Adsorption capacity of heavy metal cadmium using white sand as adsorbent

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Abstract. The aims of this study are to know the adsorption ability of white sand from Medan Indonesia to adsorb cadmium ions (Cd\(^{2+}\)) from the solution at pH 4.5. The variables were on different size of white sand, the rpm of shaker and Cd concentrations. The first step was to determine the optimum contact time and adsorption capacity. The adsorption capacity on 70 ppm Cd ions with 40 mesh sand size and stirring speed 150 rpm is 38% after 100 minutes operation time. Impact of sand size 10 mesh, 20 mesh and 40 mesh is possible to increase the adsorption capacity. Increasing the rpm will impact to interaction stability the Cd ion on sand surface. White Sand has ability to interact with metal ions dissolve in solution.

1. Introduction

Along with the development of human knowledge and understanding of the environment, pushing various efforts to protect and preserve the environment due to damage to the groundwater system around the industry. The effort that can be made by humans to reduce the level of contamination of toxic substances in groundwater of around the industry is to reduce the level of pollution in the groundwater [1].

Trace metals into environmental wastewaters has led to the discharge from industrial and non-biodegradable. The metals tend to accumulate in environment. Cadmium (Cd) is the trace metals with its toxicity and potential hazard to the natural and organisms. The World Health Organization (WHO) has regulation with maximum permissible concentration of Cd(II) in drinking water is 5 ppb [2].

Chemical precipitation, electrodialysis, membrane separations, filtration, ion exchange, and adsorption are established methods on pretreatment of wastewater those have substantially in reducing Cd(II) [2]. The adsorption method is the one method of separation that is effective, efficient, economical, environmentally friendly and proven effective for reducing the concentration of heavy metals in groundwater. It is said to be effective, efficient, economical, environmentally friendly because it has been proven by previous researchers, using various adsorbents such as zeolite [3], charcoal [4], various agricultural waste such as corn husk [5], coconut peel [6], rice husk ash [7], apu wood (Pistiastratiotes L) [8], cassava peel [9] or corn stalk [10].

Sand has reported as adsorbent. The reason to used sand because it has macro-porous and mesoporous structures. Pores contribute a more surface area and a higher selectivity on reaction and adsorption interaction. Charles W, 1994[11] has reported that sand with porous characteristic creates the intra-particle porosity. Sand as the tetrahedral silica with hydroxyl functional groups on the surface, it can be represented as =Si–OH. The functional interaction with the primary bonding force in innersphere complexes is a coordinate-covalent bonding in contrast to electrostatic bonding in outer-sphere complexes [12].
Figure 1. White sand.

The purpose of this study was to examine the ability of Indonesian white sand adsorption to absorb Heavy Metal Cadmium (Cd\(^{2+}\)) dissolved in solution. This research is useful as information regarding the contamination of sand due to waste from metal ions.

2. Method

The research was conducted at the Chemical Industry Process Laboratory, Chemical Engineering Department, Faculty of Engineering, University of Sumatra Utara, Medan and Research and Standards Agency, Ministry of Industry, Sumatra Utara Province, and PT. Indonesia Asahan Aluminum (PT. INALUM). The materials used in this study were white sand as an adsorbent, obtained from a beach located in Pantai Cermin District, Serdang Bedagai Regency, Sumatra Utara Province, Indonesia. Cadmium Chloride (CdCl\(_2\)) as a source of Cadmium ions(Cd\(^{2+}\)), Chloride Acid (HCl) and Sodium Hydroxide (NaOH) as pH regulators, and distillate water (H\(_2\)O) as solvents, purchased with the brand MERK.

The equipment used in this study is a shaker, mesh filters with sizes such as: 10, 20 and 40 mesh, then pH meters, measuring cups, beaker glass, funnel, Erlenmeyer, analytic balance, saucer, thermometer, drop pipette and Atomic Absorption Spectroscopy (AAS) which functions to measure metal content.

The measurement of adsorption kinetics was carried out by measuring the metal adsorption capacity of Cd\(^{2+}\) against the increase in operating time. At the metal ion concentration of Cd\(^{2+}\) 70 ppm, the size of the adsorbent was 40 mesh with a stirring speed of 150 rpm. A solution of Cd\(^{2+}\) 70 ppm was taken as much as 100 mL then put into Erlenmeyer, after that the white sand adsorbent was added as much as 10 grams and then stirred using a shaker at 150 rpm at room temperature. The sample was taken as much as 2 mL at an interval of 10 minutes to 2 hours. The ion concentration of Cd\(^{2+}\) in the solution after adsorption was analyzed by Atomic Absorption Spectroscopy (AAS), the qt value is the capacity of adsorbs at a certain time (t) and the R% percent capacity adsorbed by the adsorbent is calculated by formulas 1 and 2 [12][13]:

\[
q_t = \frac{(C_0 - C_t)V}{m} \quad (1)
\]

\[
R\% = \frac{(C_0 - C_e) \times 100}{C_0} \quad (2)
\]

Where: C\(_0\) is the initial metal concentration (mg/L), C\(_t\) is the metal concentration at time t (mg/L) and C\(_e\) is the metal concentration at equilibrium (mg/L); qt is (mg/g). V is the volume of solution (L) and mads is the mass of adsorbent (g) [12-13].

Measurements from the effect of the size of the adsorbent on the white sand adsorption ability were measured by the sizes of 20, 30 and 40 mesh. Adsorption capacity value with stirring speed 150 rpm and solution concentration of Cd\(^{2+}\) 70 ppm with duration of 2 hours and 24 hours. Measurements of
the effect of adsorption capacity with variations in metal ion concentration were measured at 30, 50, 70 ppm. Stirring speed was 150 rpm and size was 40 mesh white sand adsorbent. The procedure for analyzing adsorption capacity is carried out by the same process and formula.

3. Results and discussions

Sand in Indonesia has a fairly large surface area, obtained that the specific surface area of white sand adsorbent is 368 cm²/gram greater than the surface area of sand found in Indian river sand obtained by Thambavani (2014) [14], amounting to 76.75 cm²/gram. The surface area of the adsorbent is one of the important factors that are directly related to the adsorption ability and can affect the adsorption capacity of an adsorbent on substances that will be absorbed (adsorbate). If an adsorbent has a large surface area, the contact area between the adsorbent and the adsorbate will be even greater, so the adsorption process will be maximized [15]. In addition, the greater the specific surface area of an adsorbent, will increase its adsorption power. The greater the surface area of an adsorbent has the greater the adsorption power [16].

3.1. Adsorption kinetics

The adsorption process can occur because of the Van der Waals force that an adsorbent has on its molecule [17]. Figure 2. shows that the longer the contact time between white sand adsorbent and adsorbate Cd²⁺, the greater the amount of Cd²⁺ absorbed. This is caused by the longer interaction time of the adsorbent with the adsorbate causing an increase in the adsorption ability of Cd²⁺.

![Figure 2. Metal adsorption capacity of Cd²⁺ with metal ion concentration Cd²⁺ 70 ppm, adsorbent size of 40 mesh and stirring speed 150 rpm [12].](image)

According to the theory of Putranto, et al. (2014) [18], equilibrium adsorption can be achieved, sufficient contact time is needed between the adsorbate and the adsorbent. From Figure 2 it can be seen that the highest adsorbed Cd²⁺ concentration is at 360 minutes with adsorbed Cd²⁺ concentration of 39.31%. The equilibrium time is determined to find out when an adsorbent is saturated until the adsorption process has been completed. In this situation, the surface capacity of white sand adsorption is saturated and equilibrium has been reached at the contact time above 100 minutes.

According Haryanto et al., 2018 The adsorption capacity was changes largely in the first 10 minutes. It was lower in comparing the ability of white sand. After some time, the ability of the adsorption capacity starts to decline and relatively constant. The adsorption equilibrium can be achieved by measuring the contact time between the adsorbent with the adsorbate Cd²⁺. For the white sand, adsorption capacity continues to increase to adsorb Cd²⁺ ion until the time of 300 minutes with the concentrations of adsorbate Cd²⁺.
3.2. Adsorption capacity
Adsorption kinetic can be used to determine the adsorption rate on the adsorbent to the adsorbate which is affected by time. The contact time needed to achieve adsorption equilibrium is used as a measure of the adsorption rate.

![Figure 3](image1.png)

**Figure 3.** Adsorption capacity value with adsorbent size variation at stirring speed 150 rpm and Cd$^{2+}$ 70 ppm solution concentration.

![Figure 4](image2.png)

**Figure 4.** Adsorption capacity value with stirring speed variation at Cd$^{2+}$ 70 ppm concentration and white sand adsorbent size 40 mesh.

Stirring speed is also one of the important factors that can affect the ability and adsorption capacity of an adsorbent. The greater the stirring speed, the greater the adsorption constant. This is caused by the film layer on the adsorbent which is depleted so that adsorbent can penetrate the film layer [19]. In the adsorption process, if the stirring speed is small, then adsorbent will be difficult to penetrate the film layer between the surface of the adsorbent and the diffusion of the film. If the stirring speed is appropriate, it will increase the diffuse film to the diffusion pore point [20].
Figure 5. Adsorption capacity value with Cd$^{2+}$ solution concentration variation at stirring speed 150 rpm and size of white sand adsorbent 40 mesh.

The results of the above experiments show that the adsorption capacity is directly proportional to the concentration of metal ions. Interaction between metal ions and the adsorbent will increase as the concentration of the metal solution increases [21]. The greater the concentration of a metal solution, will increase the driving force which causes the solution to be absorbed into the active site of the adsorbent. In addition, variations in concentration are used to determine the model of adsorption isotherm that occurs during the adsorption process [22] [23].

4. Conclusions

These studies are to know the adsorption ability of white sand from Medan Indonesia to adsorb cadmium ions (Cd$^{2+}$) from the solution at pH 4.5 on with different size of white sand, the rpm of shaker and Cd concentrations as the variables. The impact of sand size 10 mesh, 20 mesh and 40 mesh is possible to increase the adsorption capacity with the best adsorbing Cd$^{2+}$ metal ions is 40 mesh. In determining the adsorption capacity with variations in stirring speed, the best is the speed of 150 rpm. The increasing of speed rpm will impact to interaction stability the Cd ions with sand surface functional and tend to decrease the capacity. The adsorption capacity on 70 ppm Cd ions with 40 mesh sand size and stirring speed 150 rpm is 38% after 100 minutes operation time. White Sand has potential as adsorbent to interact with metal ions dissolve in solution.

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