(a) False

(b) incompressible liquid
saturated liquid-vapor mixture

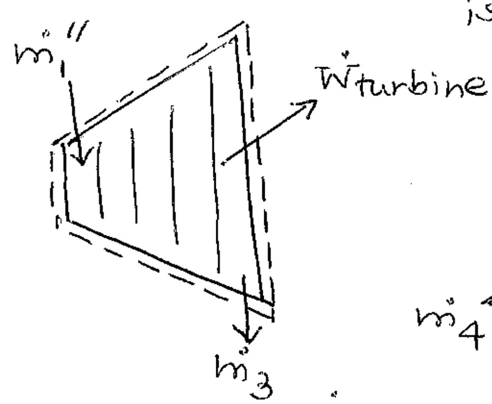
(c) turbine
nozzle

(d) mass remains constant during the process

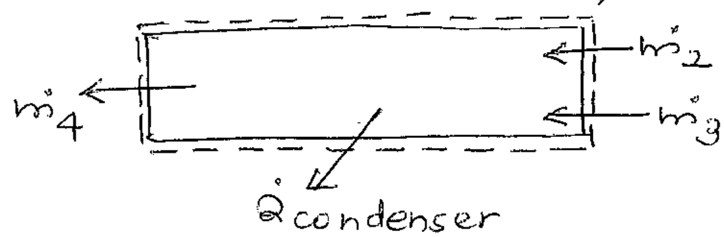
(e) 2

System

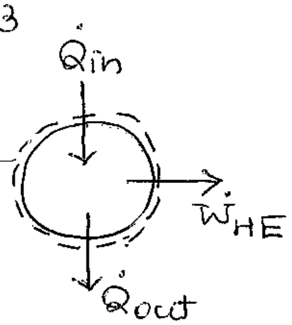
Flow of steam through the turbine is the system (a)

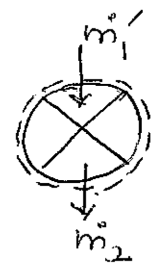


Flow of water substance through the condenser is the system (b)



Power cycle is the system (c)





Flow of steam through the throttling valve is the system (b)

Assumptions

- Open system
- Steady state, steady flow
- 1-D, uniform flow
- Ignore change in KE and PE
- Turbine : $\dot{Q} = 0$
- Throttling valve : $\dot{Q} = 0$, $\dot{W} = 0$
- Condenser : $\dot{W} = 0$

Basic Equations

$$\cancel{\left.\frac{dm}{dt}\right|_{system}} = \sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out}$$

$$\underbrace{\cancel{\left.\frac{dE}{dt}\right|_{system}}}_{0} = \sum_{in} \dot{m}_{in}(h + \cancel{ke} + \cancel{pe})_{in} - \sum_{out} \dot{m}_{out}(h + \cancel{ke} + \cancel{pe})_{out} + \dot{Q} - \dot{W}$$

Solution

(a) Turbine:

Mass balance : $0 = \dot{m}_1'' - \dot{m}_3 \Rightarrow \dot{m}_1'' = \dot{m}_3 = 0.75\,\dot{m}_1$

Energy balance: $0 = \dot{m}_1'' h_1 - \dot{m}_3 h_3 + 0 - \dot{W}_{turbine}$

$$\dot{W}_{turbine} = 0.75\,\dot{m}_1 (h_1 - h_3)$$

Mass flow rate at State 1: $\dot{m}_1 = \dfrac{\dot{W}_{turbine}}{0.75\,(h_1 - h_3)}$

State 1 $P_1 = 60$ bar, $T_1 = 540^\circ C$

$T_1 > T_{sat}(P_1) \Rightarrow$ superheated vapor

$h_1 = 3517.7 \frac{kJ}{kg}$

State 3 $P_3 = 10$ bar, $T_3 = 320^\circ C$

$T_3 > T_{sat}(P_3) \Rightarrow$ superheated vapor

$h_3 = 3094.4 \frac{kJ}{kg}$

$$\dot{m}_1 = \frac{6349.5 \ \frac{kJ}{s}}{0.75(3517.7 - 3094.4)\frac{kJ}{kg}} \qquad \boxed{\dot{m}_1 = 20 \frac{kg}{s}}$$

(b) Condenser:

Mass balance: $0 = (\dot{m}_2 + \dot{m}_3) - \dot{m}_4 \Rightarrow \dot{m}_4 = \dot{m}_2 + \dot{m}_3$

Energy balance: $0 = (\dot{m}_2 h_2 + \dot{m}_3 h_3) - \dot{m}_4 h_4 + \dot{Q}_{condenser} - 0$

Rate of heat transfer for the condenser:

$\dot{Q}_{condenser} = \dot{m}_4 h_4 - \dot{m}_2 h_2 - \dot{m}_3 h_3$

Throttling valve:

Mass balance: $0 = \dot{m}_1' - \dot{m}_2 \Rightarrow \dot{m}_1' = \dot{m}_2 = 0.25\,\dot{m}_1$

Energy balance: $0 = \dot{m}_1' h_1 - \dot{m}_2 h_2 + 0 - 0 \Rightarrow h_1 = h_2$

State 2 $P_2 = 10$ bar, $h_2 = h_1 = 3517.7 \frac{kJ}{kg}$

$\dot{m}_2 = 0.25\,\dot{m}_1 = 5 \frac{kg}{s}$

State 3 $P_3 = 10$ bar, $T_3 = 320^\circ C$, $h_3 = 3094.4 \frac{kJ}{kg}$

$\dot{m}_3 = 0.75\,\dot{m}_1 = 15 \frac{kg}{s}$

State 4 $P_4 = 10$ bar, sat. liquid, $h_4 = 762.52 \frac{kJ}{kg}$

$\dot{m}_4 = \dot{m}_2 + \dot{m}_3 = 20 \frac{kg}{s}$

$$\dot{Q}_{condenser} = 20 \frac{kg}{s} * 762.52 \frac{kJ}{kg} - 5 \frac{kg}{s} * 3517.7 \frac{kJ}{kg} - 15 \frac{kg}{s} * 3094.4 \frac{kJ}{kg}$$

$$\boxed{\dot{Q}_{condenser} = -48{,}754.1 \text{ kW}}$$ $\dot{Q}<0$ heat transfer out of the condenser

(c) Thermal efficiency of the power cycle:

$$\eta_{th} = \left|\frac{\dot{W}_{net}}{\dot{Q}_{in}}\right| = \frac{\dot{W}_{HE}}{|\dot{Q}_{condenser}|}$$

$$\dot{W}_{HE} = 0.5 * 48{,}754.1 \text{ kW} = 24{,}377 \text{ kW}$$

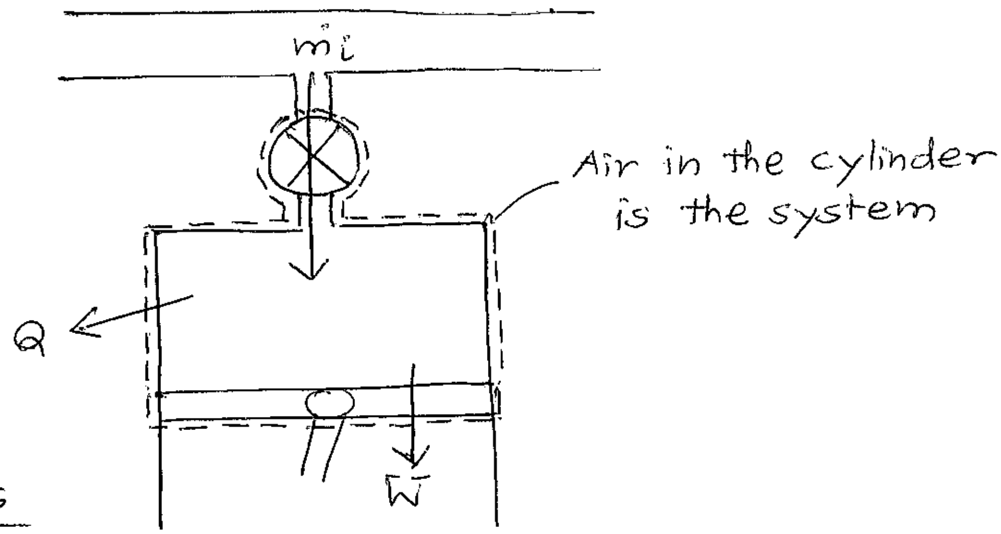
Energy balance: $\dot{Q}_{in} - |\dot{Q}_{out}| = \dot{W}_{HE}$

$$|\dot{Q}_{out}| = \dot{Q}_{in} - \dot{W}_{HE} = (48{,}754 - 24{,}377) \text{ kW}$$

Rate of heat transfer out of the power cycle:

$$\boxed{|\dot{Q}_{out}| = 24{,}377 \text{ kW}}$$

System



Assumptions

- Open system
- 1-D, uniform flow
- Ignore KE and PE
- Quasi-equilibrium process
- Air behaves as an ideal gas

Basic Equations

$$\left.\frac{dm}{dt}\right|_{system} = \sum_{in} \dot{m}_{in} - \cancel{\sum_{out} \dot{m}_{out}}$$

$$\left.\frac{dE}{dt}\right|_{system} = \sum_{in} \dot{m}_{in}(h + \cancel{ke} + \cancel{pe})_{in} - \cancel{\sum_{out} \dot{m}_{out}(h+ke+pe)_{out}} + \dot{Q} - \dot{W}$$

$$\frac{d}{dt}(U + \cancel{KE} + \cancel{PE})_{system}$$

$$W_{boundary} = \int P\,dV$$

Solution

(a) Boundary work during the process:

$$W_{12} = \int_{V_1}^{V_2} P\,dV = (P_1 = P_2)(V_2 - V_1)$$

$$= (1 \times 100)\,kPa * (1000 - 100) \times 10^{-6}\,m^3$$

$$\boxed{W_{12} = +0.09\ kJ}$$ $W > 0$ work done by the system

(b) Mass balance: $\frac{dm}{dt} = \dot{m}_{in}$

Integrating: $m_2 - m_1 = m_{in}$

Energy balance: $\frac{dU}{dt} = \dot{m}_{in} h_{in} + \dot{Q} - \dot{W}$

Integrating: $U_2 - U_1 = m_{in} h_{in} + Q_{12} - W_{12}$

Heat transfer during the process:

$Q_{12} = m_2 u_2 - m_1 u_1 - m_{in} h_{in} + W_{12}$

Ideal gas equation: $PV = m R_{air} T$

$$R_{air} = \frac{\bar{R}}{M_{air}} = \frac{8.314 \frac{kJ}{kmol-K}}{28.97 \frac{kg}{kmol}} = 0.287 \frac{kJ}{kg-K}$$

State 1 $P_1 = 100$ kPa, $T_1 = 300$ K, $V_1 = 100 \times 10^{-6}\ m^3$

$$m_1 = \frac{P_1 V_1}{R_{air} T_1} = \frac{100\ kPa * 100 \times 10^{-6}\ m^3}{0.287 \frac{kJ}{kg-K} * 300\ K} = 0.000116\ kg$$

$u_1 = 214.1 \frac{kJ}{kg}$

State 2 $P_2 = 100$ kPa, $T_2 = 350$ K, $V_2 = 1000 \times 10^{-6}\ m^3$

$$m_2 = \frac{P_2 V_2}{R_{air} T_2} = \frac{100\ kPa * 1000 \times 10^{-6}\ m^3}{0.287 \frac{kJ}{kg-K} * 350\ K} = 0.000996\ kg$$

$u_2 = 250.0 \frac{kJ}{kg}$

Inlet $P_{in} = 2$ bar, $T_{in} = 400$ K

$m_{in} = m_2 - m_1 = 0.00088$ kg

$h_{in} = 401.1 \frac{kJ}{kg}$

$$Q_{12} = 0.000996\ kg * 250.0 \frac{kJ}{kg} - 0.000116\ kg * 214.1 \frac{kJ}{kg} - 0.00088\ kg * 401.1 \frac{kJ}{kg} + 0.09\ kJ$$

$\boxed{Q_{12} = -0.0388\ kJ}$ $Q<0$ heat transfer out of the system