Answer on Question #80974, Physics / Other

A ball of radius 0.800mm and density 8.95gcm^{-3} is released from rest at the top of a tall glass tube filled with a liquid of coefficient of viscosity 0.60 Pas and density 0.900 gcm-3 . how long after release does the ball attain 98% of the terminal velocity?

Solution:

Consider the movement of a ball inside a viscous fluid:

Radius - r

Coefficient of Viscosity - η

Density of the ball - d

Density of the liquid - ρ

Acceleration due to Gravity - g

The ball is subjected to the influence of three forces: they are the weight, upthrust and the viscous force - drag or liquid friction.

$$Weight\ of\ the\ ball\ = mg\ = \frac{4}{3}\pi r^3 dg$$

$$Upthrust\ on\ the\ ball\ by\ the\ liquid\ = v\rho g\ = \frac{4}{3}\pi r^3 \rho g$$

According to Stokes Law,

$$Viscous\ force\ = 6\pi\eta rV,$$

where V is the velocity at a given a time.

At the outset, the downward force, weight, is greater than the combination of the upward forces. So, initially, the ball accelerates. The viscous force, which depends of the velocity, however, keeps increasing. As a result, at some point, the net force on the ball becomes zero and the velocity of the ball becomes constant.

It is the Terminal Velocity

$$V_t\ = \frac{2(d-\rho)gr^2}{9\eta} =$$

$$= \frac{2\times((8.95-0.90)\times 10^3 kg/m^3)\times(9.8\ m/s^2)\times(0.8\times10^{-3}m)^2}{9\times 0.60\ Pa\ s} = 0.0187\ m/s$$

Set up the sum of forces:

$$ma = mg - v\rho g - 6\pi\eta rV$$

$$a = \left(1-\frac{\rho}{d}\right)g - \frac{6\pi\eta}{\frac{4}{3}\pi r^2 d}V =$$

$$= \left(1 - \frac{0.90}{8.95}\right) \times 9.8 - \frac{6 \times 0.60}{\frac{4}{3} \times (0.8 \times 10^{-3})^2 \times 8.95 \times 10^3} V =$$

$$= 8.8145 - 471.37\, V$$

$$\frac{dV}{dt} = 8.8145 - 471.37\, V$$

$$\int_0^{0.98V_t} \frac{dV}{8.8145 - 471.37\, V} = \int_0^t dt$$

$$-0.00212148\, log(8.8145\ -\ 471.37\, V)\ |_0^{0.98V_t} = t$$

So,

$$t =\ -0.00212148\, log(8.8145\ -\ 471.37 \times 0.98 \times 0.0187) +\ 0.00212148\, log(8.8145\ ) = 0.0083\, s$$

Answer: $0.0083\, s$

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