Chemical Engineering – Unit Operations

Workshop Material

Three activities are presented in this workshop to give an understanding of chemical engineering principles and how unit operations are brought together to process materials into the final product.

The activities encourage team working and investigation of the equipment and materials to see how real life processing systems work. The task set is to understand how dirty oily water is cleaned

- Liquid Separator
- Solids Filter
- Valve

What is chemical engineering?

Modern society relies on the work of chemical, biochemical and process engineers - they help manage resources, protect the environment and control health and safety procedures, while developing the processes that make the products we desire or depend on.

Chemical engineering is all about changing raw materials into useful products you use everyday in a safe and cost effective way. For example petrol, plastics and synthetic fibres such as polyester and nylon, all come from oil.

Chemical engineers understand how to alter the chemical, biochemical or physical state of a substance, to create everything from face creams to fuels.

What is the difference between chemistry and chemical engineering?

Chemical engineers take chemists' laboratory discoveries and figure out how to use them to make a useful product safely and cost-effectively on a large scale. For example chemists might develop a new drug, but the chemical engineer is responsible for designing a process to make millions of tablets of this drug which all contain exactly the right amount of drug, so that it is safe. They must also do this in the most cost-effective way to avoid waste and help their company make a profit.

What are unit operations?

Unit operations are essentially the building blocks of the process. They are steps taken to change the raw materials into the final product, this involves processes which will change the properties of the materials. These changes can involve things like changes to the pressure, temperature or chemical make-up of the materials. A Chemical Engineer's job is to define these steps and the combination or order in which they are carried out. The main Chemical Engineering principles and related processing techniques (or unit operations) are classified as follows:

1. Fluid mechanics – i.e. moving or separating the fluids. Fluids transportation, pumping, filtration, and solids fluidisation.
   Simple examples would be water flowing through the pipes in your home or gravity separation of oil and water.
2. Heat transfer – i.e. changing the temperature. Reboilers and heat exchangers, fan air coolers.
   Simple examples would be a boiling kettle or an air conditioning fan.
3. Mass transfer – i.e. the movement of mass from one stream (or phase) to another. Gas absorption, distillation, extraction, adsorption, membrane filtration and drying.
   Simple examples would be evaporation of water from a pond to the atmosphere or the purification of blood in the kidneys and liver.
4. Thermodynamics – i.e. the influence of pressure and temperature on the fluid physical properties. Gas liquefaction, gas compression and refrigeration.
   A simple example would be the compression loop on the back of a fridge which extracts heat from inside the fridge to keep the contents cool.
5. Mechanical – i.e. physical processes that changing the nature of the materials by breaking, separating or shearing. Mixing, shaking, solids transportation, crushing, screening and sieving.
   Simple examples would be shaking oil and eggs to create an emulsion otherwise known as mayonnaise or moving biscuits along a conveyor belt in a food factory ready to be packaged.

Liquid Separator

Introduction:
This activity shows how gravity can be used to separate two fluids. It is used for many applications including water treatment plant, offshore oil and gas installations, etc. Centrifugal forces (or spinning) can also be used to separate fluids of different density, this technique is generally much quicker than using gravity alone. If the fluids are miscible (or soluble in one another) there are other methods which can be used to separate them such as fractional distillation which separates fluids based on their boiling points, or solvent extraction to separate the components of the fluid mixture (this is used in chromatography).

Equipment:
Small clear plastic bottles with lids (one for each pupil)
Marker pens to label bottles with names
2 x Jugs for pouring
2 x cups for mixing
Plastic spoons for stirring
One small funnel
Vegetable oil (or similar)
Water
Food Colouring (range of colours)
Oil-based food colouring (range of colours)
Glitter (optional)
Cotton buds for transferring oil base colouring into oil mixture (it gets messy if you try to pour it)

*Tip: Best type of **oil based** colouring to buy is Wilton's Candy Food Colouring*
https://www.stuff4crafts.com/yellow-orange-red-blue-candy-colors-1-4-ounce-4-pkg-w1913-1299.html?currency=GBP&CAWELAID=600710128&gclid=CJzBkOzxp8sCFTUz0wodfM0A6w

Cover the surface to be worked on, perhaps even use a flat tray to do the mixing and pouring. Have kitchen paper to hand to mop up spills.

Method:

1. Prepare the equipment. Fill up jugs, one with water and one with oil.
   Tip: Don't fill the cups too high, as this will make it harder to mix in the colouring and could overfill your funnel/bottle when the liquids are combined.
2. Pour water from jug into one of the cups. Choose a normal water based food colour and add a small drop to the water. Mix with a spoon.
3. Pour oil from jug into the other cup. Choose an oil based food colour and transfer a small amount with a cotton bud into the oil. Mix with a spoon.
   Tip: Choose colours which will give a good contrast between the oil and water. i.e. don't choose similar colours like pink and red.

4. Now fill the plastic bottle. Adding first the water and then the oil. Using a funnel helps to get the liquids into the bottle.
5. Place the lid on the bottle and shake the mixture. Experiment by shaking the bottle gently and more vigorously. The mixture will change colour. You should see formation of droplets at the very bottom of the bottle when it is rested on a flat surface. Given time the oil and water will completely separate again.

Key Learning Points:

Density & Volume

Fluids have different densities. Density is a measure of how heavy something is in relation to its volume. If we compare two fluids with the same volume the one which is lighter will have a lower density and will float on top of the heavier (or denser) fluid because of the effect of gravity.

Droplet Creation (Shearing)

Shaking the bottles causes the liquids to shear and form small droplets. The harder the bottle is shaken the smaller the droplets become. This mixing can also be described as homogenisation. In our experiment the oil and water become equally mixed and temporarily become a homogeneous mixture.

Droplet Forming (Coalescence)

Oil and water have different densities and are immiscible (i.e. not soluble, oil does not dissolve in water), they will want to separate. Small oil droplets will form that combine with neighbouring droplets and then these larger droplets rise to the surface. The same happens to the water, the size of droplets increases and the water sinks to the bottom. The different sized droplets should be visible in this experiment.

Interface

The point where the oil and water meet when the mixture is separated is called the interface, or oil-water interface.

Emulsions

An emulsion is a stable oil and water mixture (homogeneous mixture) that will not separate out over time. We would require an extra ingredient in our experiment to act as an emulsifying agent. For example when oil and eggs are mixed they become an emulsion called mayonnaise, the emulsion forms because of the protein in the eggs.

Separation Rates

Depending on how well mixed the oil and water is this will determine the time it takes for them to separate from each other. Pupils may wish to time how long this takes and see if there is a pattern to how many times they shake the bottle, or how hard they shake it. In mixtures which have a similar density (perhaps two different kinds of oil), the separation time will be longer. Mixtures which have a tendency to form emulsions may never fully separate and may require addition of demulsifier chemicals.

Solids Filter

Introduction:
Filters are used for many purposes, with the main function being to remove solid particles from gases or liquids. Filters are used in many everyday applications such as to remove pollen from the air entering your car, to capture the dirt in your hoover, to remove particles from your drinking water, etc. A filter works by catching particles in the filter while letting the liquids or gas pass through. Filters can be made of many different materials otherwise known as mediums or media:

- mesh or grating
- fabric or foam
- solids such as sand, gravel and stones

Equipment:
2 litre clear plastic bottle
Large-ish stones or pebbles
Gravel
Sand
Tip: Using coloured gravel and sand makes the filter more eye-catching, this can be bought from aquarium shops and craft shops, if the sand is from a craft shop make sure it is waterproof so that no dye can run out into the filtered water.
Soil/compost
Cotton wool balls
Scissors
Water
Cup (preferably clear)
Spoon for mixing
Spoon for scooping sand

Method:
1. Take the lid off the 2 litre plastic bottle. Cut the bottle in half with scissors. Turn the top half upside down and insert into the bottom. This is the filter housing.
2. Start to fill the filter housing, building up in layers. First place plenty of cotton wool to fill the curved portion, this will squash down with the weight of the other layers.
3. Add a layer of sand. Add a layer or gravel. Add a layer of stones.
4. Fill the cup with water, add some soil or compost to make the water dirty, compost with a mixture of textures works well as the larger pieces will be clearly visible in the top of the filter.
5. Pour the water into the filter over the top layer of stones.
6. After a short wait, clear water will start to come out into the bottom section.

Key Learning Points:

Particle Size

To be most efficient a filter will first remove the largest of the particles using a media with a greater voidage (spaces between the filter materials) for the fluid to pass through. Then gradually in layers reduce the size of the filter media to remove the finest (smallest) particles last of all. You could remove all the particles with the smallest filter media type, in this case the cotton wool, but this would use a lot of cotton wool and would become clogged up much quicker than using a mixture of materials with different sized spaced to trap the solids.

Surface Area

In this activity our filter is small as it only needs to clean one cup of water. The size (or surface area) of the filter could be increased to allow treatment of a larger volume of water or to treat a continuous flow of water.

Flow Distribution

The filter works more effectively if the flow of fluids is spread out (distributed) evenly across the surface, so that all of the filter materials are working to remove the solids. This is difficult to show with a small filter and a single sup of water like in this experiment, but is important to think about how the design could be adapted to improve flow. The speed (or velocity) of the flow will also affect how well the flow is distributed. Real filters may have flow distribution plates or pipes and would normally be orientated vertically like in this example.

Pressure Drop

Another reason for considering the design of the filter internals is that each will have a different pressure drop across them. In the design of the process you may only have a set pressure available to push the fluids through the process, or you may need to apply energy to a pump to increase the pressure of the fluids to get them through the filter.

Replacing and Cleaning

Eventually a filter will get clogged up with dirt until it can't hold any more, then the filter materials either need to be cleaned or replaced with new ones. This costs money each time and for this reason it is important to match the filter materials with the fluid being cleaned. Solids can easily be removed from the large stones, but doing this for the gravel and sand is more difficult and not possible for the cotton wool.

Water Contaminants

In this activity the filter cleans the water, so that to the naked eye it appear to be clean. However there will still be very small particles in the water and potentially also bacteria which would need a microscope to be able to see. The solution to this to carry out some additional steps to clean the water. This might involve treating with a UV (ultraviolet light), adding chemicals to kill the bacteria (i.e. Chlorine) or passing through a very fine membrane. Some filters can also work by having special materials which attract and capture impurities from the water.

Importance of Clean Water

Clean water is something we often take for granted, but it supports our health and has transformed the way we live. A supply of clean water is needed for drinking, washing, cleaning, cooking and growing food. Without clean water you are likely to get sick and could even die from water related diseases.

Valve (Tap)

Introduction:
Valves are used in many places to stop flow (or isolate fluids) and to control the speed of the flow. Just like the water taps in a house we use valves to direct the fluids and start and stop the flow. The valve we are making today is similar to a plug valve which is used for on/off control. This type of valve works by aligning the ports or the internals with the outside valve body, a ball valve operates in a similar way.

Equipment:
Paper cups (2 per pupil)
A4 paper
Sellotape
Scissors
Pencil
Lentils
Jug for pouring
Tray to test valve on
Dustpan and brush (for spillages)

Method:

1. Cut top off the whole way round one of the cups, about a thumb width.
2. Cut a circular hole about the size of a 10p piece in the side of this cup, near to the bottom.
   Tip: Draw with a pencil, then use the pencil to punch a hole in the centre of this to allow you to get the scissors in to cut your hole.
3. Place the second cup inside the cup which you have prepared. Draw around the inside of the hole you cut on the outer cup. This allows you to draw a circle of the same size on the second cup and in the right position to get both holes to line up. Remove the inner cup and in a similar way to before cut out the marked hole.
4. Now prepare the fixing points for the valve handle. Using a pencil punch holes round the top rim of the second (inner) cup at the 12 o'clock, 3 o'clock, 6 o'clock and 9 o'clock positions.
5. The valve handle is made by tightly rolling up paper, you will need two lengths slightly longer than the diameter of the cup to make a cross shape that pushes through the prepared holes.
6. Connect the handle to the second (inner) cup, use additional tape to secure in position if required. Test the movement of the handle by inserting the cups together.
7. You can also make a spout for the valve. Make a tube with rolled up paper. Cut short tabs up the spout and fold outwards, like making a palm tree. These folded ends will be used to attach the spout to the cup.

8. Tape the valve spout to the outer cup (the one with just the single hole near the bottom, which you made at the start).
9. Now test the operation of the valve. Turning the cup handle will align the holes and allow flow to pass through. Lentils are a good testing material, it is advised to pour these from a jug over a tray or basin. Unfortunately testing with water is not possible as the cardboard and paper quickly become soggy.

Key Learning Points:

Flowrates

Controlling the speed of the flow through the valve is difficult, this is because of how much the flow area changes in proportion to how much the handle is turned. The design of the valve, will change the flowrate (or flow characteristics) of the valve. There are many different valve types and mechanical designs which can be used depending on the purpose of the valve.

Leaky Valves

The flow of fluids through valves can wear away the internal parts. This is especially a problem for dirty fluids with solids or fluids which are corrosive (i.e. eat away at the metal). The valve will also wear just through the use of it being opened and closed. Valves can be designed to cope with this by choosing materials that will not be affected by the fluids and by replacing valves or their internals once they get old. If the valve is perhaps not properly designed and it does wear, or it has high usage, then the valve will leak, i.e. fluids will pass through even when it should be closed.

Actuators

In this activity the valve is moved open and closed by our hands. In real life the valve can be operated remotely by what is called an actuator. The actuator receives a signal with instructions on how to move. For example in your heating at home you might have a temperature gauge (thermostat) that reads a low temperature, meaning the room is colder than required, this will send a message to turn on the water boiler for the radiators, the radiator valves will open to heat up the room.