

Course Learning Outcomes for Unit V

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

5. Evaluate technologies related to the minimization of industrial and hazardous wastes.
 - 5.1 Discuss physical, chemical, and physicochemical technologies.
 - 5.2 Summarize the benefits of biological, stabilization, and thermal technologies.

Course/Unit Learning Outcomes	Learning Activity
5.1	Unit Lesson Article: "Chemical Characterization of Soil Used as a Deposit for Waste Originating From the Manufacturing of Products Based on Fiberglass" Unit V Essay
5.2	Unit Lesson Article: "Polycyclic Aromatic Hydrocarbons and Volatile Organic Compounds in Biochar and Biochar-Amended Soil: A Review" Video: <i>Disposing of Radioactive Waste</i> (Segment 14 of 18) Unit V Essay

Required Unit Resources

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

Dutta, T., Kwon, E., Bhattacharya, S. S., Jeon, B. H., Deep, A., Uchimiya, M., & Kim, K.-H. (2017). [Polycyclic aromatic hydrocarbons and volatile organic compounds in biochar and biochar-amended soil: A review](https://libraryresources.columbiasouthern.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=asn&AN=122941535&site=ehost-live&scope=site). *GCB Bioenergy*, 9(6), 990–1004. Retrieved from <https://libraryresources.columbiasouthern.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=asn&AN=122941535&site=ehost-live&scope=site>

da Rosa, G. M., Wastowski, A. D., Mendonça, A. M., Gabriel, M., & Sphor, R. B. (2017). [Chemical characterization of soil used as a deposit for waste originating from the manufacturing of products based on fiberglass](https://libraryresources.columbiasouthern.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=bsu&AN=124378872&site=ehost-live&scope=site). *Environmental Quality Management*, 26(3), 125–135. Retrieved from <https://libraryresources.columbiasouthern.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=bsu&AN=124378872&site=ehost-live&scope=site>

The following video segment appeared in the unit lesson. Be sure to watch the segment to learn about the use of vitrification.

British Broadcasting Corporation (Producer). (2015). [Disposing of radioactive waste \(Segment 14 of 18\) \[Video file\]](https://libraryresources.columbiasouthern.edu/login?url=https://fod.infobase.com/PortalPlayer.aspx?wID=273866&xtid=115676&luid=424403). Retrieved from <https://libraryresources.columbiasouthern.edu/login?url=https://fod.infobase.com/PortalPlayer.aspx?wID=273866&xtid=115676&luid=424403>

The transcript for this video can be found by clicking on "Transcript" in the gray bar to the right of the video in the Films on Demand database

Unit Lesson

Introduction

While Unit IV presented management principles related to industrial and hazardous waste, Unit V transitions to an evaluation of technologies for minimization of industrial and hazardous wastes. In general, waste minimization technologies involve physical, chemical, physicochemical, biological, stabilization, and thermal methods (LaGrega, Buckingham, & Evans, 2001). A physical treatment process can be as simple as a filter. A chemical technology involves a chemical reaction converting a hazardous chemical to a more benign chemical. A physicochemical process involves both physical and chemical processes. Biological treatment typically involves encouraging the growth of naturally occurring bacteria to digest harmful organic matter (LaGrega et al., 2001). The stabilization process involves encapsulating the waste within a nondegradable material to reduce any escape to the environment. Thermal processes involve heat to destruct harmful wastes. Examples of each type of technology will be presented.

Physical Treatment

Physical treatment is often the simplest treatment method to understand. A few physical treatment processes will be presented. These include oil/water separation, filtration, and sedimentation.

Oil and water separation: For a liquid waste containing oil and water, the lower density of the oil is helpful for treatment. A quiescent settling tank can be constructed with the oil-water mixture flowing into the tank. Given time, the oil will flow to the surface and can be skimmed off (LaGrega et al., 2001).



Water treatment plant with a round cylinder clarifier sedimentation tank. In sedimentation, a water treatment plant will use a clarifier sedimentation tank for removing material from liquid waste.
(Mityay, n.d.)

Filtration: A liquid-based waste stream may contain undesirable suspended particles. The waste stream can be passed through a filter. The filter would need to be sized properly so that the suspended matter does not pass through the filter. The filtrate would then be free of the suspended matter (LaGrega et al., 2001).

Sedimentation: In addition to filtration, a method for removing suspended material from a liquid waste stream is sedimentation. The waste stream flows into a tank designed to hold it enough for settling of the particles to occur (as shown in photo to the left). The clean liquid flows out over the top of the tank while the matter that settled is collected on the bottom of the tank. The tank can be operated in a batch or continuous flow process. Continuous flow is more typical (LaGrega et al., 2001).

As an example, let's say that research suggests that the mixture needs to stay in the tank for 8 hours in order to have good settling for a particular waste stream. If the waste stream flows at a rate of 1,000 gallons per day, then the tank size required is:

$$V = Q t_r$$

where:

t_r = Residence time = 8 hour

Q = Flow rate = 1,000 gal/day

V = Tank volume required

For our example, determine tank volume in gallons:

$$V = Q t_r = \left(1,000 \frac{\text{gal}}{\text{day}}\right) (8 \text{ hr}) \left(\frac{\text{day}}{24 \text{ hr}}\right) = 333 \text{ gallons}$$

The factor of 1 day per 24 hours is a unit conversion. Thus, in this example, a tank with a volume of 333 gallons is required to provide the necessary settling of the particles.

Chemical Treatment

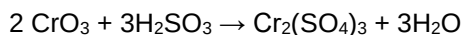
Chemical treatment is a common treatment method for industrial and hazardous waste. Two chemical treatment methods will be discussed: reduction and oxidation.



A person welding in an enclosed chamber to collect welding fumes for analysis and characterization. The goal is to identify and improve welding processes that generate as little fume, especially hexavalent chromium, as possible while maintaining good quality welds.
(National Institute for Occupational Safety and Health, 2011)

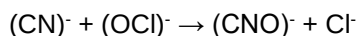
Reduction: Some chemicals are more hazardous in certain oxidation states than in other oxidation states. For instance, hexavalent chromium (Cr^{+6}) is much more toxic (as referenced in the photo above) than trivalent chromium (Cr^{+3}). However, Cr^{+6} is more useful in many more industrial processes such as a wood preservative, textile dye, paint pigment, and metal additive. If there is waste hexavalent chromium, it is chemically reduced from its oxidation state of +6 to the benign state of +3 so that it is no longer hazardous. In fact, chromium is a necessary mineral for humans but not in the +6 state. One method for reducing hexavalent chromium to trivalent chromium is to add sulfuric acid (H_2SO_3) to chromium trioxide (CrO_3). Cr in CrO_3 has an oxidation state of +6 (LaGrega et al., 2001).

The reaction is:



In the right hand side of the reaction, chromium sulfate and water are produced. The oxidation state of Cr in $\text{Cr}_2(\text{SO}_4)_3$ is +3. Thus, the chromium has been reduced from the toxic +6 state to the relatively benign +3 state.

Oxidation: While some chemicals are more hazardous in their oxidized states (such as chromium in the above example), others are more hazardous in their reduced state. For example, cyanide (CN^-), while useful in many industrial processes, is highly toxic. Sometimes a chemical is not all used, but enough is used that there isn't enough left to be useful to the process. If some still exists however, it can be oxidized to cyanate (CNO^-), which is less toxic. The CN in the reduced form has an oxidation state of -1, while the CN in the oxidized state has an oxidation state of +1. Though oxidation can occur in many ways, a common method is to use chlorine (LaGrega et al., 2001):



Physicochemical Technologies

Many industrial and hazardous treatment technologies involve both physical and chemical processes. Common physicochemical methods include carbon adsorption and air stripping.

Carbon adsorption: Activated carbon is charcoal that has been processed into a granular or powdered form that is notable for its high porosity and maze of pore space. The large amount of pore space allows a lot of opportunity for chemicals passing through to get adsorbed to the carbon. Adsorption is a surface phenomenon where chemicals essentially stick to the surface of the activated carbon within the carbon's pore spaces. This is not to be confused with absorption where a chemical, such as salt, dissolves in water.

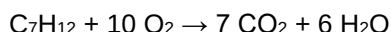
Carbon adsorption can be used for treatment of gaseous or liquid waste streams. The waste stream flows through a closed or open tank containing the activated carbon. Organic and inorganic chemicals sorb to the carbon. Thus, the effluent waste stream has fewer contaminants. A downside of the use of activated carbon is that, after use, the activated carbon material becomes a hazardous waste itself. It can be re-generated (then re-used) by heating, but the off-gas must be collected or treated (LaGrega et al., 2001; Wang, Shammas & Hung, 2008).

Air stripping: Air stripping is a common method for removing volatile contaminants that reside in a liquid waste stream. Volatile chemicals are chemicals with high vapor pressures. Volatile chemicals may evaporate from their liquid substrate given enough time. However, air stripping speeds up the process of removal. Air stripping occurs in tall, typically cylindrical, columns.

The columns are filled with packing material, which is typically plastic. The packing material has strange shapes. Clean air is blown upward from the bottom of the column. The liquid waste stream flow is injected at the top of the column. As the clean air flows up and the contaminated water flows down, both streams start to mix together and flow around the jumbled packing material. The winding pathways cause enhanced contact between the air and the water. Since the contaminants in the water are volatile (high vapor pressure), they transfer from the liquid phase into the gas phase. The now-dirty air flows out the top of the column while the cleaner liquid flows out the bottom (LaGrega et al., 2001).

Biological Treatment

In addition to using chemicals to cause oxidation or convert chemicals to less toxic forms, microbes can be used as catalysts. The following reaction shows the conversion of the flammable and toxic cycloheptene, with a chemical formula of C_7H_{12} , to common carbon dioxide or CO_2 (LaGrega et al., 2001; National Center for Biotechnology Information [NCBI], 2005):



At first, the equation looks like a typical combustion reaction, and that could happen. In the presence of oxygen, an applied spark, which is a catalyst, will immediately ignite the C_7H_{12} , which will combust to produce CO_2 and water vapor (H_2O). However, the reaction can also proceed in the presence of a different catalyst (microbes). In an aerobic environment, such as everyday air, if the C_7H_{12} passes through a medium (maybe dirt or slimy rocks) that can contain naturally occurring bacteria, the oxidation reaction can occur. The result is the same (CO_2 and H_2O) as in the combustion reaction, though there is no combustion (LaGrega et al., 2001).

Trichloroethylene (TCE) is a carcinogen with the chemical formula C_2HCl_3 and has been used as a solvent for many decades. Unfortunately, it has leaked (or been disposed of illegally) into the soil, often leaching into groundwater. Instead of excavating soil in order to remove the TCE, an in-situ biological treatment method called bioremediation can be used. To encourage TCE to break down, nutrients are added to the subsurface to encourage microbe growth. The microbes feed on the TCE, changing it to more benign chemicals (LaGrega et al., 2001).

Stabilization

Rather than converting the waste to a less hazardous form, stabilization keeps the waste as is but binds it in a surrounding—usually solid—matrix to limit its escape. For instance, an oily waste could be contained by adding other materials to essentially harden it. This has been done using a mixture of lime, cement binder, and fly ash (LaGrega et al., 2001). One of the challenges of encapsulation is that, under high temperatures or pressures, the hazardous oil could ooze out of the matrix. Mixtures of cement are the most common form of stabilization used.

In addition to using cement mixes for stabilization, plastic matrices can be useful. Plastics heated to high temperatures have properties that allow the mixing in of liquid or gaseous hazardous wastes. When cooled, the hazardous waste material is contained in the plastic, which allows control of the waste's mobility. Before using this method, tests must be conducted to make sure that the waste does not degrade the plastic over the long term.

Another advanced method for stabilization is vitrification. It is used for containing hazardous solid wastes. The waste is heated to around $1600^{\circ}C$ where it becomes molten and mixes with glass in the oven. Upon rapid cooling, the solid waste/glass mixture results in a material that keeps the hazardous material in place. View the [video *Disposing of Radioactive Waste*](#) on the use of vitrification (the transcript for this video can be found by clicking on "Transcript" in the gray bar to the right of the video in the Films on Demand database).

Vitrification is also used to stabilize contaminated soil: that is, to keep the contaminants from migrating. Electrodes are installed in the soil. An applied current causes the contaminated soil to heat up and become a semi-liquid. Molten glass is introduced. Upon cooling, the solid mixture keeps the hazardous chemicals in the soil from migrating off-site (LaGrega et al., 2001).

Thermal Treatment

Thermal destruction of materials is one of the oldest methods of waste removal. Whether burning brush to clear forested areas or to burn solid wastes, it has been around a long time. For industrial and hazardous waste, it has been used effectively for destruction of waste materials. A side benefit is that the heat produced can be used to warm buildings or converted to steam to generate electricity. However, toxic chemicals also result from thermal destruction.

In the event of toxic releases, air quality laws must be followed in order to protect the environment. Incinerators operate as combustion chambers but at very high temperature. Noncombustible materials, such as metals, may be contained in the waste stream that is fed into the incinerator. Instead of leaving the incinerator as flue gas discharged to the atmosphere, metals stay in the bottom ash. Thus, solid and hazardous waste regulations must be followed for the bottom ash.

Conclusion

This lesson has offered an evaluation of technologies used to minimize industrial and hazardous waste. It presented examples of physical, chemical, physicochemical, biological, stabilization, and thermal technologies. Considerable research is ongoing to advance treatment technologies, especially for treatment of novel waste streams. In addition to the information presented in this lesson, the required articles for the unit provide research describing specific treatment technologies.

References

- LaGrega, M. D., Buckingham, P. L., & Evans, J. C. (2001). *Hazardous waste management* (2nd ed.). Long Grove, IL: Waveland.
- Mityay, D. (n.d.). *Water treatment plant with round cylinder of clarifier sedimentation tank, aerial top view (ID 154610939)* [Photograph]. Retrieved from <https://www.dreamstime.com/water-treatment-plant-round-cylinder-clarifier-sedimentation-tank-aerial-top-view-image154610939>
- National Center for Biotechnology Information. (2005). *Cycloheptene*. Retrieved from <https://pubchem.ncbi.nlm.nih.gov/compound/cycloheptene>
- National Institute for Occupational Safety and Health. (2011). *Hexavalent chromium* [Photograph]. Retrieved from [https://commons.wikimedia.org/wiki/File:Hexavalent_Chromium_\(8743403525\).jpg](https://commons.wikimedia.org/wiki/File:Hexavalent_Chromium_(8743403525).jpg)
- Wang, L. K., Shammas, N. K., & Hung, Y.-T. (Eds.). (2008). *Advances in hazardous industrial waste treatment*. Boca Raton, FL: CRC Press.

Suggested Unit Resources

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

To learn about chemicals, click on the following web link.

National Center for Biotechnology Information. (n.d.). [Explore chemistry](https://pubchem.ncbi.nlm.nih.gov/). Retrieved from <https://pubchem.ncbi.nlm.nih.gov/>