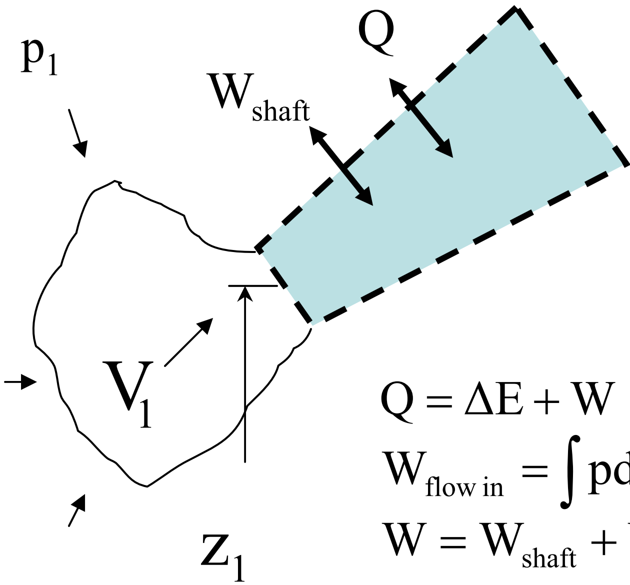
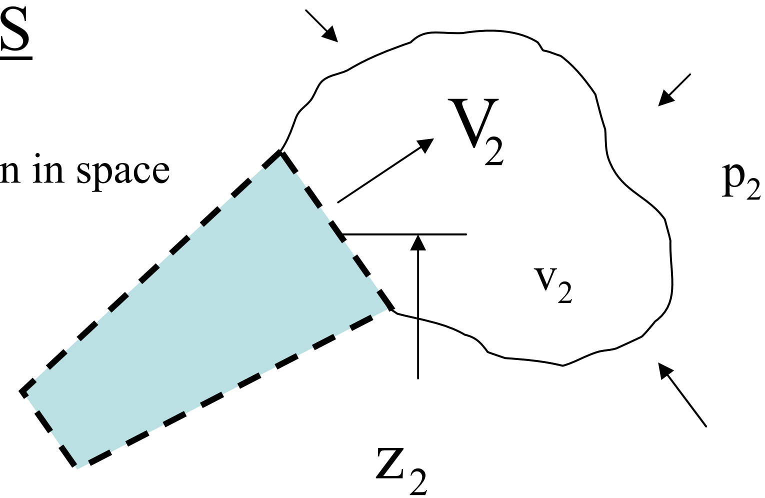
FIRST LAW IN OPEN SYSTEMS

Steady Flow Energy Equation

Open, steady flow thermodynamic system - a region in space





$$Q = \Delta E + W \quad \text{First Law}$$

$$W_{\text{flow in}} = \int p dV = p_1\left(V_{1\ \text{initial}} - V_{1\ \text{final}}\right) = p_1 V_1 = m\, p_1 v_1$$

$$W = W_{\text{shaft}} + W_{\text{flow in}} + W_{\text{flow out}} = W_{\text{shaft}} + m\, p_1 v_1 - m\, p_2 v_2$$

$$E = u(T) + KE + PE = u(T) + \frac{V^2}{2} + gz$$

$$Q = m \times (u_2 + p_2 v_2 + \frac{V_2^2}{2} + gz_1) - m \times (u_1 + p_1 v_1 + \frac{V_1^2}{2} + gz_1) + W_{\text{shaft}}$$

$$Q = m \times \Delta(u + pv + \frac{V^2}{2} + gz) + W_{\text{shaft}}$$

$$Q = m\Delta(h + \frac{V^2}{2} + gz) + W_{\text{shaft}} \qquad (5-36)$$

the units of all the energy terms must be the same

Steady Flow Processes Devices

$$Q = m\Delta(h + \frac{V^2}{2} + gz) + W_{shaft} \quad \text{Steady Flow Energy Equation}$$

Turbine, Compressor, Pump

$$\Delta \text{Velocity}, \Delta \text{Elevation}, Q = 0$$

$$W = \Delta H = m\Delta h$$

$$\mathbf{W} = \mathbf{m}(\mathbf{h}_{\mathbf{in}} - \mathbf{h}_{\mathbf{out}})$$

Boiler, Condenser, Heat Exchanger

$$\Delta \text{Velocity} \cong 0, \Delta \text{Elevation} \cong 0, \text{Work} = 0$$

$$Q = \Delta H = m\Delta\, h$$

$$\mathbf{Q} = \mathbf{m}(\mathbf{h}_{\mathbf{in}} - \mathbf{h}_{\mathbf{out}})$$

Diffuser, Nozzle

$$\Delta \text{Elevation} \cong 0, Q = 0, W = 0$$

$$\mathbf{h}_1 + \frac{\mathbf{V}_1^2}{2} = \mathbf{h}_2 + \frac{\mathbf{V}_2^2}{2}$$

Valve - throttling process

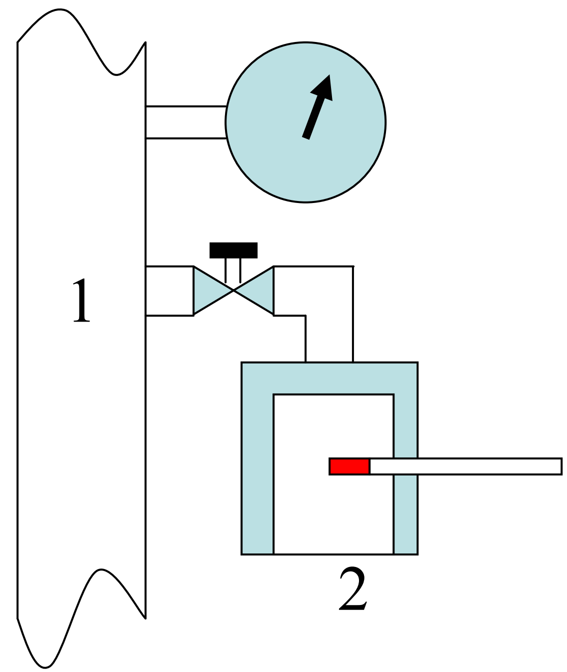
$$\Delta \text{Velocity} = 0, \Delta \text{Elevation} = 0, Q = 0, W = 0$$

$$\Delta H = 0$$

$$H_{in} = H_{out}$$

$$\mathbf{h}_{\mathbf{in}} = \mathbf{h}_{\mathbf{out}}$$

What range of 850 kPa steam quality can be meaaured with this device?



open thermodynamic system

Steady Flow Energy Equation

$$Q = \Delta(h + \frac{V^2}{2g} + zh) + W_{shaft}$$

$$\Delta KE = 0, \quad \Delta PE = 0, \quad W = 0, \quad Q = 0$$

$$h_1 = h_2(T_{2,} P_{barometer})$$

$$h_2 = h_g @P_{barometer} = 100.\ kPa$$

$$h_2 @\text{maximum mesurable quality} = 2506.1\ kJ/kg$$

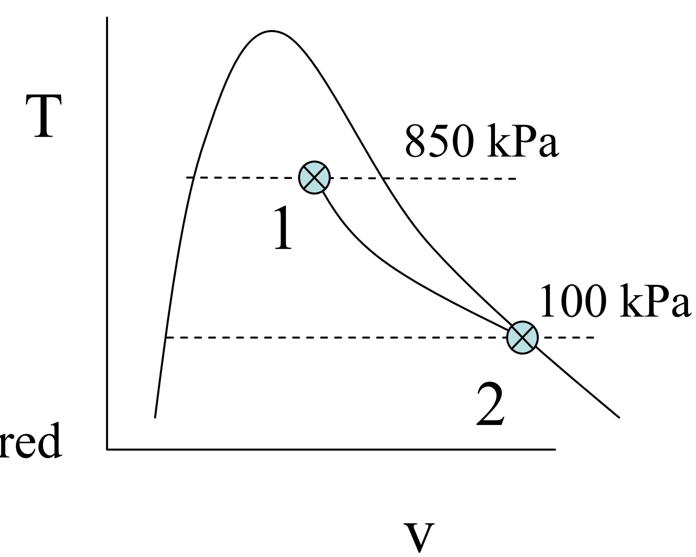
@850 kPa

$$h_v = 732.22\ kJ/kg$$

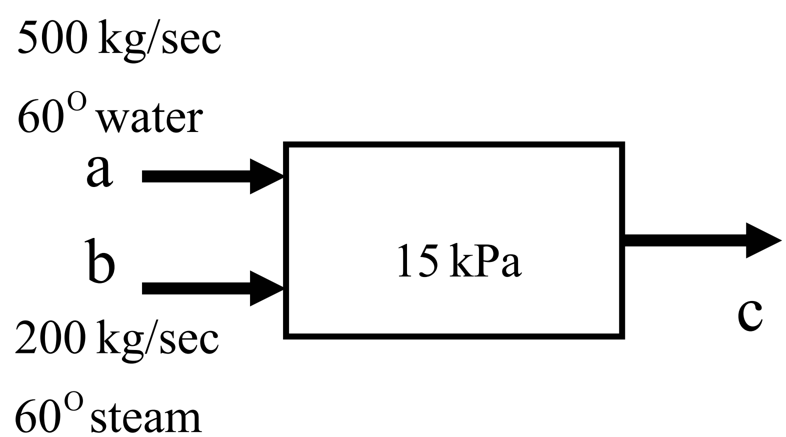
$$h_{fg} = 2039.4\ kJ/kg$$

$$x = \frac{h_2 - h_{1f}}{h_{1fg}} = \frac{2506.1\ kJ/kg - 732.22\ kJ/kg}{2039.4\ kJ/kg}$$

$x = .87$, 87% to 100% quality can be measured



500 kg/sec of 60^{O}C water is mixed with 200 kg/sec 60^{O}C saturated steam in a tank at a pressure of 15kPa.
What are the exit conditions?



open thermodynamic system

Mass Balance $m_c = m_a + m_b$

$m_c = 500\text{ kg/sec} + 200\text{ kg/sec}$

Steady Flow Energy Equation

$$Q = m\Delta(h + \frac{V^2}{2g} + zh) + W_{shaft}$$

$Q = 0,\quad W = 0,\ \Delta KE = 0,\ \Delta PE = 0,$

$mh = \text{constant}$

$m_a h_a + m_b h_b = m_c h_c$

$h_a = h_f @60^O C = 251.13\text{ kJ/kg}$

$h_b = h_v @60^O C = 2373.1\text{ kJ/kg}$

$500\text{ kg} \times 251.13\text{ kJ/kg} + 200\text{ kg} \times 2373.1\text{ kJ/kg} = 700\text{ kg} \times h_c$

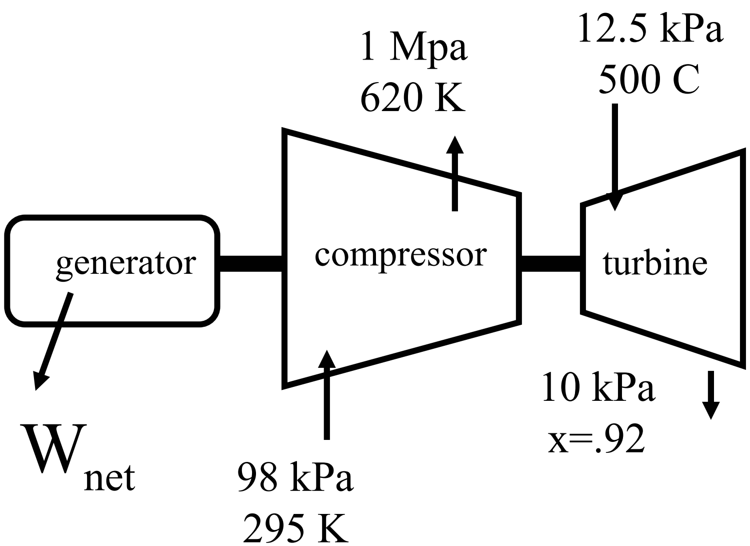
$h_c = 924.98\text{ kJ/kg}$

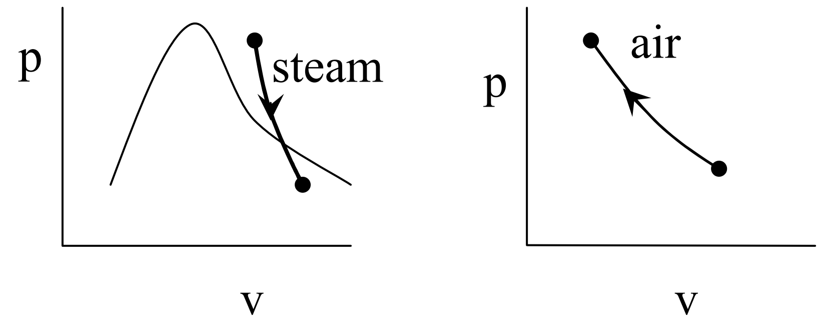
at 15 kPa $h_f = 225.94\text{ kJ/kg},\quad h_g = 2373.1\text{ kJ/kg}$

$$x = \frac{925.98 - 225.94}{2373.1} = .29,\quad 29\%\text{quality}$$

$T = 53.97^O C$

An adiabatic air compressor is to be powered by a direct coupled adiabatic steam turbine that is also driving a generator. Steam enters the turbine at 12.5 MPa and 500 C at a rate of 25 kg/sec and exits at 10 kPa and a quality of .92. Air enters the compressor at 98 kpa and 295 K at a rate of 10 kg/sec and exits at 1 MPa. Determine the net power delivered to the generator by the turbine.





$$h_{c1} = \text{airtable}@(T = 295) = 210.5\,\text{kJ/kg}$$

$$h_{c2} = \text{airtable}@(T = 620) = 628.1\,\text{kJ/kg}$$

$$h_{t1} = \text{superheat}@(T = 500, p = 12.5) = 3341.8$$

$$h_{t2} = h_f@10\text{kPa} + x h_{fg}@10\text{kPa}$$

$$h_{t2} = 191.83 + .92 \times 2392.8 = 2393.2\,\text{kJ/kg}$$

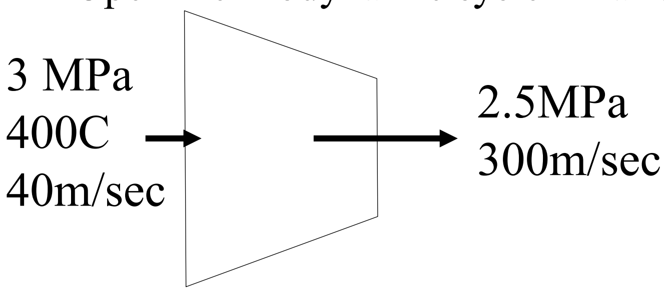
$$W_{net} = W_{turbine} - W_{compressor} = m_t\left(h_{t1} - h_{t2}\right) - m_c\left(h_{c1} - h_{c2}\right)$$

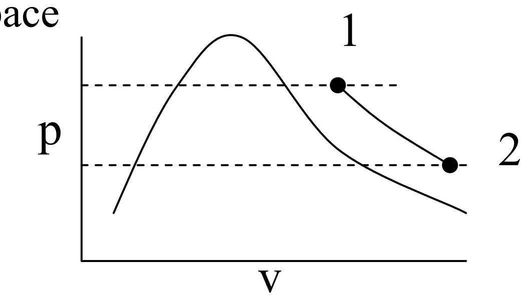
$$W_{net} = 25\frac{\text{kg}}{\text{sec}} \times \left(3341.8 - 2393.2\right) - 10\frac{\text{kg}}{\text{sec}}\left(628.1 - 210.5\right)$$

$$W_{net} = 19539\,\text{kJ/sec}$$

Steam at 3Mpa and 400 C enters an adiabatic nozzle steadily with a velocity of 40 m/sec and leaves at 2.5 MPa and 300 m/sec. Determine (a) the exit temperature and (b) the ratio of inlet to exit area.

Open thermodynamic system - a region in space





$$h_1 \,\&\, v_1 = \text{superheat} @ (T = 400., P = 3.)$$

$$h_1 = 3203.9 \text{ kJ/kg}$$

$$v_1 = .09936 \text{ m}^3/\text{kg}$$

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2} \quad \text{steady flow energy equation}$$

$$h_2 = h_1 + \left(\frac{V_1^2}{2} - \frac{V_2^2}{2}\right)$$

$$h_2 = 3203.9 \text{ kJ/kgm} + \left(\frac{40^2}{2} - \frac{300^2}{2}\right)\frac{\text{m}^2}{\text{sec}^2}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{sec}^2}\right)$$

$$h_2 = 3203.9 - 44.2 = 3159.7 \text{ kJ/kg}$$

a) $T_2 = \text{superheat} @ (h = 3159.7, p = 2.5)$

$$T_2 = 364.78 \text{ C}$$

b) $m = \rho A V = \left(\frac{p}{RT}\right) A V$

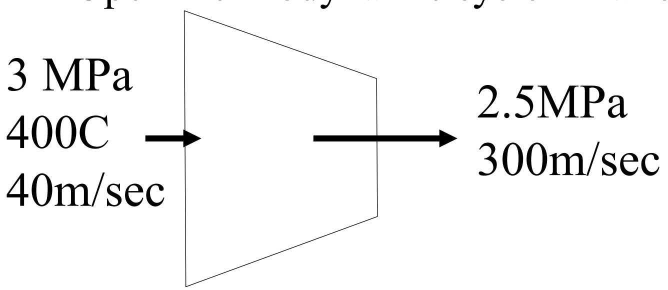
$$\left(\frac{p_1}{RT_1}\right) A_1 \, V_1 = \left(\frac{p_2}{RT_2}\right) A_1 \, V_2$$

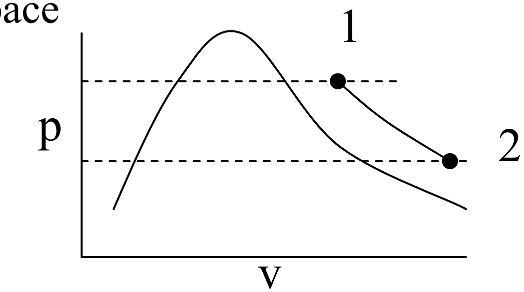
$$\frac{3 \, A_1 \, 40}{(400 + 273.15)} = \frac{2.5 \, A_2 \, 300}{(364.78 + 273.15)}$$

$$\frac{A_2}{A_1} = \frac{.1783}{1.1757} = .1517$$

Steam at 3Mpa and 400 C enters an adiabatic nozzle steadily with a velocity of 40 m/sec and leaves at 2.5 MPa and 300 m/sec. Determine (a) the exit temperature and (b) the ratio of inlet to exit area.

Open thermodynamic system - a region in space





h_1 & v_1 = superheat @ (T = 400., P = 3. Mpa)

$h_1 = 3231.7$ kJ/kg

$v_1 = .09938\ m^3/kg$

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2} \quad \text{steady flow energy equation}$$

$$h_2 = h_1 + \left(\frac{V_1^2}{2} - \frac{V_2^2}{2}\right)$$

$$h_2 = 3231.71.9\ \text{kJ/kgm} + \left(\frac{40^2}{2} - \frac{300^2}{2}\right)\frac{m^2}{sec^2}\left(\frac{1\ \text{kJ/kg}}{1000\ m^2/sec^2}\right)$$

$$h_2 = 3231.71 - 44.2 = 3187.5\ \text{kJ/kg}$$

a) T_2 @ (h = 3187.5, p = 2.5)

$T_2 = 376.5$ C,

v_2 @ (h = 3187.5, p = 2.5)

$v_2 = .11626$

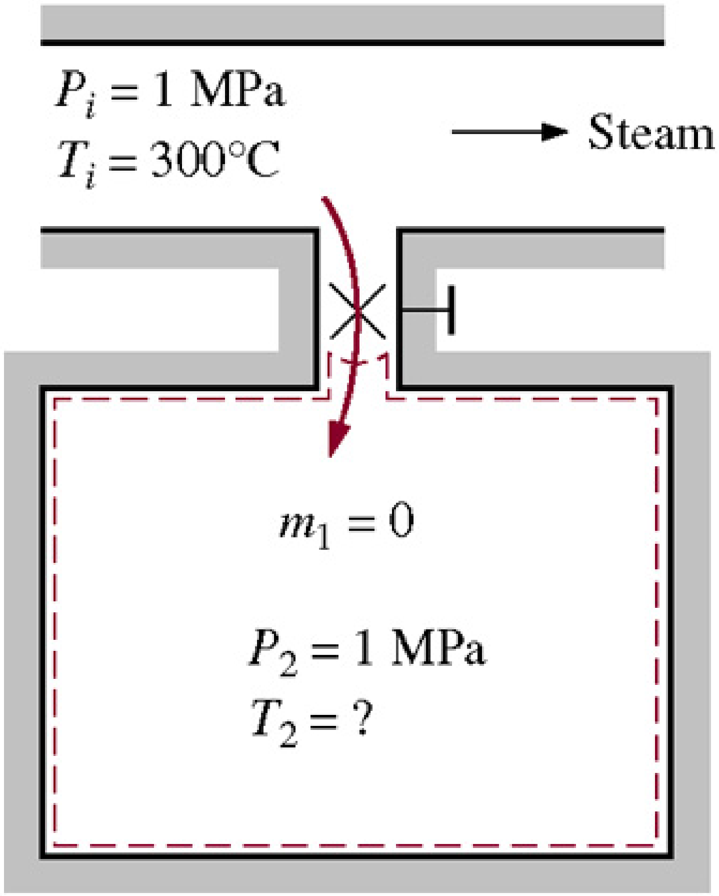
b) $m = \rho A V$

$$\frac{A_1\ V_1}{v_1} = \frac{A_1\ V_2}{v_2}$$

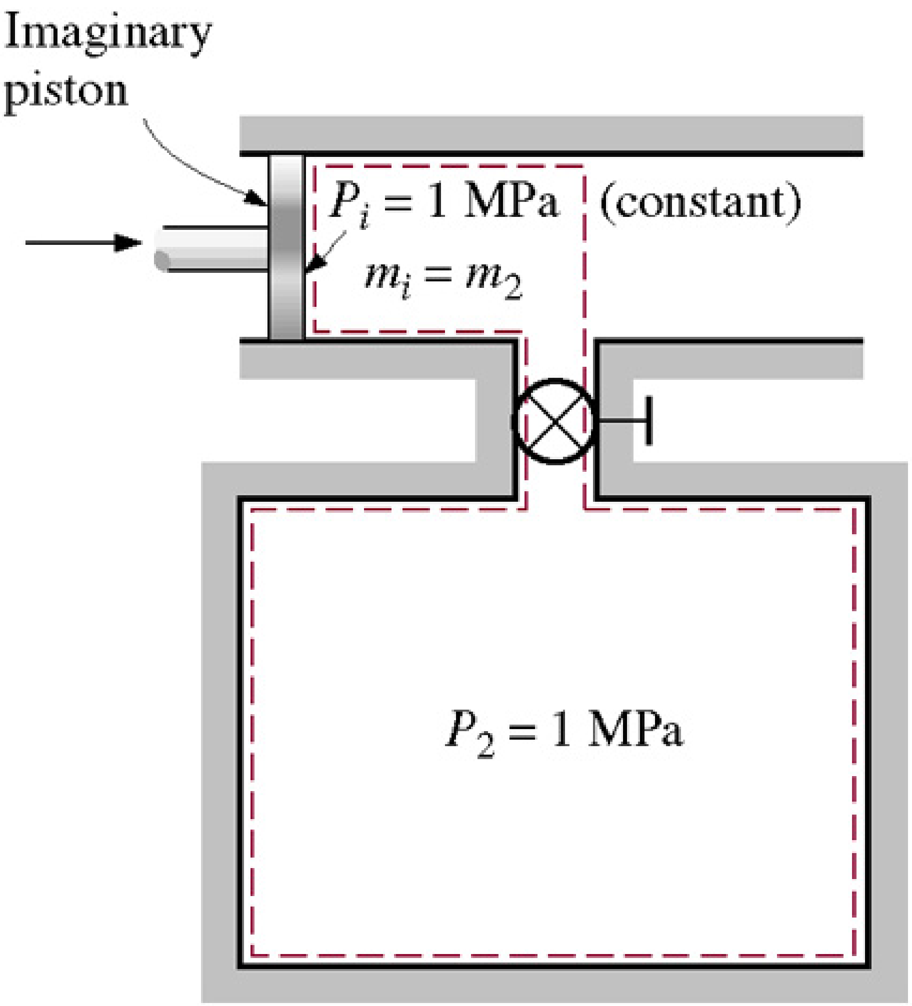
$$\frac{3\ A_1\ 40}{.09938} = \frac{2.5\ A_2\ 300}{.11626}$$

$$\frac{A_2}{A_1} = \frac{13.951}{74.535} = .1872$$

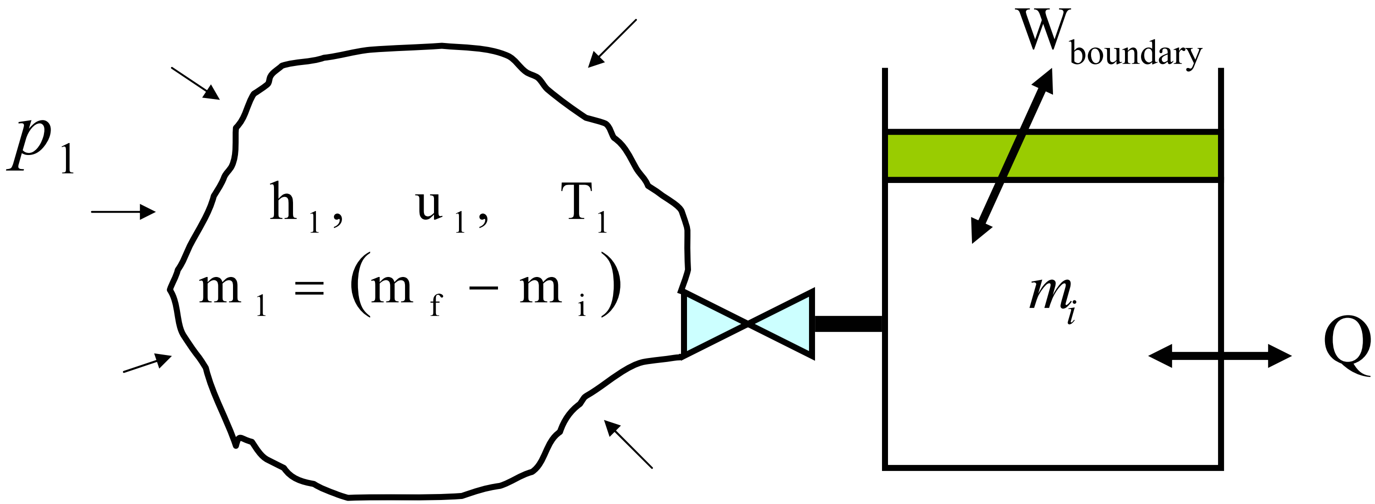
FIRST LAW IN UNSTEADY SYSTEMS



(*a*) Flow of steam into an evacuated tank



(*b*) The closed-system equivalence



$$Q = \Delta E + W$$
$$Q = E_f - E_i + (W_{flow} + W_{boundary})$$
$$E_i = m_i u_i + (m_f - m_i) u_1$$
$$E_f = m_f u_f$$
$$W_f = \int p dV = (m_f - m_i) p_1 (v_{end} - v_1)$$
$$W_f = -(m_f - m_i) \times p_1 v_1$$
$$Q = m_f u_f - m_i u_i - (m_f - m_i) \times (u_1 + p_1 v_1) + W_b$$
$$Q = m_f u_f - m_i u_i - (m_f - m_i) \times h_1 + W_b$$

FIRST LAW FOR UNSTEADY SYSTEMS

$$Q - W_b + H_{in} = \Delta U_{contents}$$

For :

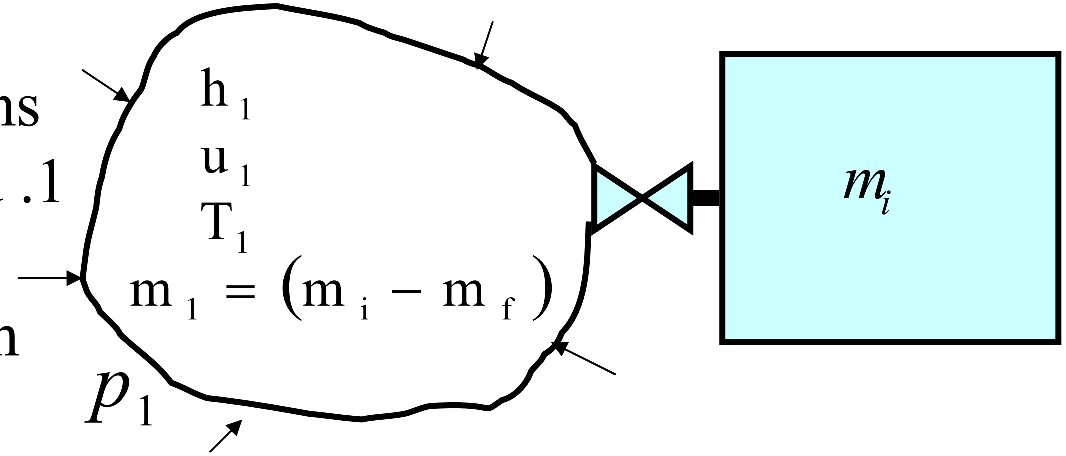
$m_i = 0$, adiabatic vacuum

$$Q = 0, W_b = 0$$
$$u_f = h_1$$
$$c_v (T_f - T_o) = c_p (T_i - T_o)$$
$$\frac{c_p}{c_v} = \left(\frac{T_f - T_o}{T_i - T_o} \right)$$

T_o is arbitrary, $T_o = 0$

$$T_f = k T_i$$

A 200 cubic ft tank contains 2. lbm carbon dioxide and .1 mole helium at an initial temperature of 70 F. 3 lbm of air at 14.7 and 70 F are admitted to the tank.



What is the final temperature of the tank?

$$Q = m_f u_f - m_i u_i - (m_f - m_i)(h_i)$$

$$m_f u_f = (3 \times .174 + 2 \times .1565 + .4 \times .745)T_f = 1.125 T_f$$

$$m_i u_i = (2 \times .1565 + .4 \times .745) \times (460 + 70) = 323.83$$

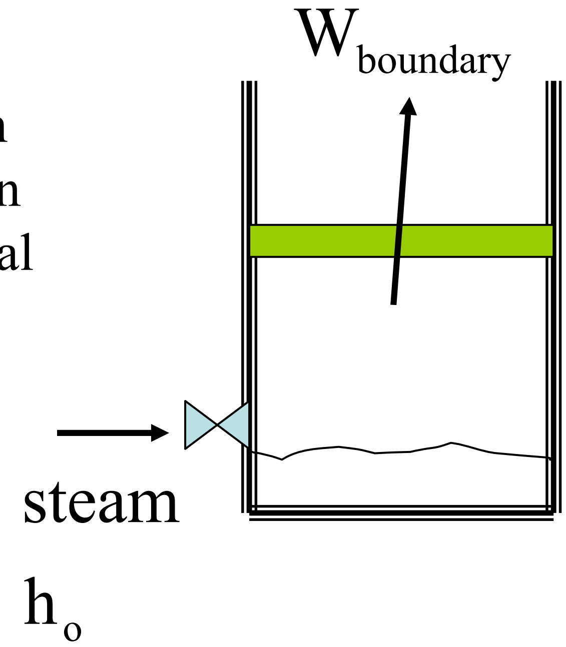
$$(m_i - m_f) h_1 = 3 \times .24 \times (460 + 70) = 381.6$$

$$Q = 1.125 T_f - 323.83 - 381.6 = 0$$

$$T_f = 627^{o} R$$

$$T_f = 167^{o} F$$

8 kg liquid water and 2 kg vapor at 300 kPa are contained in an insulated piston cylinder. Steam at .5 MPa and 350 C are admitted until the piston cylinder contains only vapor. Determine the final temperature and the amount of steam admitted.



the system is the mass finally in the piston cylinder, m_2

$$Q - W_{boundary} + (m_2 - m_1)\, h_o = m_2 u_2 - m_1 u_1$$

$$W_{boundary} = m_2 p_2 v_2 - m_1 p_1 v_1$$

substituting for $W_{boundary}$,

$$0 - (m_2 p_2 v_2 - m_1 p_1 v_1) + (m_2 - m_1)\, h_o = m_2 u_2 - m_1 u_1$$

$$0 = -m_2 h_o + m_1 h_o + m_2 u_2 - m_1 u_1 + m_2 p_2 v_2 - m_1 p_1 v_1$$

$$0 = -m_2 h_o + m_2 u_2 + m_2 p_2 v_2 + m_1 h_o - m_1 u_1 - m_1 p_1 v_1$$

since $= u + pv$,

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

$$m_2 = m_1 \frac{(h_o - h_1)}{(h_o - h_1)}$$

$$m_2 = 10\text{kg} \frac{(3167.7 \text{ kJ/kg} - 2292.51 \text{ kJ/kg})}{(3167.7 \text{ kJ/kg} - 2725.3 \text{ kJ/kg})} = 19.78 \text{ kg}$$

$$m_2 - m_1 = 19.78 \text{ kg} - 10 \text{ kg} = 9.78 \text{ kg}$$

@ 300 kPa

$$T_2 = T_{saturation} @300\text{kPa} = 133.55 \text{ C}$$

$$h_2 = v_g = 2725.3 \text{ kJ/kg}$$

$$h_1 = h_f + x \times h_{fg}$$

$$h_1 = 561.47 + .8 \times 2163.8$$

$$h_1 = 2292.51 \text{ kJ/kg}$$

@.5 MPa, 350^o C

$$h_o = 3167.7 \text{ kJ/kg}$$

First Law

Energy defined, Energy conserved

$E_{in} - E_{out} = \Delta E$ (page 72)

E is all forms, Q, W, PE, KE, U

$$(Q_{in} - Q_{out}) + (W_{in} - W_{out}) + (E_{massin} - E_{massout}) = U_2 - U_1 \qquad (2\text{-}32)$$

CLOSED SYSTEM a contained quantity of mass

$$(Q_{in} - Q_{out}) + (W_{in} - W_{out}) + \underbrace{(E_{mass\ in} - E_{mass\ out})}_{0} = U_2 - U_1 \quad \text{(page 173)}$$

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

$$Q = U_2 - U_1 + W$$

$$Q = \Delta E + W$$

OPEN SYSTEM a region in space

$$(Q_{in} - Q_{out}) + (W_{in} - W_{out}) + (E_{mass\ in} - E_{mass\ out}) = \underbrace{U_2 - U_1}_{0} \quad \text{(page 233)}$$

$$W = W_{shaft} + W_{flow}$$

$$(Q_{in} - Q_{out}) + (W_{in} - W_{out}) = (E_{mass\ out} - E_{mass\ in})$$

for $W_{net} = 0$, $Q = H_2 - H_1 = m(h_2 - h_1)$

for $Q_{net} = 0$, $W = H_2 - H_1 = m(h_2 - h_1)$

UNSTEADY SYSTEM

quantity of mass, m_1 or m_2

$$\left(Q_{in} - Q_{out}\right) + \left(W_{in} - W_{out}\right) + \left(E_{mass\ in} - E_{mass\ out}\right) = U_2 - U_1$$

0

$$\left(Q_{in} - Q_{out}\right) + \left(W_{b\ in} - W_{b\ out}\right) + \left(W_{flow\ in} - W_{flow\ out}\right) = U_2 - U_1$$

$$\left(Q_{in} - Q_{out}\right) + \left(W_{b\ in} - W_{b\ out}\right) + \left(p_o V_o\right)_{in} - \left(p_o V_o\right)_{out} = U_2 - U$$

$$\left(Q_{in} - Q_{out}\right) + \left(W_{b\ in} - W_{b\ out}\right) + \left(m_2 - m_1\right)\left(p_o v_o\right)_{in} - \left(m_2 - m_1\right)\left(p_o v_o\right)_{out} = m_2 u_2 - m_1 u_1 + \left(m_2 - m_1\right) u_{out} - \left(m_2 - m_1\right) u_{in}$$

$$\left(Q_{in} - Q_{out}\right) + \left(W_{b\ in} - W_{b\ out}\right) + \left(m_2 - m_1\right) h_{in} - \left(m_2 - m_1\right) h_{out} = m_2 u_2 - m_1 u_1$$

with W_{out}, Q_{in}, +

$$\mathbf{Q - W + \left(m_2 - m_1\right) h = m_2 u_2 - m_1 u_1}$$

UNSTEADY SYSTEM

region in space

$$\left(Q_{in} - Q_{out}\right) + \left(W_{in} - W_{out}\right) + \left(E_{mass\ in} - E_{mass\ out}\right) = U_2 - U_1$$

$$\left(Q_{in} - Q_{out}\right) + \left(W_{b\ in} - W_{b\ out}\right) + \left(E_{mass\ in} - E_{mass\ out}\right) = U_2 - U_1$$

$$\left(Q_{in} - Q_{out}\right) + \left(W_{b\ in} - W_{b\ out}\right) + \left(m_2 - m_1\right) h_{in} - \left(m_2 - m_1\right) h_{out} = m_2 u_2 - m_1 u_1$$

Problem Set Up Strategies

System
- open, closed, unsteady
- schematic at each system state

State Point
- property diagram
- locate points

Properties
- property values – tables, Ideal Gas Law
- what properties remain constant ?

Cycle
- what remains constant ?

Mass Balance

Identify Energy
- Forms
- Sources
- Uses

Energy Balance
- general equation
- from schematic
- specific for open system
- specific for closed system
- specific for unsteady system

From Chapter 1

Concepts

System

Properties

State Point

Process

Cycle

$$\text{Kinetic Energy} = \frac{V^2}{2} = \frac{m^2/\text{sec}^2}{2} \times \frac{1\ \text{kJ/kg}}{1000\ m^2/\text{sec}^2}$$

$$\text{Kinetic Eenergy} = \frac{V^2}{2g} = \frac{\text{ft}^2/\text{sec}^2}{2 \times 32.3\ \text{ft/sec}^2} \times \frac{1}{778\ \text{ft} - \text{lb/Btu}} = \text{Btu/lb}$$

$$\text{Work} = \int p dV = \text{kPa} \times m^3 \times \frac{1\,\text{kJ}}{1\,\text{kPam}^3} = \text{kJ}$$

$$\text{Work} = \int p dV = \frac{\text{lb}}{\text{in}^2} \times \frac{144\ \text{in}^2}{\text{ft}^2} \times \text{ft}^3 \times \frac{1\ \text{Btu}}{778\text{ft} - \text{lb}} = \text{Btu}$$