Lecture (1-6)

THERMODYNAMICS

Basic Concepts of Thermodynamics: Every science has its own unique vocabulary associated with it. Precise definition of basic concepts forms a sound foundation for development of a science and prevents possible misunderstandings. Careful study of these concepts is essential for a good understanding of topics in thermodynamics.

Thermodynamics and Energy

Thermodynamics can be defined as the study of energy, energy transformations and its relation to matter. The analysis of thermal systems is achieved through the application of the governing conservation equations, namely Conservation of Mass, Conservation of Energy (1st law of thermodynamics), the 2nd law of thermodynamics and the property relations.

Energy can be viewed as the ability to cause changes. First law of thermodynamics: one of the most fundamental laws of nature is the conservation of energy principle. It simply states that during an interaction, energy can change from one form to another but the total amount of energy remains constant.

Second law of thermodynamics: energy has quality as well as quantity, and actual processes occur in the direction of decreasing quality of energy. Whenever there is an interaction between energy and matter, thermodynamics is involved. Some examples include heating and air-conditioning systems, refrigerators, water heaters, etc.

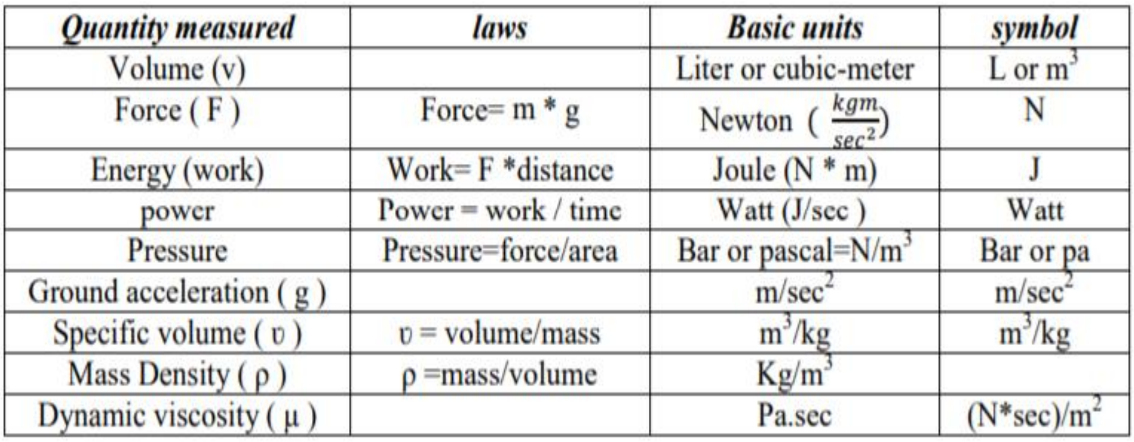
Dimension and Units

Any physical quantity can be characterized by dimensions. The arbitrary magnitudes assigned to the dimensions are called units. There are two types of dimensions, primary or fundamental and secondary or derived dimensions. Primary dimensions are: mass, m; length, L; time, t; temperature, T Secondary dimensions are the ones that can be derived from primary dimensions such as: velocity (m/s2), pressure (Pa = kg/m.s2).

There are two-unit systems currently available SI (International System) and USCS (United States Customary System) or English system. We, however, will use SI units exclusively in this course. The SI units are based on decimal relationship between units. The prefixes used to express the multiples of the various units are listed in table 1.

Table 1: Standard prefixes in SI units

Multibyte	10^{12}	10^{9}	10^{6}	10^{3}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}
Prefix	Terra,T	Giga, G	Mega, M	Killo, K	Centi,cm	Mill, M	Micro, μ	Nano, n	Pico, p



Quantity measured	***laws***	***Basic units***	***symbol***
Volume (v)		Liter or cubic-meter	L or m^3
Force (F)	Force= m * g	Newton ($\frac{kgm}{sec^2}$)	N
Energy (work)	Work= F *distance	Joule (N * m)	J
power	Power = work / time	Watt (J/sec)	Watt
Pressure	Pressure=force/area	Bar or pascal=N/m^3	Bar or pa
Ground acceleration (g)		m/sec^2	m/sec^2
Specific volume (υ)	υ = volume/mass	m^3/kg	m^3/kg
Mass Density (ρ)	ρ =mass/volume	Kg/m^3	
Dynamic viscosity (μ)		Pa.sec	$(N*sec)/m^2$

BRITISH UNIT

Length	L	inch	in
Time	t	second	s
Mass	m	pound	lb
Temp.	T	Feh.	F
Force	F	Pound	lb_f

pressure	p	lb/in^2	psi
density	ρ		lb/in^3
work	w		lb.in
power	*P*		BTU

1m=100cm=1000mm=10 dm

1in=2.54cm=25.4mm

1foot(ft)=12in

1hr=60min,=3600sec

1lb=451gm=0.45kg

1kilo=1000

1MEGA=10^6

1giga=10^9

4m to mm 4x1000=4000mm -

50cm to m 50/100=0.5m

-1metric hp=0.7355kw=735.5 watt

Example: Convert 7500w to hp

7500 /735.5=10.19 hp

-1British hp=0.7457 kw=745.7w (power unit)

Example: Convert 560 bhp to watt (power unit)

-1Cal =4.2J 1K

Important note: In engineering, all equations must be dimensionally homogenous. This means that every term in an equation must have the same units. It can be used as a sanity check for your solution.

Systems, Surroundings and Universe

In thermodynamics the ‘system’ is defined as the quantity of matter or region in space upon which the attention is concentrated for the sake of analysis. These systems are also referred to as thermodynamic systems. For the study these systems are to be clearly defined using a real or hypothetical boundary.

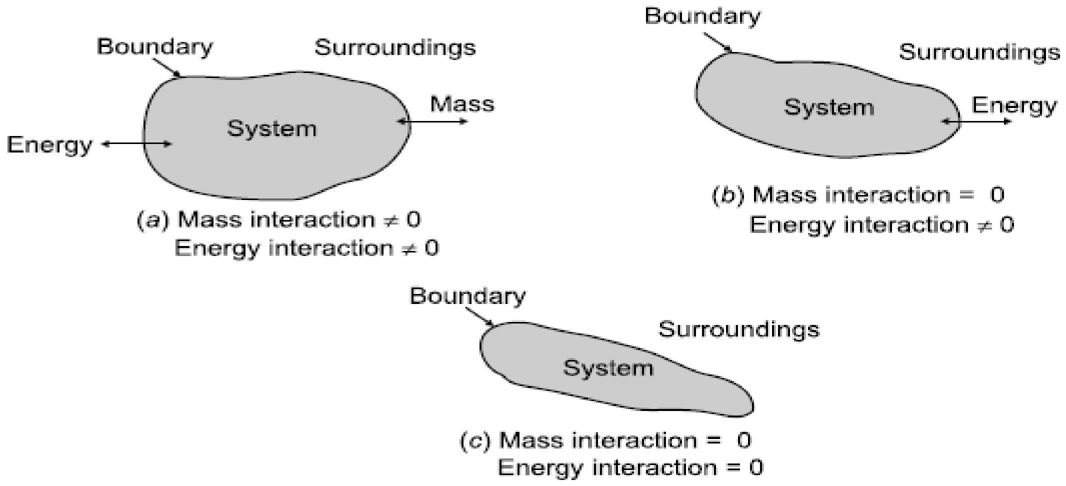
Everything outside this real/hypothetical boundary is termed as the ‘surroundings. Thus, the surroundings may be defined as everything surrounding the system. System and surroundings when put together result in universe.

Universe = System + Surroundings

The system is also sometimes defined as the control system and the boundary defined for separating it from surroundings is called control boundary, the volume enclosed within the boundary is control volume and the space enclosed within the boundary is called control space.

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.



(a) Mass interaction $\neq 0$
Energy interaction $\neq 0$

(b) Mass interaction = 0
Energy interaction $\neq 0$

(c) Mass interaction = 0
Energy interaction = 0

Figure (1) System, Surrounding and Boundary

Boundary: the real or imaginary surface that separates the system from its surroundings. The boundaries of a system can be fixed or movable. Mathematically, the boundary has zero thickness, no mass, and no volume.

Closed system or control mass: consists of a fixed amount of mass, and no mass can cross its boundary. But, energy in the form of heat or work, can cross the boundary, 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 encloses a device that involves mass flow such as a compressor. Both mass and energy can cross the boundary of a control volume.

Important note: some thermodynamics 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.

Adiabatic system: A closed or open system that does not exchange energy with the surroundings by heat.

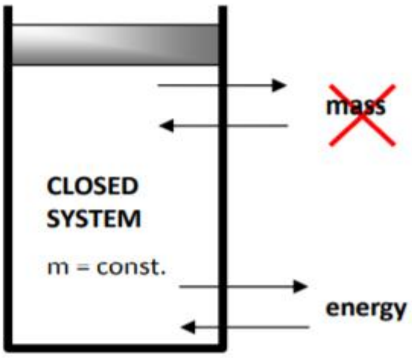


Fig. 2: Closed system, mass cannot cross the boundaries, but energy can.

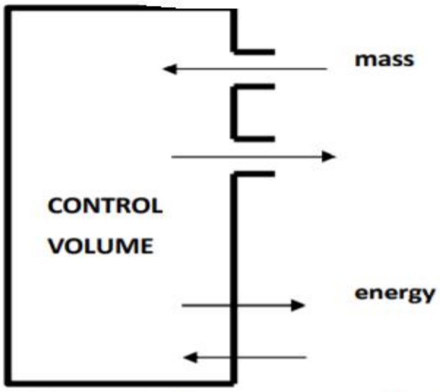
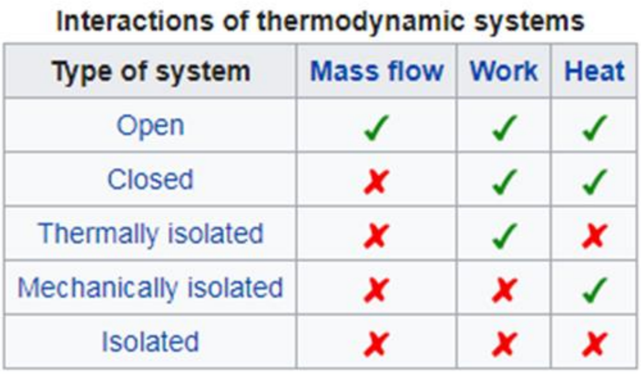


Fig. 3: Control volume, both mass and energy can cross the boundaries.



Interactions of thermodynamic systems

Type of system	Mass flow	Work	Heat
Open	✓	✓	✓
Closed	✗	✓	✓
Thermally isolated	✗	✓	✗
Mechanically isolated	✗	✗	✓
Isolated	✗	✗	✗

Energy and Its Form

In thermodynamics, we deal with change of the total energy only. Thus, the total energy of a system can be assigned a value of zero at some reference point. Total energy of a system has two groups: macroscopic and microscopic. Macroscopic forms of energy: forms of energy that a system possess as a whole with respect to some outside reference frame, such as kinetic and potential energy. The macroscopic energy of a system is related to motion and the influence of some external effects such as gravity, magnetism, electricity, and surface tension.

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:

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

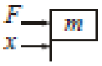
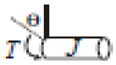
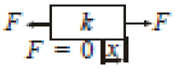
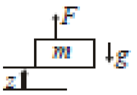
where g is the gravitational acceleration and z is the elevation of the center of gravity of the system relative to some arbitrary reference plane.

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.

- ♦ The sum of translational, vibrational, and rotational energies of molecules is the kinetic energy of molecules, and it is also called the sensible energy. At higher temperatures, system will have higher sensible energy.
- ♦ Internal energy associated with the phase of a system is called latent heat. The intermolecular forces are strongest in solids and weakest in gases.
- ♦ The internal energy associated with the atomic bonds in a molecule is called chemical or bond energy. The tremendous amount of energy associated with the bonds within the nucleolus of atom itself is called atomic energy.

S. No.	*Macroscopic form of energy*	*Governing equation*	*Energy interaction*	*Work interaction*	*Block diagram*
1.	Kinetic energy (translation)	$F = m \cdot \frac{dV}{dt}$	$\Delta E = \frac{1}{2} m \cdot (V_2^2 - V_1^2)$	$= - F \cdot dx$	
2.	Kinetic energy (rotational)	$T = J \cdot \frac{d\omega}{dt}$	$\Delta E = \frac{1}{2} J \cdot (\omega_2^2 - \omega_1^2)$	$= - T \cdot d\theta$	
3.	Spring stored energy (translational)	$F = kx$	$\Delta E = \frac{1}{2} k \cdot (x_2^2 - x_1^2)$	$= - F \cdot dx$	
4.	Spring stored energy (rotational)	$T = K \cdot \theta$	$\Delta E = \frac{1}{2} K \cdot (\theta_2^2 - \theta_1^2)$	$= - T \cdot d\theta$	
5.	Gravitational energy	$F = mg$	$\Delta E = mg \cdot (Z_2 - Z_1)$	$= - F \cdot dz$	
6.	Electrical energy (capacitance)	$u = \frac{q}{c}$	$\Delta E = \frac{1}{2} \frac{q^2}{c} = \frac{1}{2} cu^2$	$= - u \cdot dq$	
7.	Electrical energy (inductance)	$\phi = L \cdot i$	$\Delta E = \frac{1}{2} Li^2 = \frac{1}{2} \frac{\phi^2}{L}$	$= - i \cdot d\phi$	

Renewable Energy

Renewable energy is energy derived from natural sources that are replenished at a higher rate than they are consumed. Sunlight and wind, for example, are such sources that are constantly being replenished. Renewable energy sources are plentiful and all around us.

Fossil fuels - coal, oil and gas - on the other hand, are non-renewable resources that take hundreds of millions of years to form. Fossil fuels, when burned to produce energy, cause harmful greenhouse gas emissions, such as carbon dioxide.

Generating renewable energy creates far lower emissions than burning fossil fuels. Transitioning from fossil fuels, which currently account for the lion's share of emissions, to renewable energy is key to addressing the climate crisis. Renewables are now cheaper in most countries, and generate three times more jobs than fossil fuels.

Types of Renewable Energy

Solar energy

Solar energy is the most abundant of all energy resources and can even be harnessed in cloudy weather. The rate at which solar energy is intercepted by the Earth is about 10,000 times greater than the rate at which humankind consumes energy.

Solar technologies can deliver heat, cooling, natural lighting, electricity, and fuels for a host of applications. Solar technologies convert sunlight into electrical energy either through photovoltaic panels or through mirrors that concentrate solar radiation.

Wind energy

Wind energy harnesses the kinetic energy of moving air by using large wind turbines located on land (onshore) or in sea- or freshwater (offshore). Wind energy has been used for millennia, but onshore and offshore wind energy technologies have evolved over the last few years to maximize the electricity produced - with taller turbines and larger rotor diameters.

Geothermal energy

Geothermal energy utilizes the accessible thermal energy from the Earth's interior. Heat is extracted from geothermal reservoirs using wells or other means. Reservoirs that are naturally sufficiently hot and permeable are called hydrothermal reservoirs, whereas reservoirs that are sufficiently hot but that are improved with hydraulic stimulation are called enhanced geothermal systems. Once at the surface, fluids of various temperatures can be used to generate electricity. The technology for electricity generation from hydrothermal reservoirs is mature and reliable, and has been operating for more than 100 years.

Lecture 6-9
study of steam, steam properties, using steam tables

1. What Is Steam

Steam is water in the **gaseous state**. It is produced when water is heated beyond its boiling point at a given pressure.

Depending on temperature and pressure, steam can exist in different forms:

- **Wet steam:** A mixture of saturated liquid and vapor.
- **Dry saturated steam:** Steam that is fully vaporized but not superheated.
- **Superheated steam:** Steam heated beyond the saturation temperature at a given pressure.

2. Key Steam Properties

Steam has several **thermodynamic properties** used in engineering calculations:

Property	Symbol	Units	Description
Pressure	P	bar, MPa	Force per unit area
Temperature	T	°C, K	Thermal state
Specific volume	V	m^3/kg	Volume per unit mass
Specific enthalpy	H	kJ/kg	Total heat content
Specific entropy	S	kJ/kg·K	Measure of disorder/energy dispersal
Quality (Dryness fraction)	X	–	Ratio of vapor mass to total mass in wet steam

3. Steam Formation Process

1. **Heating water:** Sensible heating from 0°C to boiling temperature → liquid water.
2. **Boiling/evaporation:** Latent heating at constant temperature → mixture of water + vapor.
3. **Superheating:** Further heating of steam → superheated steam.

4. Steam Tables

Steam tables provide thermodynamic data for water and steam at various temperatures and pressures. There are three main parts:

(a) Saturated Water and Steam Table

- Lists properties at the **boiling point (saturation)** for each pressure or temperature.
- Contains:

- T_{sat}, P_{sat}
- v_f, v_g: specific volume (liquid/vapor)
- h_f, h_{fg}, h_g: enthalpy of liquid, evaporation, and vapor
- s_f, s_{fg}, s_g: entropy values

Example (at 1 bar):

Property	Value
(T_{sat})	100°C
(v_f)	0.001043 m³/kg
(v_g)	1.673 m³/kg
(h_f)	417.5 kJ/kg
(h_{fg})	2257 kJ/kg
(h_g)	2675 kJ/kg
(s_f)	1.303 kJ/kg·K
(s_g)	7.354 kJ/kg·K

(b) Superheated Steam Table

- Lists properties of steam above saturation temperature at constant pressure.
- Useful for turbines and boilers.

Example (at 1 bar, 150°C):

Property	Value
(h)	2685.8 kJ/kg
(s)	7.707 kJ/kg·K

(c) Compressed Water (Subcooled) Table

- For liquid water below the saturation temperature at given pressure.
- Often approximated by saturated liquid data.

5. Steam Quality (x)

For **wet steam**, quality (x) indicates the vapor fraction:

$$x = \frac{m_{vapor}}{m_{total}}$$

To find properties:

$$h = h_f + x\,h_{fg}$$

$$v = v_f + x\,(v_g - v_f)$$

$$s = s_f + x\,(s_g - s_f)$$

6. Example Problem

Given: Steam at 10 bar with 80% dryness.
Find: Enthalpy and specific volume.

From steam table (at 10 bar):

$h_f = 762.6\,kJ/kg,\ h_{fg} = 2015.3\,kJ/kg$

$v_f = 0.001127\,m^3/kg,\ v_g = 0.1944\,m^3/kg$

Then:

$$h = h_f + xh_{fg} = 762.6 + 0.8(2015.3) = 2380.8\,kJ/kg$$

$$v = v_f + x(v_g - v_f) = 0.001127 + 0.8(0.1944 - 0.001127) = 0.156\,m^3/kg$$

Problem 1: Wet Steam

Given:

Steam at a pressure of $P = 8\,bar$ with a **dryness fraction** $x = 0.9$.

Find:

1. Specific enthalpy h
2. Specific volume v

From the saturated steam table at 8 bar:

$$h_f = 721.1\,kJ/kg, \quad h_{fg} = 2046.7\,kJ/kg$$

$$v_f = 0.001093\,m^3/kg, \quad v_g = 0.2403\,m^3/kg$$

Solution:

1. Specific Enthalpy:

$$h = h_f + x\, h_{fg}$$

$$h = 721.1 + 0.9(2046.7) = 721.1 + 1842.0 = 2563.1\, kJ/kg$$

2. Specific Volume:

$$v = v_f + x(v_g - v_f)$$

$$v = 0.001093 + 0.9(0.2403 - 0.001093) = 0.001093 + 0.2154 = 0.2165\, m^3/kg$$

✅ Final Answers:

$$h = 2563.1\, kJ/kg, \quad v = 0.2165\, m^3/kg$$

Problem 2: Superheated Steam

Given:

Steam at a pressure of $P = 5\ bar$and temperature $T = 300°C$.

Find:

1. Specific enthalpy h
2. Specific entropy s

From the saturated steam table at 5 bar:

$$T_{sat} = 151.86^{\circ}C, \quad h_g = 2748.3\, kJ/kg, \quad s_g = 7.707\, kJ/kg{\cdot}\, K$$

Since $T = 300^{\circ}C > T_{sat}$, the steam is **superheated.**

From the superheated steam table at 5 bar and 300°C:

$$h = 3056.9\, kJ/kg, \quad s = 8.002\, kJ/kg{\cdot}\, K$$

✅ Final Answers:

$$h = 3056.9\, kJ/kg, \quad s = 8.002\, kJ/kg{\cdot}\, K$$

Applications

- Power plants (Rankine cycle)
- Heating and drying systems
- Industrial boilers and turbines
- Steam engines and sterilizers

Lecture (10-12)

First Law of Thermodynamics

All of thermodynamics can be expressed in terms of four equations:

1.Temperature (T)

2.Internal Energy (E)

3.Entropy (S)

4.Heat (Q)

First law of thermodynamics**:** It states: Energy not to perished or created but convert from shape to another.

Energy is the ability to perform work and the it shows in various figures connected by relation and may be convert any figure of energy to another.

The total energy of system =summation of energy figures.

$$\sum dQ = \sum dW$$

Example (2): in certain steam plant the turbine developed (1000 Kw) and the heat supplied to the steam in the boiler is (2800 Kj/Kg) and the heat reject to cooling water in the condenser is (2100 Kj/kg) and the feed pump work requires to pumping the condense to back in to the boiler is (5Kw) calculate the steam flow in the cycle in Kg/sec .

Solution:

$$\sum Q = 2800 - 2100 = 700\ Kj/Kg$$

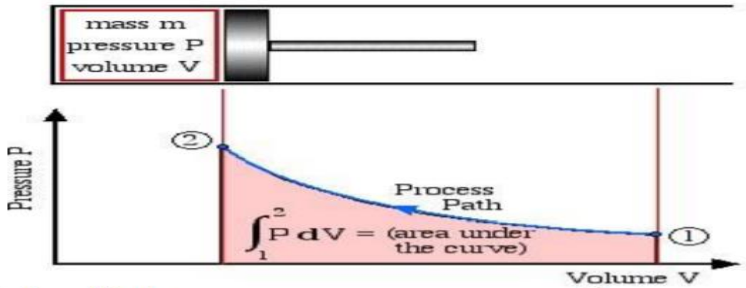
$$\sum W = 1000 - 5 = 995\ Kw$$

$$\dot{m} \sum dQ = \sum dW$$

$$m = \frac{\sum W}{\sum Q} = \frac{995}{700} = 1.44\ Kg/sec$$

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.



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

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.

$$\Delta U = Q - W$$

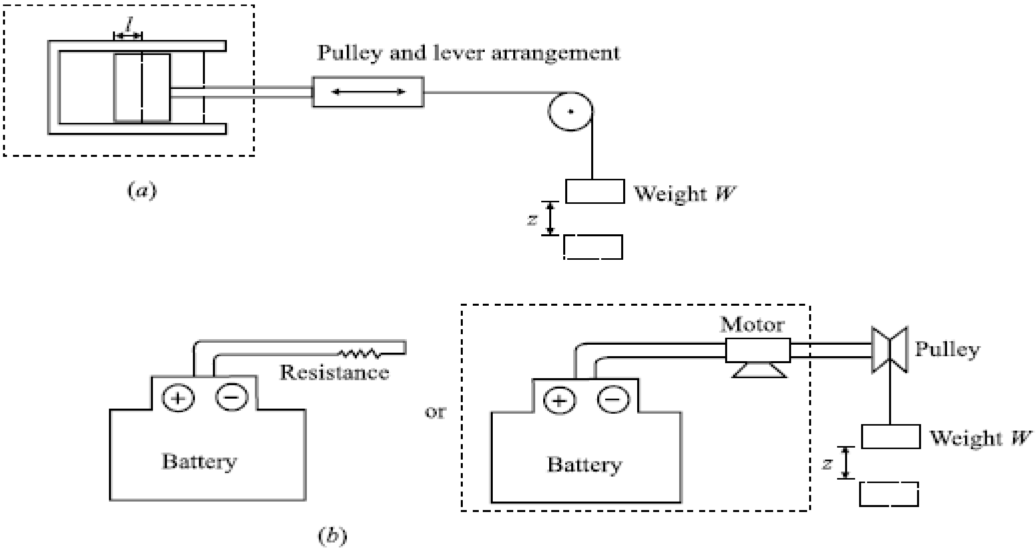


Fig.4. ***Thermodynamic work***

State and Equilibrium

At a given state, all the properties of a system have fixed values. Thus, if the value of even one property changes, the state will change to different one. In an equilibrium state, there are no unbalanced potentials (or driving forces) within the system. A system in equilibrium experiences no changes when it is isolated from its surroundings.

- Thermal equilibrium: when the temperature is the same throughout the entire system.
- Mechanical equilibrium: when there is no change in pressure at any point of the system. However, the pressure may vary within the system due to gravitational effects.
- Phase equilibrium: in a two phase system, when the mass of each phase reaches an equilibrium level.
- Chemical equilibrium: when the chemical composition of a system does not change with time, i.e., no chemical reactions occur.

Processes and Cycles

Any change a system undergoes from one equilibrium state to another is called a process, and the series of states through which a system passes during a process is called a path. : To specify a process, initial and final states and path must be specified.

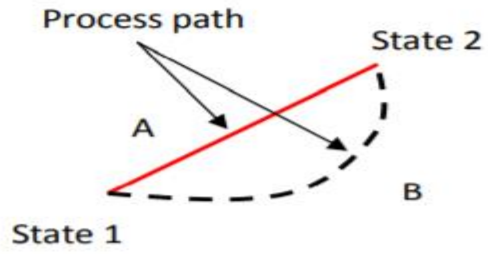


Fig.5. Process Path

Pressure

Pressure is the force exerted by a fluid per unit area.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \qquad \frac{N}{m^2} \equiv Pa$$

In fluids, gases and liquids, we speak of pressure; in solids this is stress. For a fluid at rest, the pressure at a given point is the same in all directions.

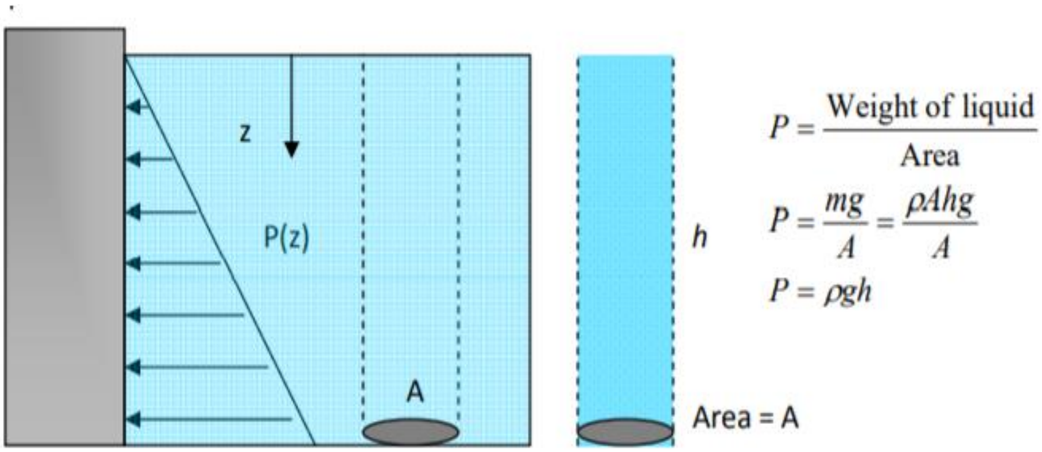


Fig.6. Pressure in Liquids

Pressure of a fluid at rest increases with depth (due to added weight), but constant in horizontal planes.

The actual pressure at a given position is called the absolute pressure, and it is measured relative to absolute vacuum.

gauge pressure = absolute pressure - atmospheric pressure

$$P_{gauge} = P_{abs} - P_{atm} \qquad P > P_{atm}$$
$$P_{vac} = P_{atm} - P_{abs} \qquad P < P_{atm}$$

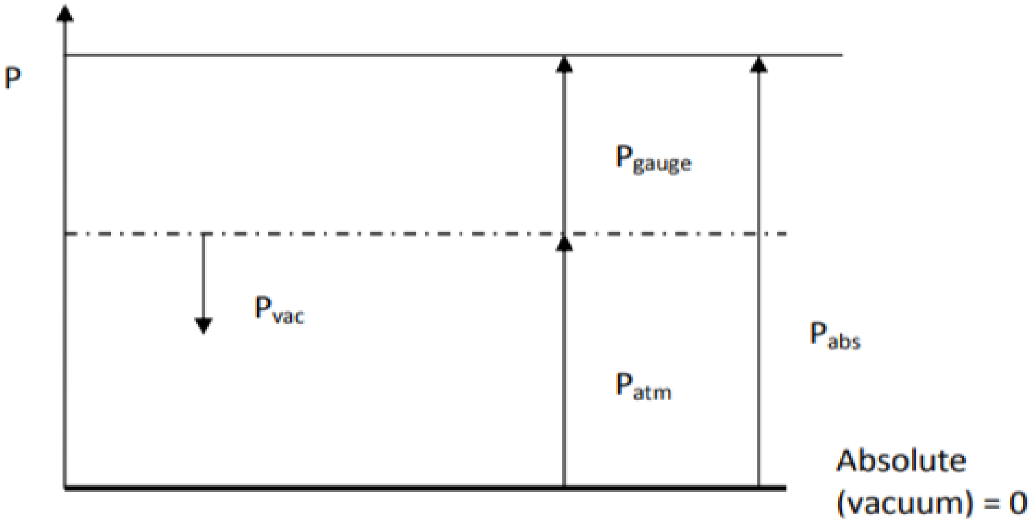


Fig.7.Absolute, gauge, and vacuum pressures.

In thermodynamics calculations, always use absolute pressure. Most pressure measuring devices are calibrated to read zero in the atmosphere (they measure Pgauge or Pvac). Be aware of what you are reading! A device that measures pressure using a column of liquid is called a Manometer. The cross-sectional area of the tube is not important. The manometer measures the gauge pressure.

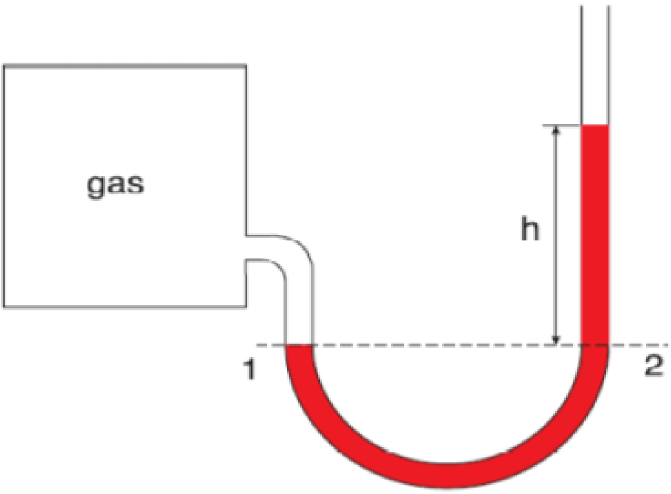


Fig.8: Basic manometer, P2=P1.

$$P_1 = P_{atm} + \rho g h \qquad (kPa)$$

Temperature:

Temperature is a pointer for the direction of energy transfer as heat.

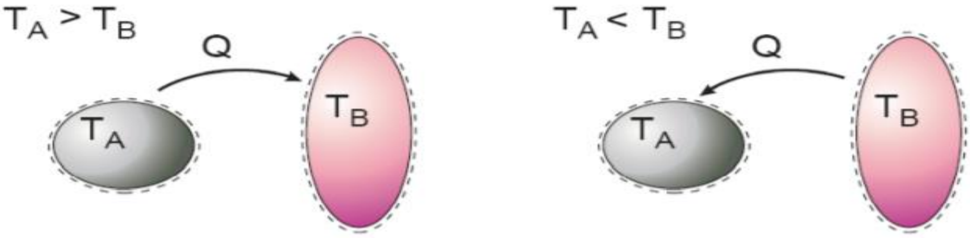


Fig. 9. Heat transfer occurs in the direction of higher-to-lower-temperature.

When the temperatures of two bodies are the same, thermal equilibrium is reached. The equality of temperature is the only requirement for thermal equilibrium. The 0th law of thermodynamics: states that if two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other. The 0th law makes a thermometer possible.

In accordance with the 0th law, any system that possesses an equation of state that relates temperature T to other accurately measurable properties can be used as a thermometer e.g. an ideal gas obeys the equation of state:

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

Temperature scales

Klvin scale K= C +273 -

Rankine scale T(R)= F + 460 -

T(R)=1.87 (K)

T(F)=1.87C +32

Examle 1: Convert the 65°C to °K , °F ,and °R.

T(K)= 65 + 273=338

T(F)=(1.8 x 65) + 32=153.55

T(R)=(1.87 x338)=632

Examle 2: Convert 760°R TO °C , °F and °K.

T(R)=1.87(K)

760=1.87 x K

K= 760 /1.87 = 406

BUT: K=C +273 406=C +273

C=133

T(F)=1.87C +32 T(F)= (1.87 x 133) +32=280.7

Example 3: Expressing Temperature Rise in Different Units

During a hearing process, the temperature of a system rises by 10°C. Express this rise in temperature in K, °F, and R. (H.W)

Heat

Is the transferred energy from body to another body as a result of temp. difference between them.

Methods of Heat Transfer

When a temperature difference is present, heat will flow from hot to cold. Heat can transfer between two mediums by conduction, convection and radiation whenever there is a temperature difference. Recall the first law of thermodynamic. The rate that heat will transfer in a closed system is presented in the following form:

$$Q=W + dU / dT$$

Where Q is the heat transfer rate, W is the work transfer rate and dU/dt is the net change in the total energy of the system.

1.Conduction method:

$$q=-k\frac{dt}{dx}$$

k is the coefficient of thermal conductivity (W/m.K)

Example:

An industrial furnace is pumping 200 °C hot air through a 3mm copper pipe (k = 400 W / m.K) insulated with 1cm of an elastomer (k = 0.4 W / m.K) on the outside of the pipe. What is the temperature distribution in the copper pipe and the heat conduction through the walls of the tube? Assume an ambient room temperature outside of the tube.

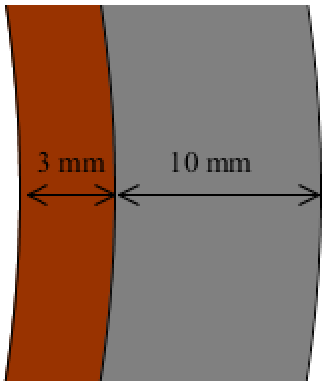


Fig.10.

Solution:

Examining the given thermal conductivities, we can see that the copper is 1000 times higher than the insulator. The temperature distribution in the copper will be much less than the elastomer here. However, once the heat flux reaches a steady state, the conservation of energy dictates that the heat flux must be equal through both materials. We can equate the two rates to obtain the temperature distribution.

$q= (-k.\ dt/dx)_{cu} = (-k.dt/dx)_{ins.}$

The sum of the heat distribution through the copper pipe and the insulator will be equal to the total change in temperature.

$(200 - 20) = dt_{cu} + dt_{ins.}$

$dt\ ins = (k.\ dt/dx)_{cu} / (k\ /dx)_{ins.}$

$180 = dt_{cu}\ .\ (1 + (k/dx)_{cu} /(k/dx)_{ins.})$

$dt_{cu}=0.05C$

NOW:

$q= - k\ .\ dt /dx$

2.Convection Method

Convection occurs when a fluid or gas flows around an object. A small layer of fluid forms around the body, called the boundary layer, where heat diffuses from the object to the fluid. The thermal energy is then carried away from the object by the fluid Newton's law of cooling states that the temperature difference between the oncoming fluid and the body is proportional to the heat flow from the body. The steady state equation of the law of cooling is written as:

$$q = h \cdot (T_{body} - T_{fluid})$$

where (q) is the heat flow rate, T_{body} is the temperature of the body and T_{fluid} is the constant temperature of the oncoming fluid. (h) is the film coefficient or heat transfer coefficient, in ($W/m^2.K$) . The heat transfer coefficient has 2 forms. denotes the value a point on the surface while with a bar is the average coefficient over the whole body.

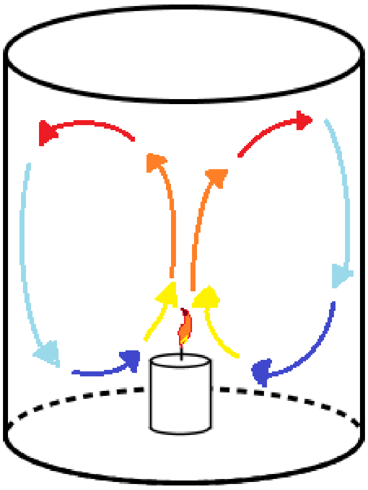


Fig.11. Convection method

3.Radiation Method

All bodies constantly emit some thermal energy by radiating heat, and energy can travel between bodies in the form of radiation. Thermal energy can radiate across a range of wavelengths but typically it is close to that of infrared. Often, the energy emitted by radiation can be neglected in the presence of conduction and convection at low temperatures. However, at high temperatures, radiation must be considered because the energy emission from a body varies as the fourth degree of the absolute temperature. As radiation strikes an object, some energy may be absorbed, pass through or reflect off of the surface. A black body is an ideal object that does not reflect radiation or let energy pass through. It absorbs all incident radiation and reemits thermal energy at a rate dependent on the black body, not the incident radiation that heats it.

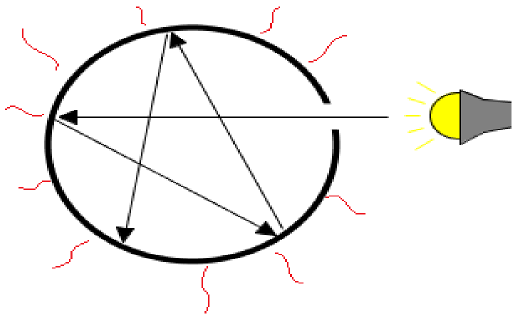


Fig.12 A black body as a cavity with a hole

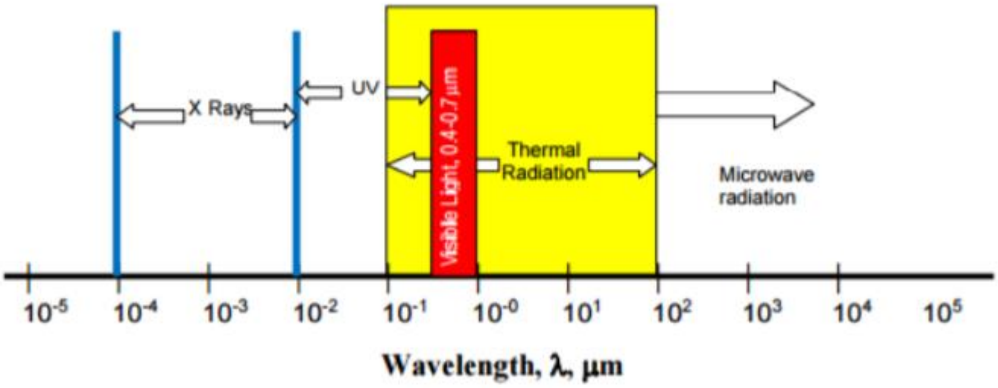


Fig.13.

$$Q = \epsilon * \sigma * A(T_{hot}^4 - T_{cold}^4)$$

$Q: heat\ transfer\ rate$

$\epsilon: surface\ emissivity$

$\sigma: \mathbf{Stephan - Boltzmann = 5.6703 * 10^{-8} \frac{watt}{m^2 k^4}}$

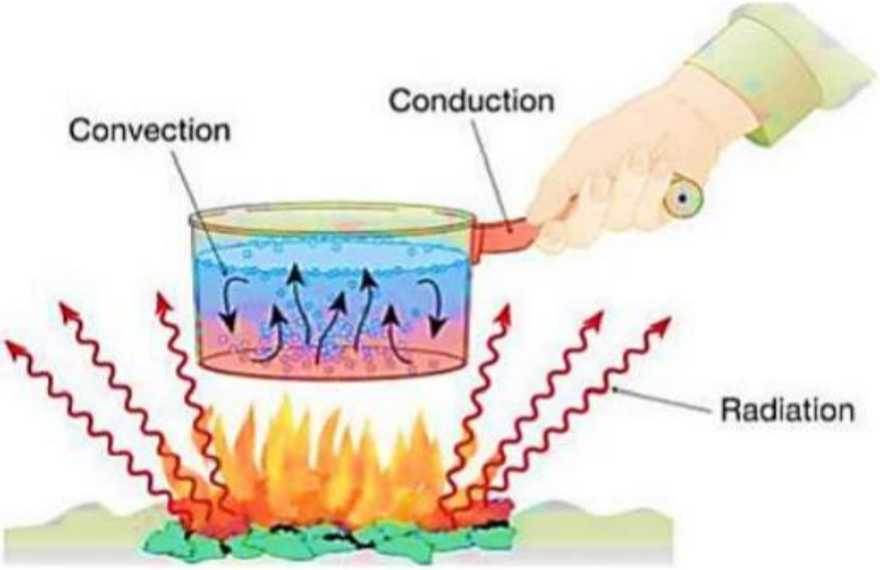


Fig.14.: All methods of heat transfer

Flow Work

When material passes inter a system or out of it there is a flow work is performed (Wf) . Flow process is the one in which fluid enters the system and leaves it after work interaction, which means that such processes occur in the systems having open boundary permitting mass interaction across the system boundary.

Figure 15 shows the flow process occurring in a system. Flow processes can be further classified into steady flow and non-steady flow processes. Examples of engineering systems having steady flow processes are flow through nozzles, turbines, compressors etc. and the examples of nonsteady flow processes are the filling or emptying of any vessel. Flow process shown indicates various energy and mass interactions taking place across the system boundary.

$W_f = F.\ L = P.A.\ L = P.V$ (Joul)

Where:

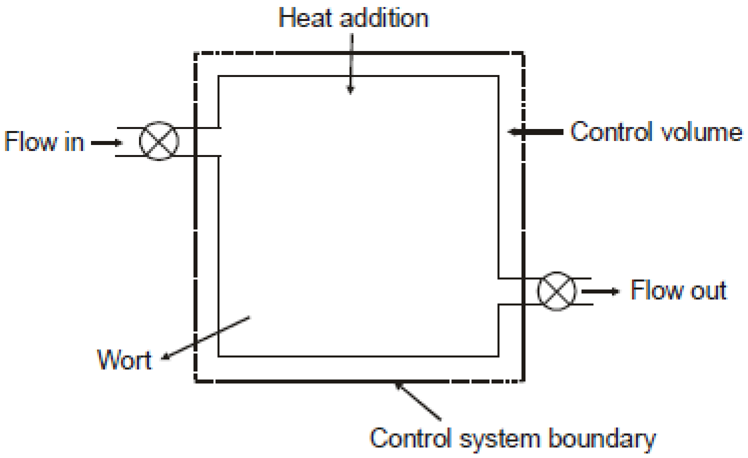
F=force required to push the material (N)

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.



Figu.15. Flow process

The change in flow work (ΔWf):

$\Delta Wf = Wf2 - Wf1 = PV2 - PV1$

Enthalpy (*H*) of a substance at any point is quantification of energy content in it, which could be given by summation of internal energy and flow energy. Enthalpy is very useful thermodynamic property for the analysis of engineering systems.

Mathematically, it is given as,

$H = U + PV$

On unit mass basis, the specific enthalpy could be given as,

$h = u + pv$

A look at expression of enthalpy shows that as we can't have absolute value of internal energy, the absolute value of enthalpy cannot be obtained. Therefore, only change in enthalpy of substance is considered. For certain frequently used substances such as steam, the enthalpy values of steam are available in tabulated form in Steam Tables at different thermodynamic states.

From the definition of enthalpy;

$h = u + pv$

or $dh = du + p \cdot dv + v \cdot dp$.

For a constant pressure process, $dp = 0$.

$dh = du + pdv$

or, $dh = dq_p$ = constt (From first law of thermodynamics)

Energy equation for open system of steady flow is:

$Q - W = \Delta H + \Delta K + \Delta P$

Steady Flow opened System Work

Steady flow refers to the flow in which its properties at any point remain constant with respect to time. Steady system is the system whose properties are independent of time, i.e. any property at a point in system shall not change with time.

$dw = -v.\ dp$

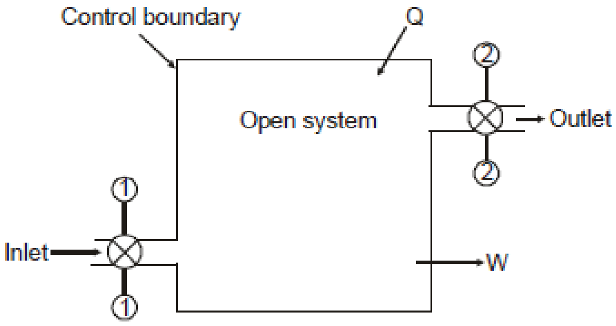


Fig.16. Open system

Lecture (9-11)

Application energy equation on closed system

Increasing in energy of system = interning energy – exiting energy.Fig 24 shows a gas inter system and heat (Q) applied on it,the gas expand against applied force (F) which = piston weight + block spring reaction.

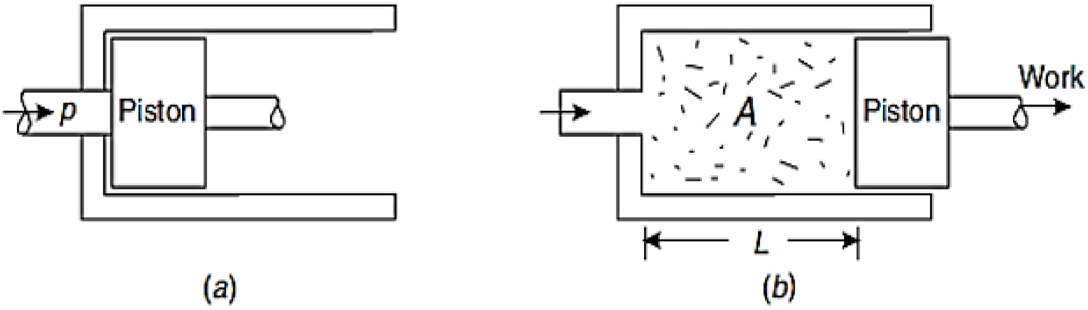


Figure.16

Q - W = ΔE

ΔE = E2 - E1

Q= Qin - Qout

W = W out - Win

Application energy equation in Nozzle

In this case there is no work (W=0) and assume no heat transfer across boundaries (Q=0) ,also no change in potential energy .

Q-W=ΔH +ΔP +ΔK

0=ΔH+ΔK

ΔK= - ΔH

K2 - K1 = H1 - H2

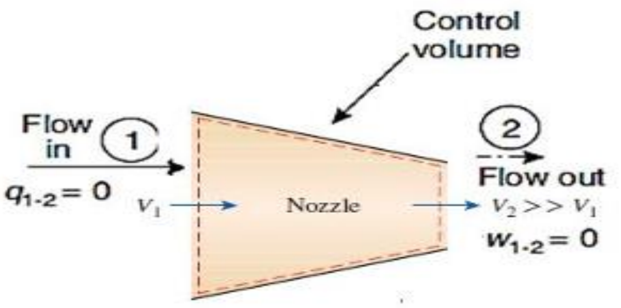


Figure.17. Nozzle

Application energy equation in throttling:

The fluid expands from certain pressure to lower pressure without work and no change in kinetic or potential energy .In throttling no heat applied therefore :

$\Delta H=0$

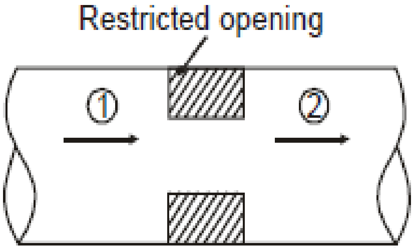


Fig.18.Throtting Process

The fluid expands from certain pressure side to lower pressure side without work ,without change in kinetic energy (ΔK) ,without change in potential energy (Δp),and no heat applied to system (Q):

$Q-W=\Delta H + \Delta P + \Delta K$

$0=\Delta H$

Application energy equation in condenser:

As in throttling .

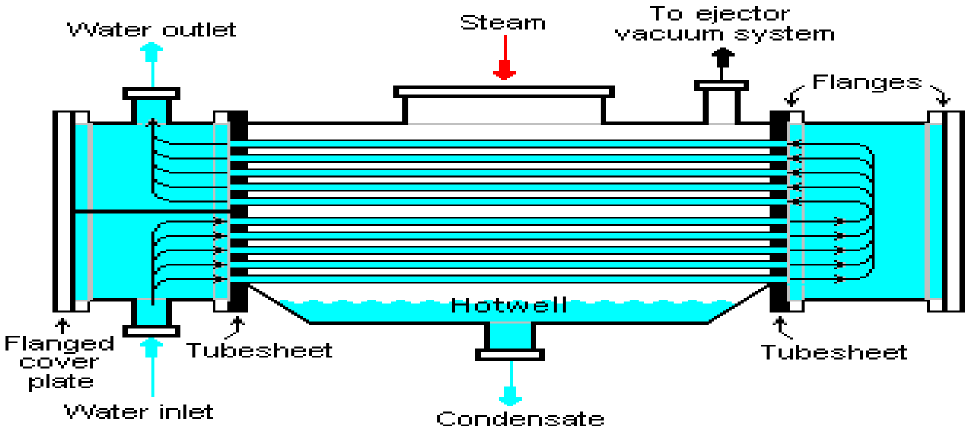


Fig.19.Condesor Process

Application energy equation in boiler:

W=ΔP =ΔK=0

Q=ΔH

Heat is added to increase the enthalpy

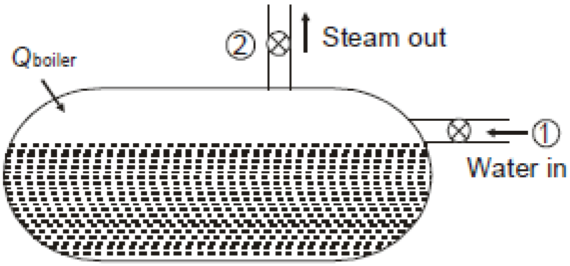


Fig.20 Boiler Process

Application energy equation in turbine:

Q=ΔP=ΔK=0

- W =ΔH

W= -ΔH=H1 - H2

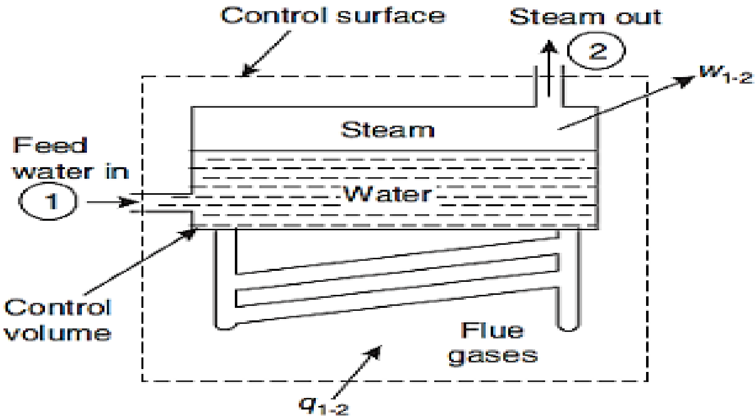


Fig.21

Application energy equation in compressor:

$\Delta p=\Delta K=0$

$Q-W=\Delta H$

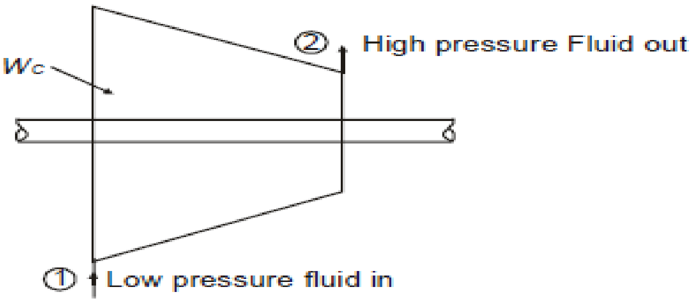


Fig.22

Surface heat exchanger

In this application there are two fluids in different temperature.Heat transfer from high temperature fluid to low one.

$Q=W=\Delta P=\Delta K=0$

$0=\Delta H=Ha-Hb$

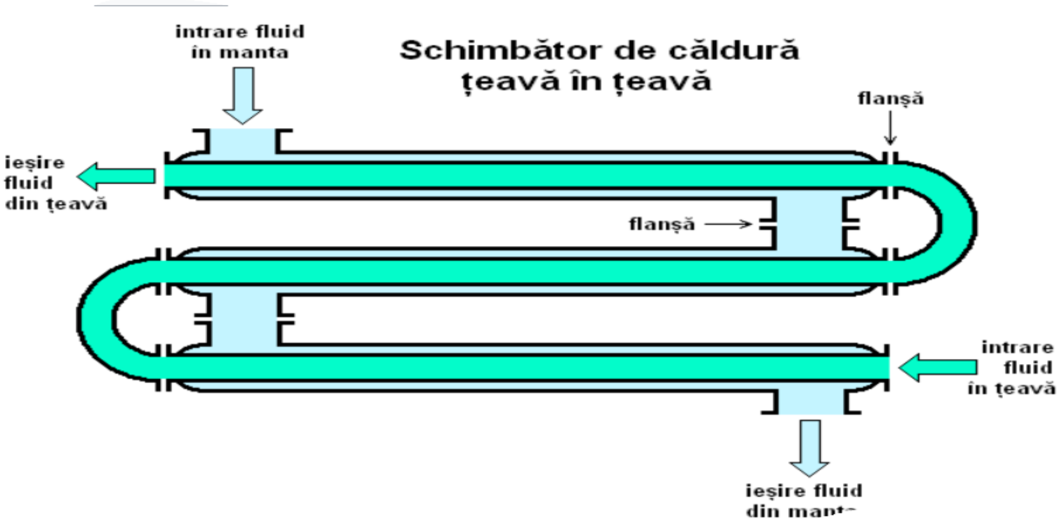


Fig.23

Opened heat exchanger

Is an exchanger which two fluids are mixed and heat transfer from high to low temp. fluid .

Qnet =Qin - Qout=0

W=ΔP=ΔK=0

ΔH=Ha+Hb

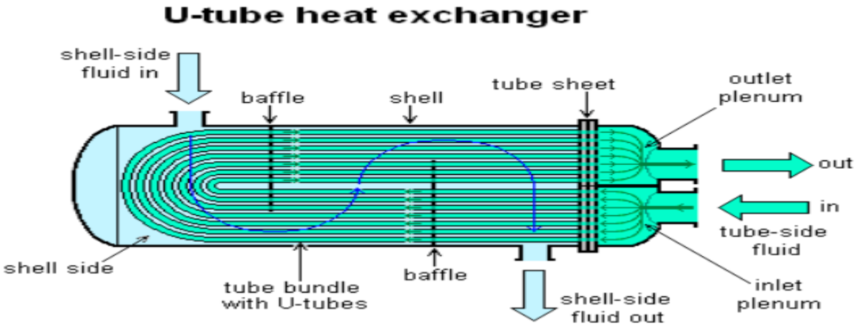


Fig.24

Solved Examples:

1. A gas in tube at height (40.64m) above sea surface , and flow by velocity of (7.04m/sec) calculate :

1. specific potential energy 2. Specific kinetic energy

Solution:

p= gz =9.81 x 40.64=398.68 j/kg

k=0.5 v^2=0.5 x $(7.04)^2$=24.78j/kg

2.R-12 vapor at (8.77bar) and specific heat of (0.0206m^3/kg),specific enthalpy is ((201.45j/kg), calculate internal energy (e) kj/kg.

Solution:

h=e +pv

e=h-pv

p= 8.77 x 10^5 /10^3 = 877 N/m^2

e=201.45 – 877 x 0.0206=184kj/kg

3.Internal energy of a closed system increases by (120kj) whereas (150kj) of work transfer out of the system. Calculate amount of heat transferred across the boundaries .Is heat added or go out of system?

Solution:

Q-W=ΔE

Q=W+ΔE=120+150=+270

The sign is positive then the heat is added to the system.

Questions and problems

1. All of thermodynamics can be expressed in terms of four equations:

1.-------2------3------and kinetic energy.

2. Steady Flow opened System Work : dW=--------.

3.----------------Any change that a system undergoes from one equilibrium state to another.

4.show the energy equation in :1.boiler 2.compressor 3.opened heat exchanger with drawing.

5.Closed system performs follower cycles to give cooling .It takes heat by 4845kj/min and go a way 6031kj/min without change in internal energy ($\Delta E=0$) .Caculate the work done which passes the boundaries of system.

Ans. (- 1186 kj/min)

6.Air compressor recives an air at 1bar and specific volume 0.6m3/kg and pressed it at 7bar and specific volume of 0.15m3/kg .Increasing in iternal energy = 120kj/kg,and work done=240kj/kg calculate heat transfer .(assume $\Delta p=\Delta k=0$)

7.Calculate the internal energy of (R-12) vapor at pressure 28bar , enthalpy =212kj/kg and specific volume=0.00526m3/kg.

8.Calculate the enthalpy of 1kg of fluid of volume 0.28m3 at pressure of 3bar if internal energy 902kjkg

9. Examining the given thermal conductivities, we can see that the aluminum is 500 times higher than the insulator. The temperature distribution in the copper will be much less than the elastomer here. However, once the heat flux reaches a steady state, the conservation of energy dictates that the heat flux must be equal through both materials. We can equate the two rates to obtain the temperature distribution.

10.Water vapor inters to the radiator by enthalpy of 2492kj/kg and after condensation exit by enthalpy of 397kj/kg. Assume $\Delta p=\Delta g=0$ calculate the heat transferred amount to heating surrounding .discuss the result.

Lecture (12-15)

The second law of thermodynamics

2nd law of thermodynamics states "heat flows spontaneously from hot object to a cold object without assistance of external work.

1.Reversible Process (Reversibility)

Reversible process or cycle is a process carries in ideal method. This mean if process perform on system then verse its direction , if the system return to first state the process called reversible.

Causes of Irreversibility:

- External Irreversibility:

a. friction between different surfaces.
b. air resistance to moved or circulated parts.
c. heat transfer as a result of temp. difference.

- Internal Irreversibility:

a. eddy motion of working materials.
b. gases mixing inter the system.

2. 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 $Q-W=\Delta E$ $W=0$(NO change in volume)

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

FOR UNIT MASS:

$q=\Delta e=cv.\Delta T$

$cv= \Delta e / \Delta T)_v = de/dt)v$

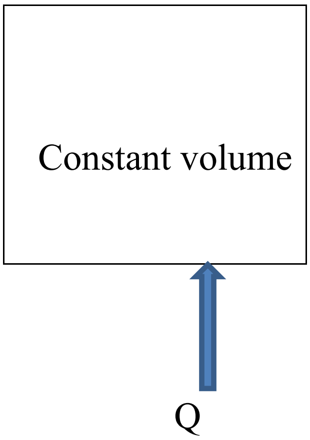


Figure.(26)

3.Specific heat at constant pressure (c_p)

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

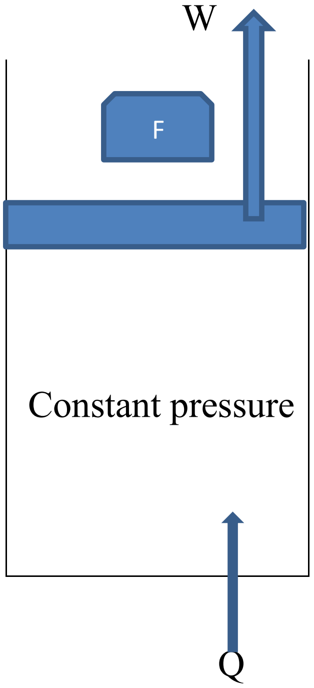


Figure.(27)

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

For unit mass:

$q = c_p.\Delta T$

Applying energy equation on closed system:

$Q=W+\Delta E$

$W=P(V2-V1)$

$\Delta E=E2-E1$

THEN:

$Q=PV2-PV1+E2-E1$

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

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

$$CP=\left.\frac{\Delta h}{\Delta T}\right]_P$$

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

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

$cp>cv$

$\gamma=cp/cv\quad>1$

4.Entropy

- Entropy is a measure of the randomness or disorder of a system

The change in entropy is:

$ds=dQ/T$ (J/°K)

by integration:

$$\Delta s={}_1^2\int dQ/T={}_1^2\int\frac{m.cv.dT}{T}\quad \text{for constant volume}$$

$S=m.cv.\ In\ T2\ /\ T1$

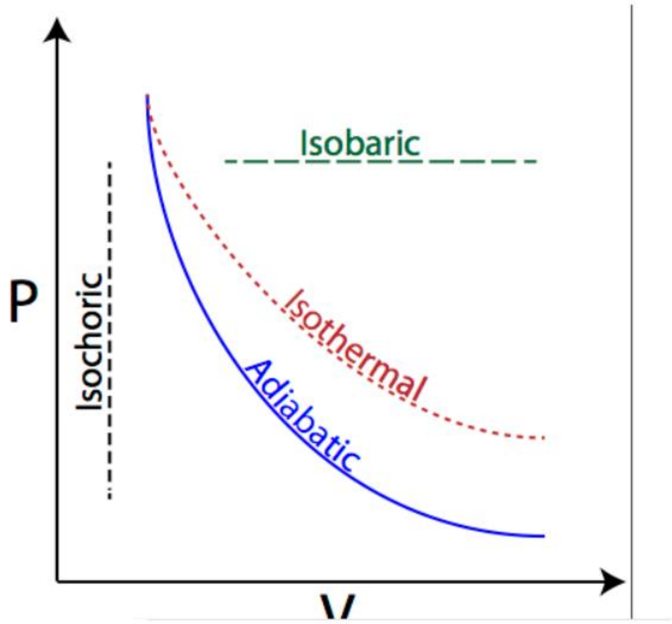
Thermodynamic processes

-Adiabatic – no heat transferred

-Isothermal – constant temp.

-Isobaric – constant pressure

-Isochoric – constant volume



Temperature. – Entropy plane

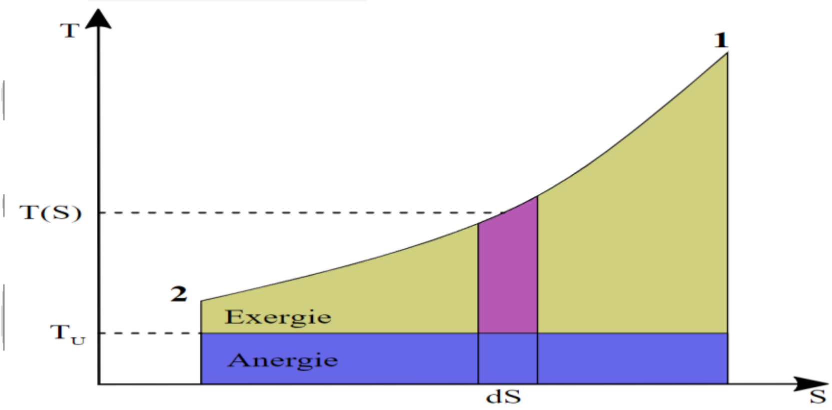


Figure.(28)

dQ=T.ds

$Q={}_1^2\int T.ds$

If the process is reversible the area under the curve is heat transferred, but if the process is irreversible the area does not represent heat transferred.

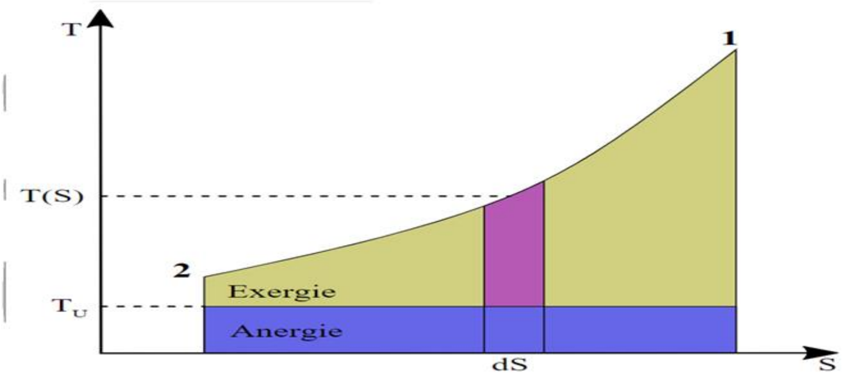


Fig.

Constant volume process on p-v and T-s plane

The reversible processes may be represent on planes for two independent properties .But irreversible processes are represented as disconnected line.

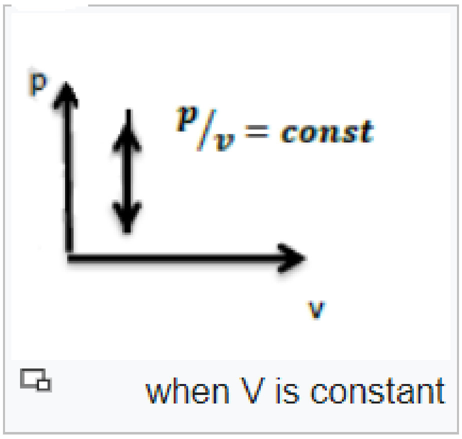


Figure. (30)

The area under the curve of T-S diagram is the amount of heat added to the system.

Q=e2-e1 j/kg

The area under the curve of P-V diagram is the work done =0

Constant pressure process on T-S and P-V planes.

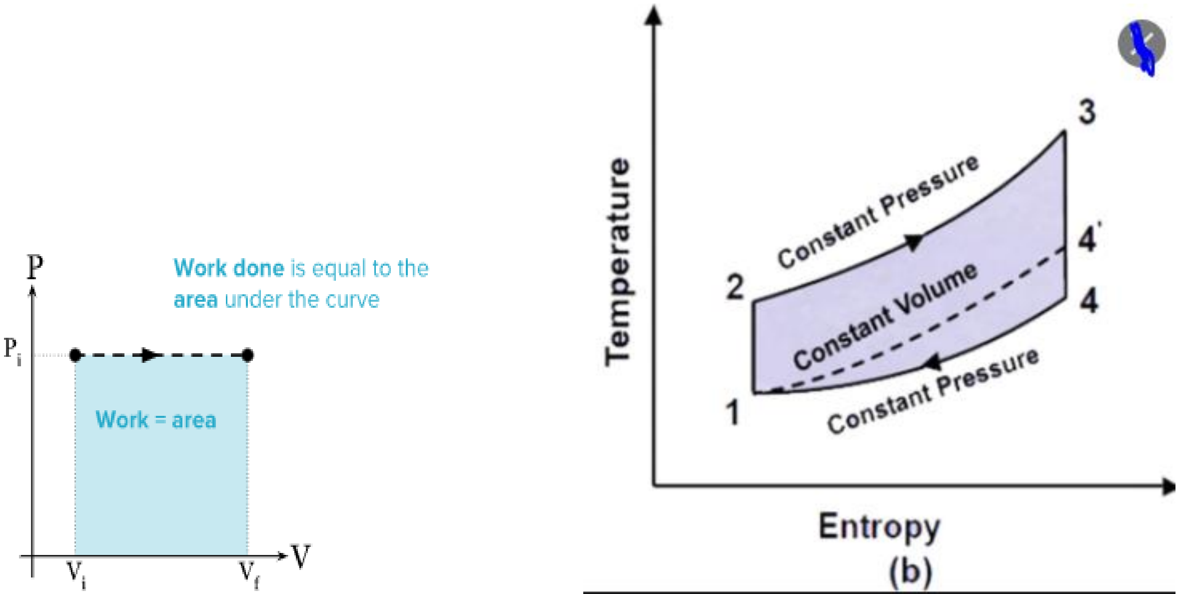


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Figure .(31)

ΔS1= cv .In T2/T1

ΔS2=cp In T2/T1

Since cp>cv then Δs2>Δs1

W=p(v2-v1) j/kg

Q=h2-h1 j/kg

Isothermal process (constant temp.) on p-v and T-s planes

On T-S plane is horizontal line and the area under it is amount of added heat to system .

Q=T.(s2-s1) j/kg

On p-v plane a curve line and the area under it is a work done from system.

$W={}_1^2\int p.dv$

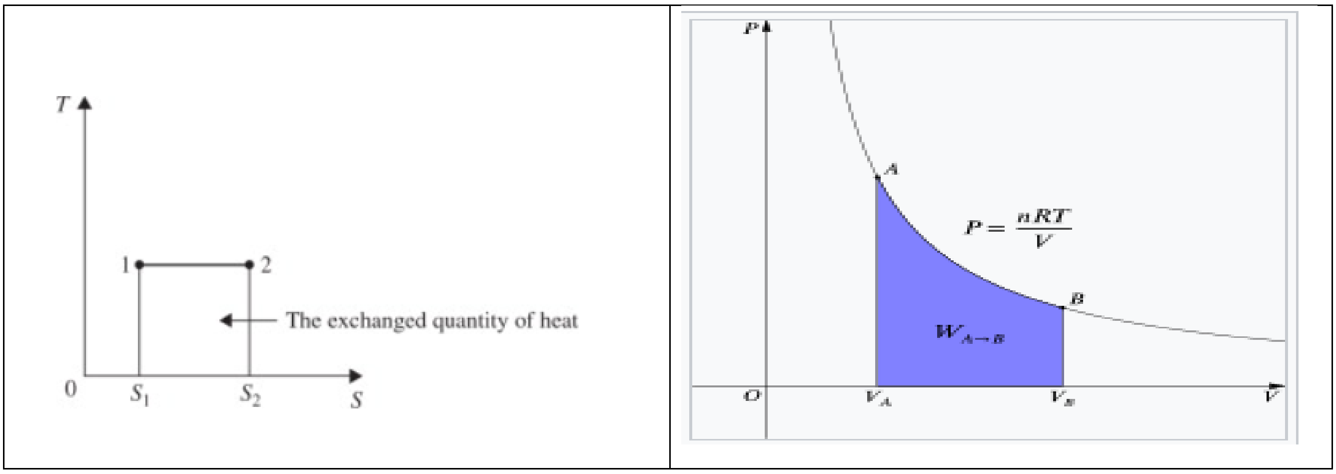


Fig.

If we reverse the direction of the two curves . what happen in the system?

Reversible adiabatic process (constant entropy) on T-S and P-V planes

Adiabatic process is that the heat transferred =0

Q=0

For reversible process Q=T.ds

0=T.ds

ds=0

s=constant

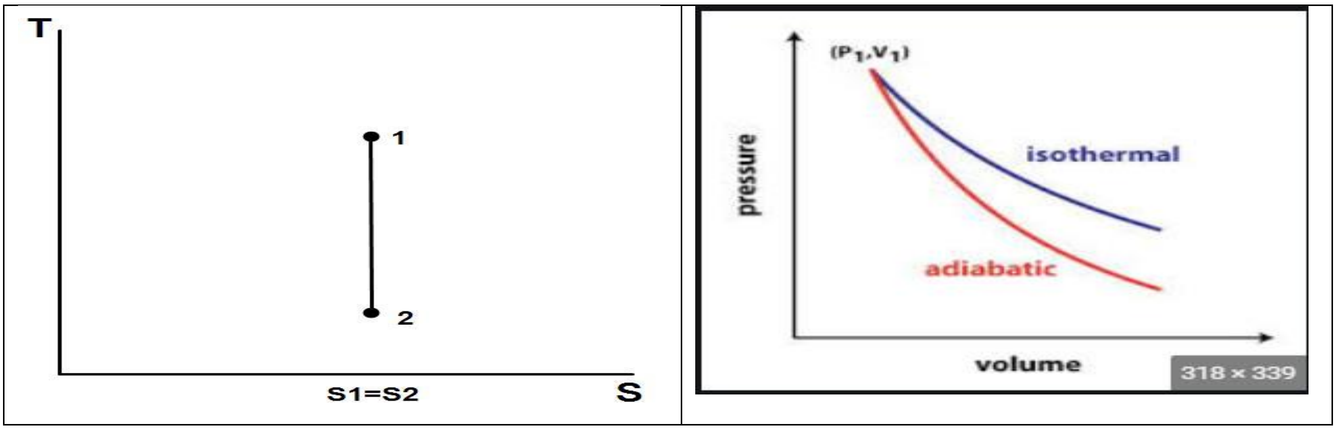


Fig.33

Solved Examples:

1.A (10 kg) mass of air was cooled inter vessel from initial temp. of (35°C) to final temp. of (20°C).Calculate the change in internal energy .(cv of air =0.718kj/kg.K)

Solution:

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

$=10 \times 0.718 \times (293 - 308)=107.7kj$

2.An electrical resistance was put in a flow air tube .If this resistance caused to in rise the temp. degree from 12°C to 27°C and the power of resistance was 1.2kw,assume constant pressure of air find the flow rate of air in kg/sec (cp of air =1.005kj/kg.K)

Solution:

$Q=m.cp.\Delta T$

$1.2=m \times 1.005 \times (300-285)=0.08kg/sec$

3.Acylinderical system with piston moves in it without friction ,if the pressure is 3bar and the air inter the cylinder was moved by tipper .The air expand from $0.04m^3$ to $0.08m^3$ find the net work . if the work by tibber equal(20)kJ

Solution:

$W1=p(v2-v1)$

$$=\frac{3\times10^{5}}{10^{3}} \times (0.08 - 0.04)$$

$=12kj$

$W2=20kj$

$W\ net= 12-20=-8kj$

4.During reversible process of constant pressure the temp. degree rises from 180°C to 270°C if cp=2.1kj/kg.K find Δs.

Solution:

$\Delta s= cp.\ In\ T2 /T1$

$$=2.1\ \mathrm{In}\ \frac{270+273}{180+273}=0.38\mathrm{kj/kg.\ K}$$

Questions and problems:

1.define the reversible process . Cite the causes of irreversibility.

2.define the cp and cv ,cite the relation between them.

3.draw the following curves:

a. Temp. – Entropy plane

b. Constant volume process on p-v and T-s plane

c. Constant pressure process on T-S and P-V planes

d. Isothermal process (constant temp.) on p-v and T-s planes

e. Reversible adiabatic process (constant entropy) on T-S and P-V planes

f. Pressure –enthalpy plane

4.A closed tank filled with air of mass 1.708kg .Calculate the added heat to rise the temp. from 27°C to 127°C (cp=1.005kj/kg.K and cv=0.718kj/kg.K)

5. 1kg of air at 20°C expands at constant pressure and the temp. rises to 90°C.Calculate the heat transferred to air.

6.A certain amount of air initial volume is 0.835m3 and its temp. 20°C expands at constant pressure of 1bar to final volume of 0.935m3 .Caculate:

a. work done from air during expansion

b. change in enthalpy in kj/kg if the final temp=55°C.

7.During braking test of electrical motor its power 13kw ,the heat transferred by friction to the surrounding at 25°C ,determine the Δs in kj/kg of air.

Lecture (16,17)

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 perform a work.

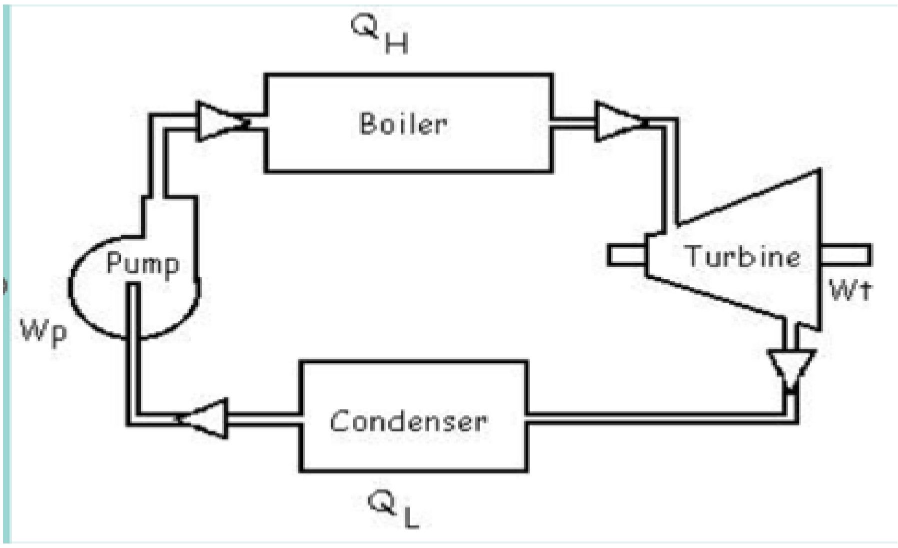


Fig.35

Work of cycle

All power generator engine and cooling devices do according to one of cycles.

Interring energy to system=exiting energy +change in stored energy (- or +).

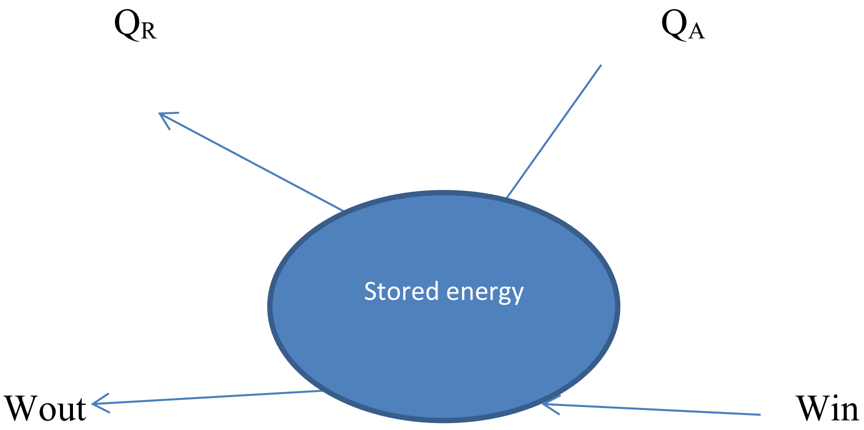


Fig 36

$Q_A + W_{in} = Q_R + Wout + \Delta$ (stored energy)

Where:

Q_A=Qadded =added heat to the system

Q_R=rejected heat from the system

Win=added work to the system.

Wout =exiting work from the system

QA - QR = Wout -Win +Δ(stored energy)

Or:

∑Q = Wnet ++Δ(stored energy)

During steady operation for any system ,the stored energy is constant then:

W=QA – QR

According to above state the 1st law of thermodynamics be:

((if no change in stored energy during periodic operation , the net energy which passes the boundaries as heat = net energy which pass the boundaries as work))

Thermal Efficiency

η_{th} =output / input

$= W / Q_A$

$$= \frac{Q_A - QR}{Q_A} = 1 - \frac{Q_R}{Q_A}$$

Carnot Cycle:

A Carnot cycle is defined as an ideal reversible closed thermodynamic cycle in which there are four successive operations involved, which are isothermal expansion, adiabatic expansion, isothermal compression and adiabatic compression. During these operations, the expansion and compression of substance can be done up to the desired point and back to the initial state.

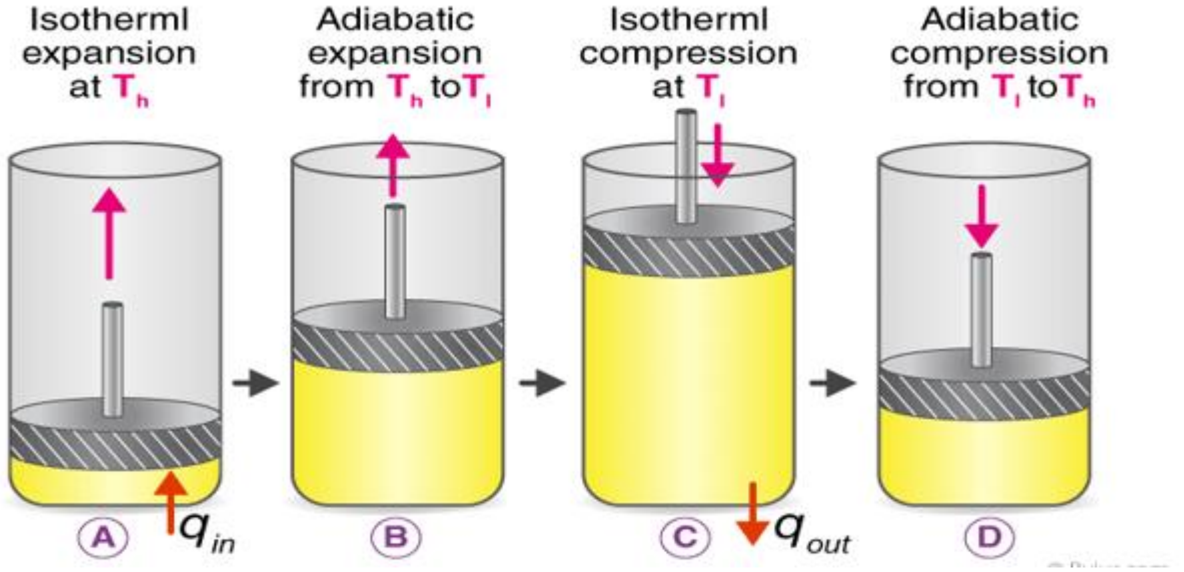


Fig. (37)

Following are the four processes of the Carnot cycle:

- In (a), the process is reversible isothermal gas expansion. In this process, the amount of heat absorbed by the ideal gas is q_{in} from the heat source, which is at a temperature of T_h. The gas expands and does work on the surroundings.
- In (b), the process is reversible adiabatic gas expansion. Here, the system is thermally insulated, and the gas continues to expand and work is done on the surroundings. Now the temperature is lower, T_l.
- In (c), the process is reversible isothermal gas compression process. Here, the heat loss q_{out} occurs when the surroundings do the work at temperature T_l.
- In (d), the process is reversible adiabatic gas compression. Again the system is thermally insulated. The temperature again rises back to T_h as the surrounding continue to do their work on the gas.

Steps involved in a Carnot Cycle

For an ideal gas operating inside a Carnot cycle, the following are the steps involved:

Step 1:

Isothermal expansion: The gas is taken from P_1, V_1, T_1 to P_2, V_2, T_2. Heat Q_1 is absorbed from the reservoir at temperature T_1. Since the expansion is isothermal, the total change in internal energy is zero, and the heat absorbed by the gas is equal to the work done by the gas on the environment.

Step 2:

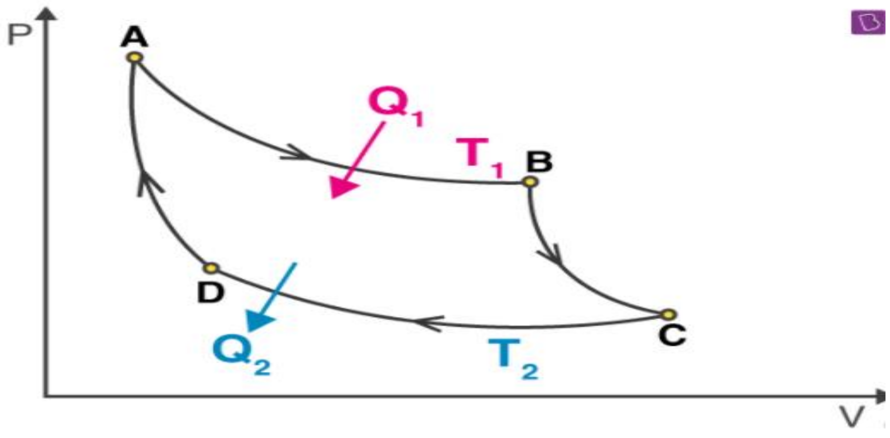
Adiabatic expansion: The gas expands adiabatically from P_2, V_2, T_1 to P_3, V_3, T_2.

Step 3:

Isothermal compression: The gas is compressed isothermally from the state (P_3, V_3, T_2) to (P_4, V_4, T_2).

Step 4:

Adiabatic compression: The gas is compressed adiabatically from the state (P_4, V_4, T_2) to (P_1, V_1, T_1).



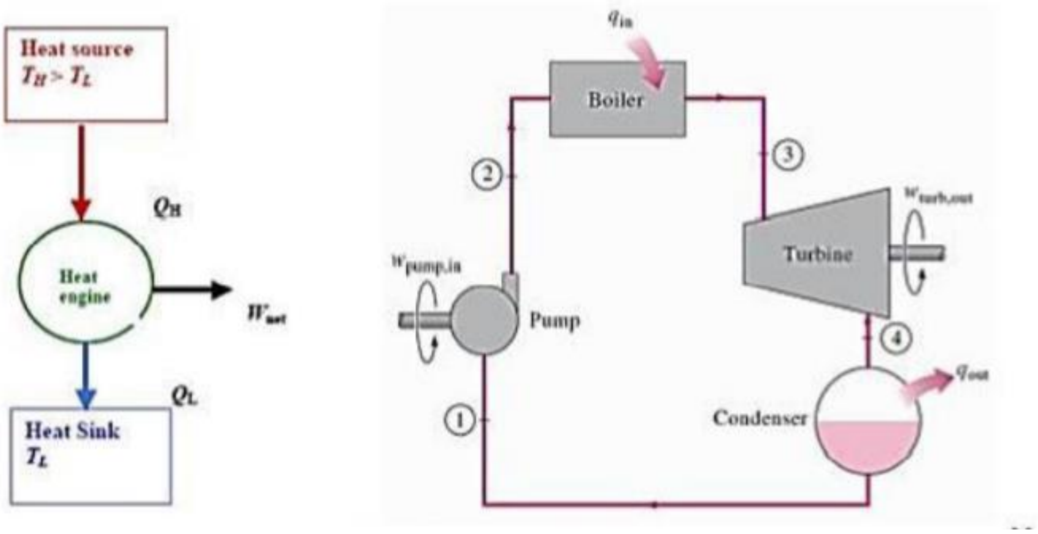


Fig.38

QA=T1(Sb – Sa)------------------------------1

QR=T2 (Sc –Sd) = T2(Sb – Sa)--------------2

But :

W=QA – QR

=T1(Sb –Sa)- T2 (Sb-Sa)

=(T1-T2) .(Sb –Sa)

ζth=W /QA

ζ= 1- (QR /QA)

SUB. From 1 and 2

ζ th= 1- (T1/T2)

EX: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

ζ= W /QA

= 780/2380=0.328

EX:carnot heating engine the high temp. of it 1000C and low temp.=200C and amont of gaied heat at high temp.=6000kj/min.Find the power of an engine.

For any cycle :

ζth=1-(QR/QA)

for carnot cycle: ζth=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

Reversed Carnot Cycle

If the direction of Carnot cycle is reversed the heat transfer in opposite direction occurs.Tadded heat process will be rejected process and the process which need work from system becomes give work to system.

The reversed cycles are used for two purposes:

1.to give cooling effect and the machine which works by this cycle called refrigerator.

2.to give heating effect and the machine called heat pump.

Work=work is done on system.

Heat transfers from heat storage.

The processes of this cycles are shown in fig. below.

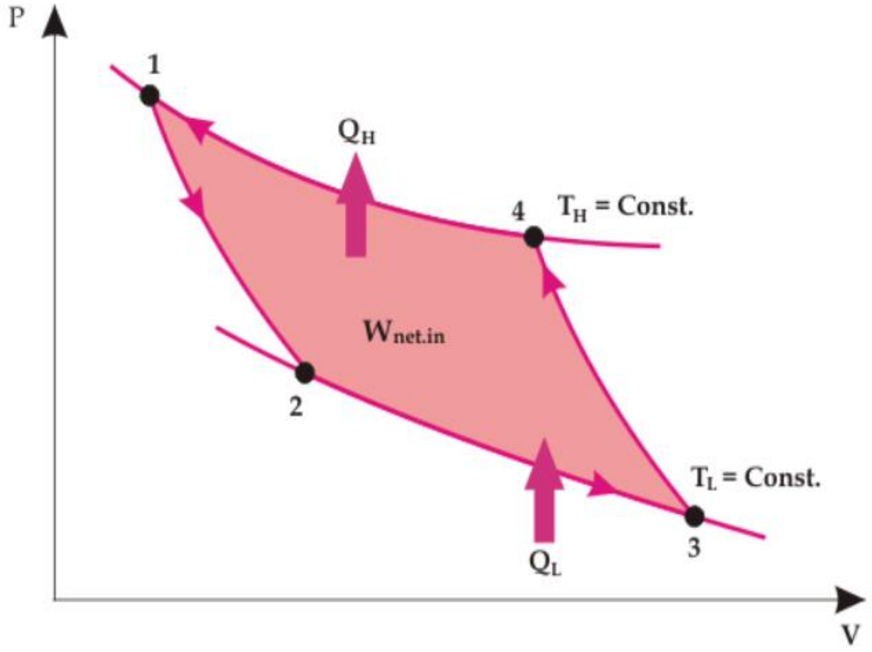


Figure.39

1.ab : expansion with constant entropy the temp. degree from T1 to T2

2.bc :heat added to work substance reversibility with constant temp.

3. cd : the medium is pressed with constant entropy to T1 temp.

4.da :heat is rejected at T1 to hot object.

The cooling effect represent by (bcfe) area on (T-S) plane and for heating the area (adfe) is the rejected heat .

In the cooling case:

Performance factor=cooling effect / net work

$$COP = QA\ /\ W = \frac{T2}{T1\ -\ T2}$$

IN the case of heating:

COP=QR /W

$$COP = \frac{T1}{T1-T2}$$

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 =$17\text{x}10^{6}$kj/hr.Find the network for station.

Lecture (18-23)

Ideal Gases

1. Introduction

Ideal gases are a simplified model used in thermodynamics and fluid mechanics to describe the behavior of gases under conditions where intermolecular forces and molecular volumes are negligible. Although no real gas is perfectly ideal, many gases (e.g., air, nitrogen, oxygen) behave nearly ideally at **low pressures** and **moderate temperatures**.

2. Assumptions of the Ideal Gas Model

The ideal gas approximation relies on the following assumptions:

1. **Gas molecules have no volume** (point particles).
2. **No intermolecular forces** exist between the molecules.
3. **Collisions are perfectly elastic**.
4. **Molecules are in constant, random motion**.
5. The **duration of collisions** is negligible compared to the time between collisions.

These assumptions allow gas behavior to be predicted using simple relations.

3. Ideal Gas Equation of State

The primary equation describing ideal gases is:

$$PV = nRT$$

Where:

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

An equivalent form using mass:

$$PV = mR_{\text{specific}}T$$

$$R_{\text{specific}} = \frac{R}{M}$$

Where $M$is molar mass (kg/mol).

4. Relationships During Thermodynamic Processes

For an ideal gas, specific relationships hold:

4.1 Isothermal Process (T = constant)

$$PV = \text{constant}$$

4.2 Isobaric Process (P = constant)

$$\frac{V}{T} = \text{constant}$$

4.3 Isochoric Process (V = constant)

$$\frac{P}{T} = \text{constant}$$

4.4 Adiabatic Process (Q = 0)

$$PV^{\gamma} = \text{constant}$$
$$TV^{\gamma-1} = \text{constant}$$
$$\frac{T^{\gamma}}{P^{\gamma-1}} = \text{constant}$$

Where $\gamma = \frac{C_p}{C_v}$.

5.Specific Heats

For ideal gases:

$$C_p - C_v = R_{\text{specific}}$$

And:

$$\gamma = \frac{C_p}{C_v}$$

Specific heats depend only on temperature for ideal gases.

6. Applications in Engineering

Ideal gas relations are widely used in:

- **Internal combustion engines**
- **Gas turbines**
- **Refrigeration systems**
- **Aviation and aerospace**
- **Heat transfer calculations**
- **Mass and energy balances**

Boyle's Law (قانون بويل)

Definition:
At **constant temperature (T = constant)**, the **pressure of a gas is inversely proportional** to its volume.

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

Or:

$$PV = \text{constant}$$

Mathematical Form (between two states):

$$P_1V_1 = P_2V_2$$

Graph:

- **P–V Curve:** A hyperbola (downward curve).
- As **pressure increases**, **volume decreases**, and vice versa.

Physical Interpretation:

If you compress a gas (reduce its volume) without changing its temperature, its pressure increases because gas molecules collide with the container walls more frequently.

Real-life Applications:

- Syringes
- Pistons in engines
- Scuba diving tanks
- Hydraulic systems

2. Charles's Law (قانون شارل)

Definition:
At **constant pressure (P = constant)**, the **volume of a gas is directly proportional** to its absolute temperature (in Kelvin).

$$V \propto T$$

Or:

$$\frac{V}{T} = \text{constant}$$

Mathematical Form (between two states):

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

Important Condition:

Temperature **must be in Kelvin** (K = °C + 273).

Graph:

- **V–T Curve:** A straight line.

- As **temperature increases**, the **volume increases**.

Physical Interpretation:

Heating a gas causes molecules to move faster, increasing their kinetic energy. At constant pressure, the gas expands (volume increases).

Real-life Applications:

- Hot air balloons
- Car tires increasing pressure in summer
- Air conditioning and refrigeration (gas expansion)

3. Combined Gas Equation (للمقارنة بين القوانين)

Often Boyle's and Charles's laws are combined:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

This is useful when **pressure, volume, and temperature** all change.

4. Summary Table

Law	Conditions	Relationship	Formula
Boyle's Law	T = constant	$P \propto 1/V$	$P_1V_1 = P_2V_2$
Charles's Law	P = constant	$V \propto T$	$V_1/T_1 = V_2/T_2$

Problem 1:A gas occupies **3.0 L** at a pressure of **100 kPa**. If the pressure increases to **150 kPa**, what is the new volume?

Solution

Given:

$$P_1 = 100\,kPa$$
$$V_1 = 3.0\,L$$
$$P_2 = 150\,kPa$$

Apply Boyle’s Law:

$$
\begin{aligned}
&P_1V_1 = P_2V_2\\
&100 \times 3.0 = 150 \times V_2\\
&300 = 150V_2\\
&V_2 = \frac{300}{150} = 2.0\ L
\end{aligned}
$$

Answer: The new volume = 2.0 L

Problem 2 – Boyle’s Law

A gas has a volume of **5.0 L** at **1.2 atm**. If the volume decreases to **3.0 L**, what is the new pressure?

Solution

Given:

$$
\begin{aligned}
P_1 &= 1.2\ atm\\
V_1 &= 5.0\ L\\
V_2 &= 3.0\ L
\end{aligned}
$$

$$
\begin{aligned}
&P_1V_1 = P_2V_2\\
&1.2 \times 5.0 = P_2 \times 3.0\\
&6.0 = 3.0P_2\\
&P_2 = \frac{6.0}{3.0} = 2.0\ atm
\end{aligned}
$$

Answer: The new pressure = 2.0 atm

2. Charles’s Law – Solved Problems

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \text{ (Pressure constant)}$$

Temperature must be in Kelvin:

$$T(K) = T(^{\circ}C) + 273$$

Problem 1 – Charles's Law

A gas has a volume of **2.0 L** at **25°C**. What is the volume at **75°C**?

Solution

Convert temperatures to Kelvin:

$$T_1 = 25 + 273 = 298\,K$$
$$T_2 = 75 + 273 = 348\,K$$

Apply Charles's Law:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$
$$\frac{2.0}{298} = \frac{V_2}{348}$$
$$V_2 = 2.0 \times \frac{348}{298}$$
$$V_2 \approx 2.34\,L$$

Answer: The new volume ≈ 2.34 L

Problem 2 – Charles's Law

A gas has a volume of **3.5 L** at **10°C**. What will its volume be at **60°C**?

Solution

Convert temperatures:

$$T_1 = 10 + 273 = 283\,K$$
$$T_2 = 60 + 273 = 333\,K$$

Apply the law:

$$V_2 = 3.5 \times \frac{333}{283}$$
$$V_2 \approx 4.12\ L$$

Answer: The new volume ≈ 4.12L

Lecture (25)

The vapor Compression cycle

The **Vapor Compression Refrigeration Cycle involves four components:** compressor, condenser, expansion valve/throttle valve and evaporator. It is a compression process, whose aim is to raise the refrigerant pressure, as it flows from an evaporator. The high-pressure refrigerant flows through a condenser/heat exchanger before attaining the initial low pressure and going back to the evaporator. A more detailed explanation of the steps is as explained below.

Step 1: Compression

The refrigerant (for example R-717) enters the compressor at low temperature and low pressure. It is in a gaseous state. Here, **compression takes place to raise the temperature and refrigerant pressure**. The refrigerant leaves the compressor and enters to the condenser. Since this process requires work, an electric motor may be used. Compressors themselves can be scroll, screw, centrifugal or reciprocating types.

Step 2: Condensation

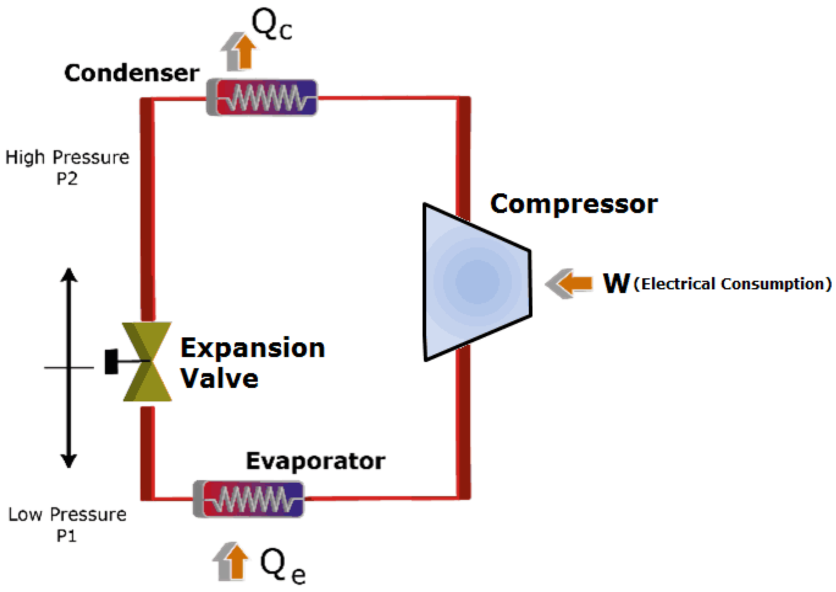
The condenser is essentially a heat exchanger. **Heat is transferred from the refrigerant to a flow of water.** This water goes to a cooling tower for cooling in the case of water-cooled condensation. Note that seawater and air-cooling methods may also play this role. As the refrigerant flows through the condenser, it is in a constant pressure. One cannot afford to ignore condenser safety and performance. Specifically, pressure control is paramount for safety and efficiency reasons. There are several pressure-controlling devices to take care of this requirement

Step 3: Throttling and Expansion

When the refrigerant enters the throttling valve, it expands and releases pressure. **Consequently, the temperature drops at this stage.** Because of these changes, the refrigerant leaves the throttle valve as a liquid vapor mixture, typically in proportions of around 75 % and 25 % respectively. Throttling valves play two crucial roles in the vapor compression cycle. First, they maintain a pressure differential between low- and high-pressure sides. Second, they control the amount of liquid refrigerant entering the evaporator.

Step 4: Evaporation

At this stage of the Vapor Compression Refrigeration Cycle, the refrigerant is at a lower temperature than its surroundings. Therefore, **it evaporates and absorbs latent heat of vaporization**. Heat extraction from the refrigerant happens at low pressure and temperature. Compressor suction effect helps maintain the low pressure. There are different evaporator versions in the market, but the major classifications are liquid cooling and air cooling, depending whether they cool liquid or air respectively.



Boilers, Types and Classification

1- A Boiler is a closed vessel in which water or other suitable liquid is heated to generate steam or vapour.The steam/vapour is then exited and is used for various purposes like heating applications (water heating, central heating), boiler based power generation or even for cooking and other purposes which could be domestic or industrial.

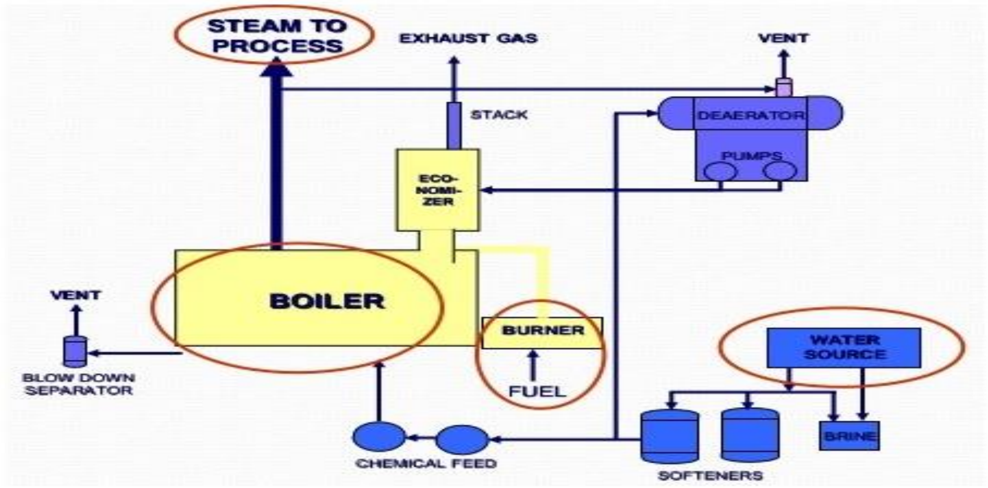
It basically follows the concept of a pressure cooker but in a bigger way. The boiler concept is used across places from domestic purposes to industrial activities. The fluid is generally incorporated into a system and it works to provide steam through connecting combustion products and the water.

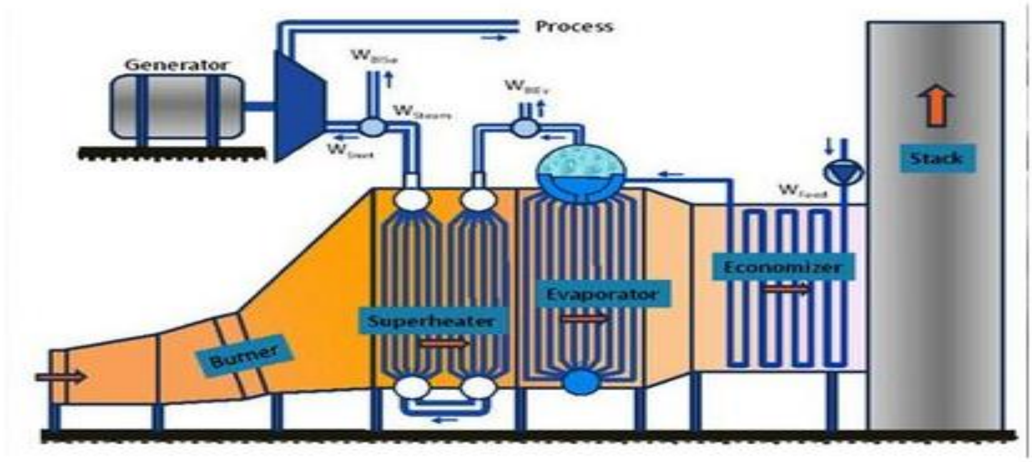
There are many types of boilers based on their uses. While domestic boilers are small and are used for daily household chores, the industrial boilers today play a magnanimous role in the production process.

Industrial boilers can also be environment friendly if the fuel used is natural gas or other types of non-harming fuels. They not only deliver the desired performance but also help industries to keep a check on the toxic emissions that are harming the environment in the worst possible way.

Ever thought of enhancing your production efficiency without wasting money on electric energy? Did you know **Industrial Boilers** are powering many industries? Did you know Industrial Boilers are of various types and have different utilities? If not, here’s everything that you must understand about **Industrial Boilers.**

The importance of **Industrial Boilers** is not unknown to manufacturing companies. They use **industrial boilers** for their many advantages; one of them is saving the cost of using electric energy for the entire process. Electric power becomes extremely expensive if used on a large scale, but **Industrial Boilers** help in keeping the extra expense in check. Boilers offer maximum efficiency and minimum menace like fewer hassles of handling and depending on electric energy.





Parts of Industrial Boiler

2- Necessary Parts of an Industrial Boiler

Burner: The burner is the starter of the combustion reaction inside the boiler. There is a mechanism that sends the message to start the process of producing heat. A nozzle in the burner that turns the fuel pumped from the fuel source ignites it to create the combustion.

Combustion Chamber: The combustion chambers are made of cast iron and can have a temperature of several hundred degrees in minutes. It burns the fuel and generates heat which is transferred to the heat exchanger.

Heat Exchanger: Also called the economiser, it is responsible for increasing the efficiency of the boiler. The heat exchanger is placed before the air heater in the fuel gas path.

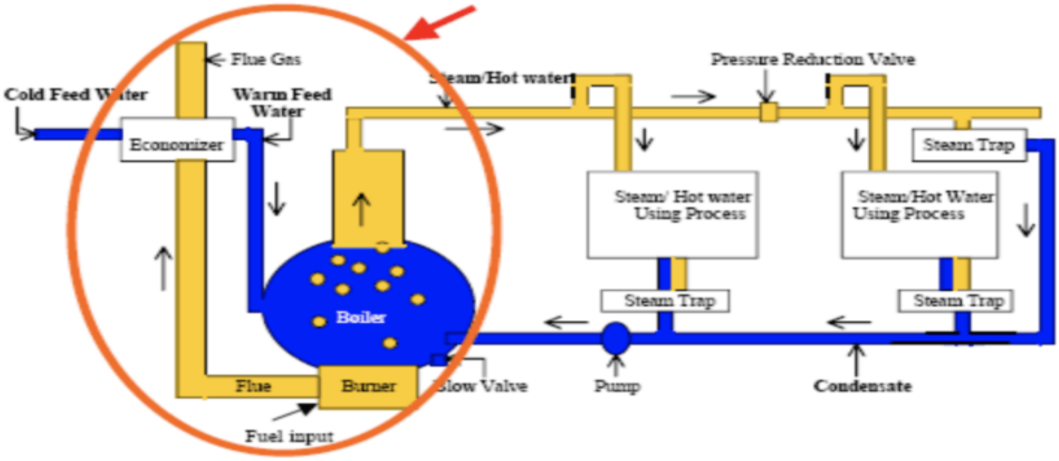
Steam Drum and Mud Drum: The steam drum collects the steam while the mud drum is placed beneath the steam drum and collects the solid which is removed periodically.

3- Fuel Sources used in boilers

From coal, kerosene to natural gases, the fuel can be of various types.

4- How does Industrial Boiler work?

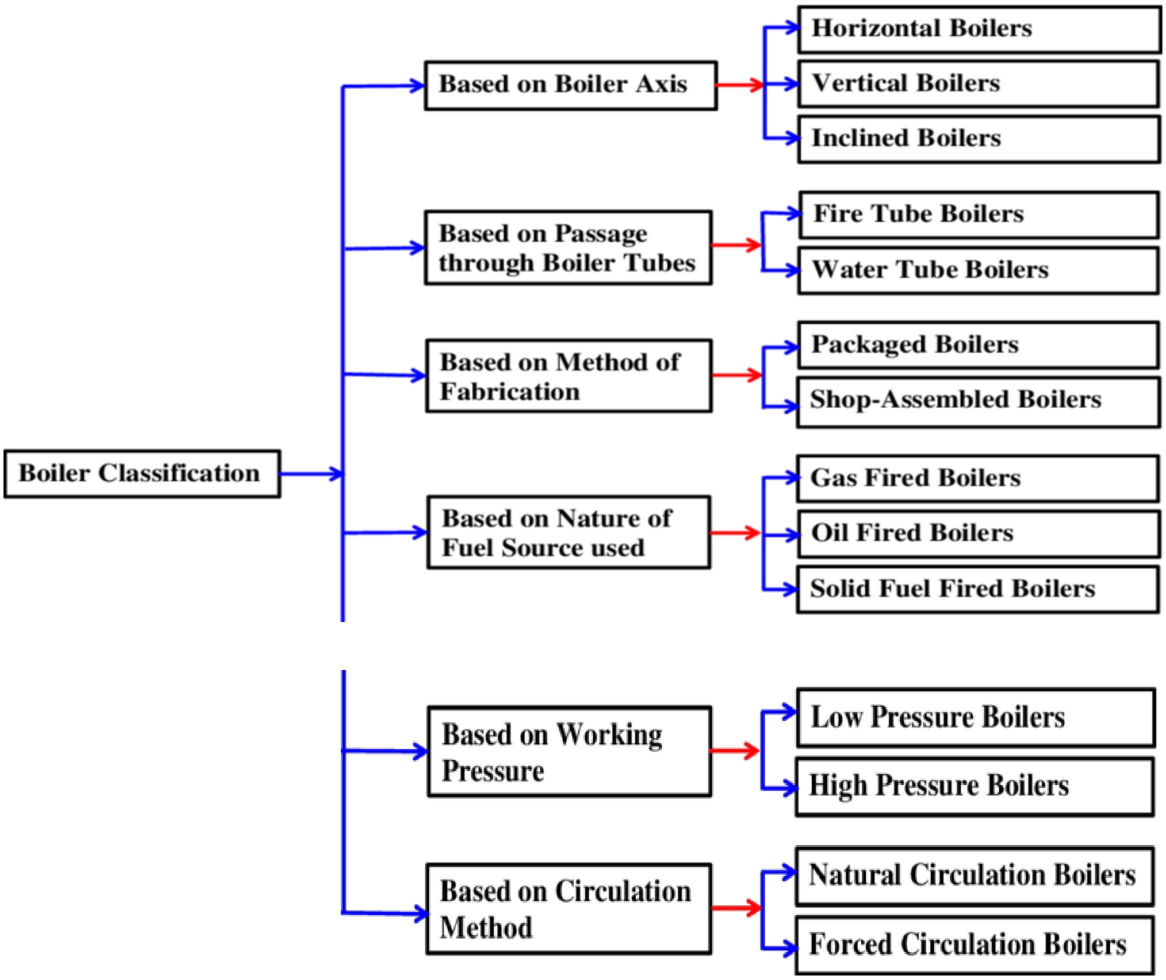
Industrial Boilers are water-containing vessels that generate heat with the help of a fuel source. It is then transferred to various tubes connecting to the various industrial equipment. The steam energy is used for running the machinery, giving industries a cost-effective way of powering their production.



Basic Functioning of Industrial Boiler

5- Types of Boilers:

The type of boiler you need will depend on your production requirements. Different types of boilers serve different purposes. The classifications are based on the amount of pressure it can create, the capacity to hold the fuel and water and the type of fuel one will be using.

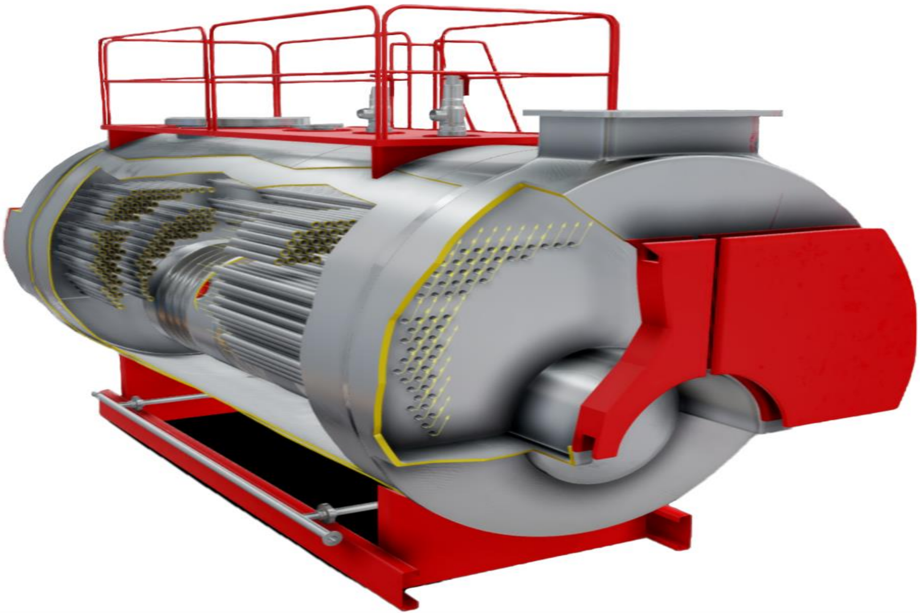


6- Boiler Classification

Fire Tube Boiler

Fire Tube Boilers are used widely in small and medium-sized industries. They are factory-made and come with pumps and control systems, all set to start operations as soon as connected to a fuel and water supply. They are often called the packaged boilers. These kinds of boilers are befitting for low to medium pressure steam requirements. Here, the combustion gases flow outside the water pipes.

They also have the capacity to produce steam with up to 2200 horsepower pressure but comes with a tremendous risk of explosion. It might be a little expensive for companies that do not need steam energy at all times.



Fire Tube Boiler

Water Tube Boiler

The Water Tube Boiler is multifaceted. They are significantly different from the fire tube boilers. The two types differ in the ways they function. Water Tube boilers are usually used in large manufacturing factories where there is a need for high-pressure requirement. There is a circulation of water between the mud and the steam drum, ensuring more control over the circulation by density differences.

They are perfect if you often need to change the steam quantity because of their lower water content. The water tube boilers are often built on sites and are usually not available in a packaged unit.

Water Tube Boiler

Electric Boiler

The most popular boiler type. It is incredibly efficient and environment friendly as it does not require any kind of fossil fuel and hence leaves a smaller carbon footprint. The best part is unlike other boilers; there are no exhaust fumes. Rural users use them widely as the installation cost is lower, less noisy and requires less space than the others as well.

Though it looks like it is the most advantageous, it has its cons as well. It runs on electricity and involves heavy electricity consumption. Electric energy is not at all cost-effective.

Electric Boiler

Condensing Boiler

Condensing boilers are different and work differently. They use natural gases and two heat exchangers, making it the most efficient boiler. They extract heat from the exhaust or waste gases. This helps in reducing the wastage. They are capable of achieving 98% thermal efficiency and are now replacing other boilers for central heating. Many HVAC experts are of the opinion that this is the most sustainable boiler as its two heat exchangers help in the reduction of wastage and expenditure.

Condensing Boiler

Oil Boiler

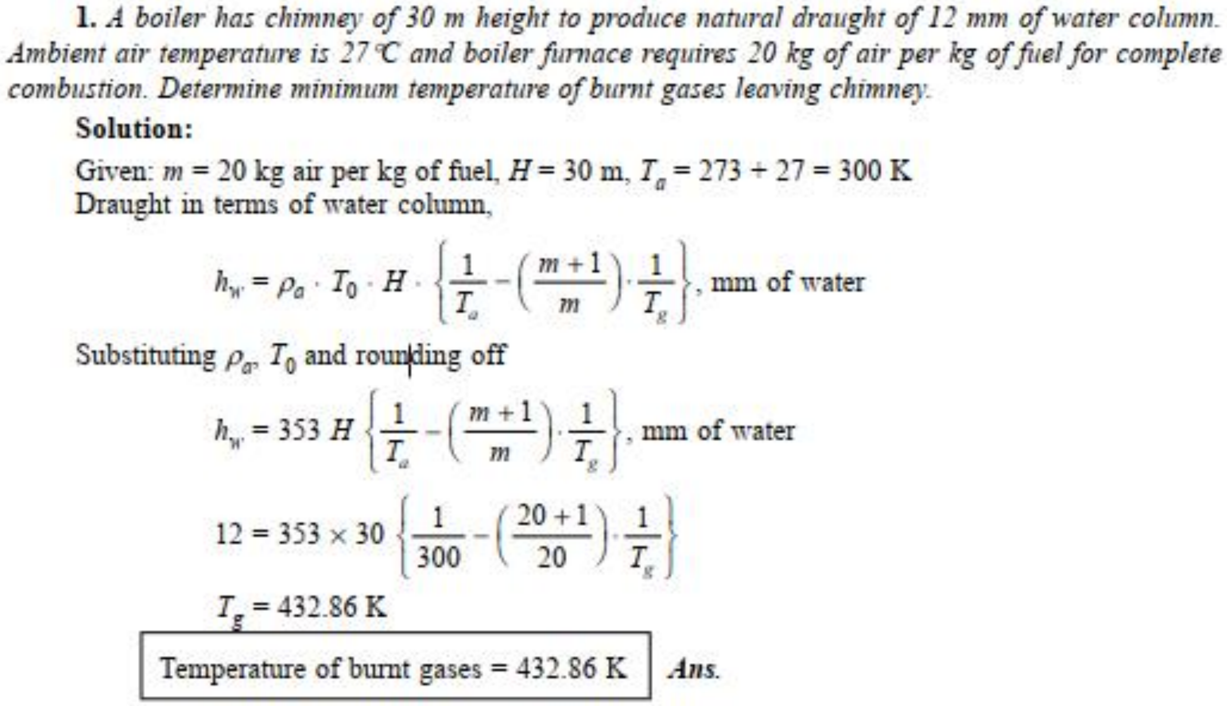
The efficiency of oil-fired boilers is usually 86% while oil-condensing boilers are 90% or more efficient. The fuel used here is not natural gas but oil. The oil is ignited in the combustion chamber, and then the heat exchanger heats the cold water. It is usually used in the household to get warm water in showers, taps or radiators.

Oil Boiler

Natural Gas Boiler

Natural Gas Boilers, as the name suggests, use natural gas as its fuel. A temperature gauge regulates it, and a thermoelectric device is used to reduce fuel wastage. The gas lights up the pilot which heats the coils in the boiler. Rural areas use propane gas most of the time.

It is essential to understand what your needs are, and this classification might be of help. It is always advisable to have a detailed discussion with experts from boiler manufacturers like Thermax or others. This will ensure you save your money and get the right one. Too small or too big, what type of fuels and more of such information you must always attain first before making a purchase decision.



1. *A boiler has chimney of 30 m height to produce natural draught of 12 mm of water column. Ambient air temperature is 27°C and boiler furnace requires 20 kg of air per kg of fuel for complete combustion. Determine minimum temperature of burnt gases leaving chimney.*

Solution:

Given: $m = 20$ kg air per kg of fuel, $H = 30$ m, $T_a = 273 + 27 = 300$ K

Draught in terms of water column,

$$h_w = \rho_a \cdot T_0 \cdot H \cdot \left\{ \frac{1}{T_a} - \left(\frac{m+1}{m} \right) \cdot \frac{1}{T_g} \right\}, \text{ mm of water}$$

Substituting ρ_a, T_0 and rounding off

$$h_w = 353\, H \left\{ \frac{1}{T_a} - \left(\frac{m+1}{m} \right) \cdot \frac{1}{T_g} \right\}, \text{ mm of water}$$

$$12 = 353 \times 30 \left\{ \frac{1}{300} - \left(\frac{20+1}{20} \right) \cdot \frac{1}{T_g} \right\}$$

$$T_g = 432.86 \text{ K}$$

$$\boxed{\text{Temperature of burnt gases} = 432.86 \text{ K}} \quad \textit{Ans.}$$

2. *Determine the height of chimney required in a boiler having natural draught equivalent to 20 mm of water. The flue gases are at temperature of 300 °C, atmospheric air temperature is 27 °C and 18 kg air per kg of fuel is required in boiler.*

Solution:

Given: m = 18 kg air per kg of fuel, h_w = 20 mm, T_a = 300K, T_g = 573 K

Draught in terms of water column,

$$h_w = 353\,H\left\{\frac{1}{T_a} - \left(\frac{m+1}{m}\right)\cdot\frac{1}{T_g}\right\}\text{mm of water}$$

$$20 = 353\,H\left\{\frac{1}{300} - \left(\frac{18+1}{18}\right)\cdot\frac{1}{573}\right\}$$

$$H = 37.99\text{ m}$$

$\boxed{\text{Height of chimney} = 37.99\text{ m}}$ ***Ans.***

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