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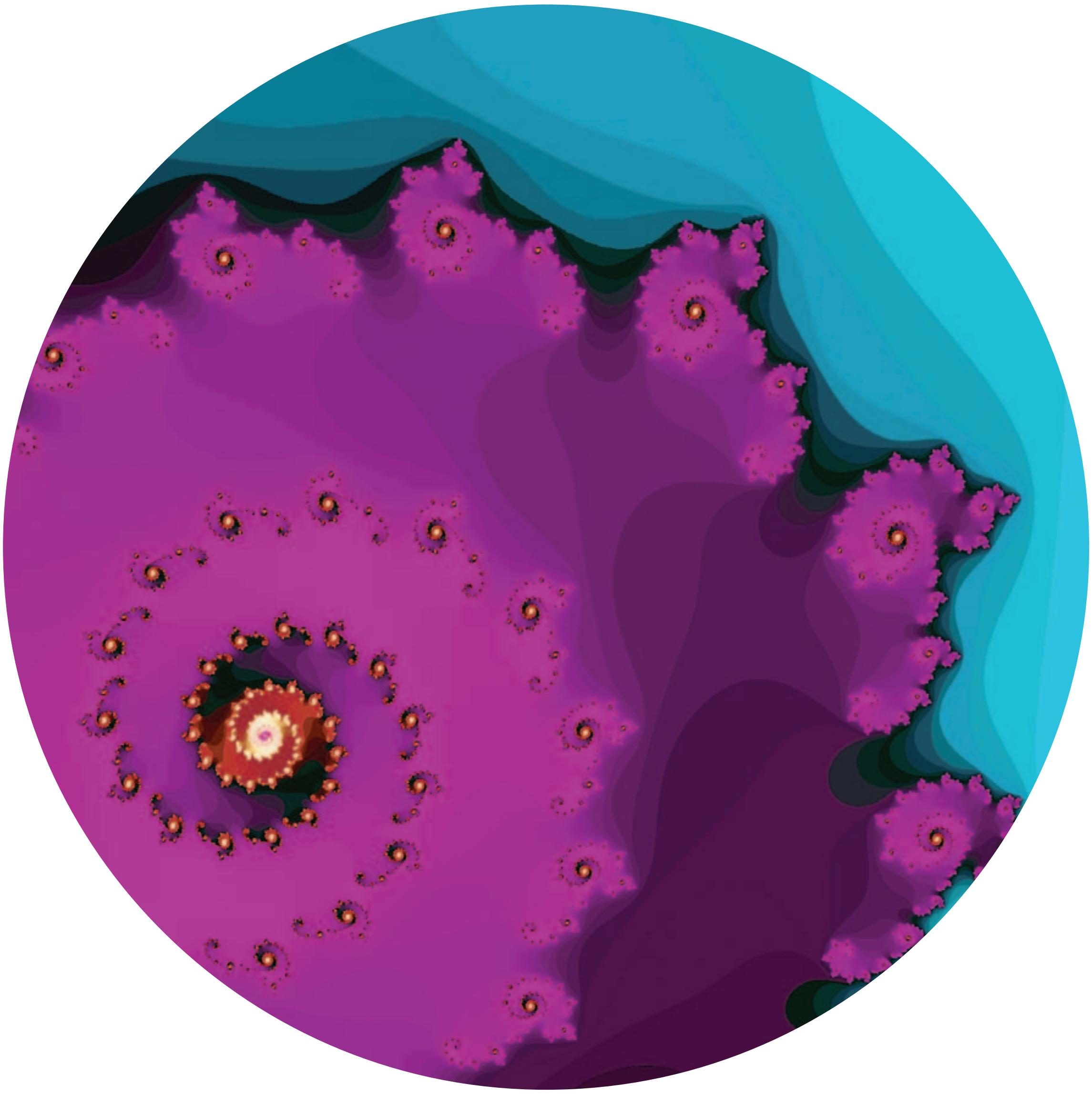
Reluctant Oil Well



see it!

Reluctant Oil Well

What's it all about then?

This experiment is all about oil. In this experiment you will be extracting glycerol (which represents oil) from a two dimensional oil well called a Hele-Shaw cell (after the British ship engineer who invented it). You can also create fractal patterns with the glycerol, which always impresses the students.

It's a messy experiment, but it's a great one to get all the students involved in.

What you can explore through this experiment

- Density
- Viscosity
- Pressure
- Surface Tension
- Hydraulics

How to present this

This is a guide to presenting the experiment. You do not have to follow it exactly, just as long as you allow the students to explore the concepts outlined above. You can expand or shorten the experiment as necessary to fill the time allocated.

The kit

- The Hele-Shaw cell. Two transparent Perspex plates with a thin gap between. The cell has 5 valves that can be used for injecting or extracting air or glycerol.
- Syringes
- Beakers
- Stopwatches
- Paper towels
- Lab coats. This is a particularly messy experiment so everyone does have to wear a lab coat.

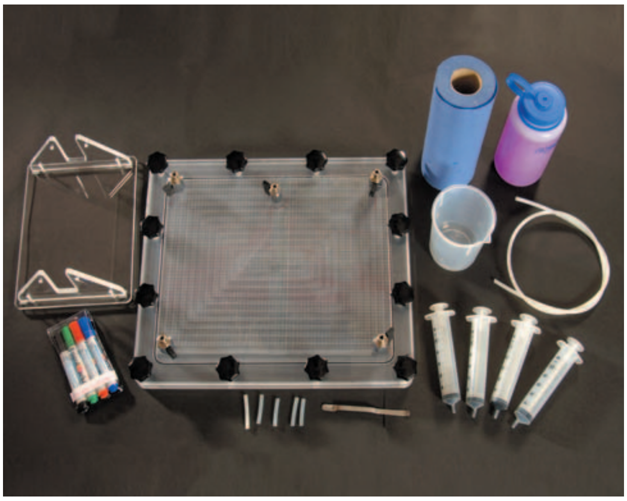


Image of the separate parts (NB this image does not show all the pieces of the kit).

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Introduction

Start by asking students what oil is, where it comes from and how it's made. 150–500 million years ago dead animals (mainly plankton) and plants were covered by sediment and squashed underground. This great pressure caused an increase in temperature which 'cooked' the animals and plants, driving off water and leaving behind the black gooey hydrocarbons that make up oil.

You could ask the students what kind of place an animals could die for it to get covered by sediment before it gets eaten or rots away. Many oil wells are found under the sea or in 'basins' or old flood plains for this reason, although in some cases what used to be under the sea a long time ago is now on land.

You could encourage the students to draw pictures of dead plankton/ fish/ algae/ plants being squashed underground to help get them involved in the discussion.

Once the oil is formed it is contained in porous rock along with water and gas. This could be a good way to introduce density – why does oil float on the water? Think about other examples of oil on water such as oil and vinegar.

Some students may believe that oil sits underground in hollow caves, however, this is not the case. Most of the oil is trapped between the grains of porous rocks and it is prevented from moving upwards due to an overlying cap rock which is impermeable.

How do you look for oil? Get some ideas from the students. Often they will say that you need to drill for it, but how do you know where to drill? You can use seismic waves (such as P waves or S waves) which travel through the rock in the subsurface. From analysing how these seismic waves travel through the subsurface you can discover the composition, fluid content and geometry of the rock and from this determine where oil can be found underground.

Part 1: Exploring viscosity and surface tension

1.1 As the oil is trapped in rocks and not sitting in a big underground lake, ask the students how they think they could extract the oil. What sort of liquid is the oil? Runny? Thick? Sticky? Introduce the concept of viscosity, the reluctance to flow. We have three clear plastic tubes of different mineral oils, each containing a bubble to help you illustrate the point of different viscosities (these tubes are called bubble races). As you turn the bubble races over, the air bubbles in the tubes travel through the liquids at different rates.

Ask the students what is making these bubbles move at different rates and use real life examples such as bubble bath, treacle or cooking oil to help them understand the concept of viscosity.

1.2 So how do you get this viscous oil out of the porous rock? A real oil reservoir is like a sponge, so the surface tension of the oil is high. This means it doesn't flow easily because it tends to stick to the rock. You can run a small experiment to demonstrate surface tension. Take a paperclip and place it on a small square

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Paper clip on water

of tissue. Then place both the tissue with the paperclip on top onto a glass of water. The tissue will sink, but the paperclip will be held on the surface by surface tension. If you drop some detergent into the water then the paperclip will sink, as detergents reduce the surface tension of the water. This also means that you have to rinse the glass thoroughly to get rid of any detergent before the experiment, or line the glass with cling film. If there is even a tiny bit of detergent in the water then the paperclip won't float.

Because the oil is very viscous and has a high surface tension being trapped in the rocks then you could push with another liquid (hydraulics) to apply a much bigger pressure to move the oil.

Once the students know the background problems surrounding oil extraction, tell them they'll be using the Hele Shaw cell to drill for oil themselves. This is where they get the opportunity to see how fluids with different viscosities behave under pressure.

Part 2: Simulation of oil extraction

2.1 Start off with the cell ¾ full of glycerol. After your introduction ask the students to extract the 'oil' from the cell. This is a great hands-on experiment and it really does work best if you let the students investigate it themselves and experiment with the kit.

The Hele Shaw cell is actually an upside down model of an oil well. Oil is less dense than water so floats on water, however, the Hele Shaw cell has oil represented by glycerol but sinking below the air (representing water). Ask the students what is wrong with the model. You could also ask why they think we are using air and not water with the glycerol – glycerol and water are miscible unlike oil and water.

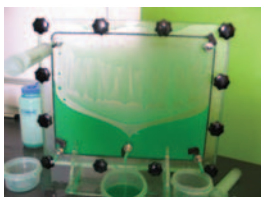
2.2 When the students start to extract the glycerol they may open some of the bottom valves and wait for the glycerol to drip out, however, there will be a point when there will be glycerol in the cell, but it will not drip out as the atmospheric pressure on the outside of the cell will be the same as on the inside.

What do we need to do to change this? Opening the top valves will allow more air into the cell and equalize the pressure.

To extract the glycerol more quickly encourage the students to use the additional kit available to them such as the syringes.

2.3 Often the students will use the syringes to pull the glycerol out from one of the bottom valves. When they do this the glycerol will dip down into a V shape. Ask the students why they think this may be happening, refer back to the concept of viscosity with the air flowing more quickly than the glycerol.

This shape is known in the oil industry as the greed curve



A greed curve

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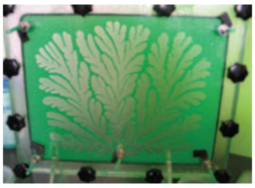
because it occurs if you attempt to extract the oil too quickly.

2.4 The most efficient way to extract the glycerol is by pushing air in through the top valves with the glycerol coming out though the bottom valves. In a real oil well they extract the oil in a similar way, pushing water into the well and forcing the oil out but even with using this method a large amount of oil remains in the ground and oil companies can only extract around 30–40% of it.

When the students have explored oil extraction refer back to your introduction and relate what they have found to the real life example of an oil well.

Part 3: Creating fractals

3.1 Fill ⅓ of the cell with glycerol and ask some of the students to extract the air from the top valves. As the air is extracted the glycerol which is remaining becomes a thin layer and almost transparent. Once the air has been removed ask the students to open one of the bottom valves. As the air rushes back into the cell a fractal pattern will form.



A fractal

Questions you may be asked

What is density?
The density of a substance is given by its mass divided by its volume. The unit of density is kg/m^3. Less dense fluids float on top of denser fluids under gravity. Therefore, oil floats on water, but air floats on glycerol.

What is viscosity?
Viscosity is a measure of the resistance of a liquid to flow. At room temperature, honey and syrup do not flow easily – they have high viscosity. Cooking oil flows more easily than honey; it has a lower viscosity. Water has an even lower viscosity. Air flows so easily that you might be tempted to say that it has zero viscosity. But it does resist flow a little, as you can prove by trying to breathe through a drinking straw. The viscosity of air is approximately 50 times less than the viscosity of water. With increasing temperature viscosity of liquids usually decreases and that of gases increases.

What is surface tension?
Surface tension is caused by the attraction between molecules on the surface of a liquid. You can see surface tension in action all over the place. Small insects such as pond skaters appear to walk on water by using surface tension.

How do detergents work?
Detergent molecules have a head that is strongly attracted to water and a long tail which is attracted to fats and grease. The detergent molecules form layers on the surface of the water with the tails sticking out. The forces between the tails are much less than the forces between the water molecules and so the surface tension is reduced.

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Why do we need to pump air into the cell?
If you are pumping a substance out of an enclosed space then there will become a point when a partial vacuum is created. This partial vacuum forms because you are not replacing what you have taken out of the enclosed space. You can explain this to the students with the example of drinking out of a large bottle of coke. If you keep drinking out of the bottle, but do not let any air back into the bottle, then there will be a point where no more drink will come out. You have to stop drinking and let some air in, from your lungs or from the atmosphere. This is one reason that water needs to be pumped into the oil wells, to replace the oil that they are taking out.

What happens at the surface when oil escapes?
A small amount of the oil is released underwater and it just seeps out slowly and floats away. Some of it is released on land to form tar pits. In America there are some tar pits that have been stable for millions of years, trapping and effectively fossilising animals.

Why are we using glycerol?
Real crude oil is too viscous, smelly and poisonous. We are using glycerol instead as it has a similar difference in viscosity compared with air as crude oil has compared with water.

How to avoid greed curves?
Several ways to reduce the greed curve problem have been developed

- Using hot water to reduce the viscosity of the oil – like heating honey to make it runnier.
- Using surfactants to reduce the surface tension of the oil (although this makes it difficult to separate the oil and water afterwards)
- Using fertilised microbes which break down the long chain molecules that oil is made of. These chain molecules normally tangle together and make the oil viscous. The microbes may also produce surfactants.
- Adding special foams to the water to increase its viscosity and reduce the difference between the viscosities of the oil and water.

What is happening when you create a fractal?
As you let the air back into the cell the plates move apart. As the plates move the air fills the gap created faster than the glycerol, creating a fractal pattern. This is due to the variations in the flow velocity of the glycerol within the cell. Fractals are repeating patterns which occur over a range of scales. They appear a lot in nature and we have a DVD on board which will give you some examples such as leaves or trees.

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Glossary

Fluid
Can be a gas or a liquid - something that can flow or change shape and move around other objects. Gases are thinner (less viscous) fluids than liquids.

Fractal
A shape that demonstrates self-similarity on all level of magnification. This gives it many interesting features, and infinite detail. Fractals combine structure and irregularity.

Chaos/Chaotic
Something that appears to behave in a complicated and unpredictable way but which is determined by the initial circumstances of the system. Chaos appears a lot in nature, in the atmosphere, in turbulent fluids (as here) and in other things such as population growth and economics!

Buoyancy
A force that pushes an object upwards when it's placed in a fluid. The buoyancy force is equal to the weight of the fluid that has been displaced by the object. If the buoyancy is greater than the weight of the object then the object floats. If the buoyancy force is not as big as the weight of the object then it will sink.

Pressure
A measurement of how much force is pushing down over a certain area. Air pressure is all around us because the air is pushing against us with a force all the time.

Molecules
Small particles that make up all material.

Density
The mass of a given substance per unit volume. Less dense fluids float on denser ones.

Glycerol
A chemical, also known as glycerine, or glycerin. It is a colourless, odourless and very viscous liquid, and is often used in soap and cosmetics. Chemical Formula $C_3H_8O_3$. For this experiment the glycerol has been dyed with green paint.

For some background information on fractals and their applications see:

http://en.wikipedia.org/wiki/Fractal

http://polymer.bu.edu/ogaf/html/chp44.htm

www.emayzine.com/infoage/math/math4.htm

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Notes

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