

# Current Biofuels

## Activity 1C - Oil viscosity

**Learning outcomes:** By the end of the session students should be able to:

- Explain the importance of identifying fuel viscosity.
- Carry out viscosity tests on a variety of different fuels.
- Evaluate the pros and cons of different transport fuels.



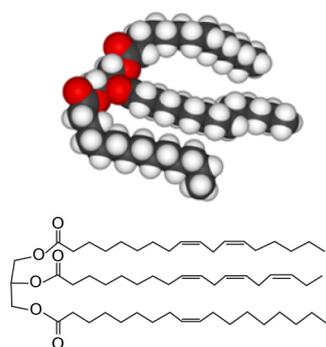
**Keywords** Bioenergy, biofuel, biodiesel, renewable, viscosity, waste, saturation, oil, density, saturation, unsaturated, double bond, Van der Waals.

## Background

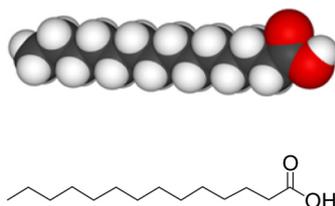
The viscosity of fuels affects their melting points, ignition temperature, heat of combustion, the rate at which they burn, density, energy density and lubricity. The amount of energy stored in a defined volume of fuel (energy density) is important for identifying the best fuels. The higher the energy density the further a vehicle will be able to travel on the same amount of fuel and thus the smaller the fuel tank needs to be. The energy density of common fuels are listed in descending order: methane, natural gas, petrol, diesel, kerosene, biodiesel, ethanol.

Oils are appealing alternatives to petrol due to their greater density, safety and lower exhaust emissions. However, the viscosity of oils also affects the ease with which they can be converted to biodiesel and the engines they are suitable for. More viscous fuels leave more deposits in car engines and can cause problems with engine pressures and injection systems. The storage and 'shelf-life' of oil-based fuels is more limited due to the oxidation of polyunsaturated hydrocarbons.

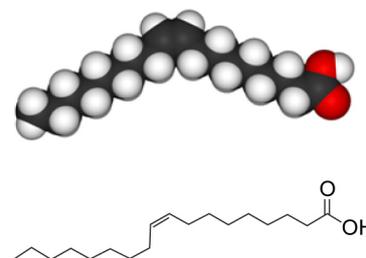
Viscosity is influenced by the molecular properties of liquids such as vegetable oils. There is a direct relationship between the chain length and degree of saturation of the fatty acids that form triacylglycerols. Generally speaking saturated oils are more viscous than unsaturated oils. Unsaturated oils have double bonds in the hydrocarbon chains, whereas saturated oils feature more single bonds and attached hydrogen atoms. The linear "zigzag" structure of saturated fatty acid hydrocarbon chains enables the molecules to line up and form intermolecular Van der Waals interactions, reducing their viscosity. Unsaturated hydrocarbon chains have double bonds that produce "kinks" in the molecule. These "kinks" prevent the molecules getting as close to each other and forming as many Van der Waals interactions, thus increasing the viscosity of the oil.



Triglyceride



Myristic acid (saturated)



Oleic acid (unsaturated)

Molecules (Jmol: an open-source Java viewer for chemical structures in 3D <http://www.jmol.org/>, CPK spacefill 50% vanderwaals)

# Current Biofuels

This activity involves testing the viscosities of a variety of vegetable oils based on the time a drop of oil takes to run down a sheet of plastic. This can be done using dropping pipettes or dropper bottles, alternatively you could also use a falling ball or cup viscometer.

Students can be introduced to the concept of differing viscosities by providing them with a selection of oils in sealed centrifuge or test tubes and asking them to arrange them in order according to how runny they are. The reason for these differences can be discussed and predictions made about the viscosity of the oils.

The experiment can be extended by repeating the investigations after warming the oils in warm water or a water bath. This will enable pupils to produce line graphs comparing the viscosity of the oils at different temperatures and establish if there is a linear relationship between viscosity and temperature.

The use of the falling ball or cup viscometer enables quantitative measurements to be made. Viscosity is measured in Pascal seconds (Pa.s) and dynamic viscosity can be calculated using the following equation:

$$\eta = \frac{2(\Delta\rho)ga^2}{9v}$$

$\eta$  = dynamic viscosity

$\Delta\rho$  = difference in density between the sphere and liquid

$g$  = acceleration of gravity

$a$  = radius of sphere

$v$  = velocity

**Age Range:** Measuring oil viscosity is suitable for secondary students and calculating viscosity is suitable for post-16 students.

**Duration:** 30-60 minutes.

**Suggested prior knowledge:** Secondary students should have a good understanding of the properties of liquids and how to carry out a fair test. Knowledge of molecules and the way their size or shape can affect their properties including the forces between molecules and the difference between saturated and unsaturated molecules will enable GCSE and post-16 students to form a better understanding of the results and evaluation of fuels.

## What you will need

- A selection of vegetable oils – sunflower, maize, olive, rapeseed
- A selection of fuels – ethanol (available from **activity 1G**), biodiesel (available from **activity 1D**), synthetic crude oil (CLEAPSS® recipe Book 32)
- Dropping pipettes or dropper bottles
- Plastic beakers
- Clamp stand, bosshead and clamp
- Timer or stopwatches
- Clean smooth polycarbonate (chemically resistant) plastic boards
- Shallow trays
- Cleaning materials especially blue roll

### Optional

- Falling ball or cup viscometer
- Water bath or warm water and thermometer

# Current Biofuels

## Health and Safety

Sesame and nut oils are not recommended due to the potential allergic reactions they can produce. Vegetable oils and fuels are flammable and should be kept away from naked flames. See also CLEAPSS® Hazcards 45 and 46 (Hydrocarbons), and guidance leaflets PS 67-01 (Testing for unsaturation) and PS 67-05 (The viscosity of motor oils).

## Method

1. The clamp stand and clamp should be arranged so that it is able to hold one end of the plastic board with the other resting in a shallow tray.
2. Mark a start and finish line on the plastic board approximately 20cm apart.
3. Decant the vegetable oils into dropper bottles or labelled containers.
4. Students drop the oil onto the plastic boards using dropping pipettes or dropper bottles.
5. They then use a timer to measure the time taken for the oil drops to cover the distance between the start and finish lines.

### Optional

6. Repeat with warmed oils and graph the results of time taken against temperature. Recommended temperatures are 20, 25, 30, 35 and 40°C. Do not use hot oils or fuels. Ensure that the plastic board is warmed to the corresponding temperature as the oils. Use pieces of plastic board that are short enough to fit in the water bath.

It is best to do some trial runs prior to starting this activity to choose a suitable angle for the plastic board and an appropriate distance between the start and finish lines. As the oil drops leave behind a residue they may not reach the finish line if the distance is too large. The plastic sheet will need to be wiped clean between each test so that residues do not affect the results.

This activity is based on one developed by the Gatsby SEP: Biofuels. 2009. [www.sep.org.uk](http://www.sep.org.uk)

## Extension activities

As an extension you could give students the chemical formulae or molecular composition of a range of liquids including oils, biofuels, short and long chain, saturated and unsaturated fatty acids and triglycerides and ask them to predict their relative viscosities. These could be laid out on a line from least to most viscous.

They could then be provided with the corresponding viscosities and asked to draw conclusions on the molecular basis of viscosity based on this information, such as the longer the molecule the greater the viscosity, or the more saturated the molecule the more viscous.

# Current Biofuels

## Liquid viscosities and molecular structures

Substance	Dynamic Viscosity @ 25°C (mPa.s)	Molecular structure
Refined sunflower oil	48.98	10% (sat. f.a.s) 20% (monounsatur. f.a.s) 70% (polunsatur.f.a.s)
Refined maize oil	51.44	12% (sat. f.a.s) 31% (monounsatur. f.a.s) 57% polunsatur.f.a.s)
Olive oil	63.28	15% (sat. f.a.s) 75% (monounsatur. f.a.s) 10% (polunsatur.f.a.s)
Glycerol	1420 (20°C)	$C_3H_8O_3$
Biodiesel	5.75	$RCOOCH_3$
Bioethanol	1.1 (20°C)	$C_2H_5OH$
Water	1 (20°C)	$H_2O$

(Data from H. Abramovic and C. Klofutar, 1998. The temperature dependence of dynamic viscosity, some vegetable oils, *Acta Chim. Slov*, **45**(1), 69-77, S. Kerschbaum and G. Rinke, 2004. Measurement of the temperature dependent viscosity of biodiesel fuels, *Fuel*, **83**(3), 287-291 and <http://physics.info/viscosity/>)

If you would like to carry out further experimental work with post-16 students the iodine value of the vegetable oils can be calculated to determine the degree of saturation (CLEAPSS® Guidance PS 67-01). Alternatively an extension activity using bromine water to test for unsaturation can be carried out. This is a common practical activity carried out in school-see CLEAPSS® Guidance PS 67-01 (Testing for unsaturation), 'Unsaturation in fats and oils' from Practical Chemistry [www.practicalchemistry.org/experiments/unsaturation-in-fats-and-oils.227.EX.html](http://www.practicalchemistry.org/experiments/unsaturation-in-fats-and-oils.227.EX.html) or SEP Biofuels activity A5: Saturation of fuels.

## Suppliers

A selection of vegetable oils – sunflower, maize, olive and rapeseed - are recommended as they are easy to obtain in the majority of supermarkets.

Falling ball viscometers and cup viscometers are available from Mindsets (UK) Ltd [www.mindsetonline.co.uk/index.php](http://www.mindsetonline.co.uk/index.php)

# Current Biofuels

## Further reading and links

Abramovic, H. and Klofutar, C. 1998. The temperature dependence of dynamic viscosity for some vegetable oils, *Acta Chim. Slov*, **45**(1), 69-77.

Kerschbaum, S. and Rinke, G. 2004. Measurement of the temperature dependent viscosity of biodiesel fuels, *Fuel*, **83**(3), 287-291.

Anand, K. Ranjan, A. and Mehta, P.S. 2010. Estimating the Viscosity of Vegetable Oil and Biodiesel Fuels, *Energy Fuels*, **24**, 664–672.

Unsaturation in fats and oils, Practical Chemistry [www.practicalchemistry.org/experiments/unsaturation-in-fats-and-oils.227.EX.html](http://www.practicalchemistry.org/experiments/unsaturation-in-fats-and-oils.227.EX.html)

CLEAPSS® Guidance PS 67-01 (Testing for unsaturation) Gatsby Science Enhancement Programme (SEP): Biofuels. 2009. [www.sep.org.uk](http://www.sep.org.uk)

The Royal Society, January 2008. *Sustainable biofuels: prospects and challenges*, ISBN 978 0 85403 662 2. <http://royalsociety.org/Sustainable-biofuels-prospects-and-challenges/>

Nuffield Council on Bioethics, April 2011, *Biofuels: ethical issues* [www.nuffieldbioethics.org/biofuels-0](http://www.nuffieldbioethics.org/biofuels-0)

## Research groups

Professor Jonathan Napier, Rothamsted Centre for Crop Genetic Improvement [www.rothamsted.bbsrc.ac.uk/Research/Centres/ProjectDetails.php?Centre=CGI&ProjectID=4950](http://www.rothamsted.bbsrc.ac.uk/Research/Centres/ProjectDetails.php?Centre=CGI&ProjectID=4950)

[www.rothamsted.bbsrc.ac.uk/Research/Centres/PressReleases.php?PRID=51](http://www.rothamsted.bbsrc.ac.uk/Research/Centres/PressReleases.php?PRID=51)

[www.rothamsted.bbsrc.ac.uk/Research/Centres/ProjectDetails.php?Centre=CGI&ProjectID=5015](http://www.rothamsted.bbsrc.ac.uk/Research/Centres/ProjectDetails.php?Centre=CGI&ProjectID=5015)

Dr Peter Eastmond, [www2.warwick.ac.uk/fac/sci/lifesci/people/peastmond/](http://www2.warwick.ac.uk/fac/sci/lifesci/people/peastmond/) Plant Lipid Metabolism Group, University of Warwick, [www2.warwick.ac.uk/fac/sci/lifesci/research/plantmetabolism/](http://www2.warwick.ac.uk/fac/sci/lifesci/research/plantmetabolism/)