Thermo

①

Sept. 4/18

Final 50% ↗ 8p to 10p ??

Midterm 30% => Oct. 4th/2018 (to change)

Term 20% (Package handed out after midterm)

Textbook: ↗ 8th edition is fine

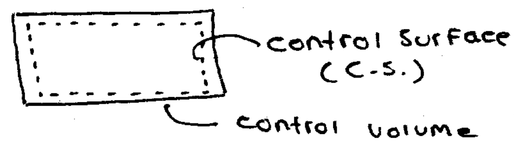
Fundamentals of Thermodynamics → Borgnakke (9th)

→ tables and charts will be provided for exams

- Conservation of mass and the control volume (c.v.)

rate of change = + in - out

$$\frac{dm_{c.v.}}{dt} = \sum \dot{m}_i - \sum \dot{m}_e$$

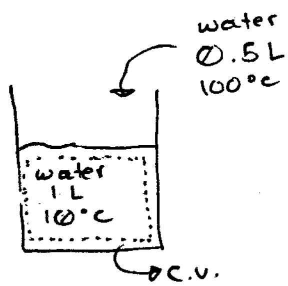


- the energy equation for a control volume

$$E_2 - E_1 = {}_1Q_2 - {}_1W_2$$ (First law of thermo.)

we have also noted this can be written as an instantaneous rate

$$\frac{dE_{c.m.}}{dt} = \dot{Q} - \dot{W}$$

- 

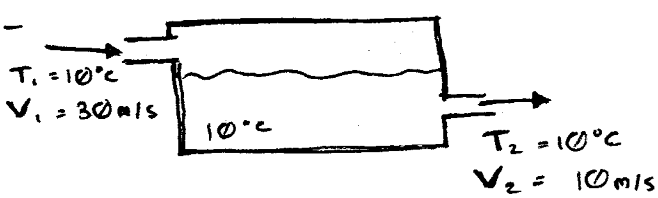
$$\frac{dm_{c.v.}}{dt} = \dot{m}_{in} - \dot{m}_{out}$$

$$\Rightarrow m_2 - m_1 = \dot{m}_{in}$$

$$m_2 - m_1 = 0.5 \text{ L}$$

$$m_2 = 1.5 \text{ L}$$

$$E_2 - E_1 = Q_{1-2}$$

- 

$$dE/dt > 0$$

$e = u + \frac{1}{2}V^2 + gZ$

- the fluid flowing across the control surface enters or leaves with an amount of energy per unit mass as

the extension of the energy equation

$$\frac{dE_{c.v.}}{dt} = \dot{Q}_{c.v.} - \dot{W}_{c.v.} + \dot{m}_i(e_i + P_i v_i) - \dot{m}_e(e_e + P_e v_e)$$

$$= \dot{Q}_{cv} - \dot{W}_{c.v.} + \dot{m}_i(h_i + \tfrac{1}{2}V_i^2 + gZ_i) - \dot{m}_e(h_e + \tfrac{1}{2}V_e^2 + gZ_e)$$

The steady-state process
(the mass (energy) of the system doesn't change w.r.t. time)
→ ($dm/dt = 0$ and $dE_{c.v.}/dt = 0$)

For one inlet + one outlet

Continuity equation:

$$\dot{m}_i = \dot{m}_e = \dot{m}$$

Energy equation:

$$\dot{Q}_{c.v.} + \dot{m}\left(h_i + \frac{V_i^2}{2} + gZ_i\right) = \dot{m}\left(h_e + \frac{V_e^2}{2} + gZ_e\right) + \dot{W}_{c.v.}$$

$$q + h_i + \frac{V_i^2}{2} + gZ_i = h_e + \frac{V_e^2}{2} + gZ_e + w$$

Example 4.3 R134a refrigerator fluid
enters @ 1.0 MPa / 60°C / 0.2 kg/s
exits @ 0.95 MPa / 35°C

→ cooling water enters @ 10°C
exits @ 20°C

→ determine the rate at which cooling water flows

$$\dot{Q}_{c.v.}^{\,0} + \sum \dot{m}_i\left(h_i + \frac{V_i^2}{2}^{\,0} + gZ_i^{\,0}\right) = \sum \dot{m}_e\left(h_e + \frac{V_e^2}{2}^{\,0} + gZ_e^{\,0}\right) + \dot{W}_{c.v.}^{\,0}$$

$$\Rightarrow \sum \dot{m}_i h_i = \sum \dot{m}_e h_e$$

From table:

$(h_i)_r = 441.89$ kJ/kg (R134a @ 1 MPa, 60°C)

$(h_e)_r = 249.1$ kJ/kg (R134a @ 0.95 MPa, 35°C)

$(h_i)_w = 42.\ kJ/kg$ (water @ 10 °C)

$(h_e)_w = 83.95\ kJ/kg$ (water @ 20 °C)

$$(\dot{m}_i)_r (h_i)_i + (\dot{m}_i)_w (h_i)_w = (\dot{m}_e)_r (h_e)_r + (\dot{m}_e)_w (h_e)_w$$

$$(\dot{m}_i)_r = (\dot{m}_e)_r = 0.2\ kg/s$$

$$(\dot{m}_i)_w = (\dot{m}_e)_w = \dot{m} = ?$$

$$(0.2)(441.89) - (0.2)(249.1) = \dot{m}(83.95 - 42)$$

$$\boxed{\dot{m} = 0.919\ kg/s}$$

Example 4.5

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Example 4.5 - From textbook

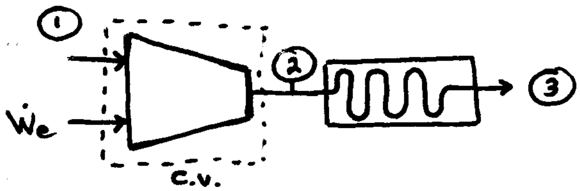


Table A-8

$h_1 = 198$ kJ/kg

$h_2 = 401.52$ kJ/kg

$h_3 = 257.4$ kJ/kg

$W = h_2 - h_1 + \frac{1}{2}V_2^2$

$W = (401.52) - (198) + (\frac{1}{2})\left[\frac{(25)^2}{1000}\right] \Rightarrow -203.8$ kJ/kg

$w = \frac{\dot{W}_e}{\dot{m}} \Rightarrow \dot{m} = \frac{\dot{W}_e}{w} \Rightarrow \dot{m} = 0.245$ kg/s

$q_{c.v._2} + (h_2 + \frac{V_2^2}{2} + gz_2) = W_{cv_2} + (h_3 + \frac{V_3^2}{2} + gz_3)$

$V_2 = V_3 \Rightarrow$ const. pressure

$q_{c.v._2} + h_2 = h_3$

$q_{c.v._2} = h_3 - h_2 = 257.4 - 401.5$

$q = -143.6$ kJ/kg (-ve because heat was removed)

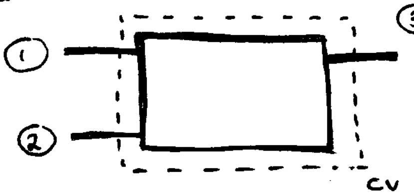
$\dot{Q}_{cv} = \dot{m}q \Rightarrow (0.245)(-143.6)$

$\Rightarrow \dot{Q}_{cv} = -35.2$ kW

Example 4.9 - From textbook

steam (Superheated)
$P_1 = 300$ kPa
$T_1 = 300$°C
$\dot{m}_1 = 3$ kg/s ①

water (liquid)
$P_2 = 300$ kPa
$T_2 = 90$°C
$\dot{m}_2 = ?$ ②



Sat. steam
$P_3 = 300$ kPa ③

- Assume steady state

$h_1 = 3064.24$ kJ/kg
$h_2 = 346.9$ kJ/kg
$h_3 = 2725.3$ kJ/kg

Continuity eq'n: $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$ → $\dot{m}_3 = \dot{m}_1 + \dot{m}_2$ ①

Conservation of energy:

$$\cancel{\dot{Q}_{c.v.}}^{0} + \dot{m}_1\left(h_1 + \cancel{\tfrac{V_1^2}{2}}^{0} + \cancel{gz_1}^{0}\right) + \dot{m}_2\left(h_2 + \cancel{\tfrac{V_2^2}{2}}^{0} + \cancel{gz_2}^{0}\right) = \ldots$$

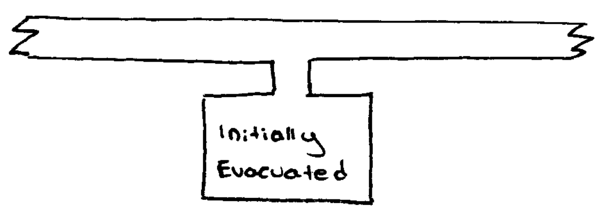
$$\ldots \cancel{\dot{W}_{c.v.}}^{0} + \dot{m}_3\left(h_3 + \cancel{\tfrac{V_3^2}{2}}^{0} + \cancel{gz_3}^{0}\right)$$

P.E. and K.E. are negligable

$\Rightarrow \dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3$ ②

$\dot{m}_1 h_1 + \dot{m}_2 h_2 = (\dot{m}_1 + \dot{m}_2) h_3$

$\ldots \Rightarrow \dot{m}_2 = 0.118$ kg/s



The transient process (conservation of mass)

$$\int_0^t \frac{dm_{cv}}{dt}\,dt = (m_2 - m_1)_{cv}$$

$$\Rightarrow \int_0^t (\Sigma \dot{m}_e)\,dt = \Sigma m_e$$

$$\Rightarrow \int_0^t (\Sigma \dot{m}_i)\,dt = \Sigma m_i$$

$$(m_2 - m_1)_{c.v.} = \Sigma m_i - \Sigma m_e$$

$$\dot{Q}_{c.v.} + \Sigma \dot{m}_i\left(h_i + \tfrac{V_i^2}{2} + gz_i\right) = \Sigma \dot{m}_e\left(h_e + \tfrac{V_e^2}{2} + gz_e\right) \ldots$$

$$\ldots + \dot{W}_{c.v.} + \frac{dE_{c.v.}}{dt}$$

$$\int_0^t \dot{Q}_{c.v.}\,dt = Q_{c.v.} \qquad \int_0^t \dot{W}_{c.v.}\,dt = W_{c.v.}$$

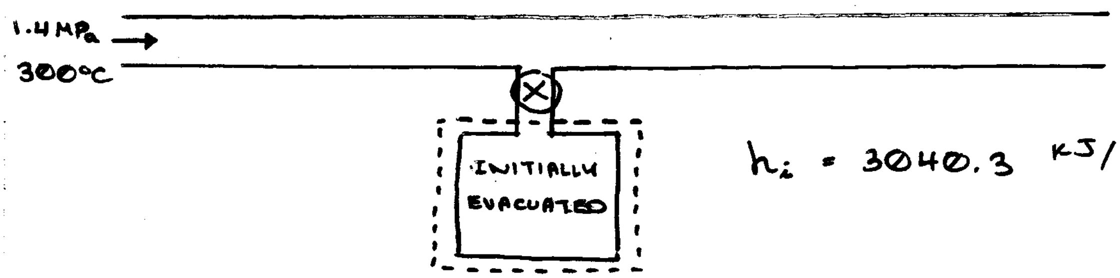
$$\int_0^t \left[\sum \dot{m}_i h_{tot_i}\right] dt = \sum m_i h_{tot_i} = \sum m_i (h_i + \tfrac{1}{2}V_i^2 + gZ_i)$$

$$\int_0^t \left[\sum \dot{m}_e h_{tot_e}\right] dt = \sum m_e h_{tot_e} = \sum m_e (h_e + \tfrac{1}{2}V_e^2 + gZ_e)$$

$$\rightarrow \quad \dot{Q}_{c.v.} + \sum m_i (h_i + V_i^2/2 + gZ_i) = \cdots$$

$$\cdots \sum m_e (h_e + V_e^2/2 + gZ_e) + [m_2(u_2 + V_2^2/2 + gZ_2) - m_1(u_1 + V_1^2/2 + gZ_1)]_{c.v.} + W_{c.v.}$$

Example 4.10



$h_i = 3040.3$ kJ/kg

$$\cancel{Q_{c.v.}}^{0} + \sum m_i (h_i + \cancel{V_i^2/2}^{0} + \cancel{gZ_i}^{0}) = \cancel{\sum m_o (h_o + V_o^2/2 + gZ_o)}^{0} + \cdots$$

$$\cdots [m_2(u_2 + \cancel{V_2^2/2}^{0} + \cancel{gZ_2}^{0}) - \cancel{m_1(u_1 + V_1^2/2 + gZ_1)}^{0}] + \cancel{W_{c.v.}}^{0}$$

$m_i h_i = m_2 u_2 \quad \Rightarrow \quad m_i = m_2 \quad \cdots \quad h_i = 3040.3 = u_2$

$h_i = u_2$

$P_2 = 1.4$ MPa

$u_2 = 3040.3$ kJ/kg

From table B1.3

$T_2 = 452$ °C