

Course Learning Outcomes for Unit VI

Upon completion of this unit, students should be able to:

1. Assess engineering principles applicable to solid and hazardous waste management.
 - 1.1 Evaluate the steps for an adsorption system design using engineering principles.
 - 1.2 Summarize engineering calculations for solid and hazardous waste treatment.

Course/Unit Learning Outcomes	Learning Activity
1.1	Unit Lesson Article: "Role of Carbohydrases in Minimizing Use of Harmful Substances: Leather as a Case Study" Unit VI PowerPoint Presentation
1.2	Unit Lesson Article: "Experimental Investigation of Adsorption Capacity of Anthill in the Removal of Heavy Metals From Aqueous Solution" Unit VI PowerPoint Presentation

Required Unit Resources

In order to access the following resources, click the links below.

Durga, J., Ramesh, R., Rose, C., & Muralidharan, C. (2017). [Role of carbohydrases in minimizing use of harmful substances: Leather as a case study](https://search-proquest-com.libraryresources.columbiasouthern.edu/docview/1905386154?accountid=33337). *Clean Technologies and Environmental Policy*, 19(5), 1567–1575. Retrieved from <https://search-proquest-com.libraryresources.columbiasouthern.edu/docview/1905386154?accountid=33337>

Yusuff, A. S., & Olateju, I. I. (2018). [Experimental investigation of adsorption capacity of anthill in the removal of heavy metals from aqueous solution](https://libraryresources.columbiasouthern.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=bsu&AN=130104586&site=ehost-live&scope=site). *Environmental Quality Management*, 27(3), 53–59. Retrieved from <https://libraryresources.columbiasouthern.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=bsu&AN=130104586&site=ehost-live&scope=site>

Unit Lesson

Introduction

Unit V presented technologies for minimization of industrial and hazardous wastes. The Unit VI Lesson builds on Unit V by assessing engineering principles. This lesson will focus on engineering design. In particular, it will explain the engineering principles for designing an adsorption tank for removal of dissolved lead from water.

Adsorption is a common process for removal of dissolved solids from water. Adsorption is a surface phenomenon in which the dissolved material is attracted to and held in the pore spaces of the adsorber material. Effective adsorbers have high porosities and mazes of pore spaces. Though carbon is the most common adsorption medium, other materials are effective. Common household filters use carbon adsorption to remove excess chlorine and trace concentrations of organic compounds from water. The image below shows the carbon from a Brita Home Water Filtration filter for household use.



A Brita Home Water Filtration system with pitcher of purified water and carbon adsorber used inside the water filter with a straw for scale is shown. This is a simple carbon adsorber process.

For treatment on an industrial scale, the container size and quantity of adsorber are much larger than for household use. Further, the adsorber material need not be carbon. Research has been conducted on many potential adsorber materials to investigate the feasibility for removing dissolved chemicals.

This lesson will consider a recently investigated material—an anthill. Anthills are common in many parts of the world. It is an inexpensive material to obtain because it is so common. Recent research by Yusuff and Olateju (2018) involved laboratory tests to remove dissolved lead and zinc from water using material gathered from anthills as the adsorbent.



An anthill, without ants, is used for collecting material for the heating process “calcination.”
(Anagoria, 2013)

In the article, the anthill material (ants removed) was collected and then heated in a furnace at 900°C. This heating process is called "calcination" even though calcium is not used. The resulting material was tested in a laboratory to appraise its ability to remove dissolved lead and zinc. This lesson will use the laboratory data from the article to design a prototype engineering process to treat an industrial wastewater. Since an anthill is somewhat new to industrial processes, our process waste stream is larger than that used in the Yusuff and Olateju (2018) article, but smaller than what might be more typical of a large-scale industrial treatment process.

Problem Statement

An industrial wastewater flowing at 100 gallons per day (100 gpd) contains 10 milligrams of dissolved lead (i.e., Pb^{+2}) per liter of water (i.e., 10 mg/L). The wastewater is to be treated so that the lead concentration is less than 1 mg/L.

Use the laboratory test data in Yusuff and Olateju (2018) to determine the tank size required and the mass of anthill required per day.

Abbreviations, Unit Conversions, and Nomenclature

Abbreviations:

g = gram
gal = U.S. gallon
gpd = gallons per day
kg = kilogram
lb = Pound
L = Liter (note that liter is typically lowercase (l), but used here in uppercase (L) to avoid confusion with the number one (1).
mg = milligram
mL = milli Liter
min = minute
rpm = Revolutions per minute
°C = Degree Celsius

Unit conversions:

1 gal = 3.785 L
1 kg = 2.205 lb
1 L = 1,000 mL
1 g = 1,000 mg

Nomenclature:

C_e = Effluent lead concentration (e.g., mg/L)
 C_o = Influent lead concentration (e.g., mg/L)
 C_{ep} = Prototype effluent lead concentration (e.g., mg/L)
 C_{op} = Prototype influent lead concentration (e.g., mg/L)
 E_A = Lead removal efficiency (%)
 k_F = Freundlich coefficient $[mg/g(L/mg)^{1/n}]$
 n = Freundlich exponent
 M_L = Mass of anthill in laboratory flask (g)
 M_p = Mass of anthill required for prototype (e.g., g)
 m_e = Prototype effluent lead mass flow rate (e.g., g/day)
 m_o = Prototype influent lead mass flow rate (e.g., g/day)
 m_{sp} = Mass rate of lead sorbed to anthill in prototype (e.g., g/day)
pH = Optimum hydrogen potential
 q_e = Mass of lead sorbed to anthill per mass of anthill (e.g., mg/g)
 R^2 = Regression coefficient
 Q = Prototype wastewater flow rate (e.g., L/day)

T = Temperature ($^{\circ}\text{C}$)
 t_L = Contact time in laboratory batch experiments (min)
 V_L = Volume of laboratory flask (mL)
 ω = Mixing rate (rpm)

Description

Yusuff and Olateju (2018) conducted tests by putting 0.2 g of anthill into 250 mL flasks and adding water containing lead at various concentrations to the flasks. Each concentration represented a different test. The lead concentrations varied from C_o of 10 to 60 mg/L. After adding the lead-containing water to a flask, the flask was stirred at a rate of 150 rpm for 90 minutes. Then, the water was filtered to keep the anthill material from passing through the filter. The water that passed through the filter was the treated effluent. Its lead concentration was determined and given the symbol C_e . Lead that was not in the effluent was adsorbed to the anthill.

For each test, the authors computed q_e , which is the mass of lead sorbed to the anthill per unit mass of anthill in the test. The tests used 0.2 g of anthill each. In Exhibits 6 and 10 of the article, the authors plot q_e versus C_e , which is the common means of graphing adsorption results. The authors then fit various equations to the graphs. These equations are called "isotherms" because the data used was collected at a constant temperature (35°C in this case). The most common isotherms are the Langmuir and Freundlich. The authors also fit the data to the less common Sip and Radke-Prausnitz isotherms (Yusuff & Olateju, 2018). However, the authors have errors in their analyses for those two, which will be addressed by you in your PowerPoint presentation assignment.

Of the Langmuir and Freundlich isotherms, the Freundlich gave the better fit for lead as indicated by the higher regression coefficient of 0.9903 (versus 0.9807) in Exhibit 7 in the article. Therefore, our engineering analysis will utilize the Freundlich isotherm (Yusuff & Olateju, 2018).

Engineering Analysis

From the problem statement:

$Q = 100 \text{ gpd} = 378.5 \text{ L/day}$

$C_{op} = 10 \text{ mg/L}$

$C_{ep} < 1 \text{ mg/L}$

From Yusuff and Olateju (2018):

$T = 35^{\circ}\text{C}$ (p. 54)

$t_L = 90 \text{ min}$ (p. 54)

$\text{pH} = 5$ (p. 55)

$\omega = 150 \text{ rpm}$ (p. 54)

$V_L = 250 \text{ mL}$ (p. 54)

$M_L = 0.2 \text{ g}$ (p. 56)

Section 3.2.2 of Yusuff and Olateju (2018) indicates that for an initial lead concentration of 10 mg/L, the percent removal was 95%. The article defines removal percentage in its equation (1) (p. 54):

$$E_A = \frac{100(C_o - C_e)}{C_o}$$

Since E_A and C_o are known, determine the effluent concentration to make sure it is below the target of 1 mg/L. Using algebra, solve for C_e . The first step is:

$$E_A C_o = 100(C_o - C_e)$$

Then:

$$E_A C_o = 100C_o - 100C_e$$

And:

$$100C_e = 100C_o - E_A C_o$$

Then:

$$100C_e = C_o (100 - E_A)$$

Resulting in:

$$C_e = C_o \left(1 - \frac{E_A}{100} \right)$$

Therefore, since $C_{op} = 10 \text{ mg/L}$ and $E_A = 95\%$, C_{ep} is:

$$C_{ep} = (10 \text{ mg/L}) \left(1 - \frac{95}{100} \right) = 0.5 \text{ mg/L}$$

Since 0.5 mg/L is below the required concentration of 1 mg/L, the anthill is capable of treating the wastewater.

Returning to the Freundlich isotherm (shown as equation 4 in the article on p. 56):

$$q_e = k_F C_e^{1/n}$$

where:

$k_F = 1.53$ from Exhibit 7 for lead (p. 57)

$n = 1.62$ from Exhibit 7 for lead (p. 57)

For $C_e = 0.5 \text{ mg/L}$:

$$\begin{aligned} q_e &= k_F C_e^{1/n} = (1.53) \left(0.5 \frac{\text{mg}}{\text{liter}} \right)^{1/1.62} = 0.9974 \frac{\text{mg}}{\text{g}} \\ &= 0.0009974 \frac{\text{g Pb}^{+2} \text{ sorbed}}{\text{g anthill}} \end{aligned}$$

Note that since the Freundlich equation is an empirical curve fit, the units do not cancel, but C_e must be in units of mg/L in order for q_e to have units of mg/g.

Determine the daily influent mass of lead:

$$m_o = Q C_{op} = \left(378.5 \frac{\text{L}}{\text{day}}\right) \left(10 \frac{\text{mg}}{\text{L}}\right) = 3785 \frac{\text{mg}}{\text{day}} = 3.785 \frac{\text{g}}{\text{day}}$$

Determine the daily effluent mass of lead:

$$m_e = Q C_{ep} = \left(378.5 \frac{\text{L}}{\text{day}}\right) \left(0.5 \frac{\text{mg}}{\text{L}}\right) = 189.3 \frac{\text{mg}}{\text{day}} = 0.1893 \frac{\text{g}}{\text{day}}$$

Therefore, the mass of lead sorbed onto the prototype anthill adsorber each day is:

$$m_{sp} = m_o - m_e = 3.785 \frac{\text{g}}{\text{day}} - 0.1893 \frac{\text{g}}{\text{day}} = 3.596 \frac{\text{g Pb}^{+2} \text{ sorbed}}{\text{day}}$$

This design will be such that only one treatment batch is run per day. A treatment batch requires 90 minutes as determined by the experiments in Yusuff and Olateju (2018). Thus, after running the treatment operation for 90 minutes, the rest of the work shift can be devoted to filtering the effluent, disposing of the contaminated anthill, and preparing the tank for the next treatment batch on the next day.

The mass of anthill required each day (one treatment batch per day) using an equation from LaGrega, Buckingham, and Evans (2001) is:

$$M_p = \frac{m_{sp}}{q_e} = \frac{3.596 \frac{\text{g Pb}^{+2} \text{ sorbed}}{\text{day}}}{0.0009974 \frac{\text{g Pb}^{+2} \text{ sorbed}}{\text{g anthill}}} = 3,605 \frac{\text{g anthill}}{\text{day}}$$

The next step is to determine the tank size. The experiments by Yusuff and Olateju (2018) were conducted in 250 ml flasks that contained 0.2 g of anthill each. If one tank is used for the prototype, the tank volume containing 3,605 grams of anthill is:

$$V = V_L \frac{M_p}{M_L} = (0.25 \text{ L}) \frac{3605 \text{ g anthill}}{0.2 \text{ g anthill}} = 4,507 \text{ L} = 1,191 \text{ gal}$$

Thus, one tank of 4,500 liters (1200 gallons) is necessary to treat a flow rate of 100 gpd of wastewater containing 10 mg/L of dissolved lead to an effluent concentration of less than 1 mg/L. The mass of anthill required for a 4,500-liter daily batch is 3.6 kg (7.9 lb). The pH is adjusted to 5 and temperature set to 35°C. After mixing at 150 rpm for 90 minutes, the water is filtered to remove the anthill. The filtered water is expected to have less than 1 mg/L of dissolved lead. The used anthill must be disposed of or regenerated. Then, on the next day, another 3.6 kg of fresh (or reclaimed) anthill is added to the 4,500 liter tank, and another 100 gallons of wastewater is added to the tank and mixed for another 90 minutes. The process is repeated each day (Yusuff & Olateju, 2018).

Conclusion

In this lesson, engineering principles applicable to solid and hazardous waste management were presented. A specific example using laboratory data for a unique adsorption material—the material found in anthills—illustrated the steps required in proceeding from laboratory test data to an engineering design. As a typical engineering problem would begin, the lesson began with a problem statement indicating the task of using anthill to remove dissolved lead from water by adsorption of the lead onto the anthill material. The lesson

provided detailed calculations for lead removal efficiency, lead equilibrium concentration using the Freundlich isotherm, mass loading into the adsorption tank, and tank volume.

References

- Anagoria. (2013). *Anthill in South Tyrol* [Photograph]. Retrieved from https://commons.wikimedia.org/wiki/File:2013-05-09_Ameisenhaufen_in_S%C3%BCdtirol_Formicidae_anagoria.JPG
- LaGrega, M. D., Buckingham, P. L., & Evans, J. C. (2001). *Hazardous waste management* (2nd ed.). Long Grove, IL: Waveland Press.
- Yusuff, A. S., & Olateju, I. I. (2018). Experimental investigation of adsorption capacity of anthill in the removal of heavy metals from aqueous solution. *Environmental Quality Management*, 27(3), 53–59. Retrieved from <https://libraryresources.columbiasouthern.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=bsu&AN=130104586&site=ehost-live&scope=site>

Suggested Unit Resources

In order to access the following resource, click the link below.

The following document provides additional information about carbon adsorption systems.

- Sorrels, J. L., Baynham, A., Randall, D. D., & Schaffner, K. S. (2018). [Chapter 1: Carbon adsorbers](https://www.epa.gov/sites/production/files/2018-10/documents/final_carbonadsorberschapter_7thedition.pdf). Retrieved from https://www.epa.gov/sites/production/files/2018-10/documents/final_carbonadsorberschapter_7thedition.pdf