$E = U + K \cdot E + P \cdot E$

$E_2 - E_1 = (U_2 - U_1) + \frac{1}{2}m(V_2^2 - V_1^2) + mg(h_2 - h_1)$ or $z_2 - z_1$ — Energy eq. for finite changes

Heat in ⇒ +ive (absorb)(endothermic)

Work done by system ⇒ +ive

Inst. rate $\dot{E}_{cv} = \dot{Q} - \dot{W}$ — Energy eq. for control mass/volume

$= +\text{in} - \text{out}$

$\Delta U = Q - W$

$U_2 - U_1 = \frac{1}{2}m(v_2^2 - v_1^2) + mg(z_2 - z_1) = {}_1Q_2 - {}_1W_2$

$\Delta U + \Delta K \cdot E + \Delta P \cdot E = Q - W$

$Q_{Total} = \int \delta Q$

Spec. heat transfer: $q = \frac{Q}{m}$

Ist law thermo. $\oint Q = \oint W$

$Q_{net\ in} = W_{net\ out}$

Isobaric ⇒ P: same

Isothermal ⇒ T: same ⇒ Ideal gas law $P_1V_1 = P_2V_2$

Insulated ⇒ $Q = 0$

Adiabatic ⇒ No heat transfer → $Q=0$

$\Delta U = Q - W = -W$

Ideal gas under isothermal Process ⇒ $\Delta U = 0$

$\eta = \frac{W_{net\ out}}{Q_{net\ in}} \times 100\%$

Work done (Ideal gas): $W = nRT \ln\left(\frac{V_2}{V_1}\right)$

$= P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$

$\delta W = F dx$

$\delta W = P dV = F \cdot ds$

${}_1W_2 = P(V_2 - V_1)$

$= (P_2 - P_1)(V_2 - V_1)$

$= m(P_2 - P_1)(v_2 - v_1)$

$KE = \frac{1}{2}mV^2$

Unit: Work ⇒ Joule (J) | Heat ⇒ Joule (J)

Power ⇒ Watt (W)

$\dot{W}$(Power) $= T$ (torque) ω (ang. velocity)

Spec. Work ⇒ $w = \frac{W}{m}$

$\frac{y_2 - y_1}{x_2 - x_1}(x - x_1) + y_1 = y$

$P \propto \frac{1}{V}$, $P \propto T$, $V \propto T$

$Pv = RT$

$PV = mRT = n\bar{R}T$

$R = \frac{\bar{R}}{m}$

$n = \frac{m}{M}$

$P\dot{V} = \dot{m}RT = \dot{n}\bar{R}T$

Steps:-

① Sketch (mass, heat, work flows; pressure forces)

② Control Mass/Volume

③ General laws (Energy Eq.)

④ Specific laws

⑤ Solve using diagrams/table P-V, T-V

⑥ Formulate

•) Conduction: due to collision of molecules (direct contact)

$\dot{Q} = -kA\frac{dT}{dx}$ — Fourier's Law of Conduction

$\dot{Q}$: rate of heat transfer; k: thermal conductivity; A: Area; $\frac{dT}{dx}$: temperature gradient

k(metals): about 100 $\frac{W}{mK}$

k (insulators): upto 0.01 $\frac{W}{mK}$

•) Convection: due to moving fluid (liquid or gas)

$\dot{Q} = hA\Delta T$ — Newton's Law of Cooling

h: convective heat transfer coeff. $\left(\frac{W}{m^2K}\right)$

① Natural

② Forced

•) Radiation: due to electromagnetic waves

$\dot{Q} = \epsilon\sigma A T_s^4$ — Stefan-Boltzman Law

ϵ: emissivity (0 to 1); σ: S-B const $(5.67 \times 10^{-8}\ W/m^2K^4)$; A: surface area; T_s: surface temp. (could be ΔT_s^4)

Spec. internal energy: $u = \frac{U}{m}$ ⇒ $U = um = mu$

$U = U_{liq} + U_{vap}$

$u = u_f + x u_{fg}$

$v = v_f + x v_{fg}$

$x = 0$ ⇒ sat. liq

$x = 1$ ⇒ sat. vap

CL	SV
$P > P_{sat}$	$P < P_{sat}$
$T < T_{sat}$	$T > T_{sat}$
$v < v_f$	$v > v_g$
$h < h_f$	$h > h_g$
$u < u_f$	$u > u_g$

$v_f < v < v_g$

$u_f < u < u_g$

$h_f < h < h_g$

Two phase $(0 \le x \le 1)$

$m = \frac{V}{v}$

⇒ $m_{liq} = \frac{V_{liq}}{v_f}$

⇒ $m_{vap} = \frac{V_{vap}}{v_g}$

$W_{12} = P(V_2 - V_1)$

$U = Q - W$
$\because Q = U + W$

$Q_{12} = (U_2 - U_1) + P(V_2 - V_1)$

Enthalpy: $H = U + PV$ Unit: $\frac{kJ}{kg}$

$Q_{12} = H_2 - H_1$ (const. pressure)

Spe. Enthalpy $h = u + Pv$ $\rightarrow Q_{12} = m(h_2 - h_1)$

$u = h - Pv$

$h = h_f + x h_{fg}$ $\qquad h = \frac{H}{m}$

Heat Exchanger: $Q = 0$, $K \cdot E = 0$, $P \cdot E = 0$, $W = 0$ $\quad \sum \dot{m}_i h_i = \sum \dot{m}_e h_e$

Nozzle: $Q = 0$, $W = 0$, $P.E_i \approx P.E_e$, $\dot{m} = \text{constant}$

Diffuser: Same as nozzle, but in opposite direction.

$K \cdot E_i \uparrow \qquad K \cdot E_e \downarrow \qquad h_i + \frac{V_i^2}{2} = h_e + \frac{V_e^2}{2}$

Throttle: $K \cdot E \approx 0$, $P \cdot E = 0$, $W = 0$, $Q = 0$

$h_i = h_e$

Turbines: $P.E = 0$, $K \cdot E_i = 0$, $Q = 0$, $K \cdot E_e = 0$

Compressor/Pump: $P \cdot E = 0$, $K \cdot E_i = 0$, $K \cdot E_e = 0$, $Q = 0$

Eq. of Continuity $\frac{dm_{c.v}}{dt} = \sum \dot{m}_i - \sum \dot{m}_{out}$

if $\frac{dm_{cv}}{dt} = 0$, mass constant

Vol. flow rate $\dot{V} = VA$ → velocity

Mass. flow rate $\dot{m} = \rho AV = \frac{AV}{v}$

unit kg/s

Energy Eq. for control mass

$E_2 - E_1 = Q_{12} - W_{12}$

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

Work flow $\dot{W} = FV = P\dot{V} = Pv\dot{m}$

Energy Eq. for control volume

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

Steady-State Process

- $\dot{m}_i$ & $\dot{m}_e$: constant
- Prop. of fluid in & out are constant
- Energy within control doesn't accumulate over time

- Control volume: stationary
- $\frac{dm_{cv}}{dt} = 0$, $\frac{dE_{c.v}}{dt} = 0$
- Rate of heat & work: constant

power unit $\left(\frac{J}{s}\right)$: watt (W)

For multiple flow streams

Continuity Eq. $\sum \dot{m}_i = \sum \dot{m}_e$

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

For single flow stream

Continuity Eq. $\dot{m}_i = \dot{m}_e = \dot{m}$

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

$q = \frac{\dot{Q}_{cv}}{\dot{m}}$ Unit: kJ/kg → heat transfer per unit mass

$w = \frac{\dot{W}_{c.v}}{\dot{m}}$ Unit: kJ/kg → work per unit mass

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