THERMODYNAMICS

It a science that deals with energy transformation, the transformation of heat into work or vice versa. It was derived from a Greek word "therme" that means Heat and "dynamis" that means Strength.

SYSTEM: Is that portion in the universe, an atom, a galaxy, a certain quantity of matter or a certain volume in space in which one wishes to study. It is a region enclosed by an specified boundary, that may be imaginary, fixed or moving.
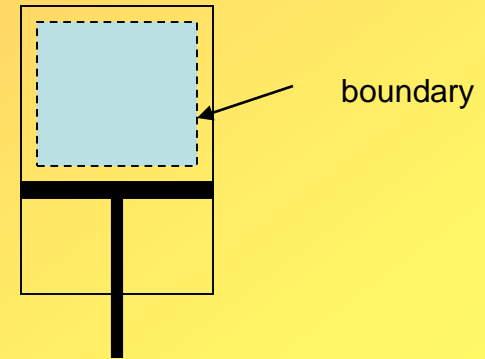
OPEN SYSTEM: A system open to matter flow or a system in which there is an exchange of mass between the system and the surroundings.

CLOSED SYSTEM: A system closed to matter flow or a system in which there's no exchange of mass between the system and the surroundings.

Open System: Steam turbine
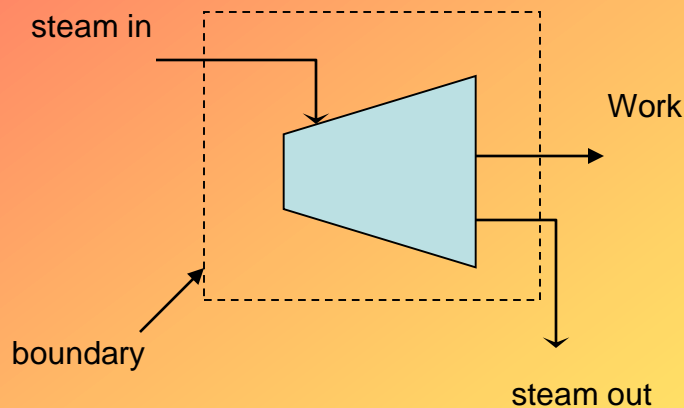
Closed System: Piston in Cylinder

steam in

Work

boundary

steam out

boundary

SURROUNDINGS OR ENVIRONMENT: It is the region all about the system.

WORKING SUBSTANCE: A substance responsible for the transformation of energy.
        example: steam in a steam turbine, water in a water pump

PURE SUBSTANCE: A substance that is homogeneous in nature and is homogeneous, or a substance that is not a mixture of different specie, or a substance that does not undergo chemical reaction.

PROPERTY: It is a characteristic quality of a certain substance.

INTENSIVE PROPERTY: Property that is independent of the mass of a system.

EXTENSIVE PROPERTY: Property that is dependent upon the mass of the system and are total values such as volume and total internal energy.

PROCESS: It is simply a change of state of a substance. If certain property of a substance is changed, it is said to have undergone a process.

CYCLE: It is a series of two or more processes in which the final and the initial state are the same.

ADIABATIC SYSTEM: A system that is impervious to heat. A system (open or closed) in which heat cannot cross its boundary.

PHASES OF A SUBSTANCE
          A. Solid phase
          B. Liquid phase
          C. Gaseous or Vapor phase

SPECIFIC TERMS TO CHARACTERIZED PHASE TRANSITION:
1. Vaporization: Change from liquid to vapor
2. Condensation: Change from vapor to liquid
3. Freezing: Change from liquid to solid
4. Melting: Change from solid to liquid
5. Sublimation: Change from solid directly to vapor without passing the liquid state.

MASS: It is the absolute quantity of matter in it.

m – mass, kg

VELOCITY: It is the distance per unit time.

$$v = \frac{d}{t} \quad \frac{m}{sec}$$

where:

v – velocity in m/sec
d – distance in meters
t – time in sec

ACCELERATION: It is the rate of change of velocity with respect to time.

$$a = \frac{dv}{dt} \quad \frac{m}{sec^2}$$

SPECIFIC VOLUME (υ): It is the volume per unit mass or the reciprocal of its density.

$$\upsilon = \frac{V}{m} = \frac{1}{\rho} \quad \frac{m3}{kg}$$

Where:

υ - specific volume in m^3/kg

SPECIFIC WEIGHT (γ): It is the weight per unit volume.

$$\gamma = \frac{W}{V} = \frac{mg}{1000V} = \frac{\rho g}{1000} \quad \frac{KN}{m^3}$$

Where:

γ - specific weight in KN/m^3

SPECIFIC GRAVITY OR RELATIVE DENSITY
1. For liquids it is the ratio of its density to that of water at standard temperature and pressure.
2. For gases it is the ratio of its density to that of either air or hydrogen at some specified temperature and pressure.

For Liquids : $S_L = \dfrac{\rho_L}{\rho_w}$

Where:

At standard Condition
$\rho_w = 1000 \text{ kg/m}^3$
$\gamma_w = 9.81 \text{ KN/m}^3$

For Gases : $S_G = \dfrac{\rho_G}{\rho_{AH}}$

VISCOSITY: It is a property of a fluid that determines the amount of its resistance to shearing stress.
      a. Absolute or Dynamic viscosity
          μ - dynamic viscosity in N-sec/m^2
      b. Kinematic viscosity
          ν - kinematic viscosity in m^2/sec

TEMPERATURE: It is the measure of the intensity of heat.
      Fahrenheit Scale
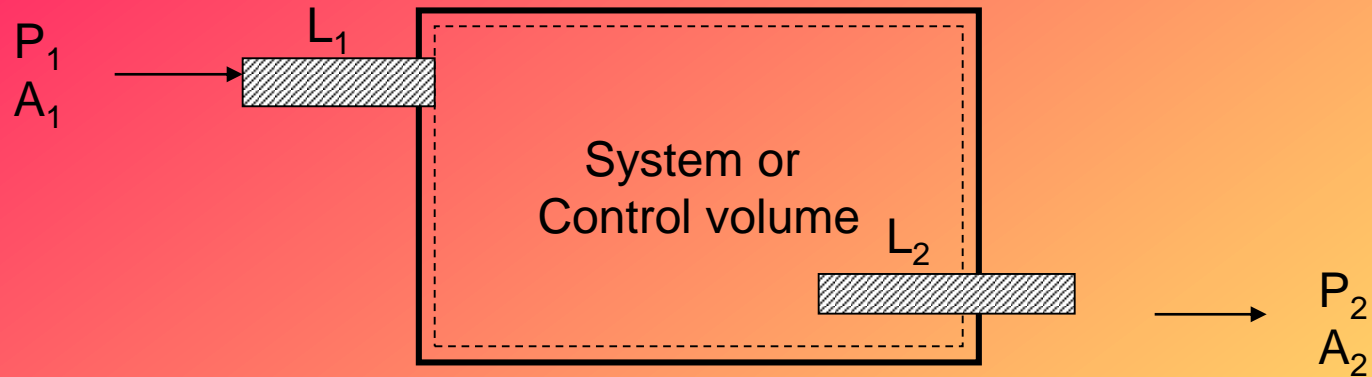   Freezing Point = 32°F
          Boiling Point = 212 °F
      Centigrade or Celsius Scale
          Freezing Point = 0°C
          Boiling Point = 100°C

$E_{f1} = F_1L_1 = P_1A_1L_1$
$A_1L_1 = V_1$
$E_{f1} = P_1V_1$

$E_{f2} = F_2L_2 = P_2A_2L_2$
$A_2L_2 = V_2$
$E_{f2} = P_2V_2$

$\Delta E_f = E_{f2} - E_{f1}$

$\Delta Ef = P_2V_2 - P_1V_1$ KJ

$\Delta E_f = \Delta(PV)$

$\Delta E_f = E_{f2} - E_{f1}$

$\Delta E_f = P_2\upsilon_2 - P_1\upsilon_1$ KJ/kg

$\Delta E_f = \Delta(P \upsilon)$

Where:

P – pressure in KPa
V – volume in m^3
υ - specific volume in m^3/kg

- Enthalpy: It a thermodynamic property that is equal to the sum of the internal energy and the flow energy of a substance.
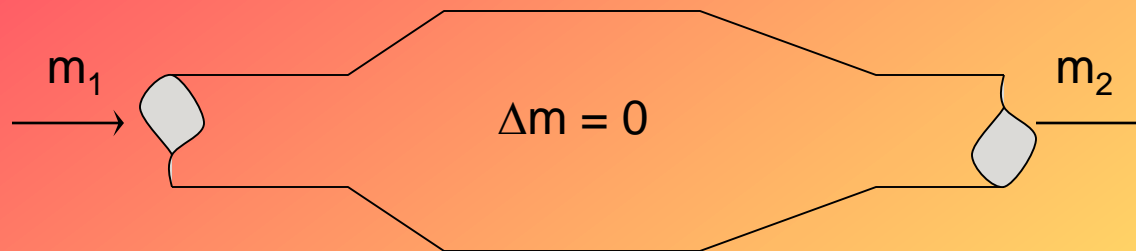
$$h = U + PV$$

LAW OF CONSERVATION OF MASS: Mass is indestructible. In applying this law we must except nuclear processes during which mass is converted into energy.

Verbal Form: Mass Entering – Mass Leaving = change of mass stored within the system

Equation Form: $m_1 - m_2 = \Delta m$

For an **Open System** (steady state, steady flow system) the $\Delta m = 0$.

m_1 $\Delta m = 0$ m_2

$m_1 - m_2 = 0$
$m_1 = m_2$

For one dimensional flow, the mass rate of flow entering or leaving a system is

$$m = \rho A v = \frac{Av}{\upsilon}$$

$$m_1 = m_2$$

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

$$\frac{A_1 v_1}{\upsilon_1} = \frac{A_2 v_2}{\upsilon_2}$$

where:

m – mass flow rate, kg/sec
A – cross sectional area, m^2
v - velocity, m/sec
ρ - density, kg/m^3
υ - specific volume, m^3/kg

Zeroth Law of Thermodynamics:
If two bodies are in thermal equilibrium with a third body, they are in thermal equilibrium with each other and hence their temperatures are equal.
Specific Heat:
It is the amount of heat required to raise the temperature of a 1 kg mass 1°C or 1°K.

$$C = \frac{dQ}{dt} = \frac{dQ}{dT}$$

$$dQ = CdT = CdT$$

by integra tion

$$Q = C(t_2 - t_1) = C (T_2 - T_1) \frac{KJ}{kg}$$

Considerin g the mass m,

$$Q = mC(t_2 - t_1) = mC (T_2 - T_1) \ KJ$$

THE FIRST LAW OF THERMODYNAMICS (The Law of Conservation of (Energy)
  "Energy can neither be created nor destroyed but can only be converted from one form to another."
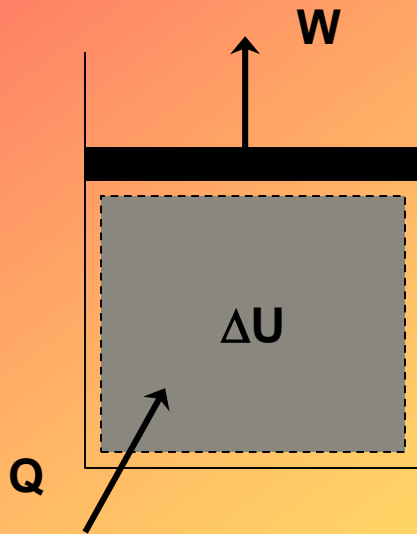
Verbal Form:

Energy Entering – Energy Leaving = Change of Energy stored in the system

Equation Form:

$$E_1 - E_2 = \Delta Es$$

1. First Corollary of the First Law: Application of first Law to a Closed System

W

ΔU

Q

For a Closed System (Non FlowSystem), PV, KE and PE are negligible, therefore the changeof stored energy **ΔEs = ΔU**

$$Q - W = \Delta U \rightarrow 1$$
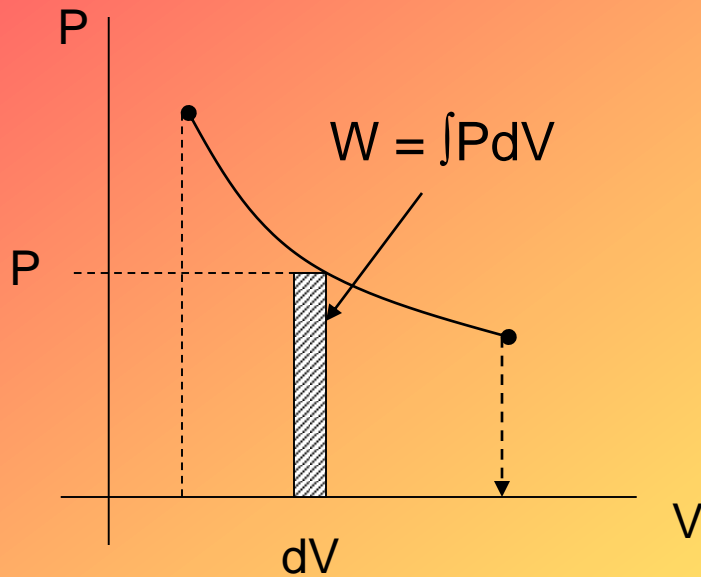$$Q = \Delta U + W \rightarrow 2$$

By differentiation:

$$dQ = dU + dW \rightarrow 3$$

where:

$$\int dQ \neq Q_2 - Q_1$$
$$\int dW \neq W_2 - W_1$$

Work of a Closed System (NonFlow)

$$W = \int PdV$$

$$W = \int Fdx$$
$$F = PA$$
$$W = \int PAdx$$
$$Adx = dV$$
$$W = \int PdV$$
$$dW = PdV$$

From Eq. 3
$$dQ = dU + dW$$
$$dQ = dU + PdV \rightarrow 4$$

IDEAL OR PERFECT GAS

1. Ideal Gas Equation of State

$$PV = mRT$$

$$Pv = RT$$

$$\rho = \frac{P}{RT}$$

$$\frac{PV}{T} = C$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Where: P – absolute pressure in KPa

V – volume in m^3

m – mass in kg

R – Gas Constant in KJ/kg-°K

T – absolute temperature in °K

2. Gas Constant

$$R = \frac{\bar{R}}{M} \quad \frac{KJ}{kg - °K}$$

$$\bar{R} = 8.3143 \quad \frac{KJ}{kg_m - °K}$$

Where:

R- Gas Constant in KJ/kg-K

$\bar{R}$- universal gas constant $\dfrac{KJ}{kg_m - °K}$

M - Molecular weight kg/kg$_m$

3. Boyle's Law

If the temperature of a certain quantity of gas is held constant the volume V is inversely proportional to the absolute pressure P.

$$V \alpha P$$

$$V = C \frac{1}{P}$$

$$PV = C$$

$$P_1 V_1 = P_2 V_2 = C$$

4.Charle's Law

A. At Constant Pressure (P = C)

If the pressure of a certain quantity of gas is held constant, the volume V is directly proportional to the temperature T during a quasistatic change of state

$$V \propto T \; ; \; V = C\,T \; ; \; \frac{V}{T} = C$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

B. At Constant Volume (V = C)

If the volume of a certain quantity of gas is held constant, the pressure P varies directly as the absolute temperature T.

$$P \propto T \; ; \; P = C\,T \; ; \; \frac{P}{T} = C$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

B SPECIFIC HEAT AT CONSTANT VOLUME (Cv)

At V = C, dV = O, and from dQ = dU + PdV

dV = 0, therefore

$$dQ = dU \rightarrow 11$$

then by integration

$$Q = \Delta U \rightarrow 12$$

then the specific heat at constant volume Cv is;

$$Cv = dQ/dT = dU/dT \rightarrow 13$$

$$dQ = CvdT \rightarrow 14$$

and by considering m,

$$dQ = mCvdT \rightarrow 15$$

and by integration

$$Q = m\Delta U \rightarrow 16$$

$$Q = mCv\Delta T \rightarrow 17$$

$$Q = m(U_2 - U_1) \rightarrow 18$$

$$Q = m\, Cv(T_2 - T_1) \rightarrow 19$$

From:

$h = U + Pv$ and $Pv = RT$

$h = U + RT$ $\rightarrow$ 20

and by differentiation,

$dh = dU + Rdt$ $\rightarrow$ 21

but $dh = CpdT$ and $dU = CvdT$, therefore

$CpdT = CvdT + RdT$ $\rightarrow$ 22

and by dividing both sides of the equation by dT,

$Cp = Cv + R$ $\rightarrow$ 23

7. Ratio Of Specific Heats

$$k = Cp/Cv \rightarrow 24$$
$$k = dh/du \rightarrow 25$$
$$k = \Delta h/\Delta U \rightarrow 26$$

From eq. 32,
$$Cp = kCv \rightarrow 27$$
substituting eq. 27 to eq. 24
$$Cv = R/k-1 \rightarrow 28$$
From eq. 24,
$$Cv = Cp/k \rightarrow 29$$
substituting eq. 29 to eq. 24
$$Cp = Rk/k-1 \rightarrow 30$$

8. Entropy Change (ΔS)

Entropy is that property of a substance that determines the amount of randomness and disorder of a substance. If during a process, an amount of heat is taken and is by divided by the absolute temperature at which it is taken, the result is called the ***ENTROPY CHANGE***.

$$dS = dQ/T \rightarrow 31$$

and by integration

$$\Delta S = \int dQ/T \rightarrow 32$$

and from eq. 39

$$dQ = TdS \rightarrow 33$$

GAS MIXTURE

☠ Total Mass of a mixture

$$m = \sum m_i$$

Where:

☠ Mass Fraction

$$x_i = \frac{m_i}{m}$$

m – total mass of a mixture

m_i – mass of a component

n – total moles of a mixture

n_i – moles of a component

☠ Total Moles of a mixture

x_i – mass fraction of a component

y_i - mole fraction of a component
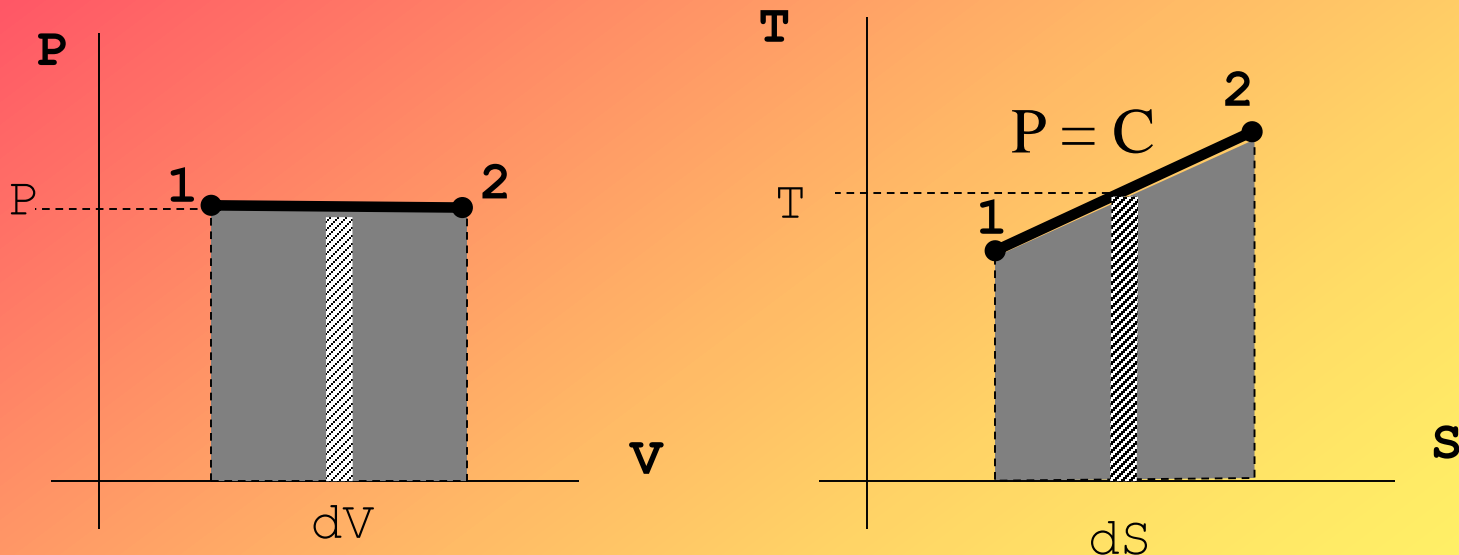
$$n = \sum n_i$$

☠ Mole Fraction

$$y_i = \frac{n_i}{n}$$

PROCESSES OF FLUIDS

1. Isobaric Process (P = C): An Isobaric Process is an internally reversible constant pressure process.

A. Closed System: (Nonflow)

$$Q = \Delta U + W \rightarrow 1 \text{ any substance}$$

$$W = \int P dV \rightarrow 2 \text{ any substance}$$

$$\Delta U = m(U_2 - U_1) \rightarrow 3 \text{ any substance}$$

$$W = P(V_2 - V_1) \rightarrow 4 \text{ any substance}$$

$$Q = \Delta h = m(h_2 - h_1) \rightarrow 5 \text{ any substance}$$

For Ideal Gas:

$PV = mRT$

$W = mR(T_2 - T_1) \rightarrow 5$

$\Delta U = mC_v(T_2 - T_1) \rightarrow 6$

$Q = \Delta h = mC_P(T_2 - T_1) \rightarrow 7$

Entropy Change

$\Delta S = \int dQ/T \rightarrow 8$ any substance

$dQ = dh$

For Ideal Gas

$dh = mC_P dT$

$\Delta S = \int dQ/T$

$\Delta S = mC_P \int dT/T$

$\Delta S = mC_P \ln(T_2/T_1) \rightarrow 9$

B. Open System:

$Q = \Delta h + \Delta KE + \Delta PE + W \rightarrow 10$ any substance

$W = -\int VdP - \Delta KE - \Delta PE \rightarrow 11$ any substance

$-\int VdP = 0$

$Q = \Delta h \rightarrow 12$

$W = -\Delta KE - \Delta PE \rightarrow 13$
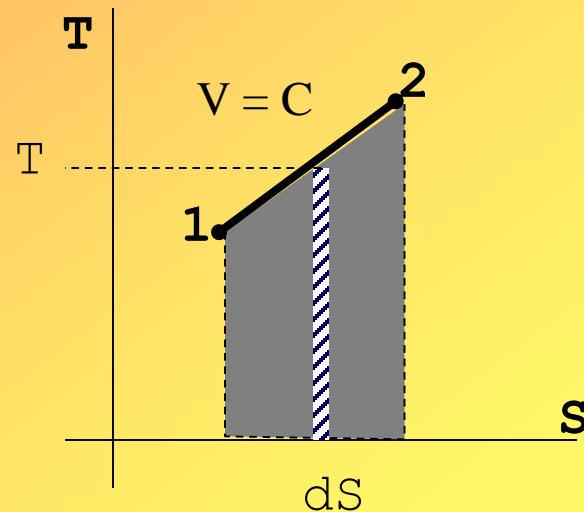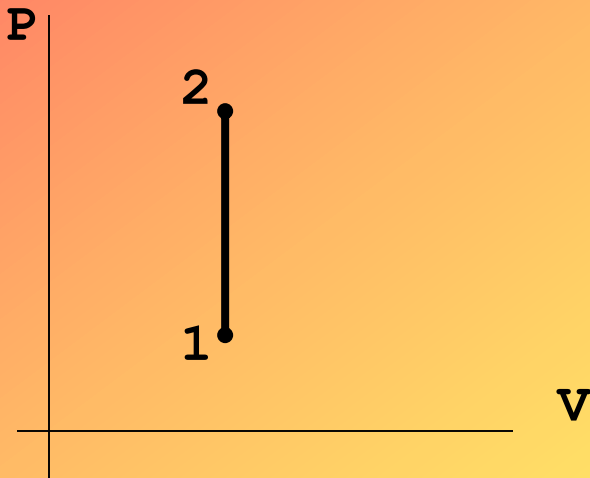
If $\Delta KE = 0$ and $\Delta PE = 0$

$W = 0 \rightarrow 14$

$Q = mC_P(T_2 - T_1) \rightarrow 15$ Ideal Gas

2. Isometric Process (V = C): An Isometric process is internally reversible constant volume process.

A. Closed System: (Nonflow)

$Q = \Delta U + W \to 1$ any substance

$W = \int P dV$ at $V = C$; $dV = 0$

$W = 0$

$Q = \Delta U = m(U_2 - U_1) \to 2$ any substance

$\Delta h = m(h_2 - h_1) \to 3$ any substance

For Ideal Gas:

$Q = \Delta U = mC_v(T_2 - T_1) \to 4$

$\Delta h = mC_P(T_2 - T_1) \to 5$

Entropy Change:

$\Delta S = \int dQ/T \to 6$ any substance

$dQ = dU$

$dU = mC_v dT$ for ideal gas

$\Delta S = \int dU/T = mC_v \int dT/T$

$\Delta S = mC_v \ln(T_2/T_1) \to 6$

B. Open System:

$Q = \Delta h + \Delta KE + \Delta PE + W \rightarrow 7$ any substance

$W = -\int VdP - \Delta KE - \Delta PE \rightarrow 8$ any substance

$-\int VdP = -V(P_2-P_1) \rightarrow 9$ any substance

$Q = \Delta U = m(U_2 - U_1) \rightarrow 10$ any substance

$\Delta h = m(h_2-h_1) \rightarrow 11$ any substance

For Ideal Gas:

$-\int VdP = -V(P_2-P_1) = mR(T_1-T_2)$

$Q = \Delta U = mC_v(T_2-T_1) \rightarrow 12$

$\Delta h = mC_P(T_2-T_1) \rightarrow 13$

If $\Delta KE = 0$ and $\Delta PE = 0$

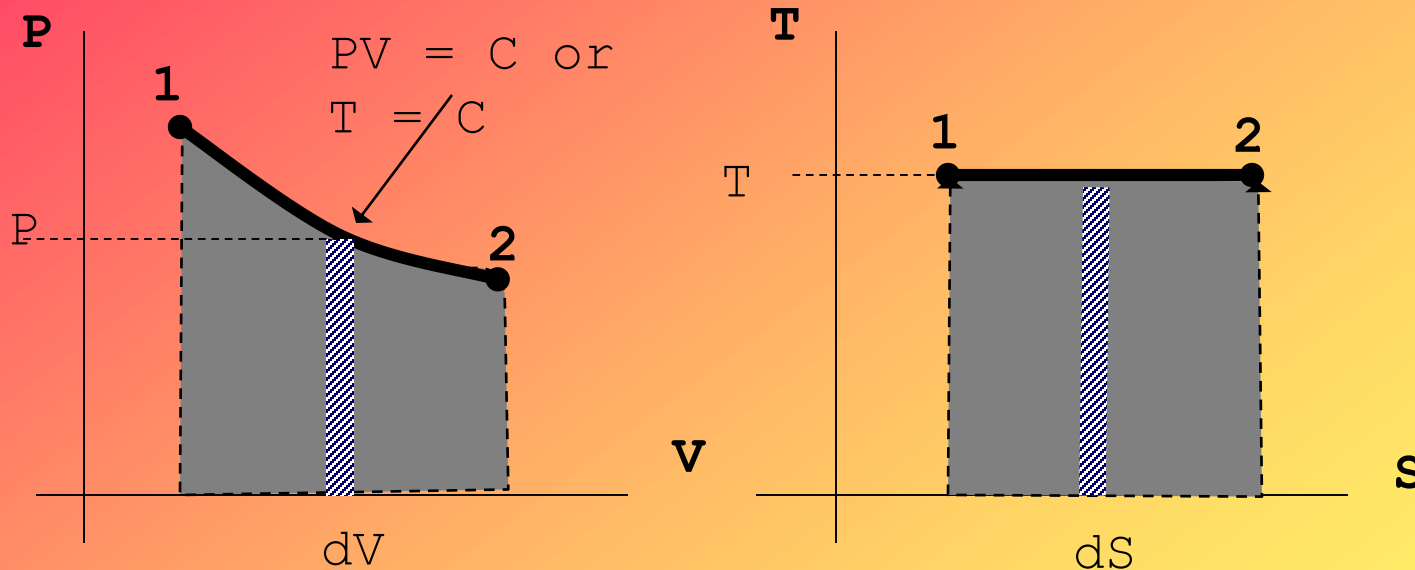$Q = \Delta h + W \rightarrow 14$ any substance

$W = -\int VdP \rightarrow 15$

$W = -\int VdP = -V(P_2-P_1) \rightarrow 16$ any substance

$W = mR(T_1-T_2) \rightarrow 16$ ideal gas

$\Delta h = mC_P(T_2-T_1) \rightarrow 17$ ideal gas

3. Isothermal Process(T = C): An Isothermal process is reversible constant temperature process.

A. Closed System (Nonflow)

$Q = \Delta U + W \rightarrow 1$ any substance

$W = \int PdV \rightarrow 2$ any substance

$\Delta U = m(U_2 - U_1) \rightarrow 3$ any substance

For Ideal Gas:

$dU = mC_v \, dT$; at $T = C$; $dT = 0$

$Q = W \rightarrow 4$

$W = \int PdV$; at $PV = C$;

$P_1V_1 = P_2V_2 = C$; $P = C/V$

Substituting $P = C/V$ to $W = \int PdV$

$W = P_1V_1 \ln(V_2/V_1) \rightarrow 5$

Where $(V_2/V_1) = P_1/P_2$

$W = P_1V_1 \ln(P_1/P_2) \rightarrow 6$

$P_1V_1 = mRT_1$

Entropy Change:

$dS = dQ/T \rightarrow 7$

$\Delta S = \int dQ/T$

$dQ = TdS$;at $T = C$

$Q = T(S_2-S_1)$

$(S_2-S_1) = \Delta S = Q/T \rightarrow 8$

$\Delta S = Q/T = W/T \rightarrow 9$ For Ideal Gas

B. Open System (Steady Flow)

$Q = \Delta h + \Delta KE + \Delta PE + W \rightarrow 10$ any substance

$W = - \int VdP - \Delta KE - \Delta PE \rightarrow 11$ any substance

$-\int VdP = -V(P_2-P_1) \rightarrow 12$ any substance

$\Delta h = m(h_2-h_1) \rightarrow 13$ any substance

For Ideal Gas:

$-\int VdP = -P_1V_1\ln(P_2/P_1) \rightarrow 14$

$-\int VdP = P_1V_1\ln(P_1/P_2) \rightarrow 15$

$P_1/P_2 = V_2/V_1 \rightarrow 16$

$dh = C_PdT;$ at $T = C;$ $dT = 0$

$\Delta h = 0 \rightarrow 16$

If $\Delta KE = 0$ and $\Delta PE = 0$

$Q = \Delta h + W \rightarrow 17$ any substance

$W = - \int VdP = P_1V_1\ln(P_1/P_2) \rightarrow 18$

For Ideal Gas

$\Delta h = 0 \rightarrow 19$

$Q = W = - \int VdP = P_1V_1\ln(P_1/P_2) \rightarrow 20$

4. Isentropic Process (S = C): An Isentropic Process is an internally "Reversible Adiabatic" process in which the entropy remains constant where S = C and PV^k = C for an ideal or perfect gas.
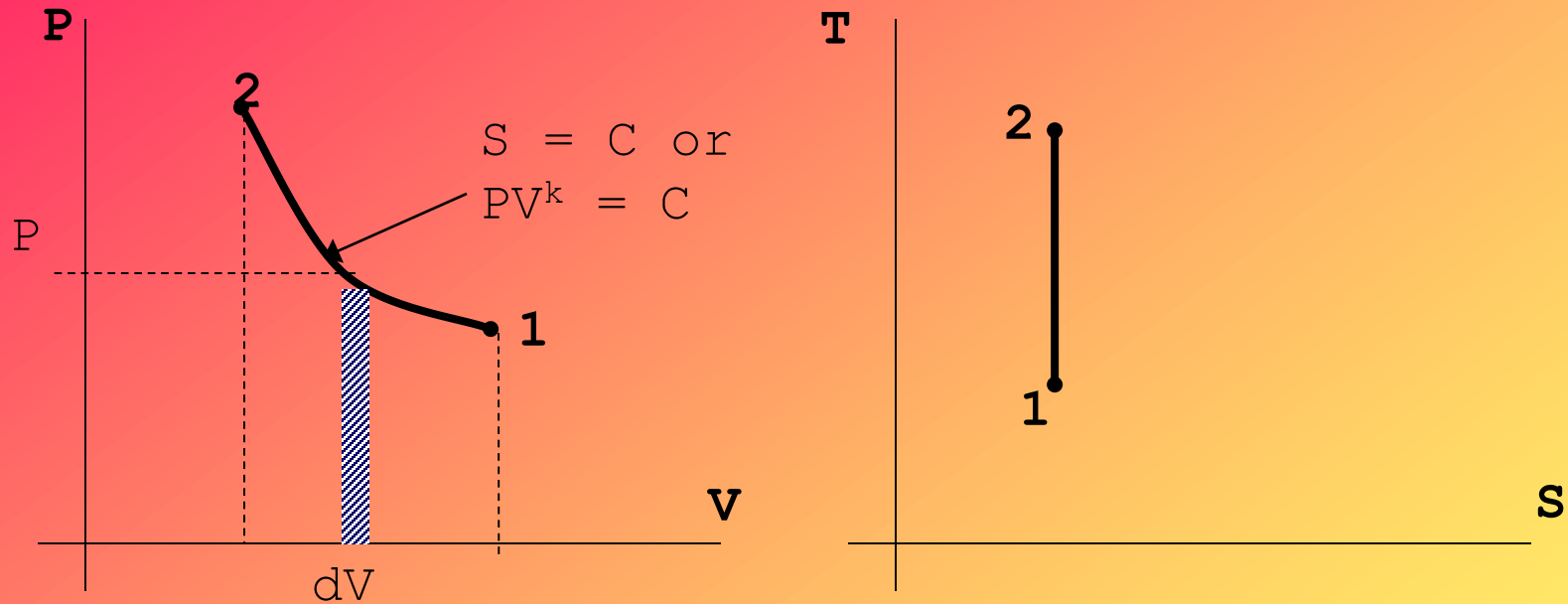
For Ideal Gas

Using $\dfrac{PV}{T}$ = C and PV^k = C

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad \text{and} \quad P_1 V_1{}^k = P_2 V_2{}^k$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = \left(\frac{V_1}{V_2}\right)^{k-1}$$

A. Closed System (Nonflow)

P

2

S = C or
PV^k = C

$PV^k = C$

P

1

V

dV

T

2

1

S

$Q = \Delta U + W \rightarrow 1$ any substance

$W = \int PdV \rightarrow 2$ any substance

$\Delta U = m(U_2 - U_1) \rightarrow 3$ any substance

$Q = 0 \rightarrow 4$

$W = -\Delta U = \Delta U = -m(U_2 - U_1) \rightarrow 5$

For Ideal Gas

$$\Delta U = mC_V(T_2 - T_1) \rightarrow 6$$

From $PV^k = C$, $P = C/V^k$, and substituting $P = C/V^k$

to $W = \int PdV$, then by integration,

$$W = \int PdV = \frac{P_2V_2 - P_1V_1}{1-k} \qquad \rightarrow 7$$

$$\int PdV = \frac{mR\left(T_2 - T_1\right)}{1-k} = \frac{mRT_1}{1-k}\left[\left(\frac{P_2}{P_1}\right)^{k-1/k} - 1\right] \rightarrow 8$$

$$\int PdV = \frac{P_1V_1}{1-k}\left[\left(\frac{P_2}{P_1}\right)^{k-1/k} - 1\right] \qquad \rightarrow 9$$

$$Q = 0$$

Entropy Change

$\Delta S = 0$

$S_1 = S_2$

B. Open System (Steady Flow)

$Q = \Delta h + \Delta KE + \Delta PE + W \rightarrow 10$ any substance

$W = - \int VdP - \Delta KE - \Delta PE \rightarrow 11$ any substance

$\Delta h = m(h_2 - h_1) \rightarrow 12$ any substance

$Q = 0$

$W = -\Delta h - \Delta KE - \Delta PE \rightarrow 13$

From $PV^k = C$, $V = [C/P]^{1/k}$, substituting V to

$-\int VdP$, then by integration,

$$- \int VdP = k \int PdV$$

$$- \int VdP = \frac{k\left(P_2V_2 - P_1V_1\right)}{1 - k} \qquad \rightarrow 14$$

$$- \int VdP = \frac{kmR\left(T_2 - T_1\right)}{1 - k} = \frac{kmRT_1}{1 - k}\left[\left(\frac{P_2}{P_1}\right)^{k-1/k} - 1\right] \qquad \rightarrow 15$$

$$- \int VdP = \frac{kP_1V_1}{1 - k}\left[\left(\frac{P_2}{P_1}\right)^{k-1/k} - 1\right] \qquad \rightarrow 16$$

If $\Delta KE = 0$ and $\Delta PE = 0$

$0 = \Delta h + W \rightarrow 17$ any substance

$W = - \int VdP = - \Delta h \rightarrow 18$ any substance

$\Delta h = m(h_2 - h_1) \rightarrow 19$ any substance

$Q = 0$

$$W = -\int VdP = k \int PdV = \frac{k(P_2V_2 - P_1V_1)}{1 - k} \rightarrow 20$$

$$W = \frac{kmR(T_2 - T_1)}{1 - k} = \frac{kmRT_1}{1 - k}\left[\left(\frac{P_2}{P_1}\right)^{k-1/k} - 1\right] \rightarrow 21$$

$$W = \frac{kP_1V_1}{1 - k}\left[\left(\frac{P_2}{P_1}\right)^{k-1/k} - 1\right] \rightarrow 22$$

$$W = -\Delta h = -mC_P(T_2 - T_1) \rightarrow 23$$

5. Polytropic Process (PVn = C): A Polytropic Process is an internally reversible process of an Ideal or Perfect Gas in which $PV^n = C$, where n stands for any constant.

$$\text{Using } \frac{PV}{T} = C \text{ and } PV^n = C$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \text{ and } P_1 V_1^n = P_2 V_2^n$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \left(\frac{V_1}{V_2}\right)^{n-1}$$

From $PV^n = C$, $P = C/V^n$, and substituting
$P = C/V^n$ to $W = \int PdV$, then by integration,

$$W = \int PdV = \frac{P_2V_2 - P_1V_1}{1 - n} \quad \rightarrow 6$$

$$W = \int PdV = \frac{mR(T_2 - T_1)}{1 - n} = \frac{mRT_1}{1 - n}\left[\left(\frac{P_2}{P_1}\right)^{n-1/n} - 1\right] \quad \rightarrow 8$$

$$W = \int PdV = \frac{P_1V_1}{1 - n}\left[\left(\frac{P_2}{P_1}\right)^{n-1/n} - 1\right] \quad \rightarrow 9$$

Entropy Change

$dS = dQ/T$

$dQ = mC_n dT$

$\Delta S = mC_n \ln(T_2/T_1) \quad \rightarrow 10$

B. Open System (Steady Flow)

$Q = \Delta h + \Delta KE + \Delta PE + W \rightarrow 11$

$W = - \int VdP - \Delta KE - \Delta PE \rightarrow 12$

$\Delta h = m(h_2 - h_1) \rightarrow 13$

$Q = mC_n(T_2 - T_1) \rightarrow 14$

$dQ = mC_n \, dT$

$W = Q - \Delta h - \Delta KE - \Delta PE \rightarrow 15$

From $PV^n = C$, $V = [C/P]^{1/n}$, substituting V to $-\int VdP$, then by integration,

$$- \int VdP = n \int PdV$$

$$- \int VdP = \frac{n(P_2 V_2 - P_1 V_1)}{1 - n} \rightarrow 16$$

$$- \int VdP = \frac{nmR(T_2 - T_1)}{1 - n} = \frac{nmRT_1}{1 - n}\left[\left(\frac{P_2}{P_1}\right)^{n-1/n} - 1\right] \rightarrow 17$$

$$- \int VdP = \frac{nP_1V_1}{1 - n}\left[\left(\frac{P_2}{P_1}\right)^{n-1/n} - 1\right] \rightarrow 18$$

If $\Delta KE = 0$ and $\Delta PE = 0$

$Q = \Delta h + W \rightarrow 19$ any substance

$W = - \int VdP = Q - \Delta h \rightarrow 20$ any substance

$\Delta h = m(h_2 - h_1) \rightarrow 21$ any substance

$\Delta h = mC_p(T_2 - T_1)$

$Q = mC_n(T_2 - T_1) \rightarrow 22$

$$W = \frac{nmR(T_2 - T_1)}{1 - n} = \frac{nmRT_1}{1 - n}\left[\left(\frac{P_2}{P_1}\right)^{n-1/n} - 1\right] \rightarrow 23$$

$$W = \frac{nP_1V_1}{1 - n}\left[\left(\frac{P_2}{P_1}\right)^{n-1/n} - 1\right] \rightarrow 24$$

Second Law of Thermodynamics:

Whenever energy is transferred, the level of energy cannot be conserved and some energy must be permanently reduced to a lower level.
When this is combined with the first law of thermodynamics,the law of energy conservation, the statement becomes:
Whenever energy is transferred, energy must be conserved,but the level of energy cannot be conserved and some energy must be permanently reduced to a lower level.

Kelvin-Planck statement of the second law:

No cyclic process is possible whose sole result is the flow of heat from a single heat reservoir and the performance of an equivalent amount of work. For a system undergoing a cycle: The net heat is equal to the network.

$$\oint dQ = \oint dW$$

$$W = \sum Q$$

Where:

W - net work

$\sum Q$ - net heat

CARNOT CYCLE

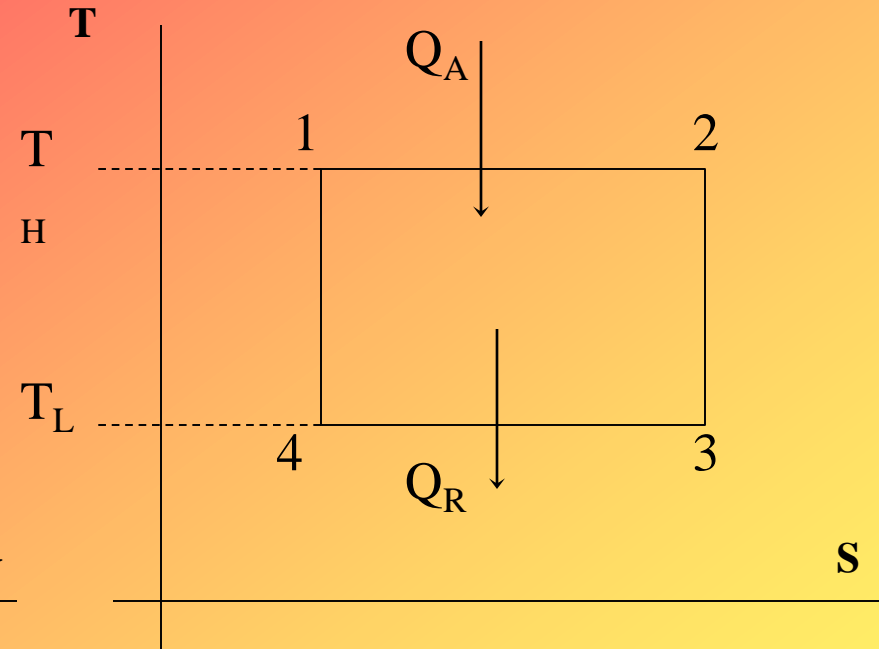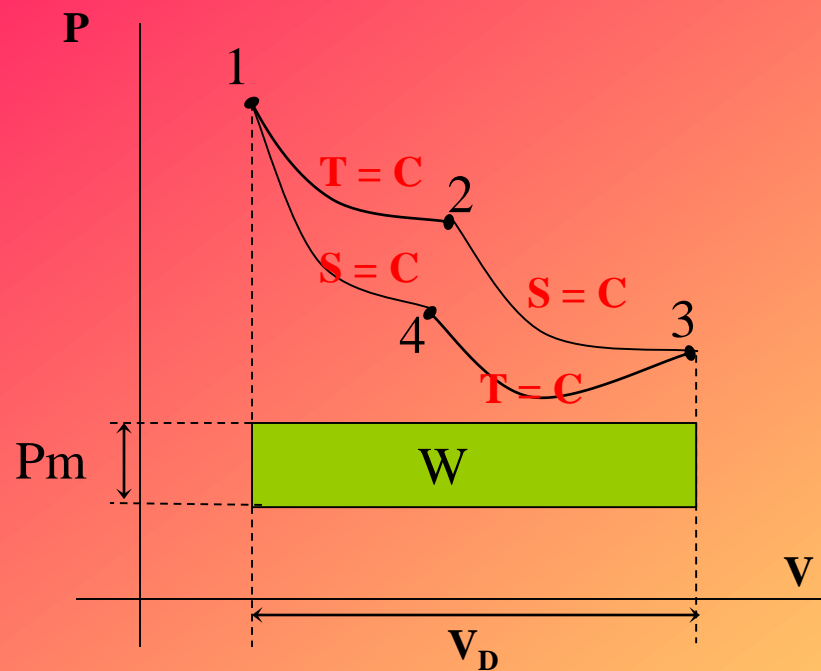Nicolas Leonard Sadi Carnot 1796-1832

1.Carnot Engine

      Processes:

           1 to 2 - Heat Addition (T = C)

           2 to 3 - Expansion (S = C)

           3 to 4 - Heat Rejection (T = C)

           4 to 1 - Compression (S = C)

Heat Added (T = C)

$$Q_A = T_H(\Delta S) \rightarrow 1$$

Heat Rejected (T = C)

$$Q_R = T_L(\Delta S) \rightarrow 2$$

$$\Delta S = S_2 - S_1 = S_4 - S_3 \rightarrow 3$$

Net Work

$$W = \Sigma Q = Q_A - Q_R \rightarrow 4$$

$$W = (T_H - T_L)(\Delta S) \rightarrow 5$$

$$e = \frac{W}{Q_A} \times 100\% \qquad \rightarrow 6$$

$$e = \frac{Q_A - Q_R}{Q_A} \times 100\% \qquad \rightarrow 7$$

$$e = 1 - \frac{Q_R}{Q_A} \times 100\% \qquad \rightarrow 8$$

Substituting eq.1 and eq. 5 to eq 6

$$e = \frac{T_H - T_L}{T_H} \times 100\% \qquad \rightarrow 9$$

$$e = 1 - \frac{T_L}{T_H} \times 100\% \qquad \rightarrow 10$$
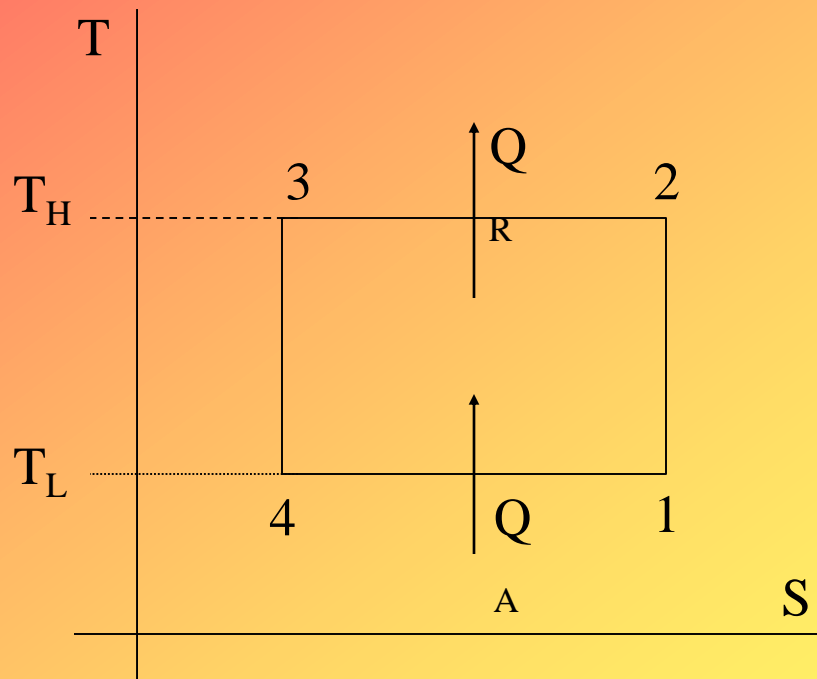
2. Carnot Refrigerator: Reversed Carnot Cycle
        Processes:
    1 to 2 - Compression (S =C)
    2 to 3 - Heat Rejection (T = C)
    3 to 4 - Expansion (S = C)
    4 to 1 - Heat Addition (T = C)

Heat Added (T=C)

$$Q_A = T_L(\Delta S) \rightarrow 1$$

Heat Rejected (T=C)

$$Q_R = T_H(\Delta S) \rightarrow 2$$

$$\Delta S = S_1 - S_4 = S_2 - S_3 \rightarrow 3$$

Net Work

$$W = \Sigma Q \rightarrow 4$$

$$W = Q_R - Q_A \rightarrow 5$$

$$W = (T_H - T_L)(\Delta S) \rightarrow 6$$

Coefficient of Performance

$$COP = \frac{Q_A}{W} \rightarrow 7$$

$$COP = \frac{T_L}{T_H - T_L} \rightarrow 8$$

$$COP = \frac{T_L}{T_H} - 1 \quad \rightarrow 9$$

Tons of Refrigeration
211 KJ/min = 1 TR

3. Carnot Heat Pump:A heat pump uses the same components as the refrigerator but its purpose is to reject heat at high energy level. Performance Factor:

$$PF = \frac{Q_R}{W} \quad \rightarrow 10$$
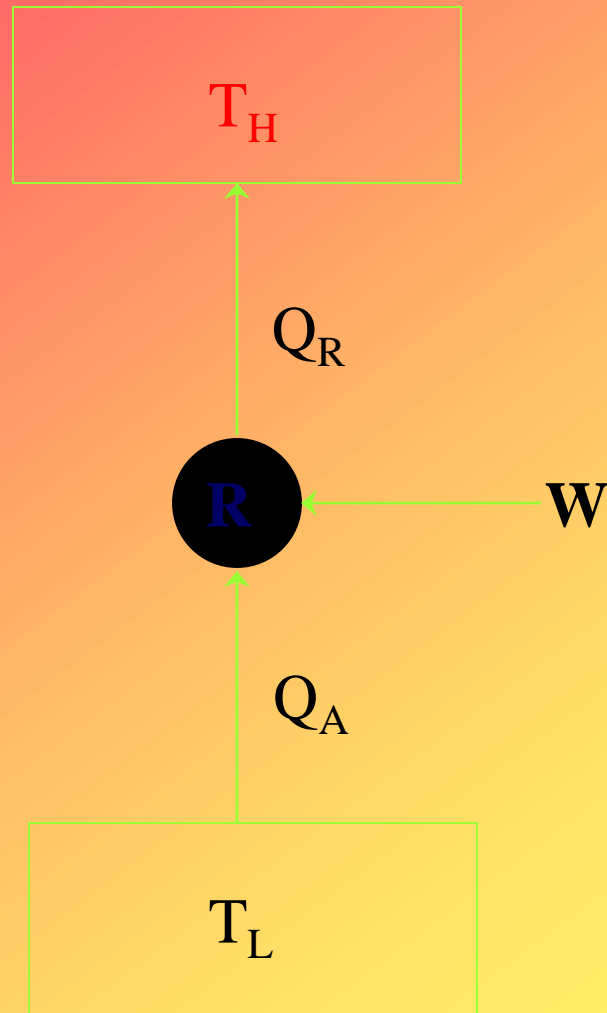
$$PF = \frac{Q_R}{Q_R - Q_A} \quad \rightarrow 11$$

$$PF = \frac{T_H}{T_H - T_L} \quad \rightarrow 12$$

$$PF = 1 - \frac{Q_R}{Q_A} \quad \rightarrow 13$$

$$PF = 1 - \frac{T_H}{T_L} \quad \rightarrow 14$$

$$PF = COP + 1 \quad \rightarrow 15$$

Carnot Refrigerator

Vapor Power Cycle

RANKINE CYCLE
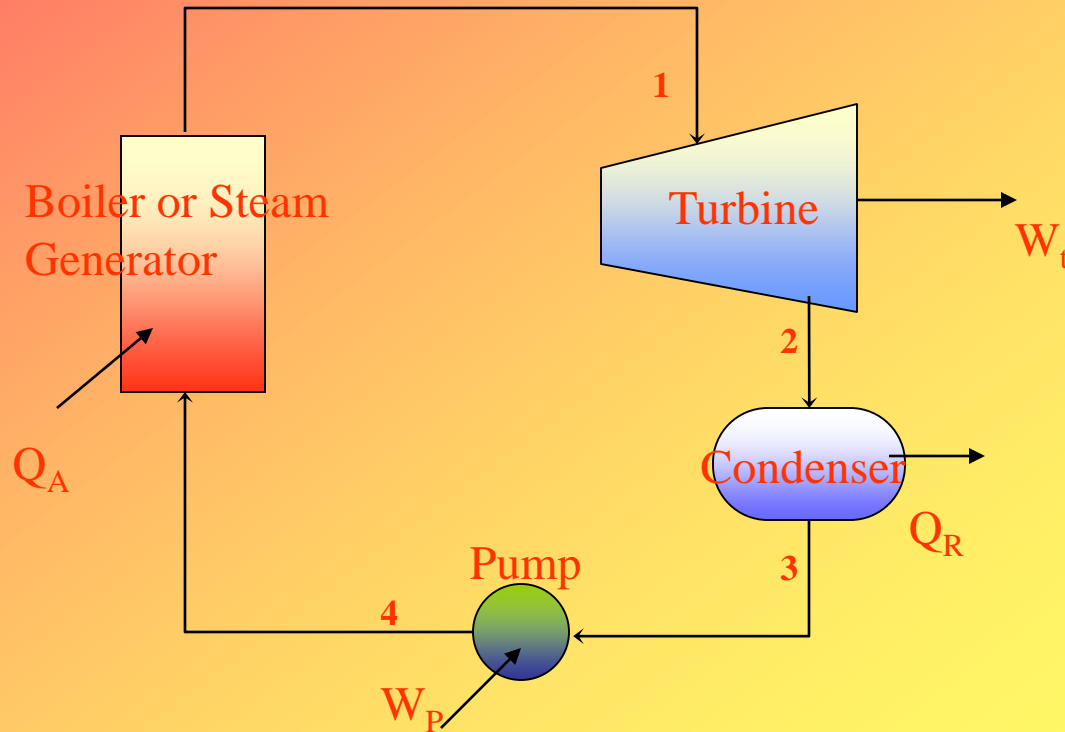
        Processes:

1 to 2 - Expansion (S = C)

2 to 3 - Heat Rejection (P = C)

3 to 4 - Compression or Pumping (S = C)

4 to 1 - Heat Addition (P = C)

Boiler or Steam Generator

Turbine

W_t

Q_A

Condenser

Q_R

Pump

W_P

1

2

3

4

Major Components of a Rankine Cycle

1. **Steam Generator or Boiler:** The working substance absorbs heat from products of combustion or other sources of heat at constant pressure which in turn changes the state of the working substance (water or steam) from sub-cooled liquid and finally to superheated vapor whence at this point it enters the turbine.

2. **Steam Turbine:** A steady state, steady flow device where steam expands isentropically to a lower pressure converting some forms of energy (h, KE, PE) to mechanical work that finally be converted into electrical energy if the turbine is used to drive an electric generator.

3. **Condenser:** Steam exiting from the turbine enters this device to reject heat to the cooling medium and changes its state to that of the saturated liquid at the condenser pressure which occurred at a constant pressure process.

4. **Pump:** It is also a steady state, steady flow machine where the condensate leaving the condenser at lower pressure be pumped back to the boiler in an isentropic process in order to raise the pressure of the condensate to that of the boiler pressure.
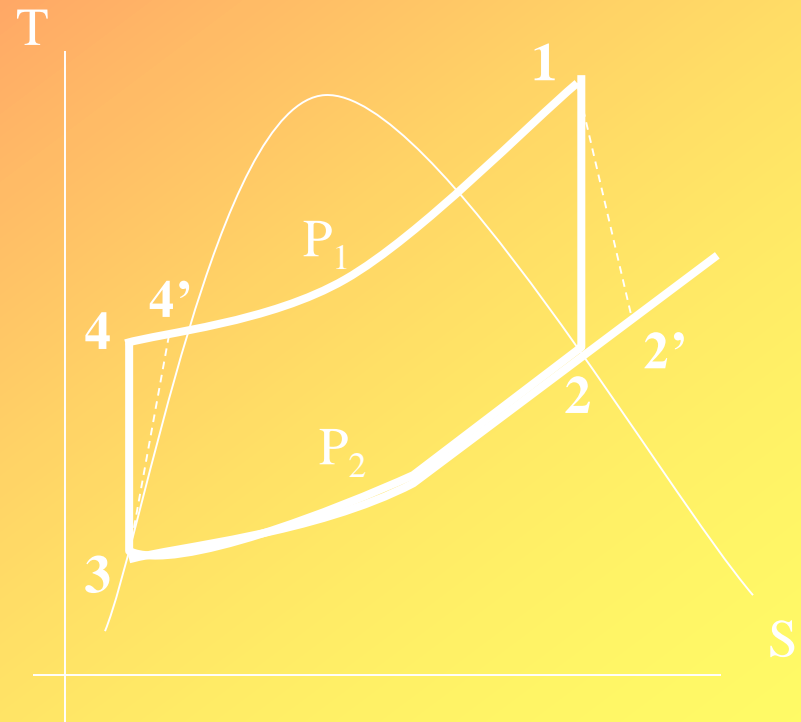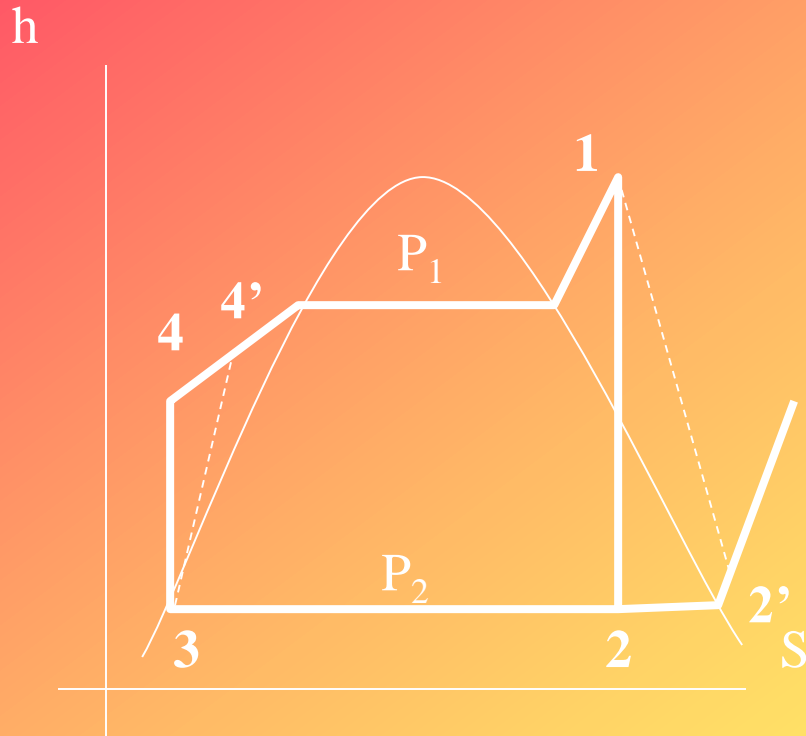
Turbine Work

a) Ideal Cycle

$$W_t = (h_1 - h_2) \text{ KJ/kg}$$

$$W_t = m_s(h_1 - h_2) \text{ KW}$$

b) Actual Cycle

$$W_{t'} = (h_1 - h_{2'}) \text{ KJ/kg}$$

$$W_{t'} = m_s(h_1 - h_{2'}) \text{ KW}$$

where: m_s - steam flow rate in kg/sec

Turbine Efficiency

$$\eta_t = \frac{W_{t'}}{W_t} \times 100\%$$

$$\eta_t = \frac{h_1 - h_{2'}}{h_1 - h_2} \times 100\%$$

Pump Work

a) Ideal Cycle

$$W_P = (h_4 - h_3) \text{ KJ/kg}$$

$$W_P = m_s(h_4 - h_3) \text{ KW}$$

b) Actual Cycle

$$W_{P'} = (h_{4'} - h_3) \text{ KJ/kg}$$

$$W_{P'} = m_s(h_{4'} - h_3) \text{ KW}$$

Pump Efficiency

$$\eta_p = \frac{W_p}{W_{p'}} \times 100\%$$

$$\eta_p = \frac{h_4 - h_3}{h_{4'} - h_3} \times 100\%$$

CLASSIFICATION OF INTERNAL COMBUSTION ENGINES

VARIOUS TYPES OF ENGINES

CLASSIFICATION OF INTERNAL COMBUSTION ENGINES

1. Application
2. Basic Engine Design
3. Operating Cycle
4. Working Cycle
5. Valve/Port Design and Location
6. Fuel
7. Mixture Preparation
8. Ignition
9. Stratification of Charge
10. Combustion Chamber Design
11. Method of Load Control
12. Cooling

CLASSIFICATION OF INTERNAL COMBUSTION ENGINES

             1.   1. Application

2.   **Automotive:** (i) Car
                          (ii) Truck/Bus
                          (iii) Off-highway

2.   **Locomotive**

3.   **Light Aircraft**

4.   **Marine:** (i) Outboard
                    (ii) Inboard
                    (iii) Ship

5.   **Power Generation:** (i) Portable (Domestic)
                                 (ii) Fixed (Peak Power)

6.   **Agricultural:** (i) Tractors
                       (ii) Pump sets

7.   **Earthmoving:** (i) Dumpers
                       (ii) Tippers
                       (iii) Mining Equipment

8.   **Home Use:** (i) Lawnmowers
                    (ii) Snow blowers
                    (iii) Tools

9.   **Others**

CLASSIFICATION OF INTERNAL COMBUSTION ENGINES

2. Basic Engine Design:

1. **Reciprocating** (a)   Single Cylinder

(b) Multi-cylinder (I)   In-line

(ii)   V

(iii)   Radial

(iv)   Opposed Cylinder

(v)   Opposed Piston

2. **Rotary:**   (a)   Single Rotor

(b)   Multi-rotor

Introduction

- Parts of the Main Steam Cycle
- Four Phases of the cycle
    - Definitions of each phase
    - Components involved with phases
    - Press-temp relationships
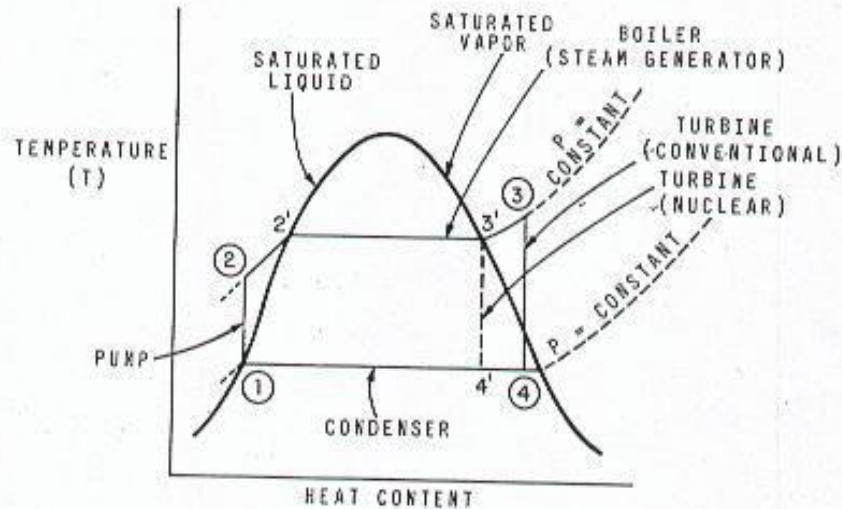
Rankine Cycle

T-s Diagram

Figure 3-2. Temperature-heat content diagrams for conventional and nuclear condensing plants.
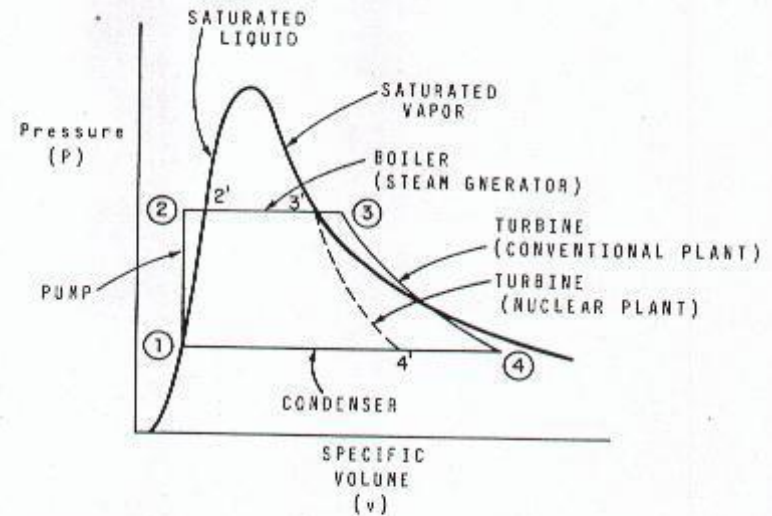
P-v Diagram

Figure 3-1. P-v diagrams for conventional and nuclear condensing steam plants.

1-2: Feed Phase ($\Delta Q=0$, $\Delta S=0$), W_{in}
2-3: Generation Phase ($\Delta P=0$), Q_{in}
3-4: Expansion Phase ($\Delta Q=0$, $\Delta S=0$), W_{out}
4-1: Condensation Phase ($\Delta P=0$), Q_{out}

Generation Phase - Conventional

- Boiler (1200 # steam)
  - Fuel burned to produce heat -› transferred to water which boils to steam
  - Steam collects in steam drum (saturated)
- Superheater
  - Increase temp of steam and dries steam
  - Three reasons for superheating?
    - Minimize erosion (dry steam better for blading)
    - Minimize corrosion (less chemicals entrained)
    - Maximize ΔT (Carnot efficiency)