Pressure and density: Part I

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Introduction

Pressure, defined as force per unit area, is a scalar. Pressure at a point in a uniform fluid in a gravitational field is isotopic (the same in all directions) and depends only on the depth, h.

$P = \rho g h$ … where ρ is the density.

The MKSA unit of pressure is the pascal (newton per square metre) but pressure is often quoted in a variety of units including kilopascals, pounds per square inch (psi), mm of mercury and cm of water. For instance: pressure in the cavities surrounding the brain is measured in cm of water by allowing fluid to rise in a vertical tube as it is being drained from the base of the spine.

In this exercise a Vernier pressure probe calibrated in kPa is connected to two manometers containing liquids of different densities.

Apparatus

A four way connection links two manometers with a pressure probe and a syringe from which air can be added or removed, increasing or lowering the pressure at the junction.

Fig 1 – syringe and connections to two manometers and a pressure probe.

A small 3 ml syringe is used to avoid accidentally expelling liquid from the manometers. Care must be taken when filling the manometers to avoid droplets in other tube locations so that both read zero (at equal levels) when the pressure in the enclosure is one atmosphere. Assembled apparatus is shown below.

Apparatus

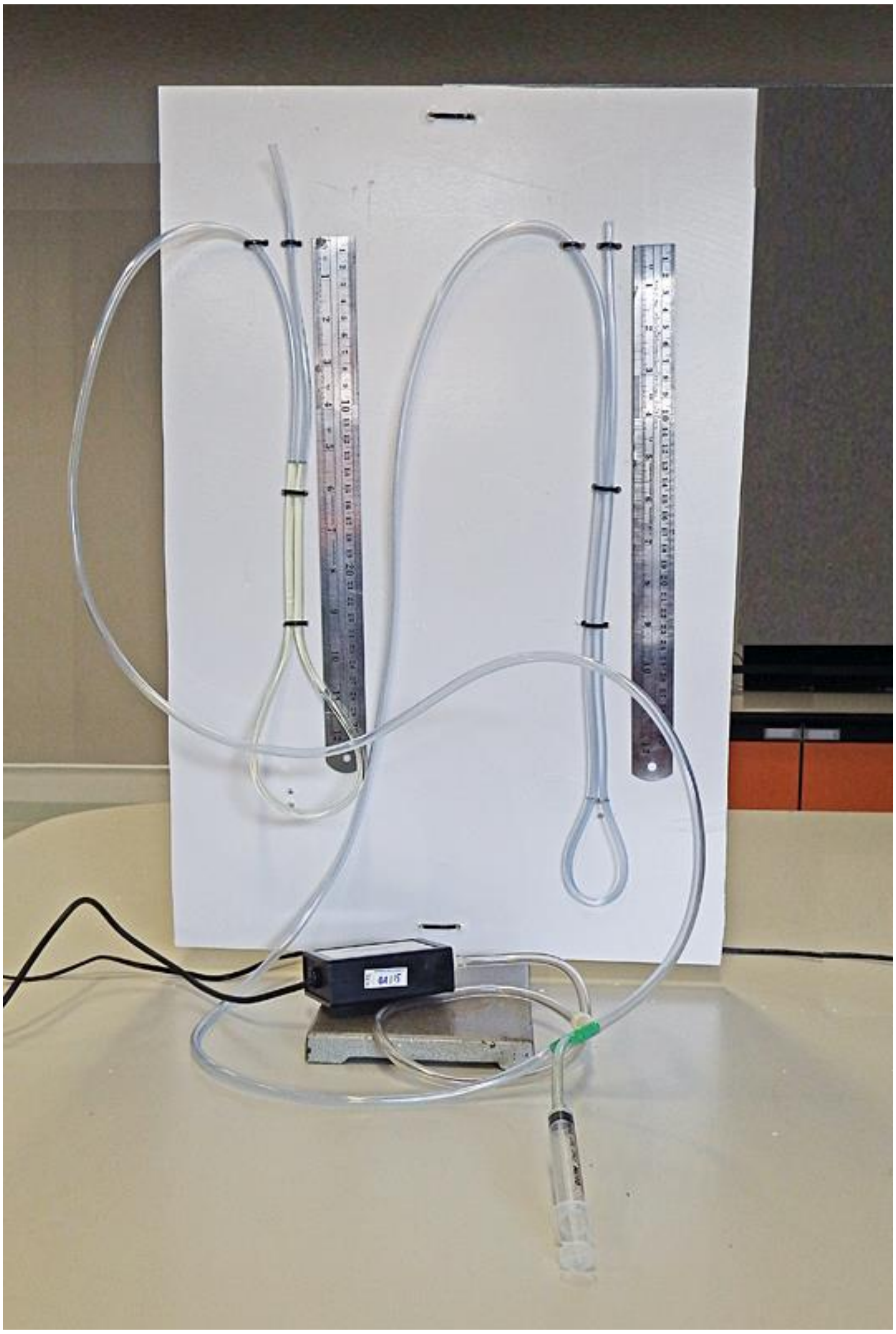


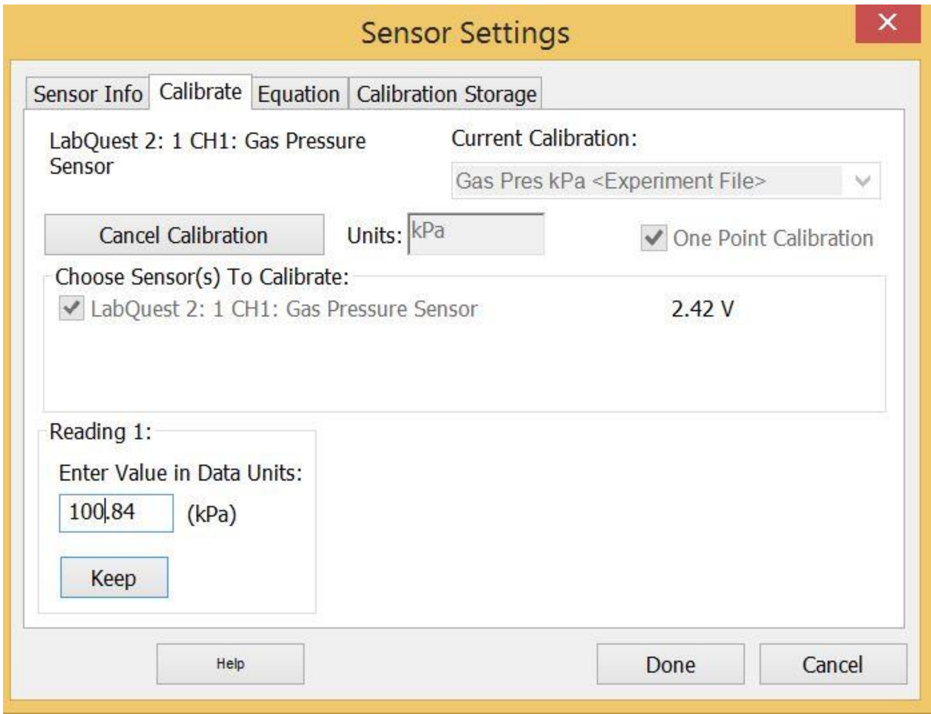
Fig 2 – Manometers made from 4 mm aquarium hose are attached to the board with plastic ties.

The apparatus shown in figure 2 has cooking oil of unknown density in the left hand manometer and water on the right. Notice that the bottom loops of the manometers are not at the same height, which does not affect the height *differences*. The manometers are made from the same 4 mm hose but if they were of different internal diameters that would also not affect the readings.

Data collection

1 The pressure sensor has factory calibration in kPa but air pressure varies. As a first approximation look on the web for a recently updated local air pressure and use that as a single point calibration.

Go to … *Experiment* … *Calibrate* … to open the window below.



Click … *Calibrate now* … Enter the value of air pressure on the day.
Click … *Keep* … *Done* … to store the calibration **for your session only**.

2 Connect the pressure sensor to the double manometer and use the syringe to add air to the system. Plot the ***absolute pressure*** in Logger Pro and record the heights of the liquids in each manometer. **(**If time permits repeat for pressures above and below one atmosphere. See Part II for a sample graph.)

3 Calculate values of the density of water and the unknown oil**.** Gauge pressure is the difference in kPa between atmospheric pressure and the measured pressure. The density of water is the *gauge pressure* in pascals over gΔh in metres. For example ….

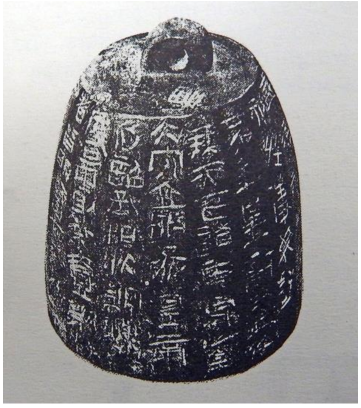
$$\rho_{water} = P/gh = 1420/(9.8 \times 15.6\text{x}10^{-3}) = 930 \text{ kg m}^{-3}$$

4 Experience shows that your calculated density of water will probably not be exactly the known value of 1000 kg.m^{-3}. Use this known value of the density of water to find the density of the oil. (Why?)

Questions to think about

1 How important is calibration in scientific work? Is calibration critical, of overriding importance, or, is it important but best left to the Bureau of Weights and Measures (in a school the teacher will do it for you), or, is it usually a good idea (calibrate if you have time).

2 How important to science and to society is a standardized system of units?

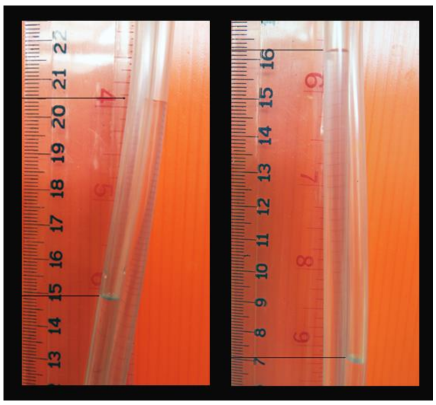


Note: This bronze bell, 7.4 cm in height was one of a large number of standard masses distributed throughout China in 221 BC. The bell was found in 1976 near the tomb of China's first Emperor in Lintong. The inscription can still be read.

3 Air pressure is close to 10^5 Pa but may vary by about 4% up and down. Which method of setting the probe to correctly account for air pressure do you think would be the most reliable? **a** An updated weather map from the web. **b** An aneroid barometer with a digital readout. **c** An (old fashioned) mercury barometer.

4 How do you suggest we improve the calibration of the pressure sensor? Would it be best to follow Vernier's suggestion to set atmospheric pressure on the day and then to set one other point by creating near zero pressure in a syringe by pulling the plunger all the way out or might it be more reliable to set the second point with a digital tire pressure gauge (at less than 2 Atm). Would it be more reliable to use a manometer?

5

The illustration shows upper and lower manometer levels for a solution of zinc chloride on the left and water on the right. Use data from the image to find the density of the zinc chloride solution. What is the maximum density of a *sodium* chloride solution? (Look it up).	

6 The diagram shows a double manometer with oil on the left and water on the right.

a Use data from the figure above to find the density of the liquid on the left (cooking oil).

b Having done the readings for yourself from the prepared diagram, how reliable do you think your height differences are? Express the differences with absolute errors and find the uncertainty in the density of the oil.

c Comment on the design and layout of the apparatus. Explain what is meant by a parallax error.

d How might it be tidied up to improve accuracy?

e When using this double manometer a student noticed that the response times for water and oil were not the same. The oil took 5-10 seconds longer to settle to new levels when pressure was changed. In a word … why? What physical property is involved?

Pressure and density: Part II

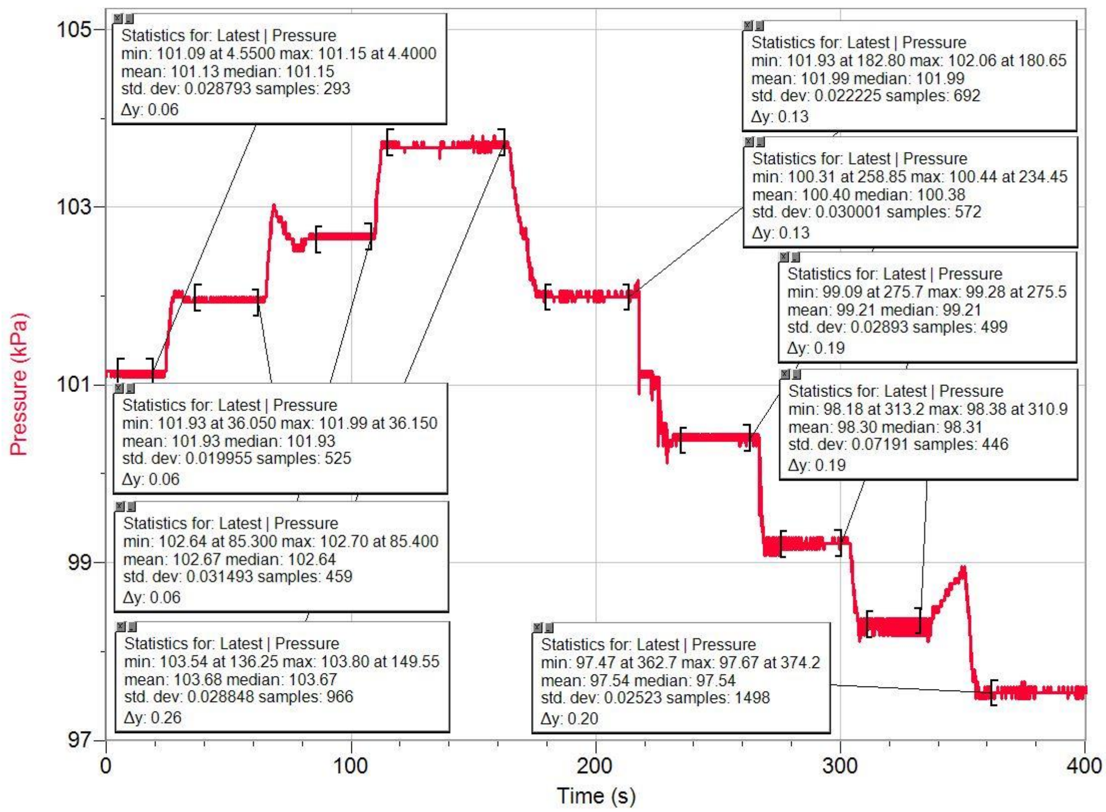
Introduction

In Part 1 you were asked to obtain just one data set, to find the calibration error of the pressure sensor, and then to compare the height differences of the oil and the water to find the density of the oil, given that the density of the water is 1000 kg m^{-3}.

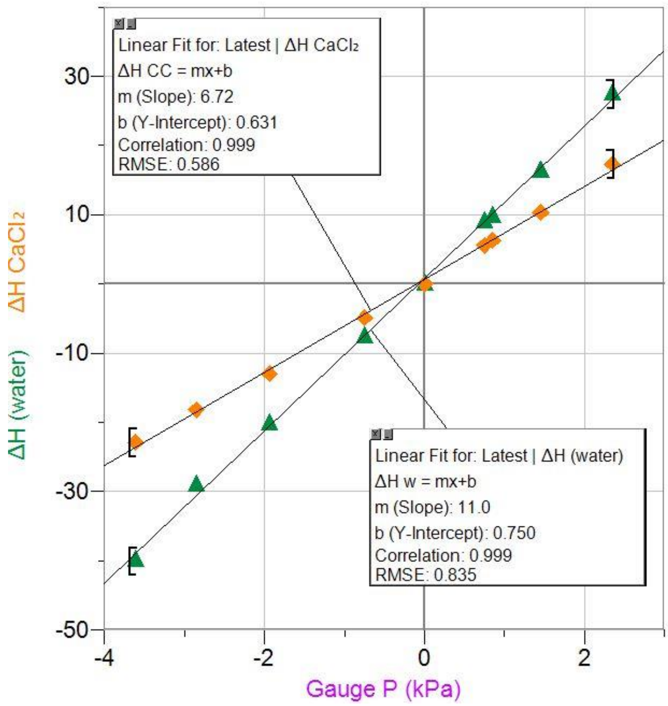
With more time a larger data set allows graphs to be plotted, lines to be fitted and errors to be estimated more reliably. Plotting data on a graph and finding a line of best fit averages data and reduces random errors. In this case we expect the lines to be straight (provided the pressure sensor response is linear), and one set of data (Part 1) was sufficient to gain an understanding of the principles.

Data collection

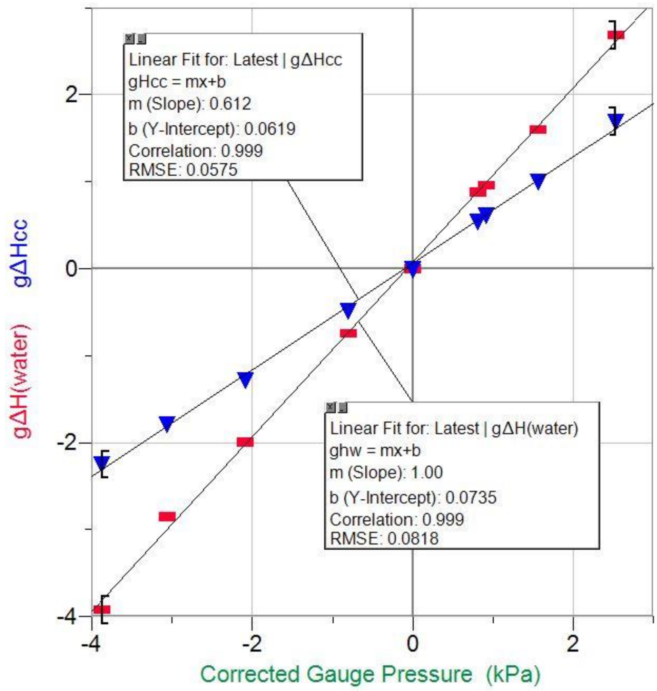
Calcium chloride is a salt that is highly soluble in water. A saturated solution at 20°C has a specific gravity above 1.8. The oil manometer used in part 1 is replaced with a manometer filled with calcium chloride solution. Pressure readings are taken over a range both above and below atmospheric pressure. Height differences on both manometers were recorded separately and entered in manual columns in Logger Pro.



Plotting height differences for both manometers against the measured pressure above and below one atmosphere (gauge pressure) gives two straight lines as expected.



In the graph below height differences are multiplied by *g* and the gauge pressure by 1.075 to correct the calibration to give ρ water = 1000 kgm^{-3}.



The inverse of the gradient of a line in the lower graph is the specific gravity of the liquid: 1.00 for water and 1.63 for the calcium chloride solution.