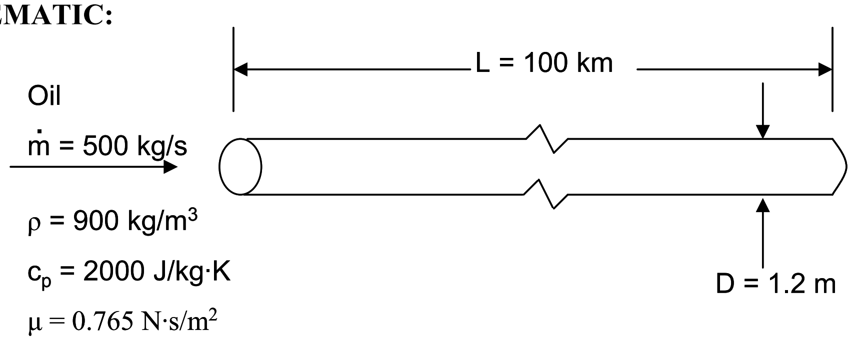
PROBLEM 04

KNOWN: Flow rate and properties of oil flowing in pipe. Dimensions of pipe.

FIND: Pressure drop, flow work, temperature rise caused by flow work.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state, (2) Incompressible flow, (3) Negligible kinetic and potential energy changes, (4) No work *other than* flow work.

ANALYSIS: We begin by determining whether the flow is laminar or turbulent. From Equation 8.6

$$Re_d = \frac{4\dot{m}}{\pi D \mu} = \frac{4 \times 500\ \text{kg/s}}{\pi \times 1.2\ \text{m} \times 0.765\ \text{N}\cdot\text{s/m}^2} = 693$$

and the flow is laminar. The friction factor is given by Equation 8.19,

$$f = 64/Re_D$$

and the pressure drop by Equation 8.22a,

$$\Delta p = f\,\frac{\rho u_m^2}{2D}(x_2 - x_1) = 32\,\frac{\rho u_m^2}{D Re_D} L$$

where u_m can be found from $\dot{m} = \rho u_m A_c$:

$$u_m = \frac{\dot{m}}{\rho A_c} = \frac{\dot{m}}{\rho \pi D^2/4} = \frac{4 \times 500\ \text{kg/s}}{900\ \text{kg/m}^3 \times \pi \times (1.2\ \text{m})^2} = 0.491\ \text{m/s}$$

Thus

$$p_{in} - p_{out} = \Delta p = \frac{32 \times 900\ \text{kg/m}^3 \times (0.491\ \text{m/s})^2 \times 100{,}000\ \text{m}}{1.2\ \text{m} \times 693} = 8.4 \times 10^5\ \text{Pa}$$

$\Delta p = 0.84$ MPa <

The flow work is then found from its definition (see discussion leading to Equation 1.11d),

$$\dot{W}_{flow} = \frac{\dot{m}}{\rho}(p_{in} - p_{out}) = 500\ \text{kg/s} \times 0.84\ \text{MPa}/900\ \text{kg/m}^3$$

$= 0.46$ MW <

Finally, with reference to Equation 1.12d, the portion of the temperature rise due to flow work is given by

$$\dot{m} c_p \Delta T_{flow} = \frac{\dot{m}}{\rho}(p_{in} - p_{out}) = \dot{W}_{flow}$$

$$\Delta T_{flow} = \dot{W}_{flow}/\dot{m} c_p = 0.46\ \text{MW}/(500\ \text{kg/s} \times 2000\ \text{J/kg}\cdot\text{K})$$

$= 0.46°$C <

COMMENTS: Despite the long length of pipeline and high viscosity of the oil, which results in a large pressure drop, the temperature rise due to the flow work is quite small.