University Learning in Schools

Chemistry

The Engineer's Guide to Cleaning up an Oil Company's Mess: Treatment Techniques for Petroleum Oil Waste Waters

Lesson 3

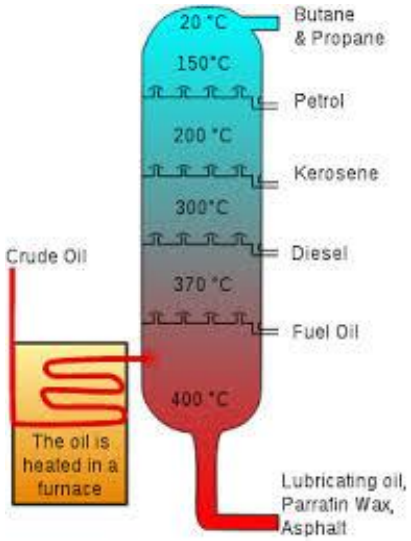
The Brilliant Club
Department for Education
SUPPORTED BY MAYOR OF LONDON

Fractional Distillation and the Waste Water Produced

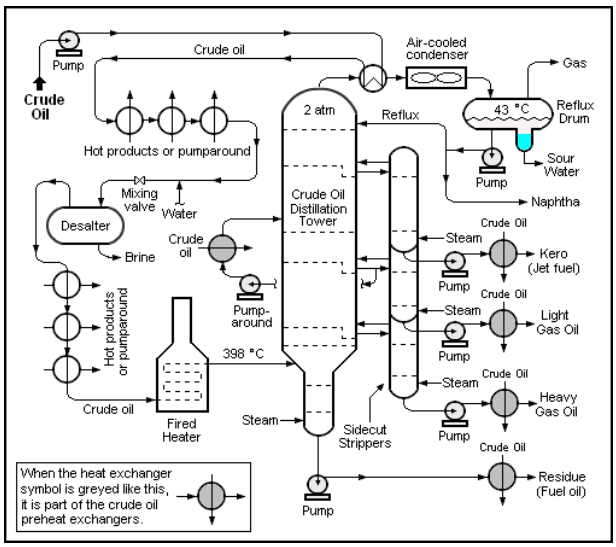
We learned that crude oil is a **mixture of hydrocarbons** that needs to be separated into its individual constituents, so that they can be used as different fuel sources.

In order to do this, we use a method called **fractional distillation**, which takes advantage of the fact that the different hydrocarbons have different lengths, and thus have different boiling points. Fractional distillation usually occurs in a piece of equipment called a distillation column.

However, the process of turning crude oil into different fuels consists of a large number of steps, and thus does not occur in a single process.



Simplified Distillation



Entire Distillation Process

One of the problems with the crude oil refining process is that it produces **petroleum waste water**, which needs to be treated before it can be disposed into the environment.

Consequences of not treating the waste water can include:

- Permanent damage to the plants in the river that receives the water.
- Permanent damage to the fish that live in the receiving water. Small amounts of oil can also damage unborn fish eggs, which can lead to permanent ecological damage.
- Damage to the animals which would use the receiving river as a drinking source.

Q: Can you spot in the above process where this waste water comes from?

Waste water produced from the fractional distillation process contains the following contaminants which need to be removed before the water can be safely disposed of into the environment.

Such contaminants include:

- Dissolved gases such as hydrogen sulfide, sulfur dioxide and ammonia.
- Crude oil.

Petroleum Waste Water disposed into the river

Petroleum Waste Water Treatment Techniques

One of the jobs that a chemical engineer can have is to design processes and equipment that can be used to treat waste water. There are different types of processes which can be used to treat petroleum waste water:

Physical Treatment Processes

Earlier this week, you learnt that oil and water have different densities, and hence oil can float in water if it is given enough time. We can take advantage of this buoyancy phenomenon and thus design a large tank which can hold the petroleum waste water for a long time to allow it to separate. This large tank is known as a clarifier.

The oil that emerges from the top can either be used as bunker oil, or it can be disposed of by being burned in an incinerator.

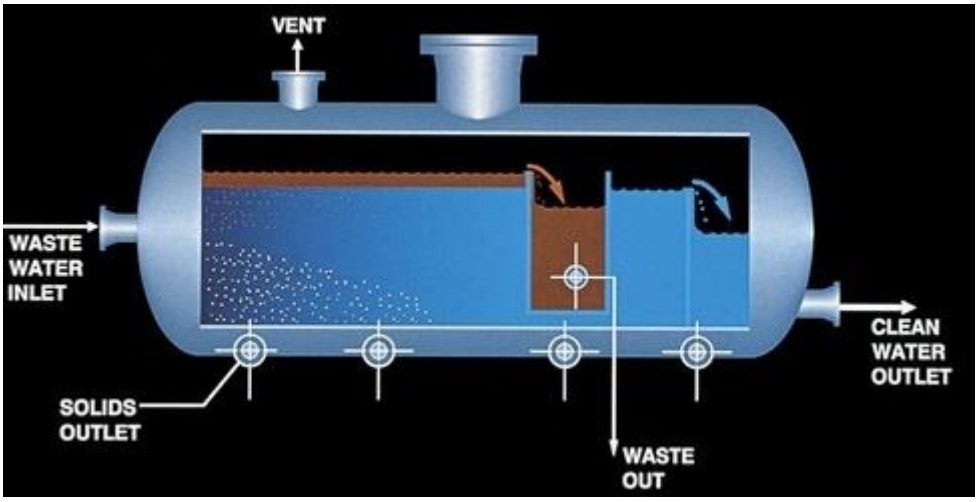
The water that emerges from the bottom of the clarifier now contains a smaller fraction of oil and can either be further treated or disposed of if the required treatment standards are met.

Advantages:

- The process works with gravity and thus there are virtually no operating costs in removing the oil from the water.

Disadvantages:

- The tank size required for the process is large.
- The oil fraction removed will need to be incinerated, which can produce a number of toxic chemicals.
- The process is not effective in treating dissolved components such as the gases in the waste water; and hence the water that emerges from this process is not fully treated.



Oil/Water Separator using gravity

Chemical Treatment Processes

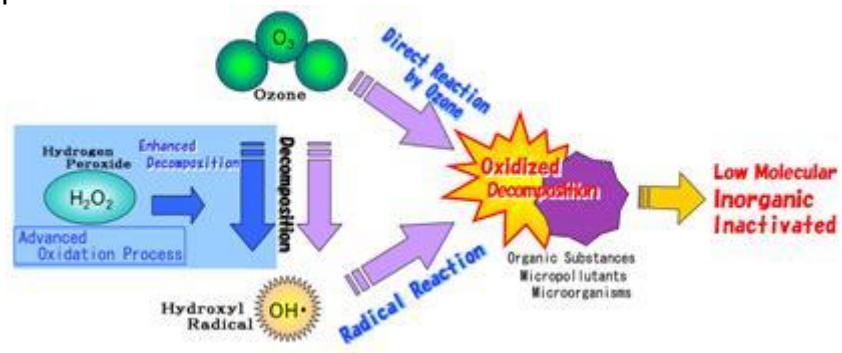
Using the addition of chemicals, we can break down the pollutants that are found within petroleum waste water. Using a compound called hydrogen peroxide in combination with ultra-violet light, we can generate a very reactive compound called the hydroxide radical. It is also possible to use ozone (O_3) to accomplish this. The hydroxide radical is able to break down pollutants within the water into smaller molecules and into CO_2. The entire process of generating the radicals and breaking down the pollutants is called **advanced oxidation**.

Advantages:

- Removes large proportions of the pollutants in the water.
- The process is really fast.

Disadvantages:

- Constant need for chemicals.
- Very expensive.



Biological Treatment Processes

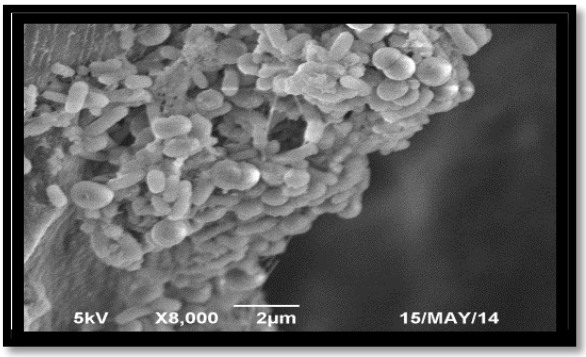
Petroleum waste water contains carbon, nitrogen, phosphorus and sulfur, and thus is an adequate environment for bacteria to grow in. It is possible to design pieces of equipment aimed at cultivating bacteria for the specific purpose of eating the contaminants within the waste effluent. This is called a bioreactor. Bioreactors are a cheap means of treating waste water since they do not require the use of chemicals. However, the effluent may require further treatment to remove micro-organisms that escape the reactor, as well as non-biodegradable components.

Advantages:

- Low cost.
- Does not require chemicals.
- Relatively efficient at removing a large fraction of waste components.

Disadvantages:

- Requires further treatment.
- It is a relatively slow process.



Microbes capable of eating mineral oil

Chemical Oxidation Demand

We need a means to quantify the amount of pollution in our waste streams. This is done via a quantity called **chemical oxygen demand**. Chemical oxygen demand, or **COD**, is the theoretical amount of oxygen that is required to turn the organic waste pollutants within the water into harmless gases. The gases are carbon dioxide and ammonia. Petroleum waste water usually contains a large amount of organic components, and hence will also have a large COD.

We can determine the effectiveness of our treatment processes by looking at how much COD they remove from the wastewater. For example, if a waste stream entering a gravity separator is 100 mg/L, and the stream leaving is 40 mg/L, then the separator removes 60 mg/L. We can then say that the process is 60% efficient at removing COD.

$$COD = Chemical\ Oxygen\ Demand\ \left(\frac{mg}{L}\right)$$

$$COD_{removed} = COD_{in} - COD_{out}$$

$$Removal\ Efficiency = \frac{COD_{removed}}{COD_{in}}$$

Homework

Physical Processes

a) Explain in your own words how physical processes work.

b) What parameters do you think affect the treatment efficiency of physical processes?

c) Why do you think the treatment efficiencies are so low? Why do people still use this technology?

Chemical Processes

a) Explain in your own words how chemical processes work.

b) If chemical processes are so expensive, when do you think people will use them? (Hint: the more waste water you treat, the more chemicals you require.)

Biological Processes

a) Explain in your own words how biological processes work.

b) Why do you think the biological process does not remove all of the pollutants?

Calculating COD removed and COD out

Suppose we have a petroleum waste stream which contains 3930 mg/L of COD. Calculate the outlet COD concentration, and the COD removed by the following technologies:

a) A gravity separator with 63.4% removal efficiency.

b) An advanced oxidation unit which removes 95% removal efficiency.

c) A bioreactor with 80% removal efficiency.

d) A gravity separator with 58% removal efficiency, followed by a bioreactor with 80% removal efficiency.

e) A gravity separator with 46% removal efficiency, followed by the advanced oxidation unit with 94% removal efficiency..

f) Calculate the overall removal efficiency of process **d)** and **e)**.