Ave = 80, High = 95, Low = 62

Exam 1 v.1.0 Key
BE-382, Winter '08-'09, Dr. C. S. Tritt

This is a 1 hour closed book, closed notes exam. Write your answers on the paper provided or your own and organize and explain you work for full and partial credit. You may use 1 double sided, 8½ by 11 inch equation sheet, EES and the provided Units Conversion Factors and Properties handout. If you use EES, e-mail me your files (the file names should encode your last name and the problem number) at the end of the exam and clearly indicate on your exam that you used EES. Please turn in your units conversion handout at the end of the test. Put your name on it if you make any marks or notes in it. There are 3 problems, point values are as indicated.

Conversion factors and the Moody chart are attached.

1. (30) The viscosity of a sample of unknown fluid is to be measured in a concentric cylinder device at 37°C. The radius of the inner cylinder is 8.00 cm, the gap between the cylinders is 1.00 mm and the length of the cylinders is 10.0 cm. The speed of the inner cylinder is varied and the following torques are measured:

Speed (rpm)	Torque (N·m)
300	20.21
450	30.32
600	40.43

   What is the viscosity or apparent viscosities of the fluid and is it Newtonian under the test conditions?

2. (35) It has been proposed that a non-lethal (or at least unlike to be deadly) device be developed to protect ships from pirates in the Gulf of Aden. In particular, a water jet device is being developed. Assuming uniform cross-sectional velocity, what velocity (in ft/s) would a 2.00 inch diameter water (ρ = 62.3 lb_m/ft^3) jet require to produce a 200 lb_f force on its target. Assume the water spatters uniformly and particularly upon impact.

3. (35) In an operating room, cooling water flows through a 1.00 cm ID tube at a rate of 6.0 l/min. The tube is 20.0 m long. Given the density of the water is 1002 kg/m^3 and its viscosity is 1.00 cp, what is the pressure drop, in Pa, from end-to-end of the tube?

1. Viscosity determination - concentric cylinder device.

General equation 9-12:

$$T = \mu \frac{4\pi^2 R^3 \dot{n} L}{\ell} \Rightarrow \mu = \frac{\ell T}{4\pi^2 R^3 \dot{n} L}$$

$R = 8.00$ cm $= 0.080$ m

$L = 20.0$ cm $= 0.200$ m

$\dot{n} = 450$ rpm $= \frac{450\ /\text{min}}{60\ \text{s}/\text{min}} = 7.5\ \text{s}^{-1}$

$\ell = 0.10$ cm $= 0.00100$ m

2nd case:

$$\mu = \frac{(0.00100\,\text{m})(30.32\ \text{N}\cdot\text{m})}{4\pi^2 (0.080^3\,\text{m}^3)(7.5\ \text{s}^{-1})(0.100\,\text{m})}$$

$$= 2.00\ \frac{\text{N}\cdot\text{s}}{\text{m}^2}$$

1st case: $\mu = 2.00\ \frac{\text{N}\cdot\text{s}}{\text{m}^2}$

3rd case: $\mu = 2.00\ \text{N}\cdot\text{s}/\text{m}^2$

So fluid is Newtonian.

-5 units

10 pts for Newtonian

2. Water jet impact force.

Start with equation from Example 13-4. (like equation 13-23).

$$F = \beta \dot{m} V_1 \quad 10 \text{ pts}$$

Uniform cross-sectional velocity $\Rightarrow \beta = 1$ 3 pts

$$F = \dot{m} V_1$$

Volumetric flow, $\dot{V} = V A_{cs}$ and mass flow, $\dot{m} = \dot{V}\rho$, so the equation becomes

$$F = \rho A_{cs} V^2 \quad \text{or} \quad V = \sqrt{\frac{F}{\rho A_{cs}}}$$

$F = 200$ lbf

$$A_{cs} = \pi r^2 = \pi\left(\frac{1}{12}\text{ ft}\right)^2 = 0.0218 \text{ ft}^2$$

$\rho = 62.3$ lbm/ft^3 (given)

$$V = \sqrt{\frac{200 \text{ lbf}\left(32.174 \frac{\text{lbm ft}}{\text{s}^2 \text{ lbf}}\right)}{\left(62.3 \text{ lbm/ft}^3\right)\left(0.0218 \text{ ft}^2\right)}}$$

$$= \sqrt{4740 \text{ ft}^2/\text{s}^2} = 68.8 \text{ ft/s}$$

Note this velocity is about 47 mph so it seems reasonable.

Not converting units − 7

3. Pressure drop in a pipe flow.

$L/D = 20\ m / 0.01\ m = 2{,}000$ so assume fully developed.

Plan to use friction factor:

$$\Delta P = f \frac{L}{D} \frac{\rho V_{ave}^2}{2} \quad (\text{Eq. } 14\text{-}21)$$

$$V_{ave} = \frac{\dot{V}}{A_{cs}} = \frac{1.00 \times 10^{-4}\ m^3/s}{7.85 \times 10^{-5}\ m^2} = \underline{\underline{1.27\ m/s}}$$

$$\dot{V} = 6.00\ \ell/min \left(\frac{1\ m^3}{1000\ \ell}\right)\left(\frac{1\ min}{60\ s}\right) = \underline{\underline{1.00 \times 10^{-4}\ m^3/s}}$$

$$A_{cs} = \pi r^2 = \frac{\pi D^2}{4} = \frac{\pi\ (0.01\ m)^2}{4} = 7.85 \times 10^{-5}\ m^2$$

$$N_{Re} = \frac{\rho V_{ave} D}{\mu} = \frac{(1002\ kg/m^3)(1.27\ m/s)(0.01\ m)}{1.00 \times 10^{-3}\ kg/m \cdot s}$$

$$\rho = 1{,}002\ kg/m^3$$

$$\mu = 1.00\ cp \left(\frac{1\ poise}{100\ cp}\right)\left(\frac{1\ kg/m \cdot s}{10\ poise}\right) = 1.00 \times 10^{-3}\ \frac{kg}{m \cdot s}$$

Note: Viscosity is defined and discussed on p. 389

$N_{Re} = \underline{\underline{12{,}700}}$, so flow is turbulent

Assume a smooth pipe ($\varepsilon/D = 0$) or smooth rubber ($\varepsilon/D = 0.01\ mm / 10\ m = 0.001$).

From chart

$f = 0.029$ (smooth) or

$f = \underline{0.031}$ (rubber)

$$\Delta P = (0.029)(2{,}000)\frac{(1002\ kg/m^3)(1.27\ m/s)^2}{2}$$

$$= 4.69 \times 10^4\ kg/(m \cdot s)\left(\frac{kPa}{1000\ kg/(m \cdot s)}\right)$$

$= \underline{46.9\ kPa}$ (or about 1/2 atm, which seems reasonable)

The value for the rubber pipe is

$\Delta P = \underline{50.1\ kPa}$

The Colebrook, Haaland or Swamee - Jain equations could also be used.

Wrong f −5
Wrong N_{Re} −5
Wrong V_{ave} −5

Wrong ΔP equation −10 (Don't include g unless you want answer in head of liquid units)

A couple of students appear to have confused Eq. 14-21 (which is for pressure loss) with Eq. 14-24 (which is for head loss). Both of these equations do, in fact relate to the energy loss in a flowing fluid, but the units are different (specifically by ρg).

Conversion Factors

[illegible]	[illegible]	[illegible]
Acceleration	1 m/s^2 = 100 cm/s^2	1 m/s^2 = 3.2808 ft/s^2 1 ft/s^2 = 0.3048* m/s^2
Area	1 m^2 = 10^4 cm^2 = 10^6 mm^2 = 10^{-6} km^2	1 m^2 = 1550 in^2 = 10.764 ft^2 1 ft^2 = 144 in^2 = 0.09290304* m^2
Density	1 g/cm^3 = 1 kg/L = 1000 kg/m^3	1 g/cm^3 = 62.428 lbm/ft^3 = 0.036127 lbm/in^3 1 lbm/in^3 = 1728 lbm/ft^3 1 kg/m^3 = 0.062428 lbm/ft^3
Energy, heat, work, internal energy, enthalpy	1 kJ = 1000 J = 1000 Nm = 1 kPa · m^3 1 kJ/kg = 1000 m^2/s^2 1 kWh = 3600 kJ 1 cal† = 4.184 J 1 IT cal† = 4.1868 J 1 Cal† = 4.1868 kJ	1 kJ = 0.94782 Btu 1 Btu = 1.055056 kJ = 5.40395 psia · ft^3 = 778.169 lbf · ft 1 Btu/lbm = 25,037 ft^2/s^2 = 2.326* kJ/kg 1 kJ/kg = 0.430 Btu/lbm 1 kWh = 3412.14 Btu 1 therm = 10^5 Btu = 1.055 × 10^5 kJ (natural gas)
Force	1 N = 1 kg · m/s^2 = 10^5 dyne 1 kgf = 9.80665 N	1 lbf = 32.174 lbm · ft/s^2 = 4.44822 N 1 N = 0.22481 lbf
Heat flux	1 W/cm^2 = 10^4 W/m^2	1 W/m^2 = 0.3171 Btu/h · ft^2
Heat generation rate	1 W/cm^3 = 10^6 W/m^3	1 W/m^3 = 0.09665 Btu/h · ft^3
Heat transfer coefficient	1 W/m^2 · °C = 1 W/m^2 · K	1 W/m^2 · °C = 0.17612 Btu/h · ft^2 · °F
Length	1 m = 100 cm = 1000 mm 1 km = 1000 m	1 m = 39.370 in = 3.2808 ft = 1.0926 yd 1 ft = 12 in = 0.3048* m 1 mile = 5280 ft = 1.6093 km 1 in = 2.54* cm
Mass	1 kg = 1000 g 1 metric ton = 1000 kg	1 kg = 2.2046226 lbm 1 lbm = 0.45359237* kg 1 ounce = 28.3495 g 1 slug = 32.174 lbm = 14.5939 kg 1 short ton = 2000 lbm = 907.1847 kg

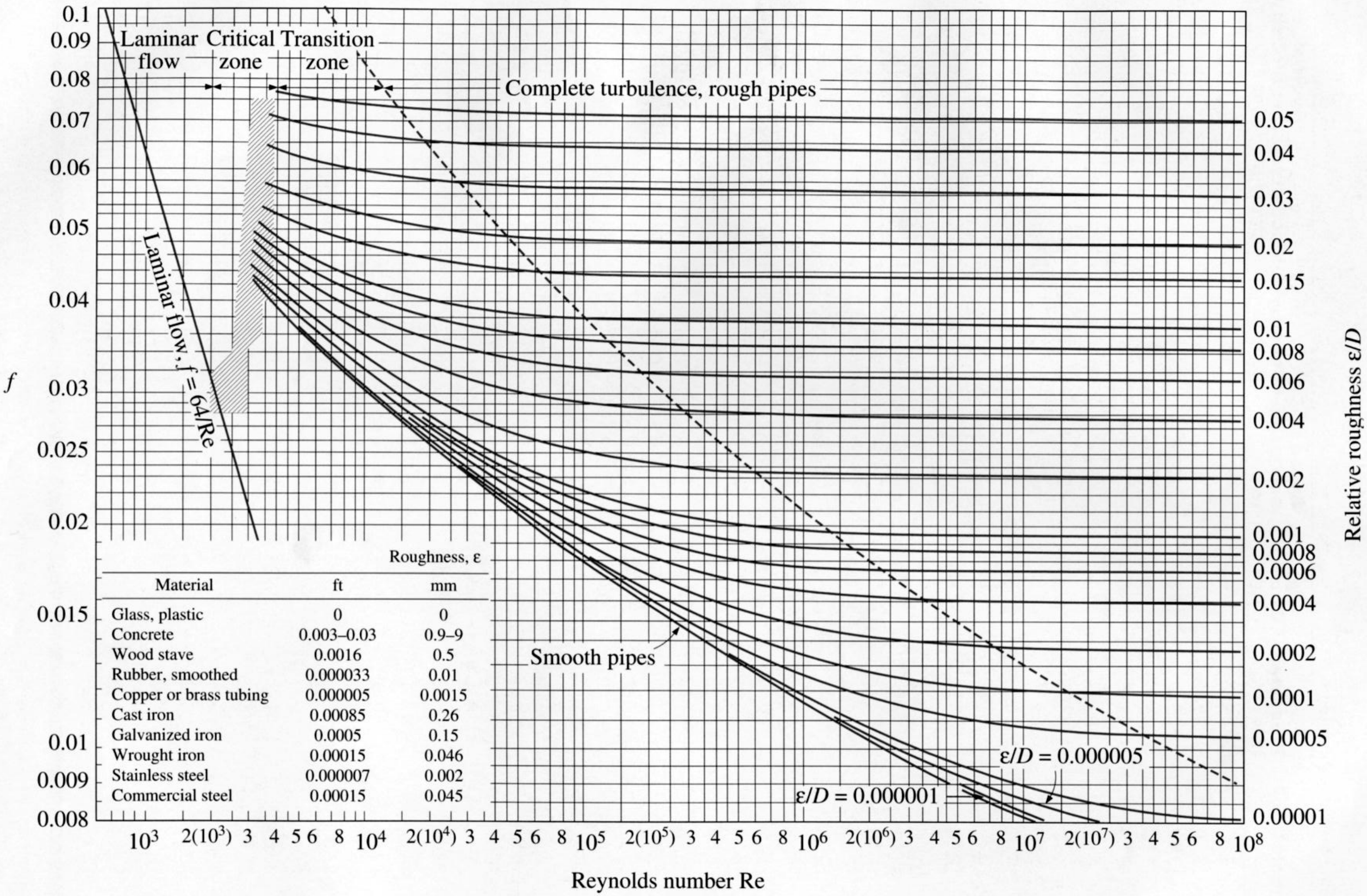
*Exact conversion factor between metric and English units.

†Calorie is originally defined as the amount of heat needed to raise the temperature of 1 g of water by 1°C, but it varies with temperature. The international steam table (IT) calorie (generally preferred by engineers) is exactly 4.1868 J by definition and corresponds to the specific heat of water at 15°C. The thermochemical calorie (generally preferred by physicists) is exactly 4.184 J by definition and corresponds to the specific heat of water at room temperature. The difference between the two is about 0.06 percent, which is negligible. The capitalized Calorie used by nutritionists is actually a kilocalorie (1000 IT calories).

[illegible]	METRIC	METRIC/ENGLISH
Power, heat transfer rate	1 W = 1 J/s 1 kW = 1000 W = 1.341 hp 1 hp[†] = 745.7 W	1 kW = 3412.14 Btu/h = 737.56 lbf · ft/s 1 hp = 550 lbf · ft/s = 0.7068 Btu/s = 42.41 Btu/min = 2544.5 Btu/h = 0.74570 kW 1 boiler hp = 33,475 Btu/h 1 Btu/h = 1.055056 kJ/h 1 ton of refrigeration = 200 Btu/min
Pressure	1 Pa = 1 N/m^2 1 kPa = 10^3 Pa = 10^{-3} MPa 1 atm = 101.325 kPa = 1.01325 bars = 760 mmHg at 0°C = 1.03323 kgf/cm^2 1 mmHg = 0.1333 kPa	1 Pa = 1.4504×10^{-4} psia = 0.020886 lbf/ft^2 1 psia = 144 lbf/ft^2 = 6.894757 kPa 1 atm = 14.696 psia = 29.92 inHg at 30°F 1 inHg = 3.387 kPa
Specific heat	1 kJ/kg · °C = 1 kJ/kg · K = 1 J/g · °C	1 Btu/lbm · °F = 4.1868 kJ/kg · °C 1 Btu/lbmol · R = 4.1868 kJ/kmol · K 1 kJ/kg · °C = 0.23885 Btu/lbm · °F = 0.23885 Btu/lbm · R
Specific volume	1 m^3/kg = 1000 L/kg = 1000 cm^3/g	1 m^3/kg = 16.02 ft^3/lbm 1 ft^3/lbm = 0.062428 m^3/kg
Temperature	$T(K) = T(°C) + 273.15$ $\Delta T(K) = \Delta T(°C)$	$T(R) = T(°F) + 459.67 = 1.8T(K)$ $T(°F) = 1.8\,T(°C) + 32$ $\Delta T(°F) = \Delta T(R) = 1.8^* \Delta T(K)$
Thermal conductivity	1 W/m · °C = 1 W/m · K	1 W/m · °C = 0.57782 Btu/h · ft · °F
Thermal resistance	1°C/W = 1 K/W	1 K/W = 0.52750°F/h · Btu
Velocity	1 m/s = 3.60 km/h	1 m/s = 3.2808 ft/s = 2.237 mi/h 1 mi/h = 1.46667 ft/s 1 mi/h = 1.609 km/h
Viscosity, dynamic	1 kg/m · s = 1 N · s/m^2 = 1 Pa · s = 10 poise	1 kg/m · s = 2419.1 lbf/ft · h = 0.020886 lbf · s/ft^2 = 5.8016×10^{-6} lbf · h/ft^2
Viscosity, kinematic	1 m^2/s = 10^4 cm^2/s 1 stoke = 1 cm^2/s = 10^{-4} m^2/s	1 m^2/s = 10.764 ft^2/s = 3.875×10^4 ft^2/h 1 m^2/s = 10.764 ft^2/s
Volume	1 m^3 = 1000 L = 10^6 cm^3 (cc)	1 m^3 = 6.1024×10^4 in^3 = 35.315 ft^3 = 264.17 gal (U.S.) 1 U.S. gallon = 231 in^3 = 3.7854 L 1 fl ounce = 29.5735 cm^3 = 0.0295735 L 1 U.S. gallon = 128 fl ounces

*Exact conversion factor between metric and English units.

[†]Mechanical horsepower. The electrical horsepower is taken to be exactly 746 W.



Material	Roughness, ε ft	Roughness, ε mm
Glass, plastic	0	0
Concrete	0.003–0.03	0.9–9
Wood stave	0.0016	0.5
Rubber, smoothed	0.000033	0.01
Copper or brass tubing	0.000005	0.0015
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Wrought iron	0.00015	0.046
Stainless steel	0.000007	0.002
Commercial steel	0.00015	0.045

FIGURE A-27

The Moody chart for the friction factor for fully developed flow in circular tubes.