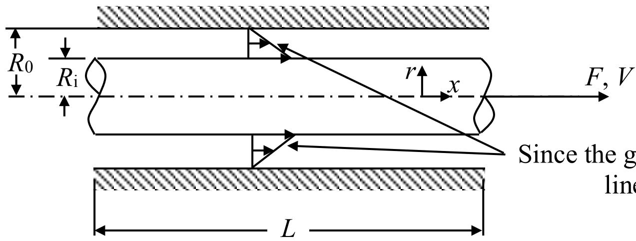
Magnet wire is to be coated with varnish for insulation by drawing it through a circular die of 0.9 mm diameter. The wire diameter is 0.8 mm and it is centered in the die. The varnish, with a dynamic viscosity of 20 centipoise, completely fills the space between the wire and the die for a length of 20 mm. The wire is drawn through the die at a speed of 50 m/s. Determine the force required to pull the wire.

SOLUTION:

Apply Newton's 2nd Law in the x-direction to the wire shown in the diagram below.



$$\sum F_x = F + \tau_{rx}\left(2\pi R_i L\right) = 0 \quad \text{(Note that the wire is not accelerating.)} \tag{1}$$

where τ_{rx} is the shear stress the fluid exerts on the wire and $(2\pi R_i L)$ is the area over which the shear stress acts. The shear stress the wire exerts on the fluid (assumed to be Newtonian) is:

$$\tau_{rx} = \mu \frac{du}{dr} \tag{2}$$

where

$$\frac{du}{dr} = \frac{0-V}{R_o - R_i} = \frac{-V}{R_o - R_i} \quad \text{(Note that } u(r = R_o) = 0 \text{ and } u(r = R_i) = V.) \tag{3}$$

Recall that the shear stress the fluid exerts on the wire will be equal to, but opposite, the value given by Eqn. (2). Substitute Eqns. (2) and (3) into Eqn. (1) and simplify.

$$F - \left(\mu \frac{V}{R_o - R_i}\right)\left(2\pi R_i L\right) = 0$$

$$\boxed{\therefore F = \frac{2\pi R_i L \mu V}{R_o - R_i}} \tag{4}$$

Use the numerical values given in the problem statement.

R_i = $4.0*10^{-4}$ m
R_o = $4.5*10^{-4}$ m
L = $2.0*10^{-2}$ m
μ = 20 cP = 0.02 kg/(m·s) (Note: 100 cP = 0.1 kg/(m·s).)
V = 50 m/s
$\Rightarrow$ $\boxed{F = 1.0 \text{ N}}$