In Session Practice Problems – Thermodynamics (EGN 3343)

February 2024

Hello everyone,

These are some problems that, in my experience, provide students with a wider understanding of the topics covered in the first third of the semester. I will go over these and other problems during my sessions. I highly recommend that you attend these sessions to solve any doubts.

Disclaimer: There is no guarantee that any of these problems will be included in any exam, so the best way to approach these problems is like practice problems that will help you familiarize yourself with important concepts learned during the semester. Finally, do not use this guide as your ONLY study resource for the exams.

Important Note: All problems and diagrams presented here were extracted from Cengel, Yunus, et al. Thermodynamics: An Engineering Approach. Available from: Yuzu Reader, (9th Edition). McGraw-Hill Higher Education (US), 2018.

1–105 A pressure cooker cooks a lot faster than an ordinary pan by maintaining a higher pressure and temperature inside. The lid of a pressure cooker is well sealed, and steam can escape only through an opening in the middle of the lid. A separate metal piece, the petcock, sits on top of this opening and prevents steam from escaping until the pressure force overcomes the weight of the petcock. The periodic escape of the steam in this manner prevents any potentially dangerous pressure buildup and keeps the pressure inside at a constant value. Determine the mass of the petcock of a pressure cooker whose operation pressure is 100 kPa gage and has an opening cross-sectional area of 4 mm^2. Assume an atmospheric pressure of 101 kPa, and draw the free-body diagram of the petcock. Answer: 40.8 g

ORG

Patm OKG

$P = \frac{F}{A} \rightarrow F = PA$

4 mm²

$P_T = P_{gage} + \cancel{P_{atm}}$

$\Sigma F_y = F_{in} - \cancel{F_{out}} - W = 0$

$\Sigma F_y = (P_{gage} + \cancel{P_{atm}})A - \cancel{P_{atm}A} - W = 0$

$P_{gage}(A) = W$

$P_{gage}(A) = mg$

$m = \frac{P_{gage}(A)}{g}$

$4\,mm^2\left(\frac{1\,m}{1000\,mm}\right)^2$

$4 \times 10^{-6}\,m^2$

$Pa = \frac{N}{m^2}$ $N = kg\frac{m}{s^2}$

$kPa = \frac{kN}{m^2}$ $kN = Mg\frac{m}{s^2}$

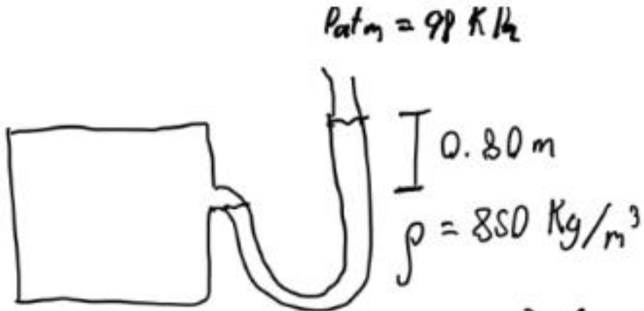
$m = \frac{100\frac{Mg\,m}{s^2\,m^2}(4 \times 10^{-6}\,m^2)}{9.81\,\frac{m}{s^2}}$

$m = 4.07747 \times 10^{-5}\,Mg\left(\frac{1000000\,g}{1\,Mg}\right)$

$\boxed{m = 40.8\ g}$

1–63 A manometer containing oil (ρ = 850 kg/m^3) is attached to a tank filled with air. If the oil level difference between the two columns is 80 cm and the atmospheric pressure is 98 kPa, determine the absolute pressure of the air in the tank. Answers: 105 kPa

1-63.



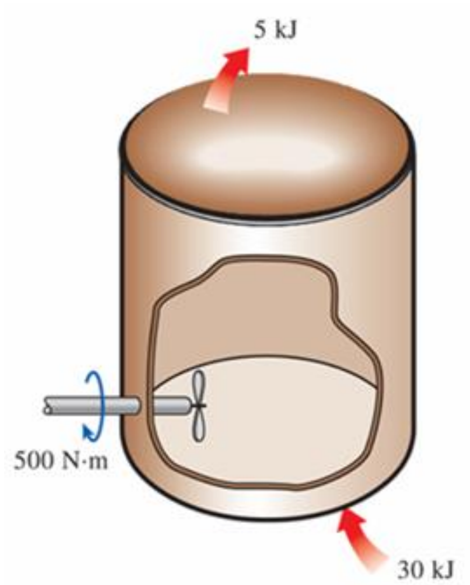
$$P_{oil} = \rho g h = 9.81 \frac{m}{s^2} (850\ kg/m^3)(0.8\ m)$$

$$P_{oil} = 6670.8\ Pa = 6.6708\ kPa$$

$$P_{Tank} = P_{oil} + P_{atm} = 6.6708\ kPa + 98\ kPa$$

$$P_{Tank} = 104.6708 \approx 105\ kPa$$

2–40 Water is being heated in a closed pan on top of a range while being stirred by a paddle wheel. During the process, 30 kJ of heat is transferred to the water, and 5 kJ of heat is lost to the surrounding air. The paddle-wheel work amounts to 500 N·m. Determine the final energy of the system if its initial energy is 12.5 kJ. Answer: 38.0 kJ



2-40

$$\Delta E = E_{in} - E_{out}$$

$$[U_2 + \cancel{\tfrac{1}{2}mV_2^2} + \cancel{mgh_2} + \cancel{P_2V_2}] - [U_1 + \cancel{\tfrac{1}{2}mV_1^2} + \cancel{mgh_1} + \cancel{P_1V_1}] = [Q_{in} + W_{in}] - [Q_{out} - \cancel{W_{out}}]$$

$$U_2 - U_1 = Q_{in} + W_{in} - Q_{out}$$

$$U_2 = Q_{in} + W_{in} - Q_{out} + U_1$$

$$U_2 = 30\,kJ + 0.5\,kJ - 5\,kJ + 12.5\,kJ$$

$$U_2 = 38\,kJ$$

3–31 10 kg of R-134a fill a 1.115-m^3 rigid container at an initial temperature of –30°C. The container is then heated until the pressure is 200 kPa. Determine the final temperature and the initial pressure. Answers: 14.2°C, 84.43 kPa

3.31 R-134A $m = 10\ \text{Kg}$

$T_0 = -30°C$ $P_F = 200\ \text{kPa}$ $V = 1.115\ m^3$

For this problem we will need to use the tables, but first, we need to determine if the material is a compressed liquid, sat mixture, or superheated vapor, so we will use the specific volume to determine this

$$v = \frac{1.115\ m^3}{10\ \text{Kg}} = 0.1115\ \frac{m^3}{\text{Kg}}$$

Now we look at table A-11 (at -30°C), we can see that our v is $< v_g$, but $> v_f$, so we know, we are a sat. mixture. Therefore, our pressure is

$$\boxed{P_0 = 84.43\ \text{kPa}}$$

Now to determine our final temperature, we go to table A-12 (at 200 kPa), we notice that our $v > v_g > v_f$, so our material is not saturated, but superheated, now we go to table A-13 (at 0.2 MPa = 200 kPa), we notice that our value is between 0.10955 and 0.11418, so our temp must be between 10 and 20°C, so we need to interpolate

$$\frac{T - 10}{0.1115 - 0.10955} = \frac{20 - 10}{0.11418 - 0.10955}$$

solve for t, and we get

$$\underbrace{T = 14.2116 \approx 14.2^\circ C}$$

3–75 A 1-m^3 tank containing air at 10°C and 350 kPa is connected through a valve to another tank containing 3 kg of air at 35°C and 150 kPa. Now the valve is opened, and the entire system is allowed to reach thermal equilibrium with the surroundings, which are at 20°C. Determine the volume of the second tank and the final equilibrium pressure of air. Answers: 1.77 m^3, 222 kPa.

3.75

Tank 1
$V = 1\ m^3$
$T = 10°C$
$P = 350\ kPa$

Tank 2
$m = 3\ kg$
$T = 35°C$
$P = 150\ kPa$

To find V_o of tank 2, we will use our ideal gas equation

$$PV = RTm \rightarrow V = \frac{RTm}{P}$$

$$V = \frac{0.287 \frac{kN \cdot m}{\cancel{K} \cdot \cancel{kg}} (3\ \cancel{kg})(35+273)\cancel{K}}{150 \frac{kN}{m^2}}$$

$$V = 1.76792\ m^3 \approx \underbrace{1.77 m^3}$$

We might want to use our ideal gas equation, to find the pressure after the valve was open, so we need to check if we have enough information

$$P = \frac{RTm}{V}$$

$T_F = 20°C$ $\quad V_F = 1.76792 + 1 = 2.76792\ m^3$

$m = 3\ kg + m_{Tank\ 1}$

We are missing $m_{Tank\ 1}$, but we can determine it, with our ideal gas equation for tank 1.

$$m = \frac{PV}{RT} = \frac{350 \frac{\cancel{kN}}{\cancel{m^2}} (1\ \cancel{m^3})}{0.287 \frac{\cancel{kN \cdot m}}{\cancel{K} \cdot kg} (10+273)\cancel{K}}$$

$$m = 4.30923\ kg$$

Now we can plug back in our ideal gas equation after the valve was open $m = 3\,kg + 4.30923\,kg \simeq 7.30923\,kg$

$$P = \frac{RTm}{V}$$

$$P = \frac{0.287 \frac{kN \cdot \cancel{m}}{\cancel{K} \cdot \cancel{kg}} (20+273)\cancel{K} (7.30923\,\cancel{kg})}{2.76792\,m^3}$$

$$\boxed{P = 222.0586\,kPa \simeq 222\,kPa}$$

4–17 A frictionless piston–cylinder device contains 5 kg of nitrogen at 100 kPa and 250 K. Nitrogen is now compressed slowly according to the relation ($PV^{1.4} = constant$) until it reaches a final temperature of 450 K. Calculate the work input during this process. Answer: 742 kJ.

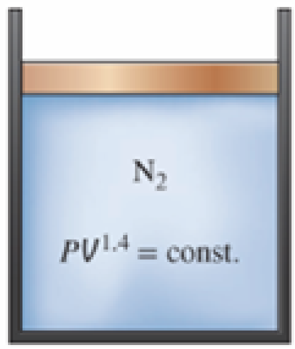


FIGURE P4–17

4-17.

$m = 5\ kg$ $\quad P_1 = 100\ kPa$ $\quad T_0 = 250\ K$

$T_F = 450\ K$

$w = \int P\,dV$ $\quad PV^n = \text{Constant } (c)$

$PV^n = C$

For this problem, we are going to derive the equation in general terms. So we write P in terms of V and integrate

$$PV^n = c \rightarrow P = \frac{c}{V^n}$$

$$W = \int_{V_1}^{V_2} \frac{c}{V^n}\, dV$$

$$W = c \int_{V_1}^{V_2} V^{-n}\, dV$$

$$W = c\, \frac{V^{1-n}}{1-n}\Bigg|_{V_1}^{V_2}$$

$$W = c\, \frac{V_2^{1-n} - V_1^{1-n}}{1-n}$$

However, we do not know c, so it would be useful to replace it by some known values

$$c = P_1 V_1^n$$

$$W = P_1 V_1^n \left(\frac{V_2^{1-n} - V_1^{1-n}}{1-n} \right)$$

$$W = \frac{P_1 V_1^n V_2^{1-n} - P_1 V^{\cancel{n+1-n}}}{1-n}$$

$$W = \frac{P_1 V_1^n V_2^{1-n} - P_1 V_1}{1-n}$$

We could further simplify by considering that $P_1 V_1^n = c = P_2 V_2^n$

$$W = \frac{P_2 V_2^n V_2^{1-n} - P_1 V_1}{1-n}$$

$$W = \frac{P_2 V_2^{\cancel{n+1-n}\,1-n} - P_1 V_1}{1-n} = \frac{P_2 V_2 - P_1 V_1}{1-n}$$

We do not know P_2, V_2, or V_1, but we could write in terms of temperature using the ideal gas equation

$$PV = RTm \rightarrow \begin{cases} P_1 V_1 = R T_1 m \\ P_2 V_2 = R T_2 m \end{cases}$$

$$W = \frac{R T_2 m - R T_1 m}{1-n} = \frac{Rm(T_2 - T_1)}{1-n}$$

Now the only value we are missing is R for N_2, but we can find this value in table A_2

$$R = 2968$$

$$W = \frac{0.2968 \frac{kJ}{kg \cdot K}(5 kg)(450 K - 250 K)}{1 - 1.4}$$

$$W = -742 \text{ kJ}$$

The negative sign means is work done into the system, so we can say that

$$\boxed{W_{input} = 742 \text{ KJ}}$$

4–38 An insulated piston–cylinder device contains 5 L of saturated liquid water at a constant pressure of 175 kPa. Water is stirred by a paddle wheel while a current of 8 A flows for 45 min through a resistor placed in the water. If one-half of the liquid is evaporated during this constant-pressure process and the paddle-wheel work amounts to 400 kJ, determine the voltage of the source. Answer: 224 V.

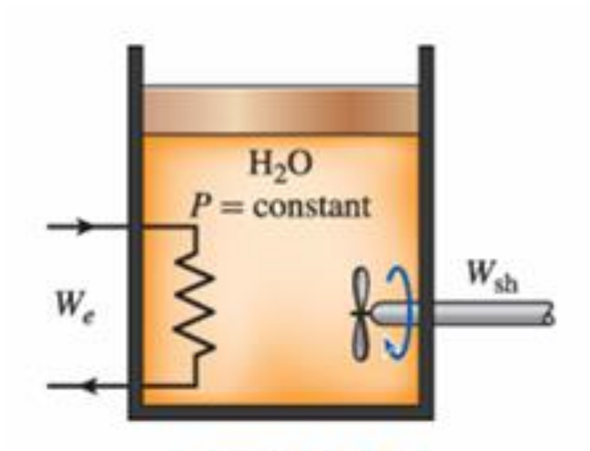
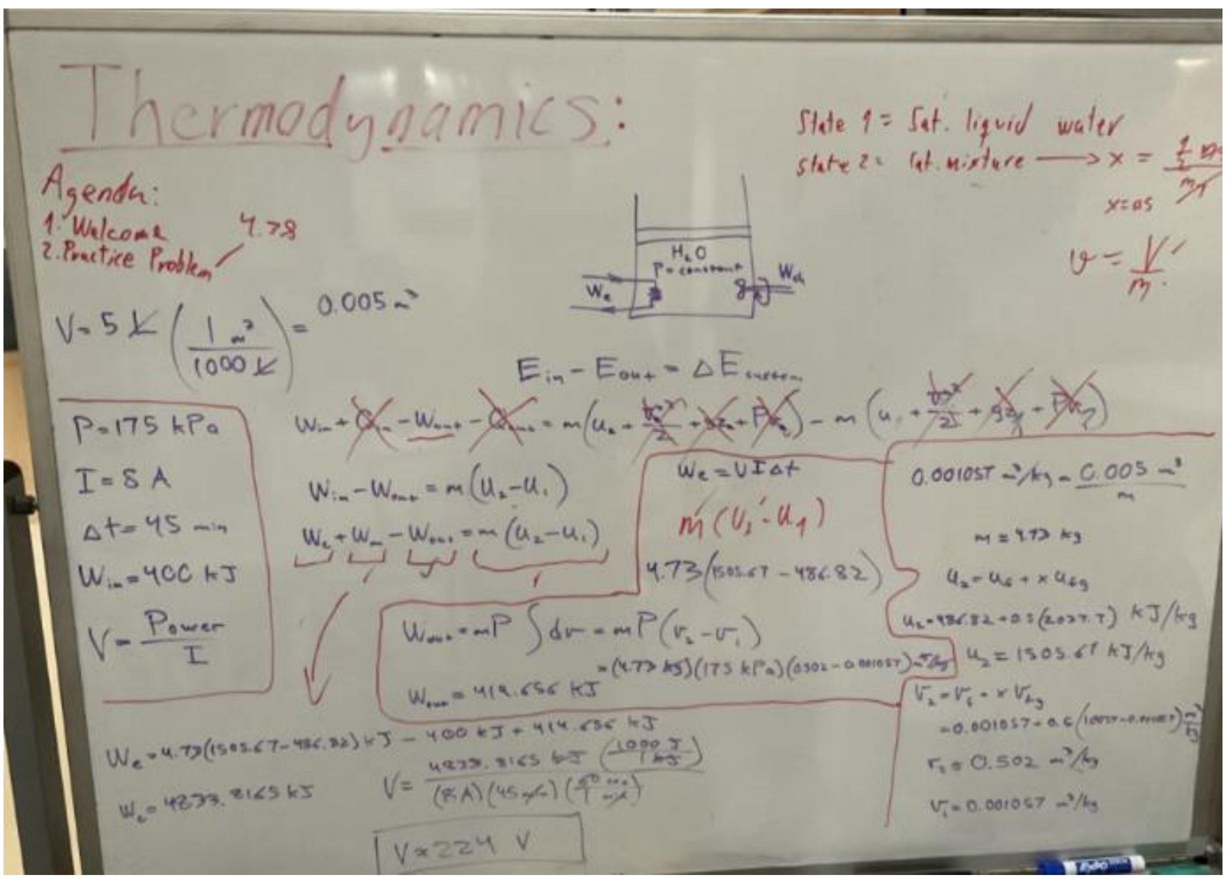
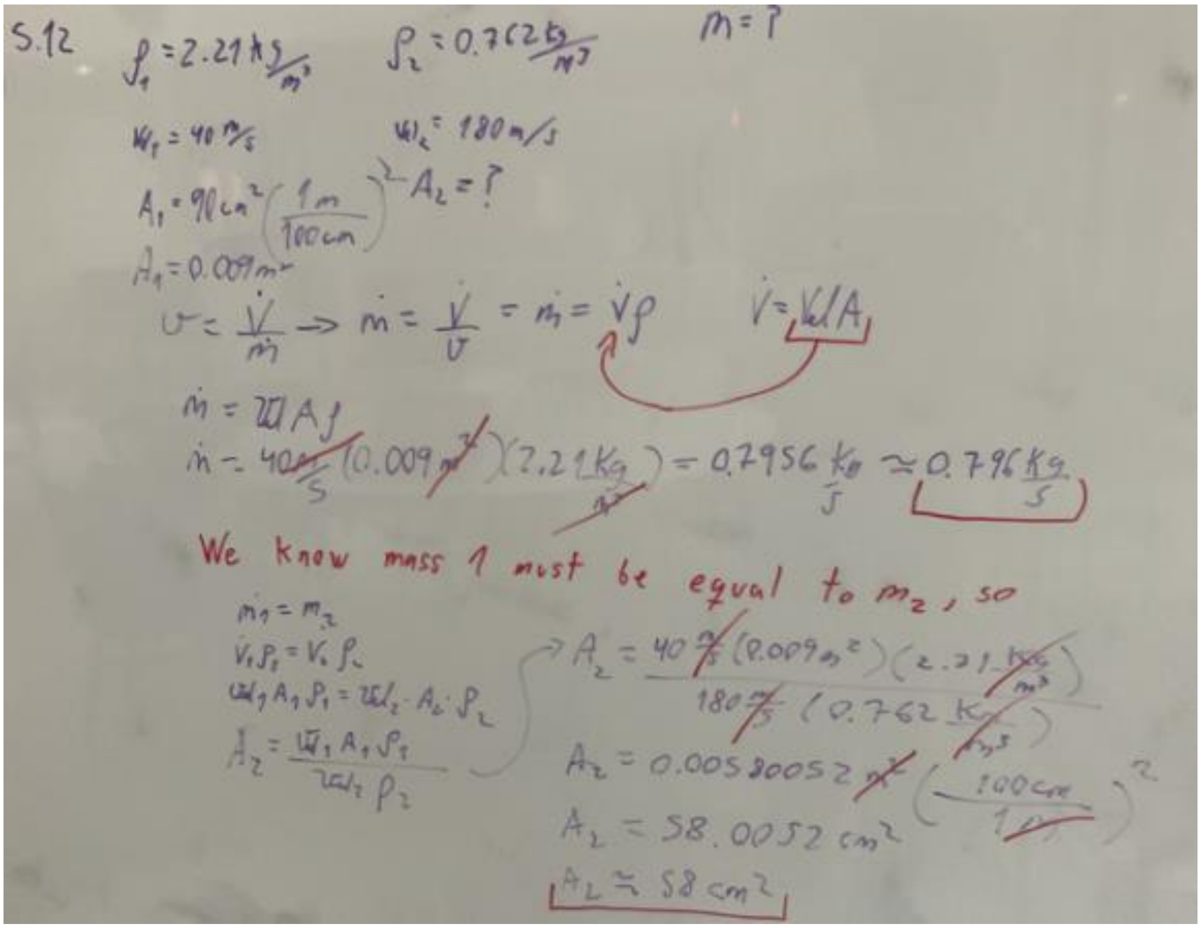


FIGURE P4–38



5–12 Air enters a nozzle steadily at 2.21 kg/m^3 and 40 m/s and leaves at 0.762 kg/m^3 and 180 m/s. If the inlet area of the nozzle is 90 cm^2, determine (a) the mass flow rate through the nozzle, and (b) the exit area of the nozzle. Answers: (a) 0.796 kg/s, (b) 58.0 cm^2.



5–48 Steam flows steadily through an adiabatic turbine. The inlet conditions of the steam are 4 MPa, 500°C, and 80 m/s, and the exit conditions are 30 kPa, 92 percent quality, and 50 m/s. The mass flow rate of the steam is 12 kg/s. Determine (a) the change in kinetic energy, (b) the power output, and (c) the turbine inlet area. Answers: (a) −1.95 kJ/kg, (b) 12.1 MW, (c) 0.0130 m^2.

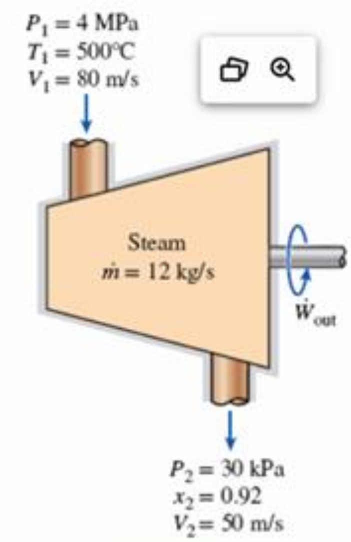


FIGURE P5–48

a) $KE = \frac{1}{2}V^2 \rightarrow \Delta KE = \frac{1}{2}(V_F^2 - V_0^2)$

$KE = \frac{1}{2}(50\frac{m}{s}^2 - 80\frac{m}{s}^2)$

$KE = -1950\frac{J}{kg} \approx -1.95\frac{kJ}{kg}$

b) $P_{out} = ?$ $E_{in} - E_{out} = \cancel{\Delta E_{syst}}^{\,0}$

$\dot{m}\left(\cancel{\frac{gh}{1000}} + \frac{V_{in}^2}{2000} + \underbrace{u_{in} + PV_{in}}_{h_{in}}\right) - \dot{m}\left(\cancel{\frac{gh}{1000}} + \frac{V_{in}^2}{2000} + \underbrace{u_{out} + PV_{out}}_{h_{out}}\right)$

$-\dot{W}_{out} + \cancel{\dot{Q}_{in}} = 0$

$\dot{m}\left(\frac{V_{in}^2}{2000} + h_{in}\right) - \dot{m}\left(\frac{V_{out}^2}{2000} + h_{out}\right) = \dot{W}_{out}$?

$h_{in} = 3446.0 \ \frac{kJ}{kg}$

From table A-5

$h_{out} =$

$h_f = 289.27 \ kJ/kg$

$h_g = 2624.6 \ kJ/kg$

$x = 0.92$

$$h_{out} = h_f(1-x) + h_g x$$

$$h_{out} = h_f - x h_f + h_g x$$

$$h_{out} = h_f + x(h_g - h_f)$$

$$\boxed{h_{out} = h_f + x h_{fg}}$$

$$h_{out} = 289.27(1-0.92) + 2624.6(0.92)$$

$$h_{out} = 2437.77 \ kJ/kg$$

$$12 \frac{kg}{s}\left(\frac{80^2}{2000} + 3446\right) - 12\left(\frac{50^2}{2000} + 2437.77\right)$$

$$= \dot{W}_{out}$$

$$\dot{W}_{out} = 12122.16 \ kW \approx \boxed{12.1 \ MW}$$

c.

$$\dot{m}_{in} = \dot{m}_{out}$$

$$\frac{A_{in}\, Vel(in)}{v_{in}} = \frac{A_{out}\, Vel(out)}{v_{out}}$$

$$v_i = 0.08644\ \frac{m^3}{kg}$$

$$\dot{V} = A\, Vel$$

$$v = \frac{\dot{V}}{\dot{m}}$$

$$\dot{m} = \frac{\dot{V}}{v}$$

$$\dot{m} = \frac{A\, Vel}{v}$$

$A_{in} =$

$$A_{in} = \frac{\dot{m}\, v_{in}}{Vel(in)} = \frac{12\ \frac{kg}{s}\left(0.08644\ \frac{m^3}{kg}\right)}{80\ \frac{m}{s}}$$

$$A_{in} = 0.012966\ m^2$$

$$\approx 0.0130\ m^2$$