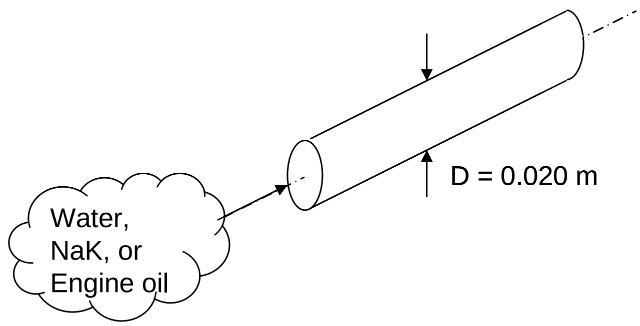
PROBLEM 8.6

KNOWN: Water, engine oil and NaK flowing in a 20 mm diameter tube, temperature of the fluids.

FIND: (a) The mean velocity as well as hydrodynamic and thermal entrance lengths, for a flow rate of 0.01 kg/s and mean temperature of 366 K, (b) The mass flow rate as well as hydrodynamic and thermal entrance lengths for water and oil at a mean velocity of 0.02 m/s at mean temperatures of 300 and 400 K.

SCHEMATIC:



ASSUMPTIONS: (1) Constant properties.

PROPERTIES:

Liquid	T(K)	Table	ρ(kg/m^3)	μ(N·s/m^2)	ν(m^2/s)	Pr
Water	300	A.6	997	855×10^{-6}	-	5.83
	366	A.6	963	303×10^{-6}	-	1.89
	400	A.6	937	217×10^{-6}	-	1.34
Oil	300	A.5	884	48.6×10^{-2}	-	6400
	366	A.5	844	2.12×10^{-2}	-	338
	400	A.5	825	0.874×10^{-2}	-	152
NaK	366	A.7	849	-	5.797×10^{-7}	0.019

ANALYSIS: (a) The mean velocity is given by

$$u_m = \dot{m}/\rho A_c = 0.01\ \text{kg/s}/\left[\rho\pi(0.020\text{m})^2/4\right] = 31.8\ \text{kg/s}\cdot\text{m}^2/\rho \qquad (1)$$

The Reynolds number is

$$Re_D = \frac{4\dot{m}}{\pi D\mu} = \frac{4 \times 0.01\ \text{kg/s}}{\pi(0.020\ \text{m})\mu} = \frac{0.636\ \text{kg/s}\cdot\text{m}}{\mu} \qquad (2)$$

The hydrodynamic entrance length is

$$x_{fd,h} = 0.05 Re_D D = 0.05 \times \frac{0.636\ \text{kg/s}\cdot\text{m}}{\mu} \times (0.020\ \text{m})$$

$$= \frac{636 \times 10^{-6}\ \text{kg/s}\cdot\text{m}}{\mu} \qquad (3)$$

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The thermal entrance length is

$$x_{fd,t} = 0.05 Re_D D Pr = x_{fd,h} Pr$$

$$= \frac{636 \times 10^{-6}\ \text{kg/s} \cdot \text{m}}{\mu} Pr \qquad (4)$$

Solving Equations (1), (3) and (4) yields <

Liquid	u_m (m/s)	$x_{fd,h}$ (m)	$x_{fd,t}$ (m)
water	0.033	2.1	3.97
engine oil	0.038	0.030	10.1
NaK	0.037	1.3	0.025

where, for the NaK, μ is found from the definition

$$\mu = \nu\rho = 5.797 \times 10^{-7} \text{m}^2/\text{s} \times 849\ \text{kg/m}^3 = 492 \times 10^{-6} \text{N} \cdot \text{s/m}^2$$

(b) The mass flow rate is given by

$$\dot{m} = \rho A_c u_m = \frac{0.02\ \text{m/s} \times \pi \times (0.020\ \text{m})^2}{4} \rho = 6.28 \times 10^{-6} \frac{\text{m}^3}{\text{s}} \rho \qquad (5)$$

The Reynolds number is

$$Re_D = \frac{4\dot{m}}{\pi D \mu} = \frac{4 \times 6.28 \times 10^{-6}\ \text{m}^3/\text{s} \times \rho}{\pi (0.020\ \text{m}) \mu} = 400 \times 10^{-6}\ \text{m}^2/\text{s} \times (\rho/\mu) \qquad (6)$$

The hydrodynamic entrance length is

$$x_{fd,h} = 0.05 Re_D D = 0.05 \times 400 \times 10^{-6}\ \text{m}^2/\text{s} \times 0.02\ \text{m}\ (\rho/\mu)$$

$$x_{fd,h} = 400 \times 10^{-9}\ \text{m}^3/\text{s}\ (\rho/\mu) \qquad (7)$$

The thermal entrance length is

$$x_{fd,t} = x_{fd,h} Pr = 400 \times 10^{-9}\ \text{m}^3/\text{s}\ (\rho/\mu)\ Pr \qquad (8)$$

Solving Equations (5), (7) and (8) yields <

Liquid	T (k)	$\dot{m}$ (kg/s)	$x_{fd,h}$ (m)	$x_{fd,t}$ (m)
Water	300	0.0063	0.464	2.72
Water	400	0.0059	1.72	2.30
Engine Oil	300	0.0056	7.27×10^{-4}	4.65
Engine Oil	400	0.0052	37.7×10^{-3}	5.74

COMMENTS: (1) As the momentum and thermal diffusivities approach similar values ($Pr \rightarrow 1$) $x_{fd,h}/x_{fd,t} \rightarrow 1$. (2) Note the variation of $x_{fd,h}/x_{fd,t}$ with Pr for large and small values of the Prandtl number. (c) The Reynolds number associated with the oil is very small. Buoyancy forces are likely to be significant and may induce secondary fluid motion which, in turn, may increase the convection heat transfer coefficients. We will treat buoyancy effects in Chapter 9.