Thermodynamic

First law of thermodynamics, kinds of energy, (dynamic energy, potential mechanical energy, internal energy, heat, work), work of a system represented on pressure – volume diagram, energy of flow, enthalpy, energy – conservation equation of first law of thermodynamics.

Closed and Open Systems

A system is defined as a quantity of matter or a region in space chosen for study. The mass or region outside the system is called the surroundings.

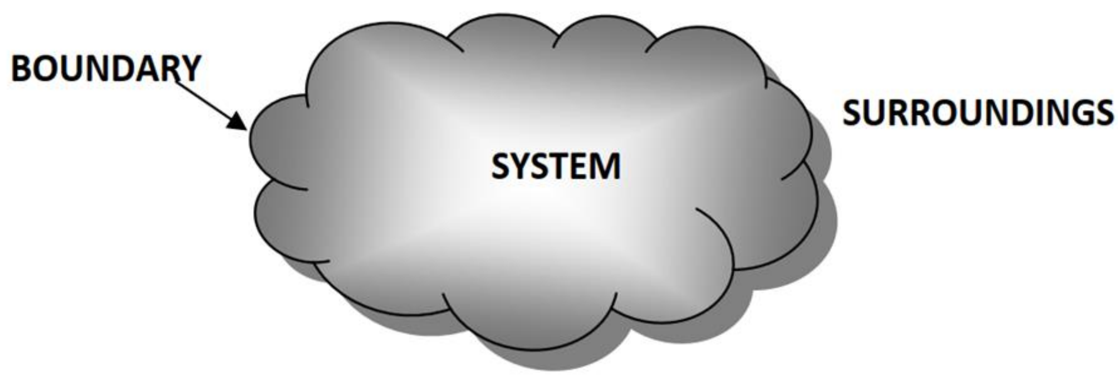


Fig. 1: System, surroundings, and boundary

Boundary: the real or imaginary surface that separates the system from its surround ings.

The boundaries of a system can be fixed or movable. Mathematically, the boundar y has zero thickness, no mass, and no volume.

Closed system or control mass: consists of a fixed amount of mass, and no mass ca n cross its boundary. But, energy in the form of heat or work, can cross the bounda ry, and the volume of a closed system does not have to be fixed.

Open system or control volume: is a properly selected region in space. It usually en closes a device that involves mass flow such as a compressor. Both mass and energ y can cross the boundary of a control volume. Important note: some thermodynami cs relations that are applicable to closed and open systems are different. Thus, it is extremely important to recognize the type of system we have before start analyzing it.

Isolated system: A closed system that does not communicate with the surroundings by any means.

Rigid system: A closed system that communicates with the surroundings by heat only.

First law of thermodynamics

The first law of thermodynamics is the principle of conservation of energy, stating that energy cannot be created or destroyed, only converted from one form to another or transferred between systems. It quantifies the relationship between the internal energy of a system and the heat and work exchanged with its surroundings, often expressed as $\Delta U = Q + W$, where ΔU is the change in internal energy, Q is the heat added, and W is the work done on the system.

Types of energy

The two main kinds of energy are kinetic energy (the energy of motion) and potential energy (stored energy). Many forms fall into these categories, including chemical, electrical, thermal (heat), radiant (light), sound, nuclear, and mechanical energy, which can all transform from one form to another.

Kinetic energy: energy that a system posse as a result of its relative motion relative to some reference frame, KE

$$KE = \frac{mV^2}{2} \qquad (kJ)$$

where V is the velocity of the system in (m/s).

♦ **Potential energy:** is the energy that a system posse as a result of its elevation in a gravitational field, PE:

$$PE = mgz \qquad (kJ)$$

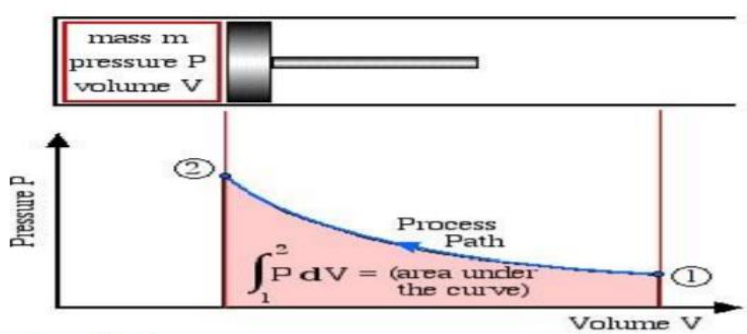
where g is the gravitational acceleration and z is the elevation of the center of gravity of the system relative to some arbitrary reference plane. Microscopic forms of energy: are those related to molecular structure of a system. They are independent of outside reference frames. The sum of microscopic energy is called the internal energy, U. The total energy of a system consists of the kinetic, potential, and internal energies:

$$E = U + KE + PE = U + \frac{mV^2}{2} + mgz \qquad (kJ)$$

where the contributions of magnetic, electric, nuclear energy are neglected. Internal energy is related to the molecular structure and the degree of molecular activity and it may be viewed as the sum of the kinetic and potential energies of molecules.

Work

In physics, work is the process of energy transfer to the motion of an object via application of a force, often represented as the product of force and displacement. A force is said to do positive work if (when applied) the force has a component in the direction of the displacement of the point of application. A force does negative work if the force has a component opposite to the direction of the displacement at the point of application of the force.



$$p = \frac{F}{A} = \frac{F}{A} * \frac{L}{L} = \frac{Work}{volume} \qquad , work = p\,v \rightarrow \quad work = \int_1^2 p\,dv$$

According to 1st law of thermodynamics:

The change in internal energy of a system is equal to the heat added to the system minus the work done by the system.

$$\Delta U = Q - W$$

Heat and Work

When two systems at different temperatures are brought into contact there are observable changes in some of their properties and changes continue till the two don't attain the same temperature if contact is prolonged. Thus, there is some kind of energy interaction at the boundary which causes change in temperatures. This form of energy interaction is called heat. Thus 'heat' may be termed as the energy interaction at the system boundary which occurs due to temperature difference only. Heat is observable in transit at the interface i.e. boundary, it cannot be contained in a system. In general, the heat transfer to the system is assigned with positive (+) sign while the heat transfer from the system is assigned with negative (–) sign. Its units are Calories. In thermodynamics the work can be defined as follows: "Work shall be done by the system if the total effect outside the system is equivalent to the raising of weight and this work shall be positive work".

In above definition the work has been defined as positive work and says that there need not be actual raising of weight but the effect of the system behavior must be reducible to the raising of a weight and nothing else. Its units are N. m or Joule. Heat and work are two transient forms of energy.

Flow Energy (or Flow Work) is the work required to push a fluid into or out of a control volume (like a pipe, compressor, or turbine). It represents the energy associated with the pressure forces acting on the fluid as it flows.

W_f =F. L=P.A. L=P.V (Joule)

Where:

F=force required to push the material (N)

A=cross sectional area of system (m^2)

L=distance of material motion (m)

V=volume (m^3)

When the material go out the system the flow work is positive, and negative when inter the system.

Enthalpy (H):

Enthalpy is a thermodynamic property of a system. It is the sum of the internal energy added to the product of the pressure and volume of the system. It reflects the capacity to do non-mechanical work and the capacity to release heat. Enthalpy is denoted as H; specific enthalpy denoted:

H= E + Wf=E +PV , For unit mass : h=e +pv

Energy equation for open system of steady flow is:

Q - W =ΔH + ΔK + ΔP

$$Energy\ in = Energy\ out$$

$$P.E._1 + K.E._1 + D.E._1 + U_1 + Q = P.E._2 + K.E._2 + D.E._2 + U_2 + W$$

$$m * g * z_1 + \frac{1}{2} m * c_1^2 + p * V_1 + U_1 + Q = m * g * z_2 + \frac{1}{2} m * c_2^2 + p * V_2 + U_2 + W$$

واذا قسمنا طرفي المعادلة على الكتلة m نحصل على

$$g * z_1 + \frac{1}{2} * c_1^2 + p * v_1 + U_1 + Q = g * z_2 + \frac{1}{2} * c_2^2 + p * v_2 + U_2 + W$$

وهذه المعادلات تسمى معادلة الطاقة للجريان المستقر

STEADY FLOW ENERGY EQUATION

Question:
A system has an internal energy (E) of 250 kJ. The pressure is 100 kPa and the volume is 2.0 m^3.
Calculate the enthalpy (H) of the system.

Given:
E = 250 kJ
P = 100 kPa
V = 2.0 m^3

Solution:

$H = E + PV = 250 + (100)(2.0 \times 10^{-3})$

But 1 kPa·m^3 = 1 kJ, so:

$H = 250 + (100)(2.0) = 250 + 200 = 450$ kJ

Answer: H = 450 kJ

Question:
A gas expands from 1.5 m^3 to 3.0 m^3 at a constant pressure of 120 kPa.Its internal energy increases by 180 kJ.Find the change in enthalpy (ΔH).

Solution:

$\Delta H = \Delta E + P\Delta V$
$\Delta H = 180 + (120)(3.0 - 1.5)$
$\Delta H = 180 + (120)(1.5) = 180 + 180 = 360$ kJ

Answer: ΔH = 360 kJ

Example: In turbine of gas turbine unit the gases flow through the turbine at ($\dot{m} = 17 kg\backslash sec$)and the power developed by the turbine is 14000 Kw the enthalpy of the gases at inlet and outlet 1200 Kj/Kg and 360 Kj/Kg respectively and the velocities of the gas at inlet and outlet are 60 m/sec and 150 m/sec respectively find rate at which heat is rejected from the turbine also find the inlet pipe cross sectional area when the inlet specific volume is 0.5m^3\kg.

1- بما ان النظام تورباين فهو نظام مفتوح
2- ظهرت لدينا كلمة enthalpy والانثالبية هي حاصل جمع الطاقة الداخلية النوعية والشغل الجريان النوعي اي

$$h = U + pv$$

3- لم يذكر في السؤال اي ارتفاع Z لذلك فان الطاقة الكامنة PE =0

$$P.E._1 + K.E._1 + D.E._1 + U_1 + Q = P.E._2 + K.E._2 + D.E._2 + U_2 + W$$

$$P.E._1 + K.E._1 + h_1 + Q = P.E._2 + K.E._2 + h_2 + W$$

$$K.E._1 + h_1 + Q = K.E._2 + h_2 + W$$

$$\frac{1}{2} * c_1^2 + h_1 + Q = \frac{1}{2} * c_2^2 + h_2 + W$$

$$Q = \frac{1}{2} * (c_2^2 - c_1^2) + (h_2 - h_1) + W$$

هنا نلاحظ

1- الطاقة الناتجة من التوربابن هي 14000 Kw ونحن نعلم ان الواط هي طاقة وفي المعادلة لدينا شغل بالجول لذلك نحول الواط الى جول

$$work = w = \frac{power}{\dot{m}} = \frac{14000(kw)(\frac{kj}{sec})}{17(\frac{kg}{sec})} = 823.53 \frac{kj}{kg}$$

نلاحظ ان الشغل اصبح kj/kg والانثالبية kj/kg توحدت الوحدات

2- نحول السرعة من j/kg اى kj/kg وذلك بتقسيم الطاقة الحركية على 1000

$$Q = \frac{1}{2} * (c_2^2 - c_1^2) + (h_2 - h_1) + W$$

$$Q = \frac{1}{2} * (150^2 - 60^2) * 10^{-3} + (360 - 1200) + 823.53 = -7.05 \frac{kj}{kg}$$

وهنا نلاحظ ان اشارة الحرارة سالبة اي انها حرارة مفقودة من التوربابن

وعند تحويل الحرارة من kj/kg الى كيلوا واط kw

$$q = \dot{m} * Q = 17 \left(\frac{kg}{sec}\right) * (-7.05) \left(\frac{kj}{kg}\right) = 119.85 \frac{kj}{sec}(kw)$$

Example: Air flows a rate of (0.4 kg/kj) through an air compressor entering at (6 m/sec) , (1 bar) and (0.85 $^{m3}/_{kg}$) and leaving at (4.5 m/sec) , (6.9 bar) and (0.16 $^{m3}/_{kg}$) the internal energy of the air leaving is greater than that of entering air by (88 kj/kg) cooling water in the socket surrounding the cylinder absorbs heat from the air at the rate of (59 kj/sec) find the power required to drive the compressor and the inlet and outlet pipe cross –sectional area .

1- بما ان النظام كومبريسر فهو نظام مفتوح اذن نطبق عليه

STEADY FLOW ENERGY EQUATION

$$Energy\ in = Energy\ out$$

$$P.E._1 + K.E._1 + D.E._1 + U_1 + Q = P.E._2 + K.E._2 + D.E._2 + U_2 + W$$

2- لم يذكر في السؤال اي ارتفاع Z لذلك فان الطاقة الكامنة PE =0

3- الحرارة المعطاة بالسؤال (59 kj/sec) نحتاج نحولها الى Kj/Kg

$$q = \dot{m} * Q$$

$$Q = \frac{q}{\dot{m}} = \frac{59}{0.4} = 147.5\ \frac{kj}{kg}$$

$$K.E._1 + D.E._1 + U_1 + Q = +K.E._2 + D.E._2 + U_2 + W$$

$$W = (D.E._1 - D.E._2) + (U_1 - U_2) + (K.E._1 - K.E._2) + Q$$

$$W = (p_1v_1 - p_2v_2) + (U_1 - U_2) + \frac{1}{2} * (c_1^2 - c_2^2) * 10 * 10^{-3} + Q$$

$$W = (1 * 10^2 * 0.85 - 6.9 * 10^2 * 0.16) + (-88) + \frac{1}{2} * (6^2 - 4.5^2) * 10 * 10^{-3} + (-147.5) = -260.9\ \frac{KJ}{kg}$$

اما تحويل الشغل من $\frac{KJ}{kg}$ الى $\frac{KJ}{sec} = kw$

$$power = \dot{m} * w = 0.4 * (-260.9) = -104.35\ \frac{KJ}{sec} = kw$$

اما ايجاد مساحة مقطع الدخول

$$A = \frac{\dot{m}}{c_1 * \rho} = \frac{\dot{m}}{c_1} * \frac{1}{\rho} = \frac{\dot{m}}{c_1} * v_1 = 0.057\ m^2$$

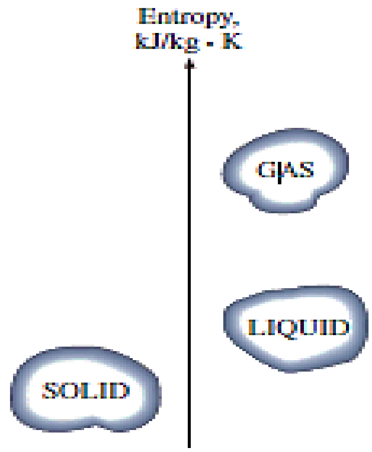
Second law of thermodynamics:
Reversible process, entropy, temperature-entropy diagram, coordinates place on T-S diagram, cycles, work of cycle, thermal efficiency of cycle, examples.
State of second law for heat engine, and for heat pump.

The **second law of thermodynamics** states that the total entropy of an isolated system always increases over time, or remains constant in ideal cases where the system is in a steady state or undergoing a reversible process. The increase in entropy accounts for the irreversibility of natural processes, and the asymmetry between future and past

$$\Delta S = \frac{\Delta Q}{T} \text{ closed system, reversible, ideal}$$

$$\Delta S > \frac{\Delta Q}{T} \text{ closed system, irreversible, actual}$$

Reversible process
Entropy It is clear from the previous discussion that entropy is a useful property and serves as a valuable tool in the second-law analysis of engineering devices. But this does not mean that we know and understand entropy well. Because we do not. In fact, we cannot even give an adequate answer to the question, what is entropy? Not being able to describe entropy fully, however, does not take anything away from its usefulness. We could not define energy either, but it did not interfere with our understanding of energy transformations and the conservation of energy principle. Granted, entropy is not a household word like energy. But with continued use, our understanding of entropy will deepen, and our appreciation of it will grow. The next discussion should shed some light on the physical meaning of entropy by considering the microscopic nature of matter. Entropy can be viewed as a measure of molecular disorder, or molecular randomness. As a system becomes more disordered, the positions of the molecules become less predictable and the entropy increases. Thus, it is not surprising that the entropy of a substance is lowest in the solid phase and highest in the gas phase (Fig.). In the solid phase, the molecules of a substance continually oscillate about their equilibrium positions, but they cannot move relative to each other, and their position at any instant can be predicted with good certainty. In the gas phase, however, the molecules move about at random, collide with each other, and change direction, making it extremely difficult to predict accurately the microscopic state of a system at any instant. Associated with this molecular chaos is a high value of entropy. When viewed microscopically (from a statistical thermodynamics point of view), an isolated system that appears to be at a state of equilibrium may exhibit a high level of activity because of the continual motion of the molecules. To each state of macroscopic equilibrium there corresponds a large number of possible microscopic states or molecular configurations. The entropy of a system is related to the total number of possible microscopic



Heat Engines

As pointed out earlier, work can easily be converted to other forms of energy, but converting other forms of energy to work is not that easy. The mechanical work done by the shaft shown in Fig. for example, is first converted to the internal energy of the water. This energy may then leave the water as heat. We know from experience that any attempt to reverse this process will fail. That is, transferring heat to the water does not cause the shaft to rotate. From this and other observations, we conclude that work can be converted to heat directly and completely, but converting heat to work requires the use of some special devices. These devices are called **heat engines.** Heat engines differ considerably from one another, but all can be characterized by the following

1. They receive heat from a high-temperature source (solar energy, oil furnace,nuclear reactor, etc.).

2. They convert part of this heat to work (usually in the form of a rotating shaft).

3. They reject the remaining waste heat to a low-temperature sink (the atmosphere, rivers, etc.).

4. They operate on a cycle.

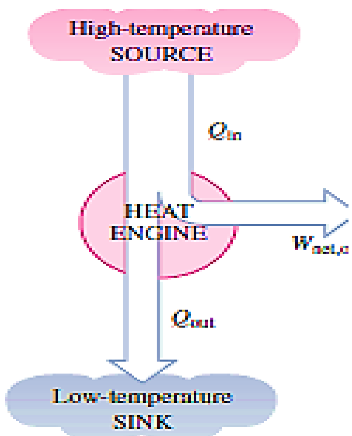
Heat engines and other cyclic devices usually involve a fluid to and from which heat is transferred while undergoing a cycle. This fluid is called the **working fluid.**The term *heat engine* is often used in a broader sense to include workproducing devices that do not operate in a thermodynamic cycle. Engines that involve internal combustion such as gas turbines and car engines fall into this category. These devices operate in a mechanical cycle but not in a thermodynamic cycle since the working fluid (the combustion gases) does not undergo a complete cycle. Instead of being cooled to the initial temperature, the exhaust gases are purged and replaced by fresh air-and-fuel mixture at the end of the cycle. The work-producing device that best fits into the definition of a heat engine is the *steam power plant*, which is an external-combustion engine. That is, combustion takes place outside the engine, and the thermal energy released during this process is transferred to the steam as heat. The schematic of a basic steam power plant is shown in Fig. 6–10. This is a rather simplified diagram, and the discussion of actual steam power plants is given in later chapters. The various quantities shown on this figure are as follows:

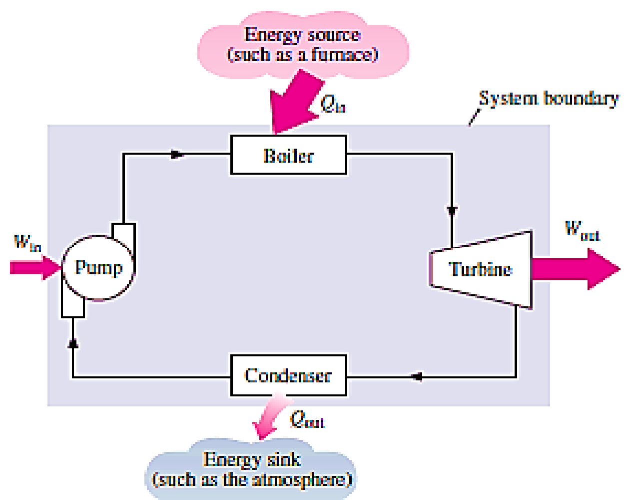
Qin _ amount of heat supplied to steam in boiler from a high-temperature Source (furnace)

Qout _ amount of heat rejected from steam in condenser to a low temperature sink (the atmosphere, a river, etc.)

Wout _ amount of work delivered by steam as it expands in turbine

Win _ amount of work required to compress water to boiler pressure





Ideal Gas:

Specific heat at constant volume, specific heat at constant pressure, equation of ideal gas state, gas constant, universal gas constant

Constant volume process, constant pressure process, constant temperature process, studying of process on P – V diagram and T – S diagram, examples.

Boyle's Law (Constant Temperature)

At constant temperature, the pressure of a given mass of gas is inversely proportional to its volume.

$$P \propto \frac{1}{V} \text{(when T is constant)}$$

or

$$PV = k_1 \text{(constant for a given mass of gas at constant T)}$$

Charles's Law (Constant Pressure)

At constant pressure, the volume of a given mass of gas is directly proportional to its absolute temperature (in Kelvin).

$$V \propto T \text{(when P is constant)}$$

or

$$\frac{V}{T} = k_2 \text{(constant for a given mass of gas at constant P)}$$

Combining Boyle's and Charles's Laws

From Boyle's law:

$$PV = \text{constant (when T fixed)}$$

From Charles's law:

$$\frac{V}{T} = \text{constant (when P fixed)}$$

Now, if we combine both relationships for a variable **P**, **V**, and **T**, we get:

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

or equivalently,

$$PV \propto T$$

To remove the proportionality sign, introduce a constant R:

$$PV = RT$$

But this equation holds for **one mole** of gas.For **n moles**, the equation becomes:

$$PV = nRT$$

Final Form – The Ideal Gas Law

$$\boxed{PV = nRT}$$

where:

- P= Pressure (Pa or atm)
- V= Volume (m^3 or L)
- n= Number of moles (mol)
- R= Universal gas constant = 8.314 J/mol·K
- T= Absolute temperature (K)

Joule's Second Law (Thermodynamics)

The internal energy of an ideal gas depends only on its temperature, and not on its pressure or volume. In other words:

$$E = f(T)$$

That means if the **temperature** of an ideal gas does not change, its **internal energy** also remains constant — even if the gas expands or is compressed.

Specific heat at constant volume (cv)

Is an added heat to unit mass of constant volume material.

$Q = m.Cv.\Delta T$

Applying energy equation $Q\text{-}W=\Delta E$ W=0 (NO change in volume)

$Q=\Delta E = m.Cv.\Delta T$

For unit mass:

$q=\Delta e=Cv.\Delta T$, $Cv= (\Delta e\ / \Delta T)v = de/dt)v$

Specific heat at constant pressure (Cp)

Is the amount added heat to unit mass at constant pressure to rise the temp. one degree.

$Q=m.Cp.\ \Delta T$ JOUL

For unit mass:

$q=cp.\Delta T$

Applying energy equation on closed system:

$Q=W+\Delta E$

$W=P(V2-V1)$

$\Delta E=E2-E1$

THEN:

$Q=PV2 - PV1 + E2 - E1$

From definition of enthalpy $Q=\Delta h = h2-h1$

$Cp.\Delta T=\Delta h$ and $m.Cp.\Delta T= \Delta H$

$Cp = (\frac{\Delta H}{\Delta T})P$

SINCE the relation between enthalpy and internal energy is : $\Delta h=\Delta e + \Delta pv$

i.e. $\Delta h > \Delta e$

$Cp>Cv$

$\gamma=Cp/Cv >1$

$$R = \frac{R_\circ}{M}$$

R: Specific gas constant it is variable for each type of gas, M: Molecular weight.

$$cp = cv + R \ldots\ldots..(1) \qquad , \qquad \gamma = \frac{cp}{cv} \ldots\ldots\ldots(2)$$

$$cp = \frac{\gamma R}{\gamma - 1}$$

Example:

A prefect gas has specific heats as Cp=0.846 Kj/Kg.k ,Cv=0.657 Kj/Kg.k

Find the gas constant and molecular weight of gas

Solution:

$$cp = cv + R \ggg R = cp - cv = 0.846 - 0.657 = 0.189 \frac{kj}{kg.k}$$

$$R = \frac{R_0}{M} \ggg M = \frac{R_0}{R} \qquad \rightarrow M = \frac{8.314}{0.189} = 44$$

Example:

A prefect gas has molecular weight of (26) and a value of (γ=1.26) calculate the heat rejected per 1Kg when.

1- The gas is contained in a rigid vessel at (3 bar) and temperature 315 C and cooled until the pressure falls to (1.5 bar).

50

2- The gas enters pipeline at 280 C and flow steady to end of the pipe where T=250C neglect any change in velocity of the gas .

Solution : (γ=1.26) , M=26

1- $Q = W + \Delta U$ where $v = constant \rightarrow w = 0$

$Q = \Delta U = m * cv * (T_2 - T_1)$

هنا نحتاج الى Cv و الدرجة الحرارية الثانية

$$R = \frac{R_0}{M} = \frac{8.314}{26} = 0.3198 \frac{kj}{kg.k}$$

$$cv = \frac{R}{\gamma - 1} = \frac{0.3198}{1.26 - 1} = 1.23 \frac{kj}{kg.k}$$

From ideal gas equation

$$\frac{p_1 * v_1}{T_1} = \frac{p_2 * v_2}{T_2} \quad \rightarrow v = constant \rightarrow \frac{p_1}{T_1} = \frac{p_2}{T_2}$$

Process using ideal gas

Process using ideal gas (close system reversible)

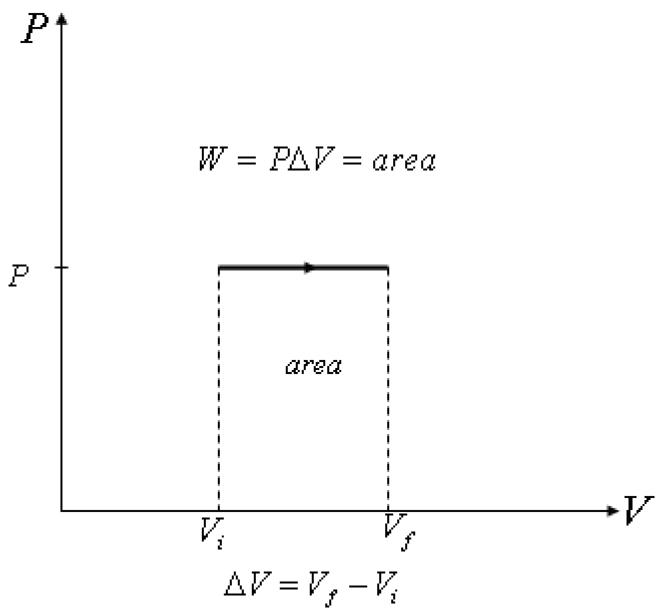
a- Constant pressure (isobaric)

Non-flow energy equation

$$Q = W + \Delta U$$

$$w = \int_1^2 p\,dv = p \int_1^2 dv = p(v_2 - v_1) = P_2 v_2 - P_1 v_1$$

$$Q = P_2 v_2 - P_1 v_1 + U_2 - U_1 = h_2 - h_1$$

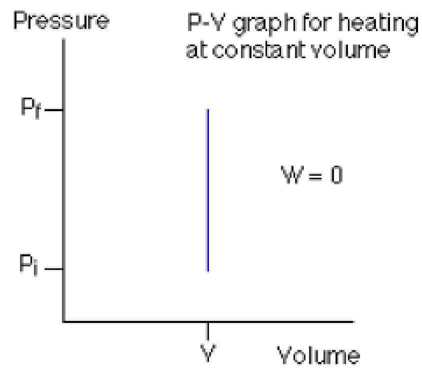


b- Constant volume (isometric)

Non-flow energy equation

$Q = W + \Delta U \gg\gg\gg \; w = 0$

$Q = \Delta U = U_2 - U_1 = m * cv * (T_2 - T_1)$



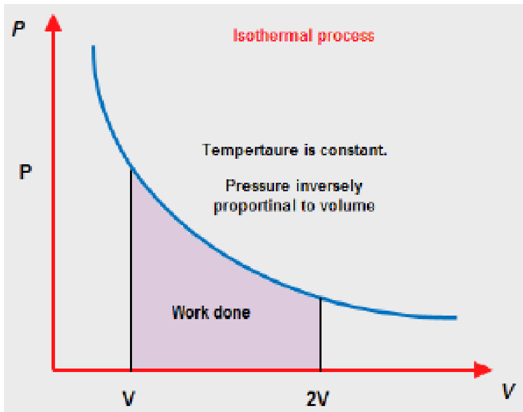
c- Constant temperature process (isothermal)

Non-flow energy equation

$Q = W + \Delta U \gg\gg\gg \; \Delta U = 0$

$$Q = W = \int_1^2 p\,dv \quad \to\to \frac{PV}{T} = C \to PV = C \to P = \frac{C}{V}$$

$$Q = W = \int_1^2 p\,dv \; = \int_1^2 \frac{c}{v}\,dv \; = c\int_1^2 \frac{dv}{v} = pv\int_1^2 \frac{dv}{v} \; = pv * lin(v)$$



d- Adiabatic process

الاجراء الاديباتيكي :

في هذا الاجراء يتم عزل النظام عزلا حراريا حيث يمنع تبادل الحرارة بين النظام والمحيط

$Q = W + \Delta U \ggg\ggg\ggg Q = 0$

$0 = W + \Delta U \rightarrow W = -\Delta U$

ويخضع هذا الاجراء لقانون

$P * V^{\gamma} = Constant$

من الاشتقاقات المطلوبة في هذا الاجراء هو

The relation between (p,v,T) in adiabatic process

Air Cycle (Carnot cycle)

Carnot Cycle

The **Carnot cycle** is a theoretical thermodynamic cycle proposed by the French scientist **Sadi Carnot** in 1824. It represents the **maximum possible efficiency** that any heat engine can achieve when operating between two fixed temperatures.

Elements of a Cycle

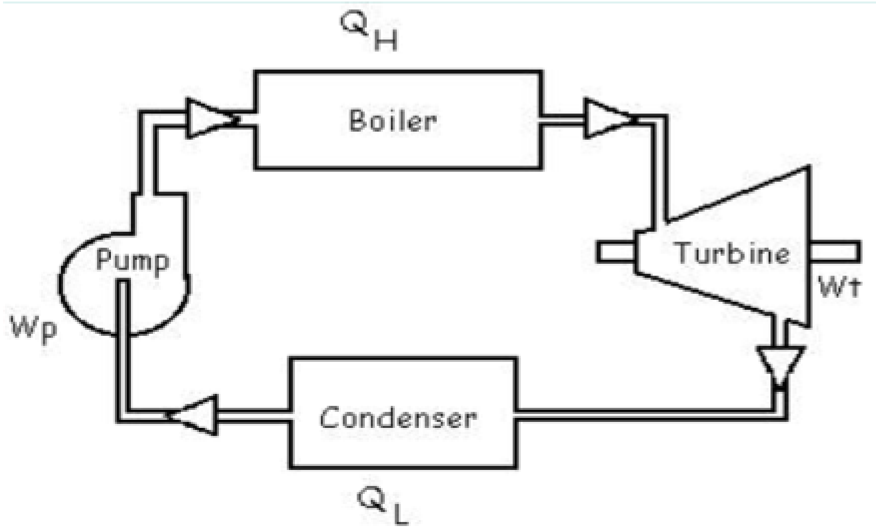
1.working substance

Is the mean which receive the heat and give it.

2.source of heat which heat added from it.

3.heat sink is a heat tank of low temp. or cold body.

4.engine: the work substance performed a work.



Carnot Principle:

No heat engine operating between two thermal reservoirs can be more efficient than a Carnot engine operating between the same two temperatures.

This means that if two engines operate between the same temperatures T_1(the higher temperature) and T_2(the lower temperature), the efficiency of any real engine will always be less than that of a Carnot engine.

Processes of the Carnot Cycle

The Carnot cycle consists of **four reversible processes**:

1. **Reversible Adiabatic Compression:**
   - No heat exchange with surroundings, $Q = 0$.
   - Entropy remains constant, $\Delta S = 0$.
   - Temperature increases from $T_2$to T_1.
2. **Isothermal Heat Addition:**
   - Heat $Q_1$is absorbed from the hot reservoir at a constant temperature T_1.
   - The gas expands and performs work on the surroundings.
3. **Reversible Adiabatic Expansion:**

- No heat exchange, $Q = 0$.
- $\Delta S = 0$.
- The temperature decreases from $T_1$to T_2.

4. **Isothermal Heat Rejection:**
   - Heat $Q_2$is rejected to the cold reservoir at a constant temperature T_2.
   - The system returns to its initial state.

Efficiency of the Carnot Cycle

$$\eta = 1 - \frac{T_2}{T_1}$$

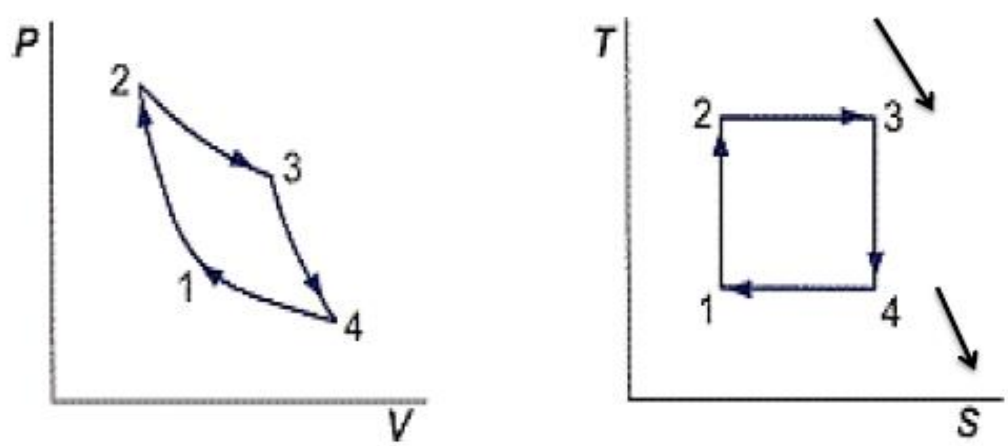
where:

- η: Thermal efficiency of the engine.
- T_1: Absolute temperature of the hot reservoir (in Kelvin).
- T_2: Absolute temperature of the cold reservoir (in Kelvin).

$\eta th = W / QA$

$\eta = 1 - (QR / QA)$

Where: W



Carnot cycle

Example: A Carnot engine operates between a hot reservoir at **600 K** and a cold reservoir at **300 K**. **Find:** The thermal efficiency of the engine.

Given: $T_H = 600$ K, $T_C = 300$ K.
Formula: $\eta = 1 - \frac{T_C}{T_H}$.

$$\eta = 1 - \frac{300}{600} = 1 - 0.5 = 0.5 = 50\%.$$

Answer: $\eta = 50\%$.

Example: A Carnot engine absorbs **500 J** of heat from a high-temperature source at **500 K** and rejects heat to a sink at **300 K**.
Find:

1. The efficiency.
2. The work done per cycle.
3. The heat rejected to the sink.

Given: $T_H = 500$ K, $T_C = 300$ K, $Q_{in} = 500$ J.
Step 1 — Efficiency:

$$\eta = 1 - \frac{300}{500} = 1 - 0.6 = 0.4 = 40\%.$$

Step 2 — Work per cycle: $W = \eta\, Q_{in}$
$W = 0.4 \times 500 \text{ J} = 200 \text{ J}.$
Step 3 — Heat rejected: $Q_{out} = Q_{in} - W$
$Q_{out} = 500 \text{ J} - 200 \text{ J} = 300 \text{ J}.$
Answers: Efficiency = 40%. Work = 200 J. Heat rejected = 300 J.

Example: Carnot heating engine the high temp. of it 1000C and low temp.=200C and amount of gained heat at high temp.=6000kj/min. Find the power of an engine.

η =1-(QR/QA)

for Carnot cycle: η =1- (T2/T1)

Then

Q_R/Q_A = T2/T1

Q_R/6000 = (200+273)/(1000+273)

Q_R=2229KJ/min

W=QA – QR

=6000-2229=3771kj/min

Power = 3771 /60=62.85kw

Example: The rejected heat from power forces station =1600kj/kg, whereas the performed work =800kj/kg and the required work for water pump=20kj/kg. Find the efficiency of station.

Wnet= 800-20=780kj/kg

W= QA –QR

QA=W+QR=780+1600=2380KJ/kg

$\eta = W\ /QA$

= 780/2380=0.328

Problems:

1. The rejected heat from power forces station =1400kj/kg, the efficiency of station =37% and the required work for pump=70kj/kg. Find the performed work.

2.what is the more effective factor to increase the efficiency of motor does according to Carnot cycle between 1000K AND 400K?

a) increasing the tank temp. by 100C with remaining cold tank temp. or:

b) reducing the tank temp. by 100C and remaining the hot tank temp.

3.power generation station does by 30% efficiency if adde heat =17x10^6kj/hr. Find the network for station.

Otto cycle, constant volume cycle, petrol engine cycle

Otto Cycle: The Ideal Cycle
For Spark-Ignition Engines

The Otto cycle is the ideal cycle for spark-ignition reciprocating engines. It is named after Nikolaus A. Otto, who built a successful four-stroke engine in 1876 in Germany using the cycle proposed by Frenchman Beau de Rochas in 1862. In most spark-ignition engines, the piston executes four complete strokes (two mechanical cycles) within the cylinder, and the crankshaft completes two revolutions for each thermodynamic cycle. These engines are called four-stroke internal combustion engines. A schematic of each stroke as well as a *P-v* diagram for an actual four-stroke spark-ignition engine is given in Fig.The thermodynamic analysis of the actual four-stroke or two-stroke cycles described is not a simple task. However, the analysis can be simplified significantly if the air-standard assumptions are utilized. The resulting cycle, which closely resembles the actual operating conditions, is the ideal Otto cycle. It consists of four internally reversible processes:

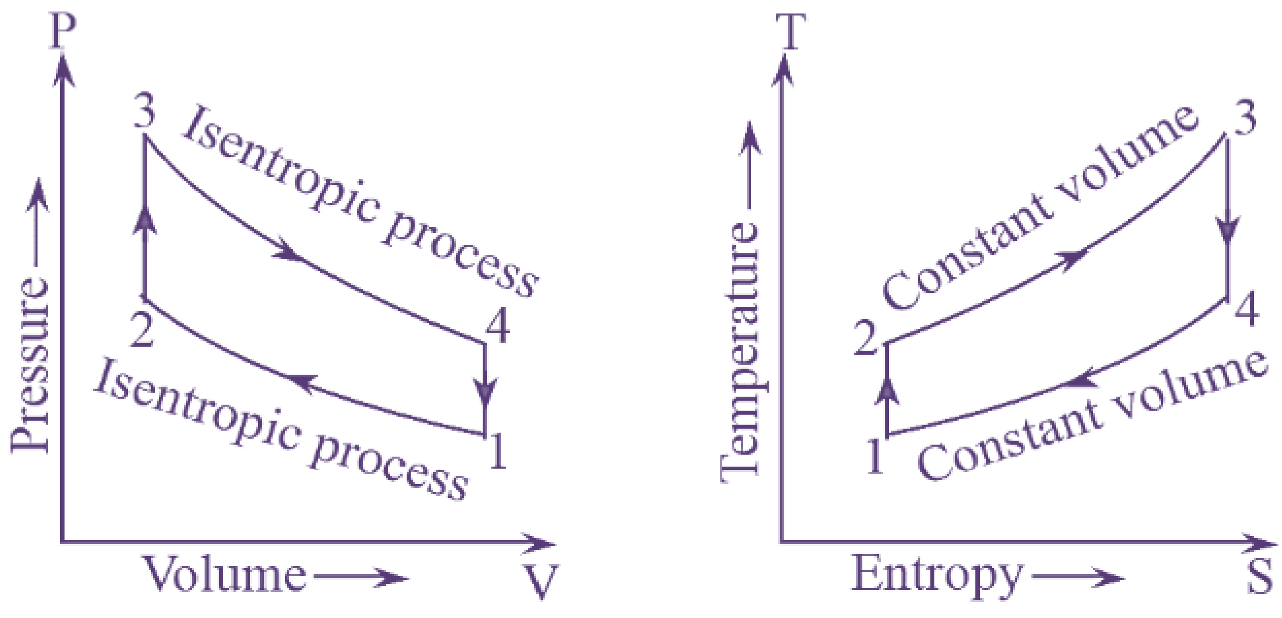
1-2 Isentropic compression

2-3 Constant-volume heat addition

3-4 Isentropic expansion

4-1 Constant-volume heat rejection

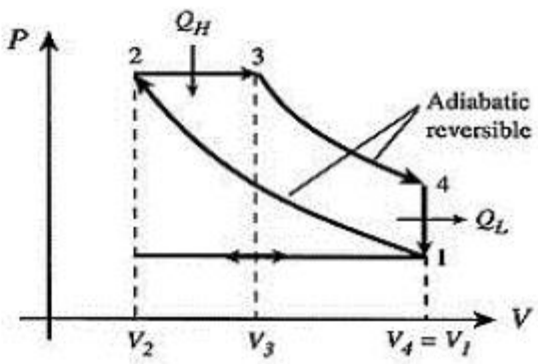
The execution of the Otto cycle in a piston–cylinder device together with a *P-v* , *T-s* diagram of the Otto cycle, is given in Figure.



(Qin - Qout) + (Win - Wout) = ΔW
Q_{in} =m.cv.(T3-T2)
Q_{out}= m.cv.(T4-T1)
η =1- (T4-T1 /T3-T2)
T1/T2 = $(V2/V1)^{k-1}$
T4/T3 =$(V3/V4)^{k-1}$

The Diesel Cycle

In 1893, Rudolf Diesel invented an engine that used fuel instead of steam. He based his idea on compressing air to a very high pressure so that its temperature increased significantly. Then, fuel was injected into the hot air, causing it to ignite automatically. This process resulted in a much higher efficiency compared to other types of combustion engines.



1-2 isentropic(adiabatic) compression

$\boldsymbol{P * V^{\gamma} = C}$

isentropic معنى

$\boldsymbol{\Delta S = 0 \ , Q = 0}$

$Q = W + \Delta U \ \rightarrow \ Q = 0 \ \rightarrow W = -\Delta U = m * C_v * (T_1 - T_2)$

2-3 Reversible constant pressure heat add

اضافة حرارة

$\boldsymbol{p = constant}$

$Q = W + \Delta U = \ m * C_p * (T_3 - T_2)$

3-4 isentropic(adiabatic) Expansion

$\boldsymbol{P * V^{\gamma} = C}$

$\boldsymbol{\Delta S = 0 \ , Q = 0}$

$Q = W + \Delta U \ \rightarrow \ Q = 0 \ \rightarrow W = -\Delta U = m * C_v * (T_3 - T_4)$

4-1 Reversible constant volume heat reject

$v = constant \quad \rightarrow w = 0$

$Q = W + \Delta U \quad \rightarrow \quad w = 0 \quad \rightarrow Q = \Delta U = m * C_v * (T_4 - T_1)$

Thermal efficiency (η)

$$thermal\ efficiency = \frac{net\ work}{heat\ added} = \frac{Q_{add} - Q_{reject}}{Q_{add}} = 1 - \frac{Q_{reject}}{Q_{add}} \quad *$$

$$thermal\ efficiency = 1 - \frac{C_V(T4 - T1)}{C_p(T3 - T2)} = 1 - \frac{C_V}{C_p} * \frac{T4 - T1}{T3 - T2}$$

$$thermal\ efficiency = 1 - \frac{1}{\gamma} * \frac{T4 - T1}{T3 - T2}$$

$$thermal\ efficiency = 1 - \frac{T4 - T1}{\gamma(T3 - T2)}$$

Example: A diesel engine has an inlet temperature is (15C) and inlet pressure of (1 bar) the compression ratio is (12:1) the maximum cycle temperature is (1100 C) calculate the air standard thermal efficiency based the diesel cycle.

Solution :

$compression\ ratio = \frac{v_1}{v_2} = 12 \quad , \quad v_4 = v_1$

$T_1 = 15 + 273 = 288\ K$

$T_3 = 1100 + 273 = 1373\ K$

$P_1 = 100\ Kpa$

$$thermal\ efficiency = 1 - \frac{T4 - T1}{\gamma(T3 - T2)}$$

1-2 isentropic(adiabatic) compression

$$T_2 = T_1 * \left(\frac{v_1}{v_2}\right)^{\gamma-1} = 288 * (12)^{0.4} = 778.1\ K$$

$$P_2 = P_1 * \left(\frac{v_1}{v_2}\right)^{\gamma} = 100 * (12)^{1.4} = 3242.3\ Kpa$$

$$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{\gamma-1} = \left(\frac{v_3}{v_2} * \frac{v_2}{v_1}\right)^{\gamma-1} = \left(\frac{T_3}{T_2} * \frac{v_2}{v_1}\right)^{\gamma-1}$$

$$T_4 = T_3 \left(\frac{T_3}{T_2} * \frac{v_2}{v_1}\right)^{\gamma-1} = 1373 * \left(\frac{1373}{778.1} * \frac{1}{12}\right)^{0.4} \rightarrow T_4 = 638\ K$$

$$thermal\ efficiency = 1 - \frac{T4 - T1}{\gamma(T3 - T2)} = 1 - \frac{638 - 288}{1.4(1373 - 778.1)} = 0.58$$

The actual cycle comparing between actual cycle and air standard cycle

When studying internal combustion engines, it is observed that there are some advances and delays depending on the operating conditions of the engine — such as ignition timing or the opening and closing of the intake and exhaust valves. In the actual cycle, the following differences can be noticed:

1. **Intake Stroke:**
   The pressure inside the cylinder must be lower than the atmospheric pressure in order for the air or the air-fuel mixture to enter the cylinder.
2. **Compression Stroke:**
   This stroke begins after the intake and exhaust valves are closed. However, in practice, these valves may not close completely at the ideal moment. The combustion process is assumed to occur when the piston reaches the top dead center, but in the actual cycle, ignition starts slightly before or after this point, causing a difference in temperature and pressure.
3. **Power Stroke:**
   During this stroke, the piston moves from the top dead center to the bottom dead center. Ideally, combustion occurs right at the top, but in reality, ignition may begin earlier, and the exhaust valve may open slightly before the piston reaches the bottom to allow smoother expulsion of exhaust gases.

4. **Exhaust Stroke:**
   In this stroke, exhaust gases are expelled from the cylinder. For the gases to leave the cylinder, the pressure inside must be higher than the atmospheric pressure.

Heat transfer

Steady state heat conduction, conduction through homogenous plane wall, conduction through composite wall, thermal resistance, heat conduction through homogenous cylindrical wall, heat conduction through multi layers cylindrical wall, examples.

Type of heat transfer

1- Conduction

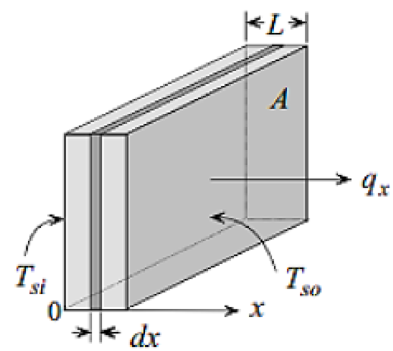
2- Convection

3- Radiation

Conduction

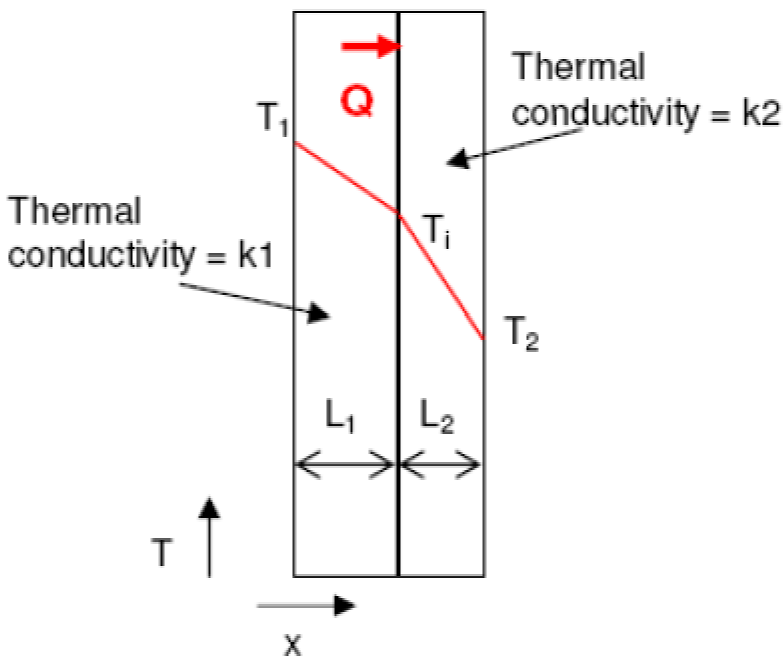
Fourier's Law of Conduction Our experience shows that if one end of a metal bar is heated, its temperature at the other end will eventually begin to rise. This transfer of energy is due to molecular activity. Molecules at the hot end exchange their kinetic and vibrational energies with neighboring layers through random motion and collisions. A temperature gradient, or slope, is established with energy continuously being transported in the direction of decreasing temperature. This mode of energy transfer is called conduction. We now turn our attention to formulating a law that will help us determine the rate of heat transfer by conduction. Consider the wall shown in fig.

of one surface (x = 0) is and of the other surface (x = L) is The wall thickness is L and its surface area is A. The remaining four surfaces are well insulated and thus heat is transferred in the x-direction only. Assume steady state and let q_x the rate of heat transfer in the x-direction. Experiments have shown that is directly proportional to A and (T_{si} -T_{so}) and inversely proportional to L. That is



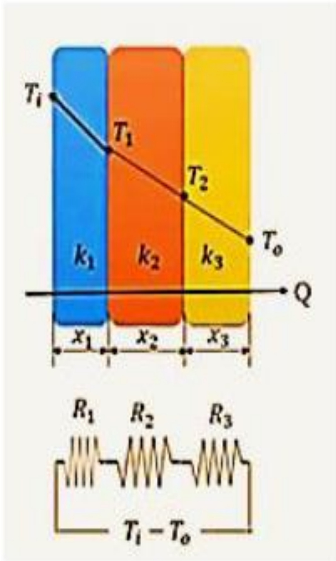
$$q_x \propto \frac{A(T_{si} - T_{so})}{L}$$

$$q_x = K\frac{A(T_{si} - T_{so})}{L}$$



1- Heat transfer through composite wall in series

$Q = q_1 = q_2 = q_3$



$$Q = \frac{T_i - T_1}{R_1} = \frac{T_1 - T_2}{R_2} = \frac{T_2 - T_o}{R_3}$$

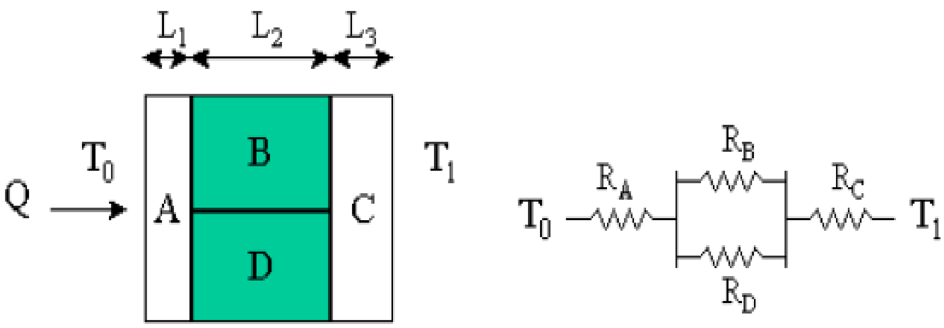
$$R_1 = \frac{x_1}{k_1 A} \quad , \ R_2 = \frac{x_2}{k_2 A} \quad , R_3 = \frac{x_3}{k_3 A}$$

When walls are in series

$$\sum R = R_1 + R_2 + R_3 \ , \ \ R: thermal\ resistance$$

$$Q = \frac{T_i - T_o}{\sum R} = \frac{T_i - T_o}{R_1 + R_2 + R_3}$$

2- Heat transfer through composite wall in Parallel



$$Q = Q_A = Q_B + Q_D = Q_C$$

$$Q = \frac{T_0 - T_1}{\sum R}$$

$$R = R_A + R_{B-D} + R_C$$

$$\frac{1}{R_{B-D}} = \frac{1}{R_B} + \frac{1}{R_D}$$