000), attenuated total reflection (Bruker Alpha II), and analytical balances (Ohaus).

Research Design

The research method used is experimental. The research design used for the adsorbent weight and contact time variable is a non-parametric test, meanwhile, the heavy metal type variable is a randomized block design. The batch adsorption method is applied with various variables. The adsorbent weight used is P1 (0.1 gram), P2 (0.2 gram), P3 (0.3 gram), P4 (0.4 gram) and P5 (0.5 gram). The contact time used is 20 and 30 minutes. Each treatment has triplicate.

Work Procedure

Adsorbent Preparation

Cockle (*A. granosa*) shell waste was washed with aquadest to remove dust and other debris. Then it was sun-dried for 2 days to reduce moisture. The dried cockle shell was crushed and sieved to particles (200 µm). The sieved powder was stored in the desiccator, and used for the batch experiment.

Adsorbent Characterization

The metal composition of the cockle (*A. granosa*) shell was determined by x-ray fluorescence (XRF), which was analyzed in Laboratorium Energi-LPPM Institut Teknologi Sepuluh Nopember, Surabaya. The functional group was determined using attenuated total reflectance-fourier transform infrared (ATR-FTIR) (Bruker Alpha II).

Heavy Metal Solution

The solutions of cadmium, copper, and lead ions were prepared by dissolving certain amounts of heavy metal in 1 % HNO_3 into 1000 ml volumetric flasks. The amount of cadmium used is 2.3950 grams, copper is 2.5370 grams, lead is 1.8408 grams. The initial heavy metal concentration is 20 ppm.

Adsorption Experiment

The adsorption experiment was carried out by adding amounts of the adsorbent to 10 ml of heavy metal solution in beaker glass (100 ml), then placed on a magnetic plate and stirred using a magnetic stirrer (0.8 cm) at a speed of 90 rpm. Separation of heavy metal solutions using Whatman 42 filter paper. The initial and final heavy metal concentrations were determined by atomic absorption spectrophotometer.

Adsorption Ability

The adsorption ability was calculated according to the following equations (Mustapha *et al.*, 2019):

$$R = \frac{(Co - Ce)}{Co} \times 100\%$$

$$Qe = \frac{(Co - Ce) \times v}{m}$$

Where:
R = removal (%)
Qe = adsorption capacity (mg/kg)
Co = initial metal concentration (ppm)
Ce = final metal concentration (ppm)
v = volume of metal solution (ml)
m = mass of adsorbent (g)

Adsorption Isotherm

The adsorption isotherm and constant were calculated according to the following equations (Mustapha *et al.*, 2019):

Freundlich Isotherm:

$$\text{Log Qe} = \text{Log KF} + \frac{1}{n} \times \text{Log Ce}$$

Langmuir Isotherm:

$$\frac{Ce}{Qe} = \frac{1}{qmax\,.\,KL} + \frac{1}{qmax} \times Ce$$

Where:
Qe = adsorption capacity (mg/kg)
Ce = final metal concentration (ppm)
KF = maximum adsorption capacity (mg/kg)
qmax = maximum adsorption capacity (mg/kg)
n = affinity parameter
KL = affinity parameter

Data Analysis

Statistical analysis was performed with SPSS (version 22). The results are expressed as mean±SD. Kruskal-Wallis test was used to analyze the correlation between adsorbent weight with adsorption ability. Mann-Whitney test was used to analyze the correlation between contact time with adsorption ability. The effect of heavy metal type was examined using One-Way ANOVA, then followed by Duncan's multiple range test. The isotherm model and constant were analyzed using Microsoft Excel (version 2013).

RESULTS AND DISCUSSION

Adsorbent Characteristics

Cockle (*A. granosa*) shell contains chitin–protein fiber that is associated with various amounts of $CaCO_3$ and other minerals (de Paula and Silveira, 2009), representation of cockle shell as given in Figure 1. Mineral composition and certain functional groups are responsible for the heavy metal uptake from an aqueous solution. Figure 2 shows that the most mineral element which is contained in adsorbent is calcium (93.315 %). The amount of other mineral is aluminium (0.74 %); silicon (1.55 %); sulfur (0.08 %); titanium (0.255 %); vanadium (0.013 %); manganese (0.17 %); iron (3.065 %); copper (0.086 %); strontium (0.691 %); barium (0.04 %); and zirconium (0.0025 %).

Figure 3 shows the ATR-FTIR analysis result of adsorbent, which was further confirm to contain $CaCO_3$ phase with a characteristic peak at 699, 712, 765, 861, and 1470 cm^{-1}, which indicates the CO_3^{2-} group. Besides that, the peak was shown at 1785 and 2508 cm^{-1} also attributed to the combination modes of different CO_3^{2-} spectrum (Khiri *et al.*, 2016). Adsorbent had the characteristic peak which indicates polymorph form of $CaCO_3$, that is aragonite at 699 and 861 cm^{-1}, calcite at 712 cm^{-1}, vaterite at 765 cm^{-1}. The peak at 3201 until 3703 cm^{-1} corresponds to N-H stretching group

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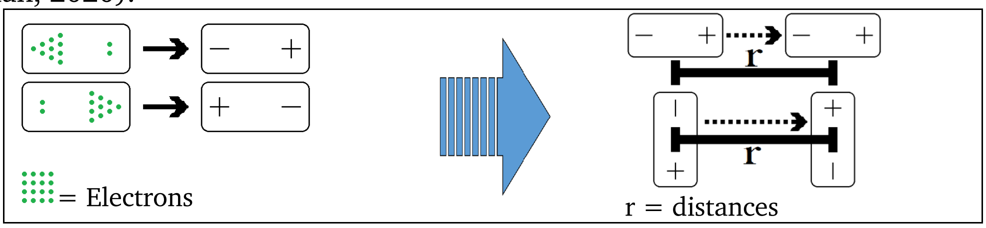
present in chitin and protein. The peak at 3819 and 3849 cm^{-1} is related to O-H stretching group present in CaO (Konwar and Baruah, 2017). Based on the adsorbent characteristics, it can be concluded that the cockle (*Anadara granosa*) shell contains various mineral oxide compounds (such as SiO_2, Al_2O_3, Fe_2O_3, $CaCO_3$, and MnO) and functional groups (such as CO_3^{2-}, N-H, and O-H) that can be used as heavy metal adsorbent.

Adsorption Ability

The highest removal value is Pb.P5.30 (98,44±0,02 %) (lead; 0.5 gram adsorbent weight; contact time for 30 minutes), meanwhile the lowest removal value is Cd.P1.20 (21,76±0,79 %) (cadmium; 0.1 gram adsorbent weight; contact time for 20 minutes). The highest adsorption capacity value is Pb.P1.30 (711,9±51,7 mg/kg) (lead; 0.1 gram adsorbent weight; contact time for 30 minutes), meanwhile the lowest adsorption capacity value is Cd.P5.20 (312,9±0,8 mg/kg) (cadmium; 0.5 gram adsorbent weight; contact time for 20 minutes). The increase in adsorbent weight affects removal and adsorption capacity ($P < 0.05$; Figure 4; Table 1). This could be due to the increase in adsorbent weight is followed by an increase in the adsorbent surface area, pore size and volume, and the availability of vacant sites (Handayani and Sulistiyono, 2009).

The type of heavy metals affects removal and adsorption capacity ($P < 0.05$; Figure 4; Table 1). This could be due to the electronegativity of heavy metal. The more electronegative an element, the more it can attract electrons (Shaheen *et al*., 2018). The contact time does not affect removal and adsorption capacity ($P > 0.05$; Figure 4; Table 1). This could be due to the contact time has not reached the equilibrium point. The longer the contact time, the more opportunities for the adsorbent to interact with heavy metals (Handayani and Sulistiyono, 2009). Sorption is a general term that refers to all phenomena at adsorbent–heavy metal solution interface, the mechanism of heavy metal adsorption by the adsorbent can be explained by the following examples.

(i) Van der Waals force: attraction forces between heavy metals ion and adsorbent surface ion (Than, 2020).



(ii) Co-precipitation: the reaction of heavy metals with adsorbents to form water-insoluble substances (Handoko *et al*., 2013).

$2CO_3^{2-}$	$+ 5Cd^{2+}$	$+ 6H_2O$	$\rightarrow Cd_5(CO_3)_2(OH)_6$	$+ 6H^+$
$2SiO_4^{2-}$	$+ 5Cu^{2+}$	$+ 6H_2O$	$\rightarrow Cu_5(SiO_4)_2(OH)_6$	$+ 6H^+$
$2PO_4^{3-}$	$+ 3Pb^{2+}$	$+ 6H_2O$	$\rightarrow Pb_3(PO_4)_2(OH)_6$	$+ 6H^+$

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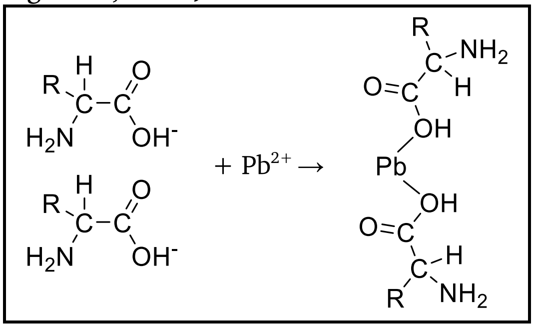
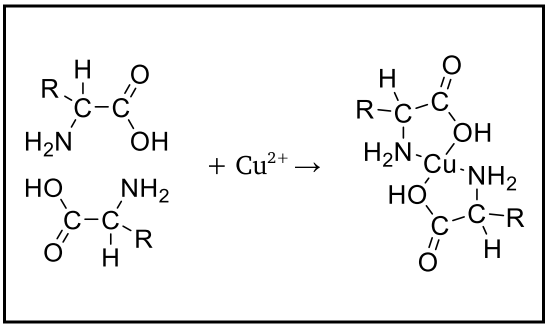
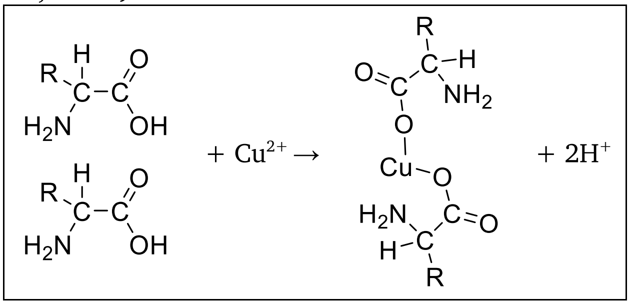
(iii) Electrostatic Attraction: attraction interactions between different charges molecules (Yang *et al*., 2019).





(iv) Ion Exchange: exchange one or more heavy metals ion with equivalent adsorbent ion (Said, 2010).



$CaCO_{3\,(s)} + Cd^{2+} \rightarrow CdCO_{3\,(s)} + Ca^{2+}$
kation exchange stage:
$CaCO_{3\,(s)} \rightarrow Ca^{2+} + CO_3^{2-}$
$CO_3^{2-} + H^+ \rightarrow HCO_3^-$
$HCO_3^- + H^+ \rightarrow H_2O + CO_{2\,(g)}$
$CO_3^{2-} + Cd^{2+} \rightarrow CdCO_{3\,(s)}$

Adsorption Isotherm

The adsorption isotherm is a relationship between adsorbate in the liquid phase and the adsorbate adsorbed on the surface of the adsorbent at equilibrium at constant temperature (Handayani and Sulistiyono, 2009). The decrease in the value of n and R_L correlated with the lower value of removal and adsorption capacity between the three metals, which indicates favorable heavy metal uptake; as given in Table 1 and 2. The n values measure the favourability of the adsorption process. The n values for the metal ions correspond to the favorable adsorption process of $0 < n < 10$. The R_L value describe whether the adsorption is irreversible ($R_L = 0$), favourable ($0 < R_L < 1$) or linear or unfavourable ($R_L = 1$ or $R_L > 1$) (Mustapha *et al*., 2019).

The Freundlich isotherm showed a better fit to the experimental data with higher correlation coefficients (R^2) for all the heavy metals; as given in Table 2. The Freundlich isotherm was used to reveal chemisorption, while Langmuir isotherm to informed about physisorption (Handayani and Sulistiyono, 2009). The reason behind physisorption is Van der Waals forces, whereas chemical bonds lead to chemisorption. Physisorption is reversible; multilayer adsorption; favor in low temperatures; forming weak bonds; has less activation energy. Chemisorption is irreversible; monolayer adsorption; favor in high temperatures; forming strong bonds; has high activation energy (Murachman *et al*., 2014).

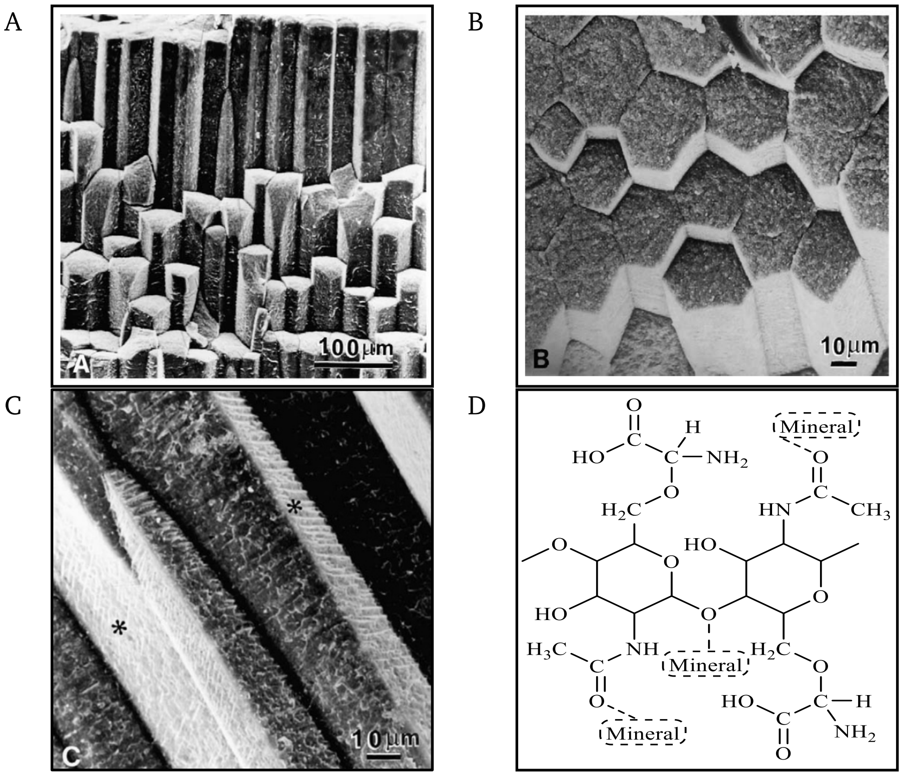


Figure 1. The prismatic layer of the Bivalve shell, fractured in a plane perpendicular to its outer surface (SEM, 25 kV) (de Paula and Marina Silveira, 2009). A. The aragonitic simple prisms, about 1 mm high, were cut at different levels. B. End-on view of the crystals showing hexagonal or pentagonal bases; their polycrystalline character is evident. C. Periodic growth steps (*) and remains of the biological matrix decorate the lateral surfaces of all prisms. D. Illustration of a mineral-chitin-protein complex in cockle shell.

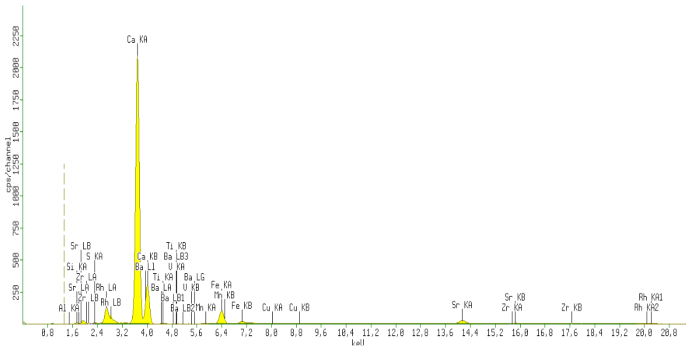


Figure 2. XRF analysis result of adsorbent mineral element composition.

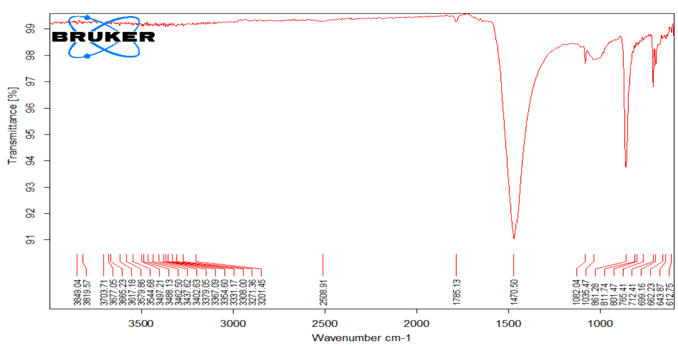


Figure 3. ATR-FTIR analysis result of adsorbent functional group.

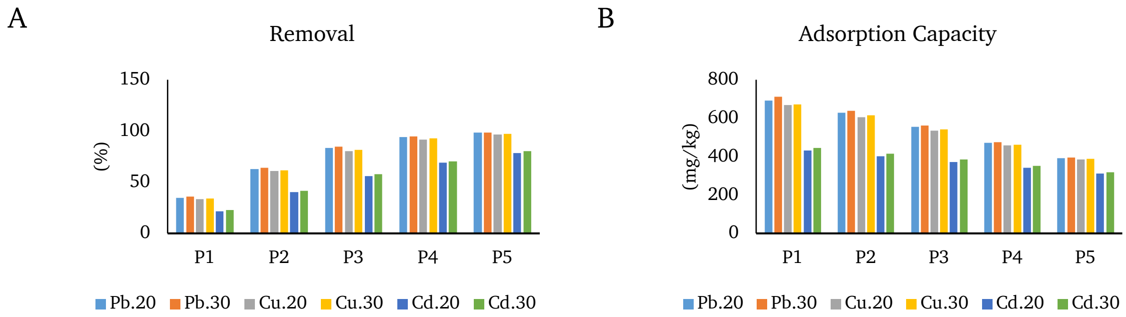


Figure 4. (A) Removal (%), (B) Adsorption capacity (mg/kg). Description: adsorbent weight at P1 (0.1 gram), P2 (0.2 gram), P3 (0.3 gram), P4 (0.4 gram), P5 (0.5 gram); Pb (lead), Cu (copper), Cd (cadmium); contact time for 20 minutes (20) and 30 minutes (30).

Table 1. Adsorption ability.

Treatments	Removal (%)			Adsorption Capacity (mg/kg)		
	Lead (Pb)	Copper (Cu)	Cadmium (Cd)	Lead (Pb)	Copper (Cu)	Cadmium (Cd)
t: 20						
P1	34,76±1,68^{a}	33,67±0,68^{a}	21,76±0,79^{a}	690,2±33,1^{a}	666,6±13,0^{a}	430,7±15,6^{a}
P2	62,93±0,42^{b}	60,94±0,19^{b}	40,40±0,60^{b}	627,6±3,3^{ab}	606,5±2,8^{ab}	401,9±6,3^{ab}
P3	83,48±0,26^{c}	80,57±0,20^{c}	56,00±0,45^{c}	556,2±0,9^{bc}	535,4±0,5^{bc}	372,1±2,7^{bc}
P4	94,04±0,19^{d}	91,60±0,09^{d}	68,76±0,44^{d}	470,2±0,6^{cd}	456,9±0,3^{cd}	343,0±2,0^{cd}
P5	98,22±0,02^{e}	96,63±0,04^{e}	78,37±0,21^{e}	392,7±0,1^{d}	385,8±0,1^{d}	312,9±0,8^{d}
t: 30						
P1	35,88±2,57^{a}	33,99±0,70^{a}	22,53±0,79^{a}	711,9±51,7^{a}	673,0±12,8^{a}	446,4±14,9^{a}
P2	64,11±0,51^{b}	61,74±0,38^{b}	41,79±0,58^{b}	639,4±5,3^{ab}	614,3±3,3^{ab}	415,8±5,0^{ab}
P3	84,55±0,17^{c}	81,55±0,21^{c}	57,86±0,43^{c}	562,9±1,4^{bc}	542,0±1,0^{bc}	384,4±2,6^{bc}
P4	94,65±0,17^{d}	92,59±0,06^{d}	70,55±0,29^{d}	473,4±0,9^{cd}	461,9±0,2^{cd}	351,8±0,9^{cd}
P5	98,44±0,02^{e}	97,22±0,03^{e}	80,00±0,19^{e}	393,5±0,4^{d}	388,1±0,5^{d}	319,3±0,9^{d}

[*a,b,c,d,e]: different superscript letters within the same column indicate significant differences ($p < 0.05$). Description: adsorbent weight at P1 (0.1 gram), P2 (0.2 gram), P3 (0.3 gram), P4 (0.4 gram), P5 (0.5 gram); Pb (lead), Cu (copper), Cd (cadmium); contact time for 20 minutes (20) and 30 minutes (30).

Table 2. Isotherm model and constant.

Isotherm Model	Isotherm Constant	Contact Time for 20 Minutes			Contact Time for 30 Minutes		
		Lead (Pb)	Copper (Cu)	Cadmium (Cd)	Lead (Pb)	Copper (Cu)	Cadmium (Cd)
Freundlich	K_F (mg/g)	461	416,1	217,4	472,2	432,1	226,6
	n	6,39	5,43	4,03	6,35	5,78	4,03
	R^2	0,9997	0,9999	0,9999	0,9992	0,9999	1
Langmuir	q_{max} (mg/g)	1111	769,2	175,4	1111	909,1	188,7
	R_L	0,07	0,05	0,02	0,07	0,06	0,02
	R^2	0,9968	0,9964	0,9977	0,9958	0,9967	0,9978

CONCLUSION

Cockle (*A. granosa*) shell waste can be used as an adsorbent for cadmium (Cd), copper (Cu), and lead (Pb). Pb.P5.30 (lead; 0.5 gram; contact time for 30 minutes) treatment had the highest average removal value of 98.44 %. Cadmium (Cd), copper (Cu), and lead (Pb) tend to exhibit the Freundlich isotherm pattern.

Based on the results of the research, it is recommended to modify the preparation of cockle (*A. granosa*) shell waste as an adsorbent to increase its effectiveness. Then, further research is needed through in vivo tests on fishery products to confirm the quality of the

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adsorbent in order to qualify food-grade standards.

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