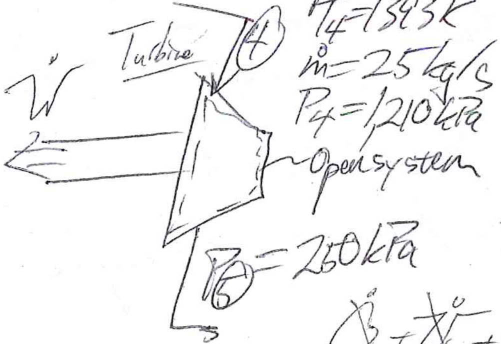
Turbine: The purpose of a turbine is to use high pressure fluid to produce mechanical (shaft) work.



a) Temperature of air leaving turbine

Mass Balance: $\dot{m}_{in} = \dot{m}_{out} + \frac{dm}{dt}$ 0(1)

Assumptions: 1) SS

2) adiabatic

3) ΔPE, ΔKE negligible

Energy Balance: $\dot{E}_{in} = \dot{E}_{out} + \frac{dE}{dt}$ 0(1)

$$\underbrace{\dot{Q}_{in}}_{0(2)} + \underbrace{\dot{W}_{in}}_{0} + \dot{m}_4\left(h_4 + \underbrace{\frac{v_4^2}{2} + g z_4}_{0(3)}\right) = \underbrace{\dot{Q}_{out}}_{0(2)} + \dot{W}_{out} + \dot{m}_5\left(h_5 + \underbrace{\frac{v_5^2}{2} + g z_5}_{0(3)}\right)$$

$$\dot{m} h_4 = \dot{W}_{out} + \dot{m} h_5 \Rightarrow \dot{W}_{out} = \dot{m}(\overbrace{h_4 - h_5}^{h_{in} - h_{out}})$$ General 1st Law equation for turbine

Apply fluid model (Ideal constant cp): $\dot{W}_{out} = \dot{m} C_p (T_4 - T_5)$ now rearrange for T_5

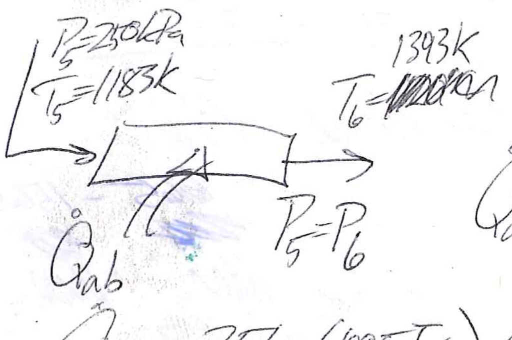
$$\Rightarrow T_5 = T_4 - \frac{\dot{W}_{out}}{\dot{m} C_p} \Rightarrow 1393k - \frac{5{,}272{,}000 \, W}{25 \frac{kg}{s} \left(1005 \frac{J}{kg \cdot k}\right)} \Rightarrow \boxed{T_5 = 1183k}$$

($\dot{W}_{out} = \dot{W}_c$)

$$1393k - \frac{5{,}272{,}000 \, W}{25 \frac{kg}{s} \left(1{,}142 \frac{J}{kg \cdot k}\right)} \Rightarrow \boxed{T_5 = 1208k}$$

Afterburner: Dumps fuel into flow for an additional boost. (like a rocket)

Find: Rate of heat transfer $\dot{Q}$



Same as Combustor

$$\dot{Q}_{ab} = \dot{m}(h_6 - h_5) \Rightarrow \dot{Q}_{ab} = \dot{m} C_p (T_6 - T_5)$$

$$\dot{Q}_{ab} = 25 \frac{kg}{s} \left(1005 \frac{J}{kg \cdot k}\right)(1393k - 1183k) \Rightarrow \boxed{\dot{Q}_{ab} = 5{,}272{,}000 \, W}$$

10.2 ME301 F2010

Nozzle: The purpose of a nozzle is to make a low velocity, high Pressure flow, into a high velocity, low pressure flow. (Reverse of Diffuser)

On a jet, the nozzle must accelerate the flow to a speed faster than the plane itself is flying, producing thrust like a rocket engine

Find nozzle exit velocity.

$T_7 = 1173K$

$P_7 = P_1$

$\vec{V}_7 = ?$

Mass Balance: $\dot{m}_{in} = \dot{m}_{out}$

Assumptions: 1) SS 2) Adiabatic 3) No work 4) ΔPE negligible

Energy Balance: $\dot{E}_{in} = \dot{E}_{out} + \frac{dE}{dt}$

$$\underbrace{\dot{Q}_{in}}_{0(2)} + \underbrace{\dot{W}_{in}}_{0(3)} + \dot{m}\left(h_6 + \underbrace{\frac{\vec{V}_6^2}{2}}_{0} + \underbrace{gz_6}_{0(4)}\right) = \underbrace{\dot{Q}_{out}}_{0(2)} + \underbrace{\dot{W}_{out}}_{0(3)} + \dot{m}\left(h_7 + \frac{\vec{V}_7^2}{2} + \underbrace{gz_7}_{0(4)}\right)$$

$$\cancel{\dot{m}} h_6 = \cancel{\dot{m}}\left(h_7 + \frac{\vec{V}_7^2}{2}\right) \Rightarrow \sqrt{2(h_6 - h_7)} = \vec{V}_7 \quad \text{apply fluid model}$$

$$\Rightarrow \sqrt{2C_p(T_6 - T_7)} = \vec{V}_7 = \sqrt{2\left(1005 \tfrac{J}{kgK}\right)(1393 - 1173\,K)} \Rightarrow \boxed{\vec{V}_7 = 665\ m/s}$$

What is the thrust produced by the engine? → the Goblin II is rated ≈ 14kN

What did we find?

$$F_{thrust} = \dot{m}(\vec{V}_7 - \vec{V}_1) = 25 kg/s\,(665\ m/s - 1565\ m/s)$$

$$F_{thrust} = 12.7kN \text{ vs. } 14kN \rightarrow \text{not too bad!}$$

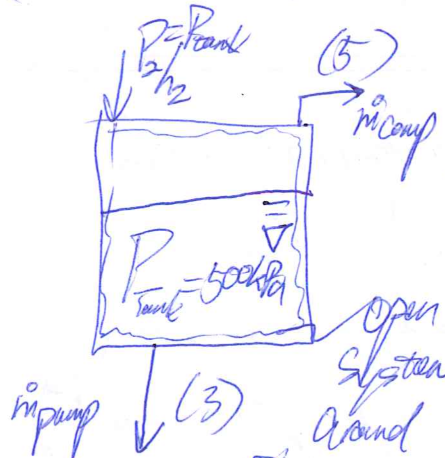
Talk about alternative system choices, HEX's etc.

11.2 ME301 Sp2011

Purpose of a phase separator → seperate phases, Mixer → to Mix

Step 1: Define Open System

Step 2: Define System Assumptions



open system around Phase Separator mixer

1) Steady State, 2) Adiabatic, 3) Rigid, No Shafts, 4) $\Delta PE, \Delta KE$ negligible

Step 3: Apply Balances: Mass: $\dot{M}_{in} = \dot{M}_{out} + \cancel{\frac{dM_{stored}}{dt}}^{O(1)}$

$$\dot{M}_2 = \dot{M}_3 + \dot{M}_5$$

We only know $\dot{M}_2$ & we don't know $\dot{M}_3$ or $\dot{M}_5$, we need another equation to solve this. Where will we find it?

Energy Balance: $\dot{E}_{in} = \dot{E}_{out} + \cancel{\frac{dE_{stored}}{dt}}^{O(1)}$

$$\underbrace{\dot{Q}_{in}}_{O(2)} + \underbrace{\dot{W}_{in}}_{O(3)} + \dot{M}_2\left(h_2 + \underbrace{\frac{\vec{v}_2^2}{2} + gz_2}_{O(4)}\right) = \underbrace{\dot{Q}_{out}}_{O(2)} + \underbrace{\dot{W}_{out}}_{O(3)} + \dot{M}_3\left(h_3 + \underbrace{\frac{\vec{v}_3^2}{2} + gz_3}_{O(4)}\right) + \dot{M}_5\left(h_5 + \underbrace{\frac{\vec{v}_5^2}{2} + gz_5}_{O(4)}\right)$$

$$\dot{M}_2 h_2 = \dot{M}_3 h_3 + \dot{M}_5 h_5$$

h_3? → yes $X_3 = 0.0$, $P_3 = P_{tank}$

h_5? → yes $X_5 = 1.0$, $P_5 = P_{tank}$

Can we solve? System: Yes 2eq. 2unks.

$$\dot{M}_3 = \frac{\dot{M}_2 h_2 - \dot{M}_5 h_5}{h_3}$$

$$\dot{M}_2 = \frac{\dot{M}_2 h_2 - \dot{M}_5 h_5}{h_3} + \dot{M}_5 \quad \leftarrow \text{1eq. 1unk.}$$

$$\cancel{\frac{\dot{M}_2 h_3 - \dot{M}_2 h_2 + \dot{M}_5 h_5}{h_3}} = \dot{M}_5 \qquad \dot{M}_2 h_3 - \dot{M}_2 h_2 = \dot{M}_5 (h_3 - h_5) \Rightarrow$$

$$\Rightarrow \frac{\dot{M}_2 h_3 - \dot{M}_2 h_2}{(h_3 - h_5)} = \dot{M}_5 \qquad \dot{M}_3 = \dot{M}_2 - \dot{M}_5$$

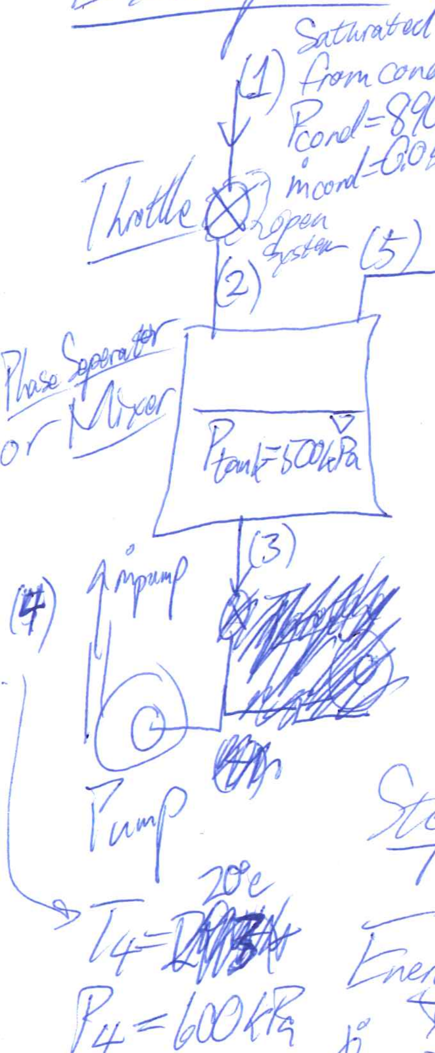
$\dot{M}_5 = 0.007446 \text{ kg/s}$

$\dot{M}_3 = 0.04255 \text{ kg/s}$

Open System Energy Balances (cont.): Throttles, Mixers, & Pumps

Example:

Phase Seperator in a Refrigerant System.



Find the mass flow rate to the compressor & the work required by the pump.

How do we Start?

Throttle: Purpose of a throttle is to expand a fluid to a lower P.

Step 1: Define system, Open system in throttle

Step 2: Assumptions about system

1) Steady State, 2) Adiabatic, 3) No Shafts, rigid

4) ΔPE & ΔKE negligible,

Step 3: Apply balances: Mass Balance: $\dot{M}_{in} = \dot{M}_{out} + \overset{0(1)}{\frac{dM_{stored}}{dt}} \Rightarrow \dot{M}_1 = \dot{M}_2$

Energy Balance: $\dot{E}_{in} = \dot{E}_{out} + \overset{0(1)}{\frac{dE_{stored}}{dt}}$

$$\Rightarrow \underset{0(2)}{\dot{Q}_{in}} + \underset{0(3)}{\dot{W}_{in}} + \dot{M}_{in}\left(h_{in} + \underset{0(4)}{\frac{V_{in}^2}{2} + gz_{in}}\right) = \underset{0(2)}{\dot{Q}_{out}} + \underset{0(3)}{\dot{W}_{out}} + \dot{M}_{out}\left(h_{out} + \underset{0(4)}{\frac{V_{out}^2}{2} + gz_{out}}\right)$$

$\dot{M}_1 h_1 = \dot{M}_2 h_2 \Rightarrow \underline{h_1 = h_2}$ Throttles are isenthalpic: constant enthalpy

Can we find h_1 → yes! $x_1 = 0.0$, $P_1 = 890\ kPa$ → Real fluid tables or EES

$T_4 = 293K$
$P_4 = 600kPa$

Pump: Purpose of a pump is to increase Pressure of a liquid.

Step 1: Define System

Step 2: System Assumptions

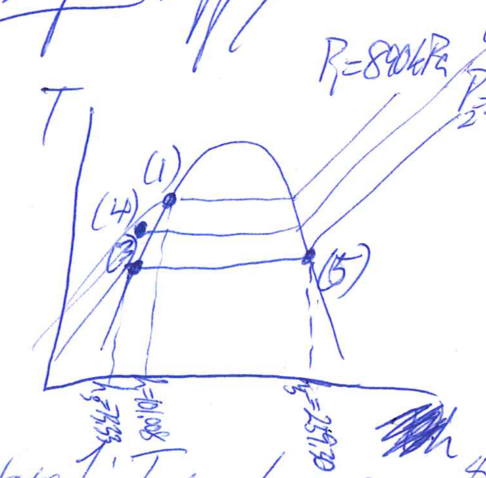
1) Steady State, 2) Adiabatic, 3) ΔPE & ΔKE negligible

Step 3: Balances: Mass: $\dot{M}_{in} = \dot{M}_{out} + \frac{dM_{stored}}{dt}$ 0(1) Energy: $\dot{E}_{in} = \dot{E}_{out} + \frac{dE_{stored}}{dt}$ 0(1)

$$\underbrace{\dot{Q}_{in}}_{0(1)} + \dot{W}_{in} + \dot{M}_{in}\Big(h_{in} + \underbrace{\frac{v_{in}^2}{2} + g z_{in}}_{0(3)}\Big) = \underbrace{\dot{Q}_{out}}_{0(1)} + \underbrace{\dot{W}_{out}}_{0(2)} + \dot{M}_{out}\Big(h_{out} + \underbrace{\frac{v_{out}^2}{2} + g z_{out}}_{0(3)}\Big)$$

$$\dot{W}_{pump} + \dot{M} h_3 = \dot{M} h_4 \Rightarrow \dot{W}_{pump} = \dot{M}(h_4 - h_3) \rightarrow h_4 \Rightarrow \text{yes}, T_4 \,\&\, P_4$$

Step 4: Apply Fluid Model: Real fluid R134a



State	T	P	x	h	U	Table
1		890kPa	0.0	101		A-12
2		500kPa		101.008		A-12
3		500kPa	0.0	73.33		A-12
4	20°C	[illegible]	~~1.0~~	~~259.30~~		[illegible]
5		500kPa	1.0	259.30		A-12

State 1: Interpolate

$$\frac{\overset{40}{890-850}}{\underset{50}{900-850}} = \frac{h_1 - 98.60}{\underset{3.01}{101.61 - 98.60}} \Rightarrow h_1 = 101.008 \frac{kJ}{kg} = h_2$$

State 2: Is state saturated? $h_f = 73.33$, $h_g = 259.30$ yes!

$= h_3$ State 3, $= h_5$ State 5

State 4: State 4 is compressed Liquid R134a → no tables!! $h_4 = 79.32\, kJ/kg$?

What do we do? Software Estimate h_4 @ T_4 @ $x = 0.0$

→ Incompressible substance?

11.4 ME 301 Sp. 2011

~~Real Actual~~ Software answer: $\dot{W}_{pump} = 257.2\,W$

Book Answer: $\dot{W}_{pump} = 254.87\,W$

Incompressible Substance: $\dot{W}_{pump} = \dot{m}(h_4 - h_3) \Rightarrow u_4 - u_3 + v(P_4 - P_3)$

$\dot{W}_{pump} = \dot{m}\left(C(T_4 - T_3) + v(P_4 - P_3)\right)$ Table A-3 R134a $C = 1.43\ \frac{kJ}{kg \cdot K}$, $\rho = 1207\ \frac{kg}{m^3}$

$\dot{W}_{pump} = 0.04255\,kg/s \left(\frac{1430\,J}{kg \cdot K}(20 - 15.7) + \frac{m^3}{1207\,kg}(600000 - 500000\,Pa)\right) \Rightarrow \dot{W}_{pump} = 265.2\,W$

6149 82.85