University of Cape Town
Department of Physics

PHY1004W

Laboratory
Tuesday 28 September 2010

The viscosity of synthetic oil

You are working for Physichem, a research company which develops new products for use in industry. One of your top researchers is working on manufacturing synthetic oils and has produced a liquid which he hopes will form the basis of a new oil that can be used in motor vehicles. All the early indications are very promising - the new liquid has all the chemical properties necessary. However, it is necessary to determine whether the new liquid has a comparable viscosity to normal refined oil (which you are told has a coefficient of viscosity of 0.85 N s m^{-2}). If the viscosity of the new liquid is similar to that of normal oil then Physichem will initiate pre-production testing of the new product. Your supervisor has asked you to complete the necessary experiments and then to write a report by 14:00 on Tuesday 5 October 2010, making appropriate recommendations. You are told that the new liquid has a density of 969 kg m^{-3}. Be careful to include a full analysis of uncertainties in your report.

In order to characterize the viscosity of a liquid, it is possible to define a *coefficient of viscosity* η (look in any first year physics textbook). The coefficient of viscosity of a liquid may be measured using a "falling ball" technique. For a spherical ball falling at its terminal speed v_T (i.e. with no acceleration) in a viscous liquid, by considering the forces acting on the falling ball (its weight, the buoyancy force and the viscous force, given by Stokes' equation), it is straightforward to show that the coefficient of viscosity of the liquid η is given by

$$\eta = \left(\frac{2g\left(\rho_b - \rho_f\right)}{9} \right) \frac{r^2}{v_T}$$

where

- ρ_f : density of the fluid (in this case 969 kg m^{-3})
- ρ_b : density of the steel ball = 7780 kg m^{-3}
- g : acceleration due to gravity (use 9.80 m s^{-2} at UCT)
- r : radius of the steel ball
- v_T : terminal speed of the ball falling in the fluid.

What to do.

Measure the radius r of the steel balls using a micrometer screwgauge. Remember to take both an "open" and a "closed" reading with the screwgauge. The best estimate of the diameter d of the ball is then given by the difference between the open and closed readings, i.e. $d = l_{open} - l_{closed}$.

Determine a Type B standard uncertainty for both the open and closed readings of the micrometer screwguage. Then the standard uncertainty for d is given by $u(d) = \sqrt{u(l_{open})^2 + u(l_{closed})^2}$.

(Do you understand where this equation comes from?)

Since the radius r of the ball is half of the diameter (of course), then the standard uncertainty for r is given by $\frac{u(r)}{r} = \frac{u(d)}{d}$.

To obtain a reliable value of v_T, identical balls which are falling in the liquid are timed over a number of different distances. Each ball can be timed between two marks on the measuring cylinder. To allow each ball to reach its terminal velocity, the top mark (the "start timing" mark) must be *about* 40 mm below the surface of the liquid. Drop a single ball through the hole situated centrally in the cylinder cover, and measure the time t it takes to fall a distance s. Think about how many measurements of t to take at each s. How many different distances s are necessary? Note that the top ("start timing") mark should be the same for all the balls timed. Note also that once the balls are in the liquid you won't be able to get them out again. Use a metre rule to measure the distances s.

Plot an appropriate graph (s versus t). This should result in a straight line through the origin with a slope equal to v_T. Now use the program `CURFIT` to provide you with a best estimate of the slope (v_T) and the standard uncertainty in the slope, $u(v_T)$.

You now are able to calculate a best estimate for η using the equation $\eta = \left(\frac{2g\left(\rho_b - \rho_f\right)}{9} \right) \frac{r^2}{v_T}$.

Be careful! Are you using SI units everywhere?

What about $u(\eta)$? Since the uncertainties in ρ_b, ρ_f and g are negligible (why?), we use the equation $\frac{u(\eta)}{\eta} = \sqrt{\left(2\frac{u(r)}{r}\right)^2 + \left(-1\frac{u(v_T)}{v_T}\right)^2}$. (Where does this equation come from?)

You now have a measured value of $\eta \pm u(\eta)$. Does this agree with the book value of η = 0.85 N s m^{-2} for refined oil? Think about your result carefully. Does it make sense?

AB/18092010