$\frac{62}{100}$

ENME 3770 Engineering Thermodynamics
Test # 2, Summer 2010

Part 1: Closed Books and Notes (60 points, Recommended Time: 40 minutes) Name: Nicholas March

1. What are the mass and momentum equations for transient process? (3%)

$m_i = m_e = m$

-3

2. Defile the compressibility factor. What is it for? (3%)

$Z = \frac{PV}{RT}$

Z is the compressibility factor and it shows the difference between an ideal and real gas.

$Z = 1$ ideal gas $Z \neq 1$ real gas

3. Why is the Generalized Compressibility Chart called "generalized"? What parameters are used to form the Generalized Compressibility Char? Explain these parameters in detail. (5%)

It is generalized because it applies to both ~~ideal~~ and real gases.

The parameters used are Z, T_R, & P_R

Z = compressibility factor = $\frac{PV}{RT}$

-2

T_R = temperature reduction = $\frac{T}{T_c}$ P_R = pressure reduction = $\frac{P}{P_c}$

4. Show how can the equation $0 = \dot{Q} - \dot{W} + \dot{m}_i\left(u_i + \frac{V_i^2}{2}\right) - \dot{m}_e\left(u_e + \frac{V_e^2}{2}\right)$ become $0 = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}_i\left(h_i + \frac{V_i^2}{2}\right) - \dot{m}_e\left(h_e + \frac{V_e^2}{2}\right)$? (8%)

$W = W_{cv} - m_e(v_e + P_e) + m_i(v_i + P_i)$

substitute How -1

$0 = Q - (W_{cv} + m_i v_i + m_i P_i - m_e v_e - m_e P_e) + m_i\left(u_i + \frac{V_i^2}{2}\right) - m_e\left(u_e + \frac{V_e^2}{2}\right)$

$0 = Q_{cv} - W_{cv} + m_i\left(u_i + P_i v_i + \frac{V_i^2}{2}\right) - m_e\left(u_e + P_e v_e + \frac{V_e^2}{2}\right)$

$h = u + pv$

So, $0 = Q_{cv} - W_{cv} + m_i\left(h_i + \frac{V_i^2}{2}\right) - m_e\left(h_e + \frac{V_e^2}{2}\right)$

-3

5. Explain the major functions of the following devices. (6%)

Diffuser decreases velocity of substance flowing through it while increasing pressure

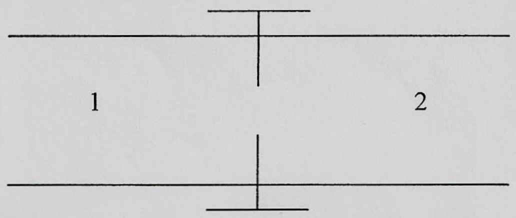
Compressor use work to create fluid energy

-1

Heat Exchanger transfers heat between two fluids

Nicholas Merch

6. (a) Use the energy conservation equation to explain why a throttling process can be approximated as an isenthalpic process. (4%)
(b) Fill in <, =, or > between inlet (1) and outlet (2) conditions corresponding to a throttling process of an incompressible flow and provide a brief explanation to support your answer. (6%)
(c) What is the main purpose of applying a throttling process? (2%)



a) $\frac{dE_{cv}}{dt} = \cancel{Q} - \cancel{W} + m_1\left(h_1 + \frac{V_1^2}{2} + gz_1\right) - m_2\left(h_2 + \frac{V_2^2}{2} + gz_2\right)$

$0 = m_1(h_1) - m_2(h_2)$

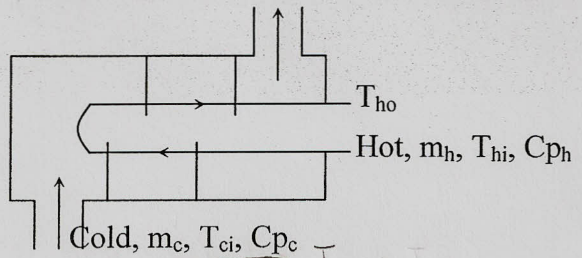
since, $m_1 = m_2 = m$

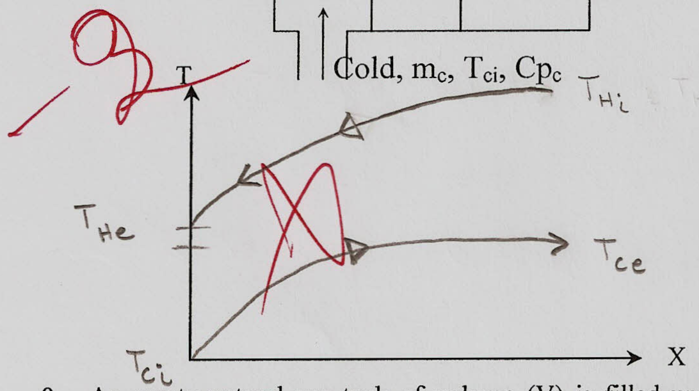
so, $0 = m(h_1 - h_2) \Rightarrow h_1 = h_2$

A_1	$=$	A_2	Area	Explanation
Z_1	$=$	Z_2	Elevation	
P_1	$>$	P_2	Pressure	significant reduction by definition
V_1	$\approx$	V_2	Velocity	negligible difference
T_1	$\neq$	T_2	Temperature	depends on Joule-Thompson coefficient
m_1	$=$	m_2	Flow Rate	does not change because energy conserved

c) Throttling process is a constant enthalpy process. There is a significant reduction in pressure, PE, KE, & Q are negligible changes.

7. (a) Qualitatively plot the trend of the temperature distribution of the following parallel flow heat exchanger. (3%)
(b) Determine the cold outlet temperature based on the conditions shown in the figure, assuming no heat loss. (3%)





$C_p = \left(\frac{dh}{dt}\right)_P$

$C_p = \frac{u + pv}{t} = \frac{u(T) + RT}{t}$

$C_p(t) = u(T) + R(T_2 - T_1)$

$C_p(t) - u(T) = R(T_2 - T_1)$

$\frac{C_p(t) - u(T)}{R} = T_2 - T_1$

$\boxed{T_2 = \frac{C_p(t) - u(T)}{R} + T_1}$

8. An empty natural gas tank of volume (V) is filled up by compressing the natural gas with constant enthalpy (h_i) through a compressor. The temperature and pressure of the natural gas inside the tank is monitored and known at any moment. Assuming the natural gas is an ideal gas, derive an equation to show that the heat transfer can be determined in terms of pressure, temperature and appropriate properties of the natural gas. (12%)

compression so $W < 0$

$\Delta E = Q - W \Rightarrow \Delta U = Q - W \Rightarrow m(u_2 - u_1) = Q - W \Rightarrow Q = m(u_2 - u_1) - W$

$h = u + pv \Rightarrow u = h - pv$

Substitute

9

$Q = m(h_2 - P_2V_2 - (h_1 - P_1V_1)) - W = m(h_2 - P_2V_2 - h_1 + P_1V_1) - \int_{V_1}^{V_2} p\,dV$

$Q = m(h_2 - P_2V_2 - h_1 + P_1V_1) - \frac{R_2T_2 - R_1T_1}{1-n} \quad (n \neq 1)$

$Q = m(h_2 - P_2V_2 - h_1 + P_1V_1) - R_2T_2 \ln\left(\frac{P_2}{P_1}\right) \quad (n = 1)$

9. Define the Joule-Thompson coefficient. What is it for? (5%)

$\mu_g = \left(\frac{\partial T}{\partial P}\right)_h$

It is used to provide information about temperature change after a throttling process.

If $\mu_g > 0$ then $T_1 > T_2$

If $\mu_g < 0$ then $T_1 < T_2$

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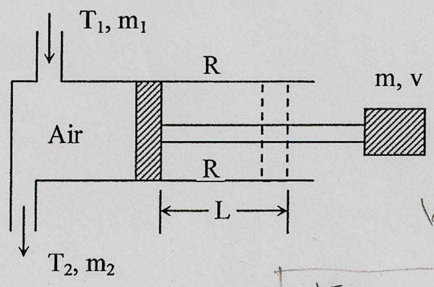
Part 2: Open Books and Notes (40 points, Recommended Time: 35 minutes) Name: Nicholas March

10. Air flows into a cylinder at a flow rate m_1 and temperature T_1 and flow out the cylinder at a flow rate of m_2 and T_2. In the meantime the cylinder is heated at a rate of Q. During a time period of t, the piston moves outward and pushes an object (of mass m), which starts moving at velocity v. the cross section area of the cylinder is A. The friction force between the piston and the cylinder is negligible. Set up an energy balance equation for this system. (15%)



$$\frac{dE_{cv}}{dt} = Q_{cv} - W_{cv} + m_1\left(h_1 + \frac{V_1^2}{2}\right) - m_2\left(h_2 + \frac{V_2^2}{2}\right)$$

W = force × distance = (mass × velocity) × distance

$$W = (m \times v) \times L = +mvL$$

$$0 = \boxed{\frac{dE_{cv}}{dt} = Q_{cv} - (mvL) + m_1\left(h_1 + \frac{V_1^2}{2}\right) - m_2\left(h_2 + \frac{V_2^2}{2}\right)}$$

IN	OUT
T_1	T_2
M_1	M_2

−6

11. Air expands through a turbine from 15 bar, 1400K to 1 bar, 600K. The inlet velocity is small compared to the exit velocity of 100m/s. The turbine operates at steady state and develops a power output of 1800kW. Heat transfer between the turbine and its surroundings and PE effects are negligible. Calculate the mass flow rate, in kg/s, and the exit area. If the specific heat is assumed to be constant (=1.005 kJ/kg.K), find the mass flow rate and compare between two mass flow rates. Comment on the difference you get from these two calculations. (15 + 5 + 5 = 25 %)

expansion so W = +

$P_1 = 15$ bar $\quad P_2 = 1$ bar $\quad W = 1800$ kW $= 1800{,}000$ W $= 18E5\ \frac{J}{s} = 18E2\ \frac{kJ}{s}$

$T_1 = 1400$ K $\quad T_2 = 600$K $\quad Q$ & $PE = 0$

$V_1 << V_2 \quad V_2 = 100$ m/s $\quad$ Find $\dot{m}$ in $\frac{kg}{s}$ & A_e

$$0 = \cancel{Q_{cv}}^{0} - W_{cv} + m\left[(h_1 - h_2) + \frac{\cancel{V_1^2}^{0} - V_2^2}{2} + g(\cancel{z_1 - z_2})^{0}\right]$$

$$W_{cv} = m\left[(h_1 - h_2) - \frac{V_2^2}{2}\right] \qquad h = \cancel{u}^{0} + RT \qquad m = \frac{AV}{v}$$

−10

−2

$$\dot{m} = \frac{W_{cv}}{(RT_1 - R_2T_2) - \frac{V_2^2}{2}} = \frac{1800\ \frac{kJ}{s}}{\left[\left(\frac{8.314\ \frac{kJ}{kmol\cdot K}}{28.97\ \frac{kg}{kmol}}(1400\ K)\right) - \left(\frac{8.314}{28.97}\right)600\right] - \frac{(100\ m/s)^2}{2}}$$

$$= \frac{1800\ \frac{kJ}{s}}{(0.287(1400) - 0.287(600)) - \frac{100^2}{2}} = \frac{1800\ \frac{kJ}{s}}{229.6\ \frac{kJ}{kg} - 5000\ m^2/s^2} = 7.839\ \frac{kg}{s} - 0.36\ \frac{kJ}{m^2/s}$$

Nicholas March

(Extra space for Problem # 11)

$$C_V = \left(\frac{dT}{dP}\right)_V = \frac{T_2 - T_1}{P_2 - P_1} = \frac{600^K - 1400^K}{1\,bar - 15\,bar} = 57.143\,\frac{K}{bar}$$