ME 201

Mechanical Engineering Fundamentals

Introduction to Thermodynamics

Md. Abdul Hamid

Thermodynamics

1. Thermodynamics: Science of energy.

2. Thermodynamics (Heat engineering) basically deals with :
    1. Internal Energy
    2. Enthalpy
    3. Entropy

3. Thermodynamics also deals with various thermodynamic processes and cycles.

Some terminology

Internal Energy: (u)

* Sum of all microscopic forms of energy
* Related to molecular structure and degree of molecular activity.
* Can be viewed as sum of kinetic and potential energy.

Enthalpy: (h)

* Sum of Internal energy and work done to create the volume.
* So, $h = u + pv$
* Absolute enthalpy measurement is not possible, only the change in total enthalpy is measurable.

Some terminology

Entropy: (*s*)

* Measure of disorder and randomness.
* Entropy of a system never decreases.

Understanding of u, h and s

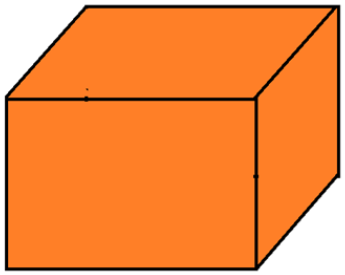


Fig: 1

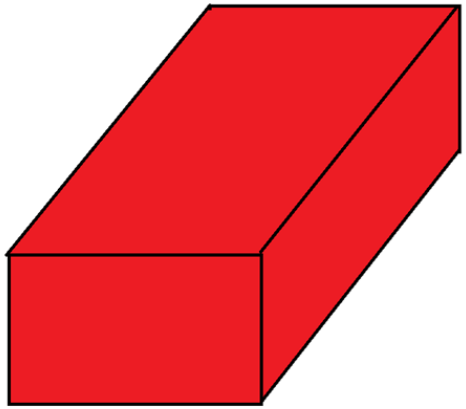


Fig: 2

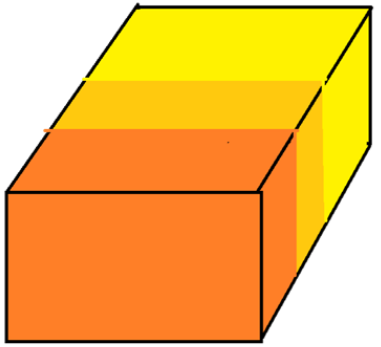


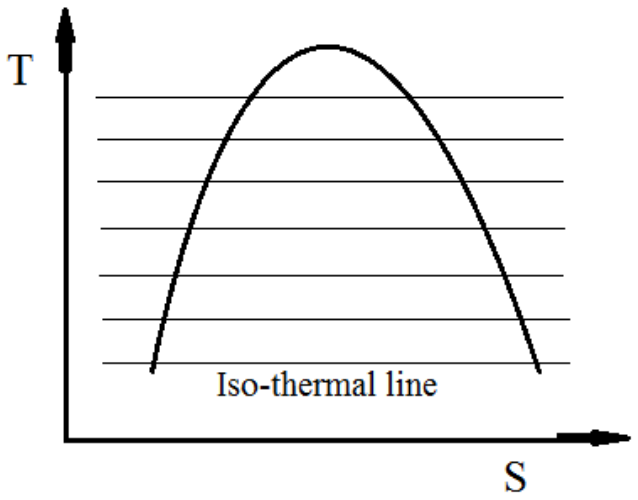
Fig: 3

Thermodynamic Process

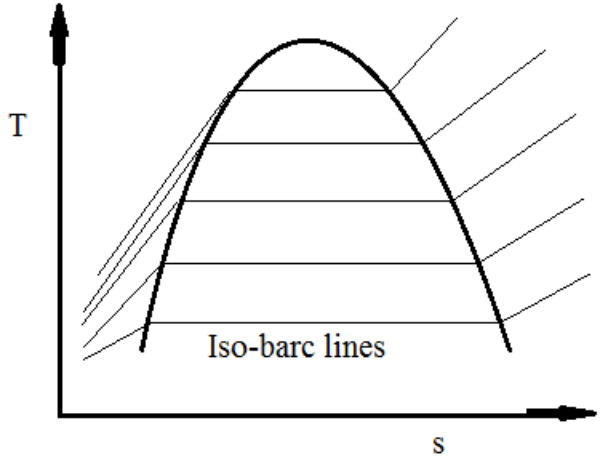
1. Iso-thermal Process (T = constant)
2. Iso-baric Process (P = constant)
3. Iso-chronic Process (V = constant)
4. Isentropic Process (s = constant)
5. Iso-enthalpic process (h = constant)

Thermodynamic Process

1. <u>Iso-thermal Process (T = constant)</u>
   * No change in temperature
   * Heat can be removed or added
   * Represented by horizontal lines in T—s diagram

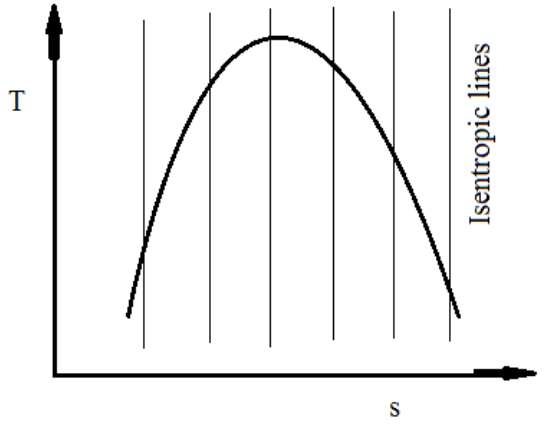


2. Iso-baric Process (P = constant)
   * No change in pressure
   * Heat can be removed or added
   * Represented by Zigzag lines in T—s diagram

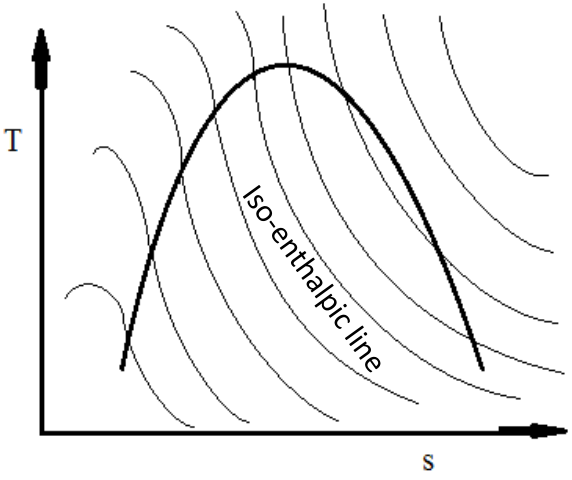


Thermodynamic Process

3. Isentropic Process (s = constant)
   * No change in entropy
   * Heat can't be removed or added
   * Represented by vertical lines in T—s diagram



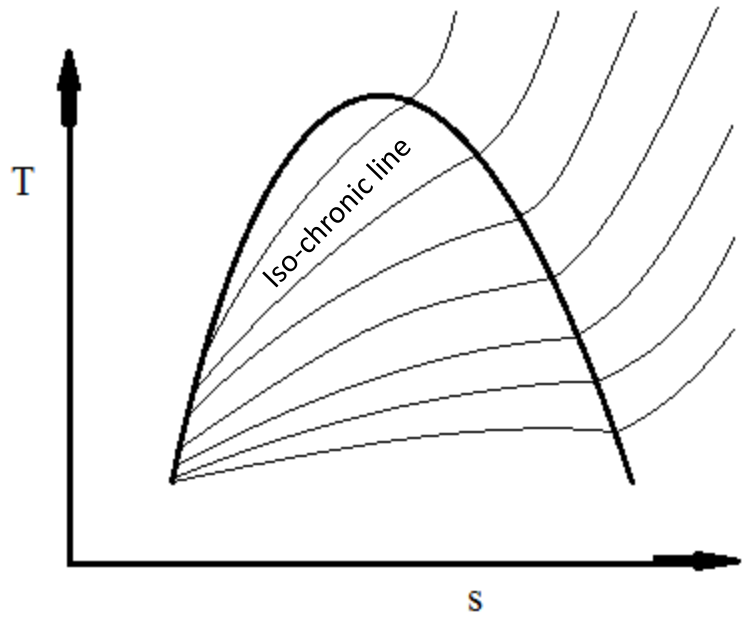
4. Iso-enthalpic Process (h = constant)
   * No change in enthalpy
   * Heat or work can be removed or added
   * Represented by curved lines in T—s diagram



Thermodynamic Process

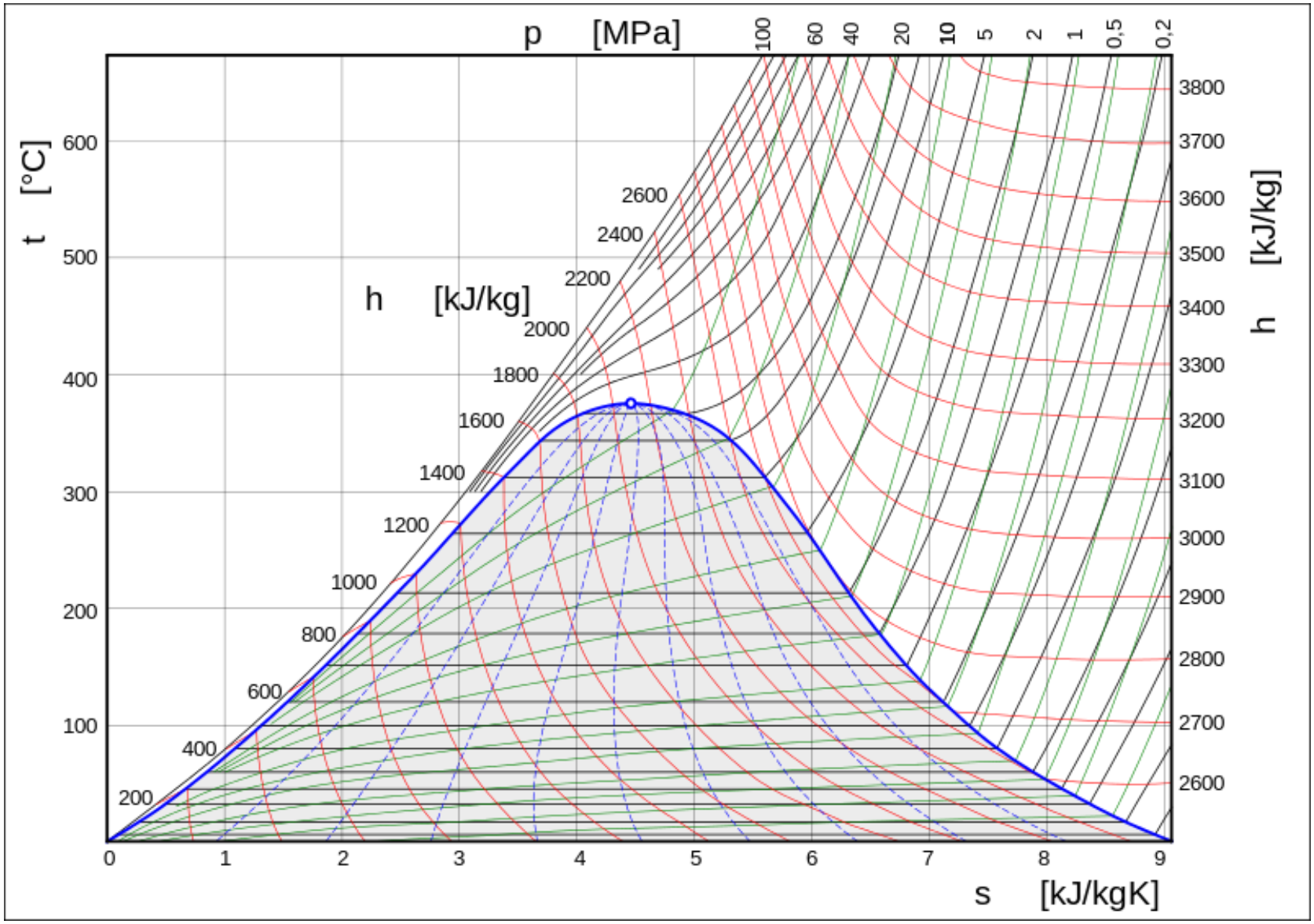
5. Iso-chronic Process (V = constant)

* No change in volume
* Heat can be removed or added
* Represented by curved lines in T—s diagram
* In sub-cooled liquid region usually there is no change in volume,



So no one worry about the iso-chronic lines in sub-cooled liquid region

Complete T—s diagram of water



?

Mechanical Engineering Fundamentals

Prepared by:
Md. Abdul Hamid

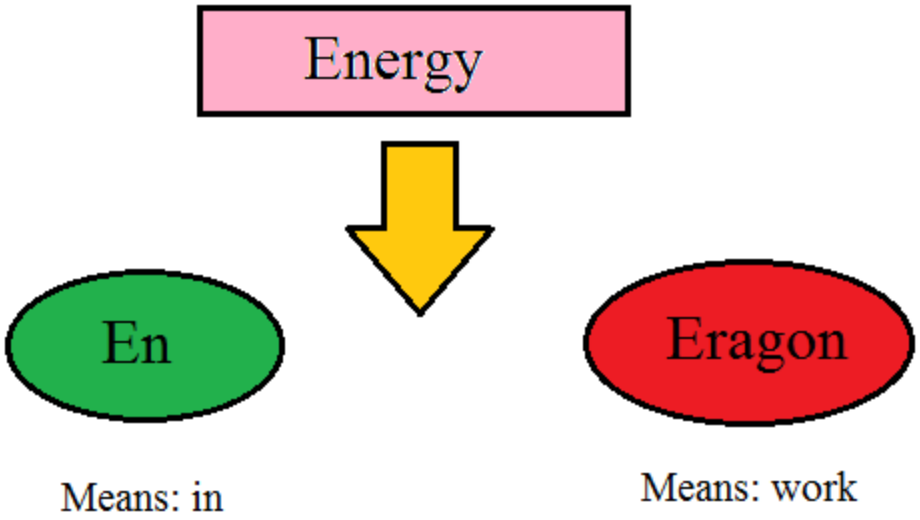
Mechanical Engineering

1. Engineering is “Applied Science”.
2. Engineers apply science for design, analysis, manufacturing and maintenance.
3. Engineering = Science + Safety + Economy
4. There are four broad discipline of Mechanical Engineering:
    a) Thermal Engineering
    b) Fluid Mechanics
    c) Solid Mechanics
    d) Control/Mechatronics

Energy

Characteristics:

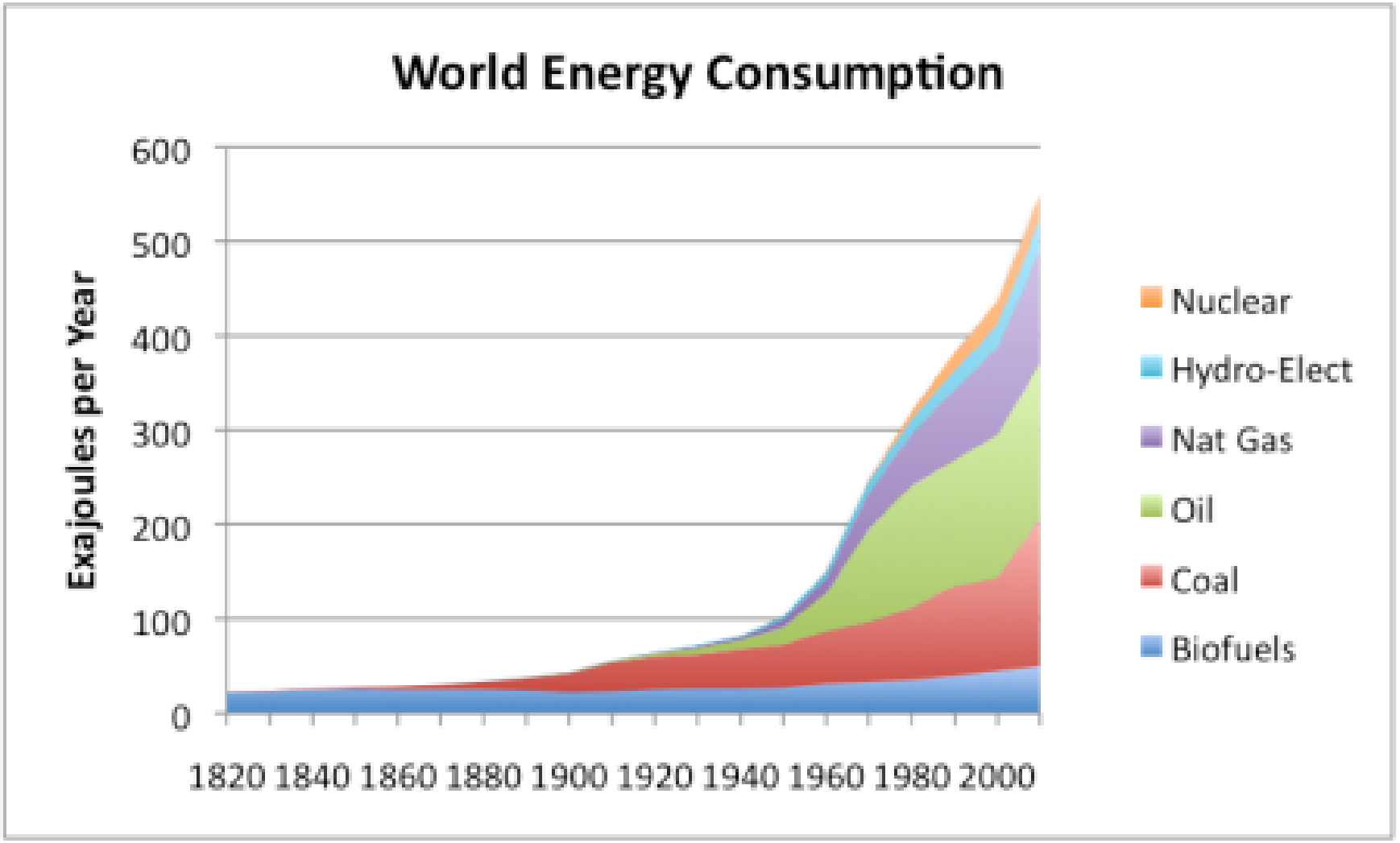
1. Ability to work
2. In-destructible
3. Form shifting



Definition:

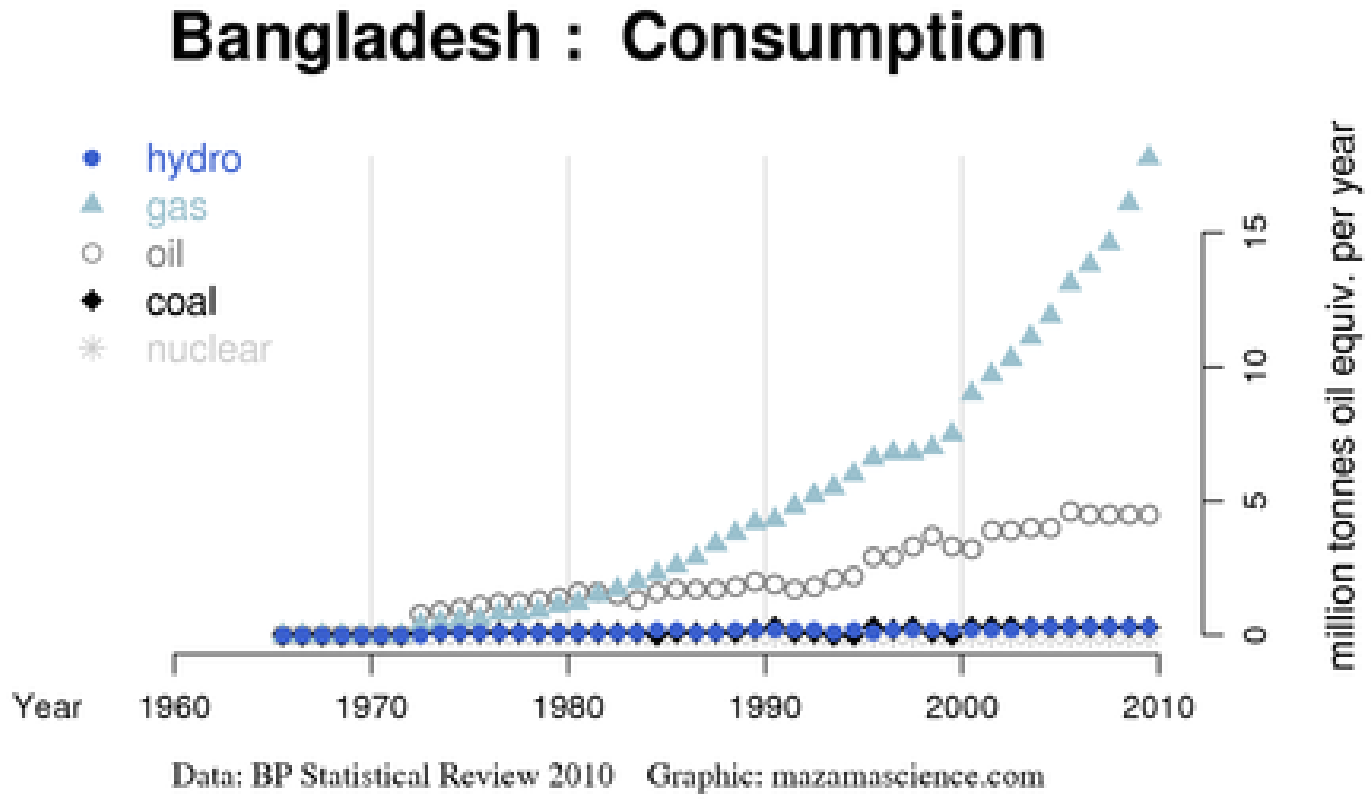
Energy is something that is indestructible, can shift form and while shifting form there is a possibility of some work been done.

Energy Consumption scenario of world

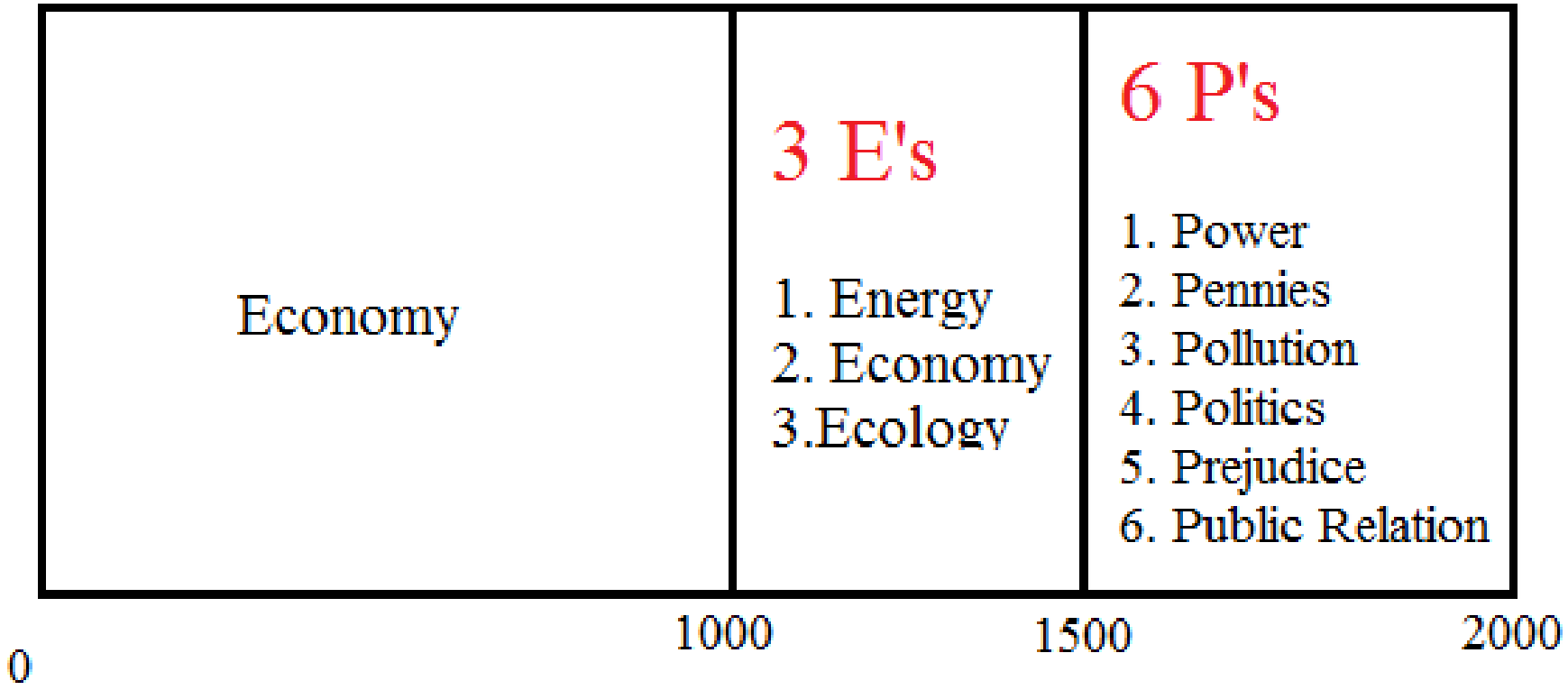


1 Exa Joul = 1e18 Joul

Energy consumption in Bangladesh



Major Concern Regarding Energy Conversion



Different forms of Energy

Basic 6 forms of Energy:

1. Mechanical
2. Electrical
3. Electromagnetic
4. Chemical
5. Nuclear
6. Thermal

Mechanical Energy

1. Transitional Form: (Kinetic Energy/Work)
    * This are transitional.
    * This energy can move

2. Stored Form: (Potential Energy/Strain Energy)
    * Stationary form
    * Energy cant move without moving the system
    * Elevated weight, springs, compressed gas, Fly-wheel etc.

Electrical Energy

Electrical associated with flow or accumulation of electron.

* Easy to transport
* Best form of energy

Transitional Form: Due to flow of electron.

Electrical transmission line.

Stored Form: Due to accumulation of charges.

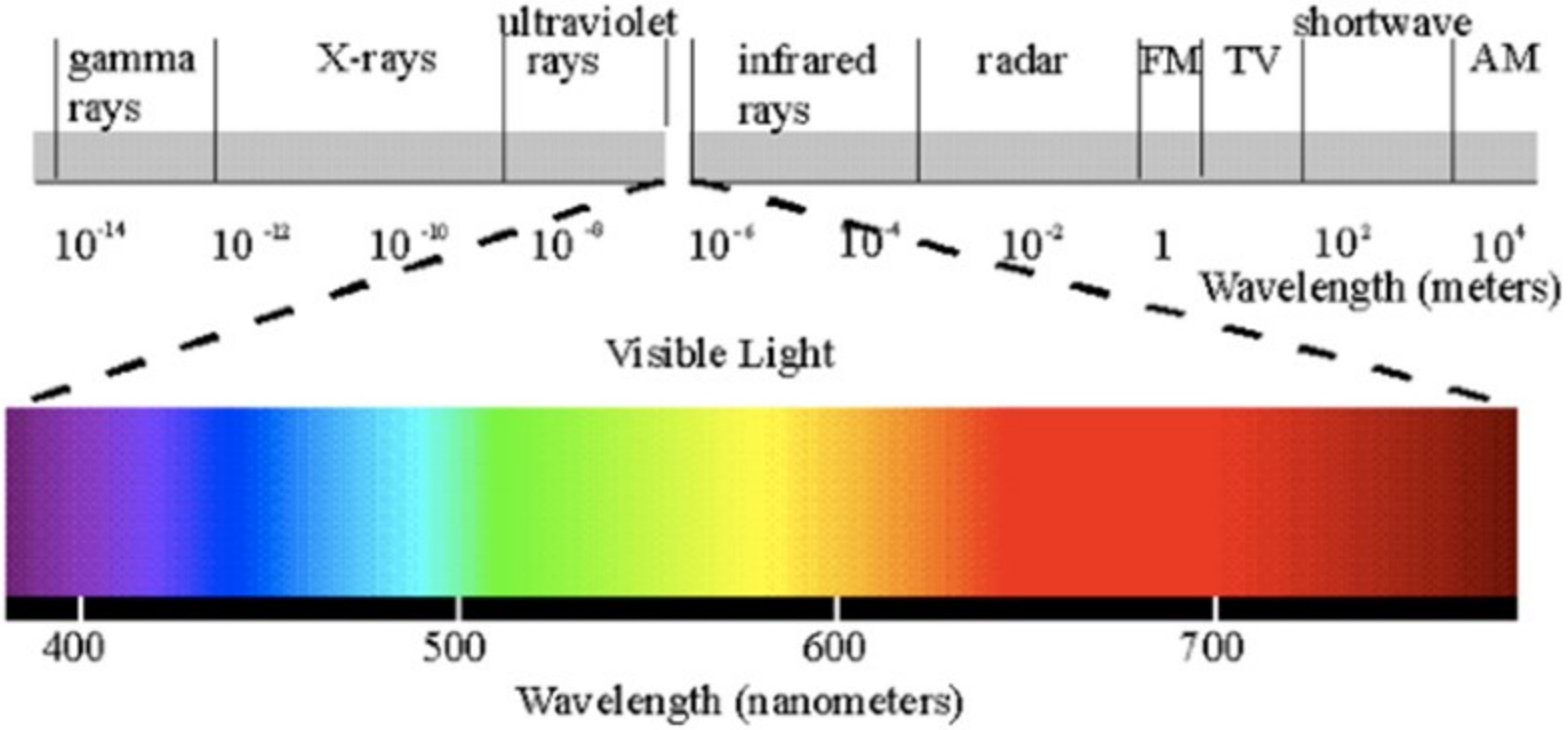
Capacitor, Solinoid.

Electro-magnetic Energy

1. Energy associated with electromagnetic radiation.
2. This energy is calculated by the equation:

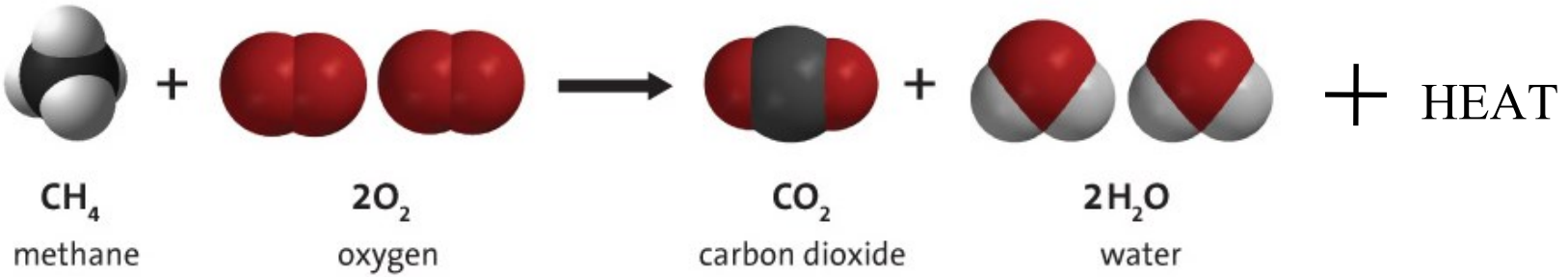
$$E = h\upsilon = h\,(c/\lambda)$$

3. Examples are: Sun Light, light etc.



Chemical Energy

1. Energy associated with molecular bond.
2. This Energy has stored form only.
3. Example: Energy in Gas, Coal, Oil etc.



Nuclear Energy

1. Energy associated with particle interaction.
2. Only stored form is available.

- Decay: **M** ⟶ **N + Energy**
- Fission: **M** ⟶ **N1 + N2 + Energy**
- Fusion: **M1 + M2** ⟶ **N + Energy**

Thermal Energy

1. Associated with atomic molecular vibration.
2. Can be both transitional and stored form.
3. Basically deals with **HEAT.**
4. Heat is two types:

    a) Sensible heat ($Q = mS\Delta\theta$)

    b) Latent heat ($Q = ml_f$)

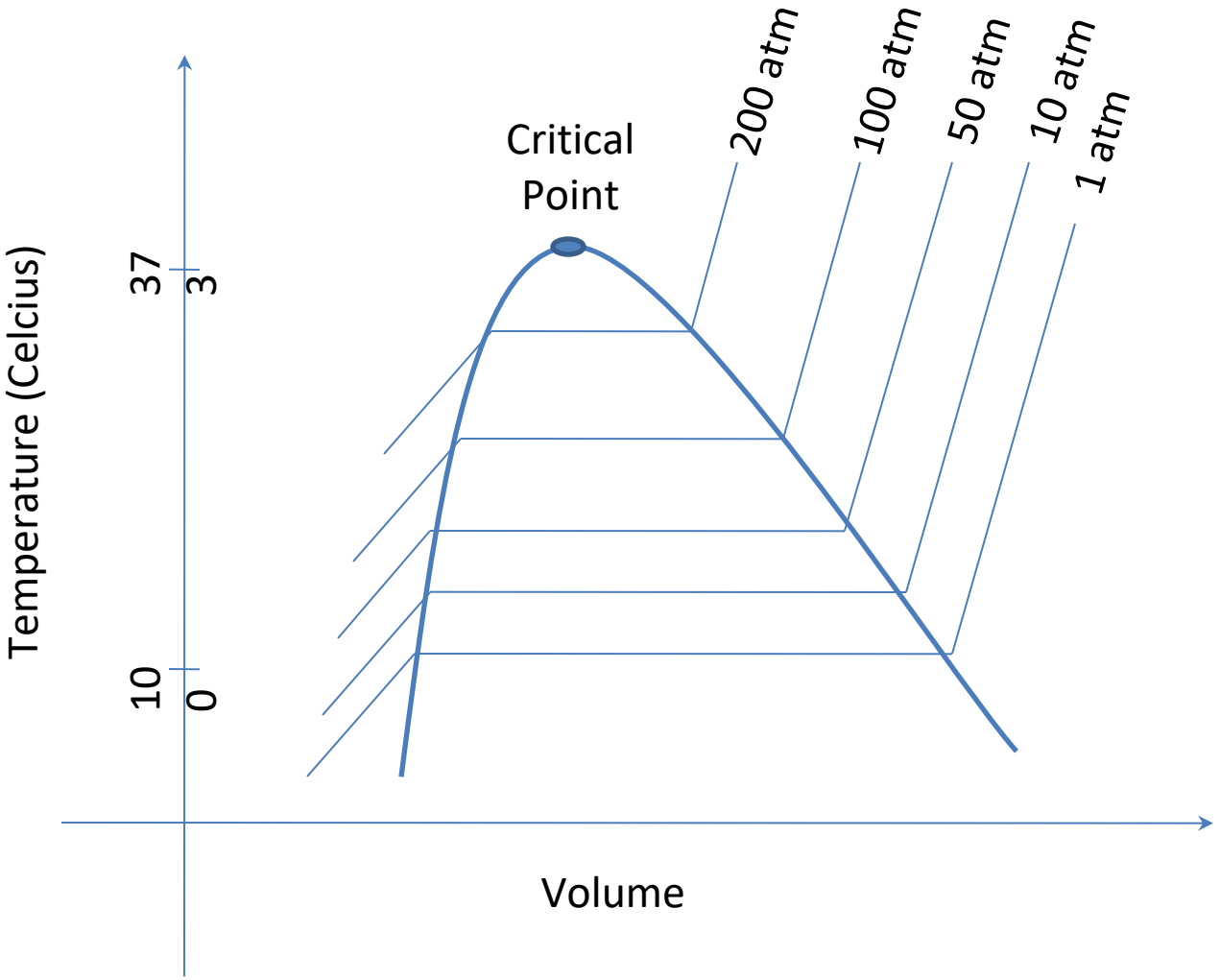
Here, m = mass,

S = specific heat

$\Delta\theta$ = temperature diference

l_f = latent heat

Temperature Vs Volume plot for Water



Sources of Energy

1. Energy comes from two types of Sources.
   a) Income Source (come from outside of earth)
   b) Capital Source (stored into earth)

- Capital Sources:
  * Limited, Developed Technlogy.
- Income Sources:
  * Unlimitd/Non-deplitable, Renewable.

Renewable Energy

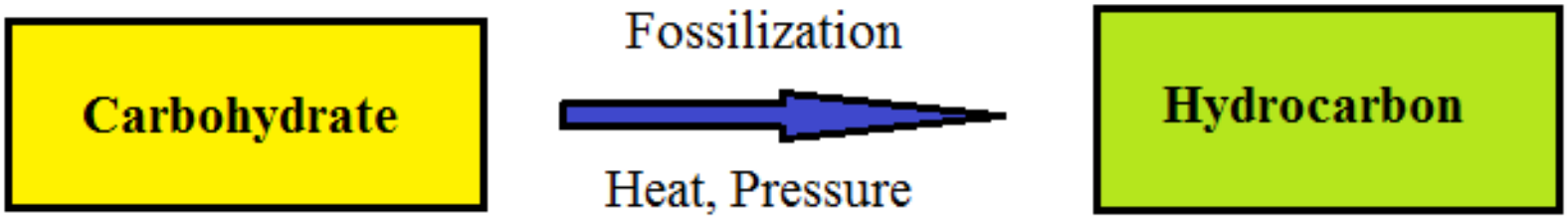
- Energy coming from outer-space.
- Some Energy are stored on the earth but considered as renewable energy.
    1. Wind energy: (Due to earth rotation).
    2. Ocean energy: (tidal energy, OTEC)
    3. Rain: (due to sun light)
    4. Biomass: (due to photo-systhesis)

"These energy's are called indirect renewable energy"

Capital Sources of Energy

Fossil fuels: (Natural Gas, Oil, Petroleum)

* Produced by process named fossilization.
* Takes millions of years to transform.



This reaction takes places in absence of oxygen

Capital sources of Energy

Geo-thermal Energy: (Volcanic eruption, Hot rock)

1. Energy trapped within or beneath earth crust.
2. This energy is two types:

a) Hydrothermal:

associated with hot water, springs etc.

b) Petrothermal:

associated with hot rock.

Capital sources of Energy

Nuclear fuels:

1. Uranium-233
2. Uranium-235
3. Plutonium-238
4. Plutonium-239
5. Plutonium-241
6. Neptunium-237
7. Curium-244

Conventional Sources of Energy

1. These are capital energy source:
2. Conventional Energy sources are:
    1. Coal (Solid)
    2. Oil (liquid)
    3. Natural gas (gas)

These fuels are conventional today, may be someday other fuels will be considered as conventional fuel also.

Conventional sources of Energy

Coal: (capital/nonrenewable/conventional)

* ASTM classify coal by its grade/rank.
* Four grade of coal are available:
    1. Anthracite coal.
    2. Bituminus coal.
    3. Sub-bituminus coal
    4. Lignite coal.

ASTM: American Society of Testing and Materials.

Comparison between different coal

	Anthracite	Bituminus	Sub-bituminus	Lignite
Fixed Carbon (%)	86-98	46-86	35-45	25-35
Volatile Material (%)	2-14	20-40	up to 45	Higher then 50
Moisture Content (%)	Appx. 15	Appx. 20	15-30	Up to 45
Heating Value (MJ/kg)	Appx. 28	26-32	19-26	15-19

Conventional source of energy

Oil: (Diesel, Petrol, Kerosene, Octane)

* Produced by distillation of Crude Oil

1. Liquefied Petroleum Gas (LPG)
2. Gasoline (Petrol)
3. Naphtha
4. Kerosene (And Aircraft fuel)
5. Diesel
6. Fuel Oil
7. Lubricating oil
8. Paraffin wax
9. Asphalt and tar
10. Coke

Conventional source of energy

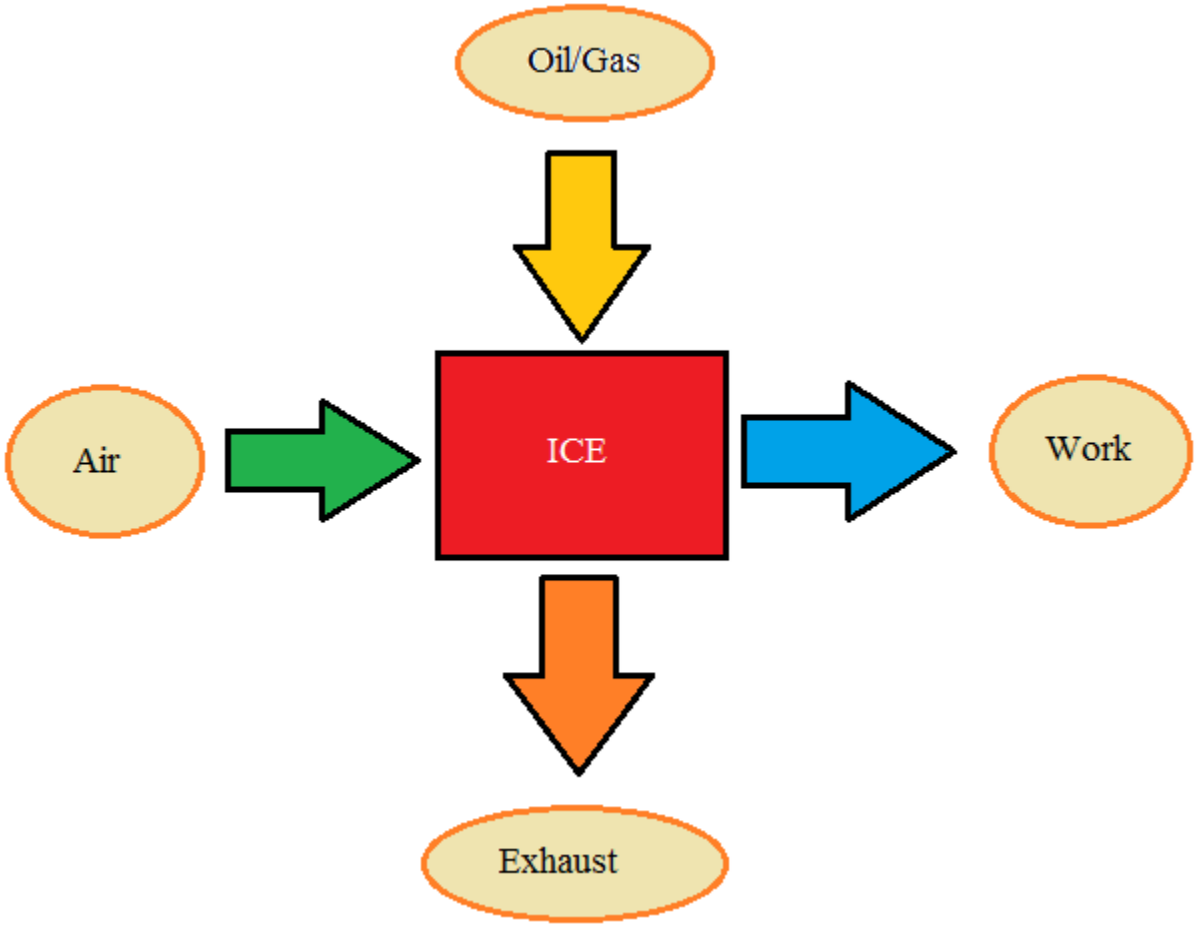
Natural Gas:

* Produced Naturally.
* Main energy source of Bangladesh (75%).
* In compressed form Called CNG.
* Heating Value: Appx: 50 MJ/kg

Typical composition of natural gas. From naturalgas.org		
Methane	CH_4	70-90%
Ethane	C_2H_6	0-20%
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8%
Oxygen	O_2	0-0.2%
Nitrogen	N_2	0-5%
Hydrogen sulphide	H_2S	0-5%
Rare gases	A, He, Ne,	trace

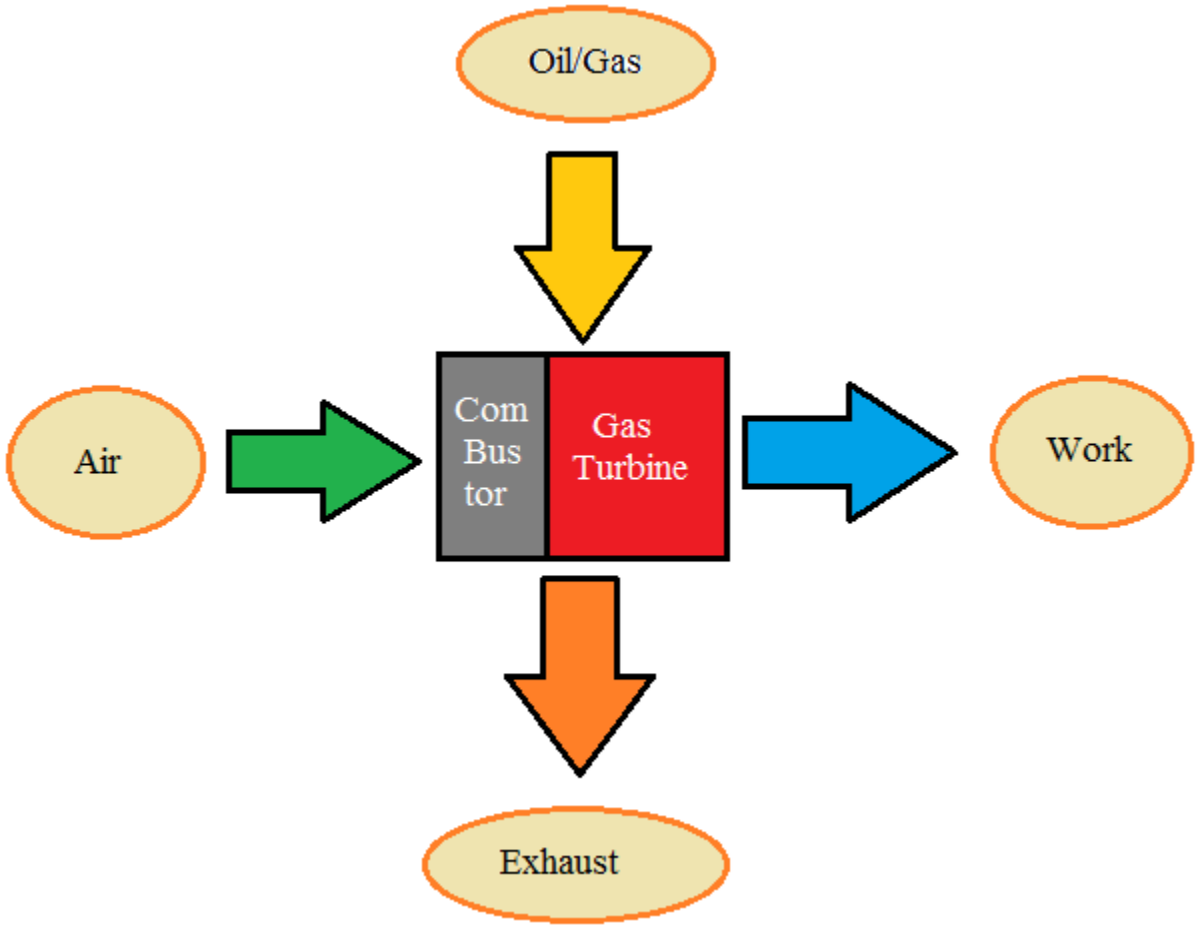
Production of Mechanical Energy

1. ICE: (Internal Combustion Engine)



Production of Mechanical Energy

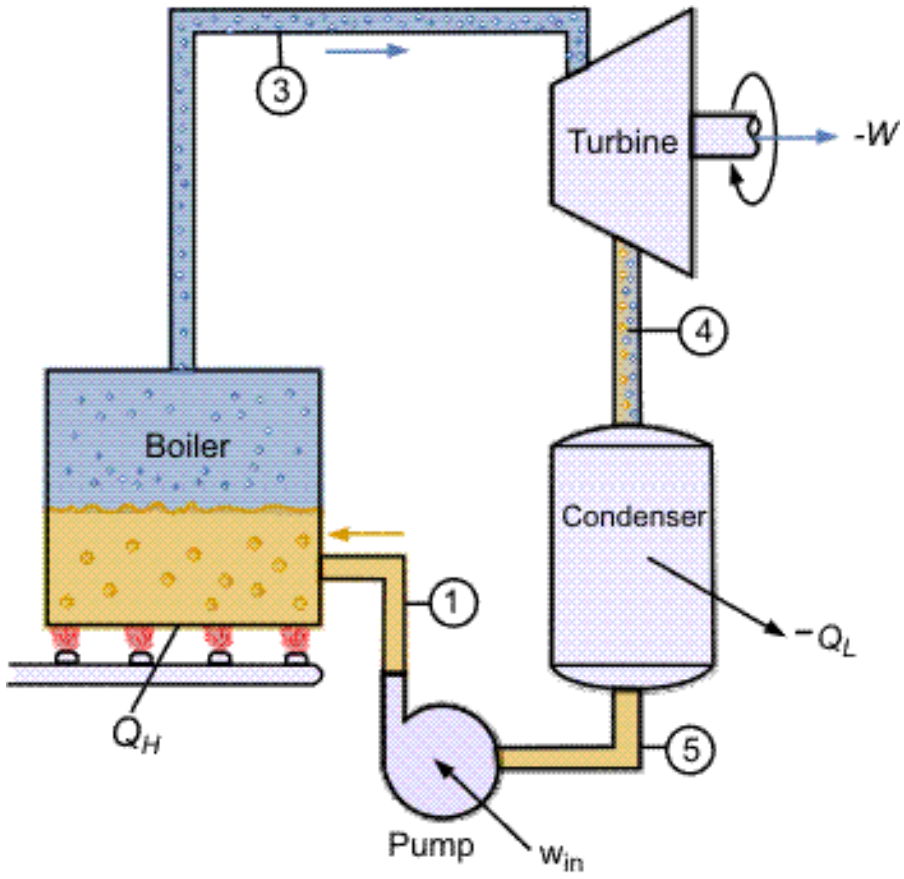
2. Gas Turbine:



Production of Mechanical Energy

3. Steam Turbine:

* Operate according to ‘Rankine Cycle’.
* Boiler produces Steam, that flows into the turbine.
* The energy of steam is converted into work.

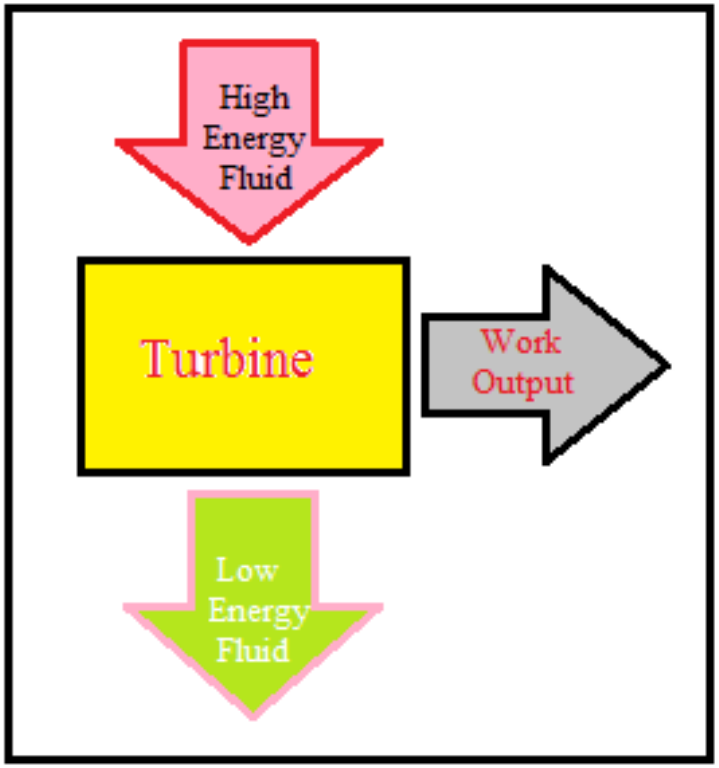


The low energy steam is condensed and then pumped into the boiler

Production of Mechanical Energy

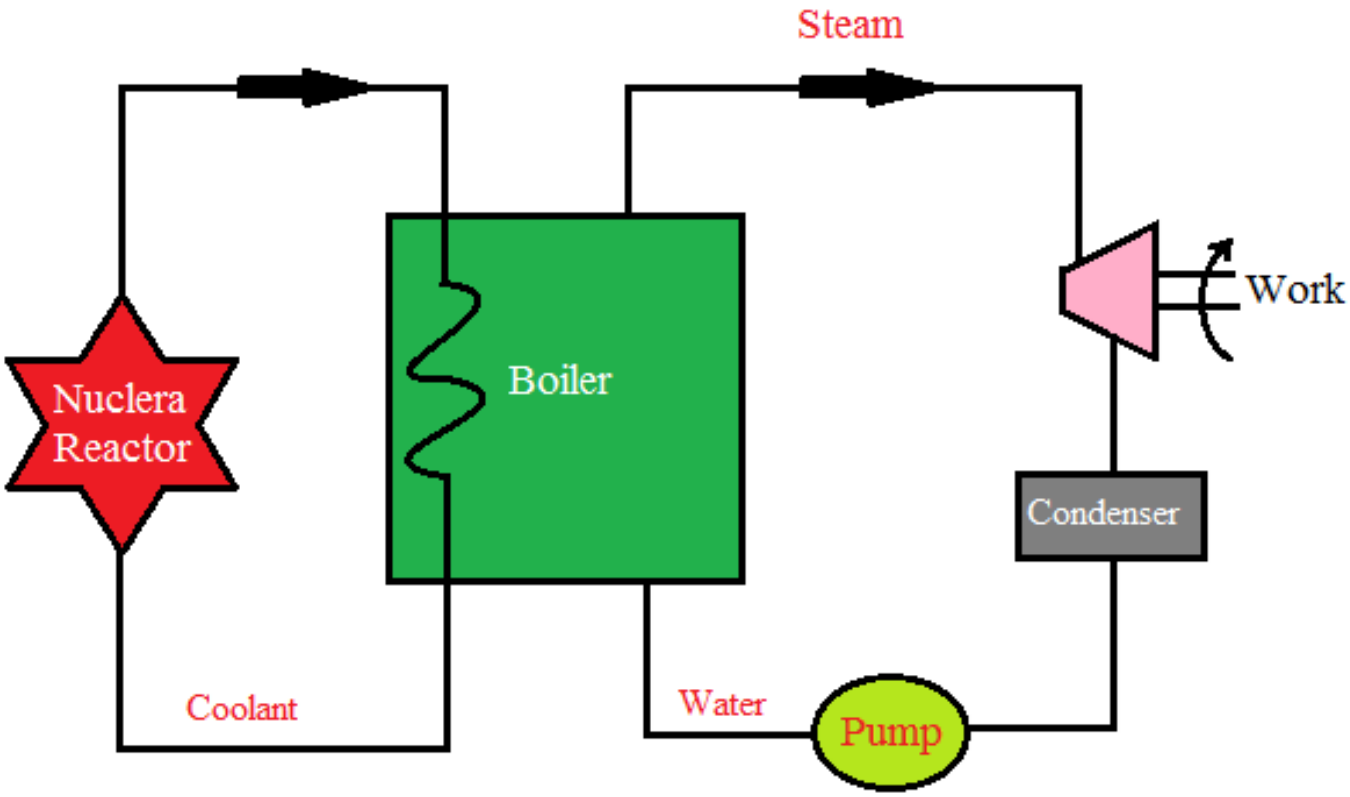
4. Water Turbine:

* Produces energy from Hydraulic energy.
* Hydraulic energy:
  Energy due to
  1. Pressure,
  2. Velocity,
  3. Elevation,
  4. Temperature



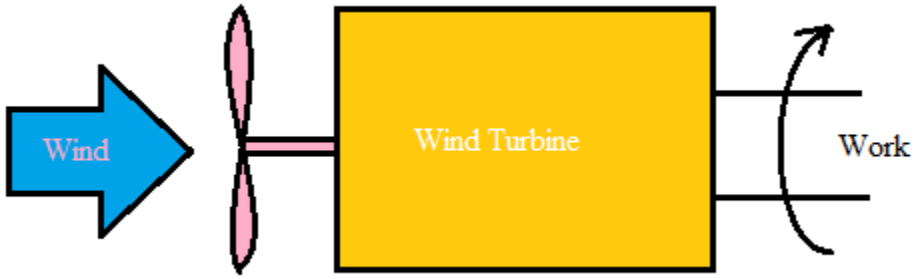
Production of Mechanical Energy

5. Nuclear Power Plant:

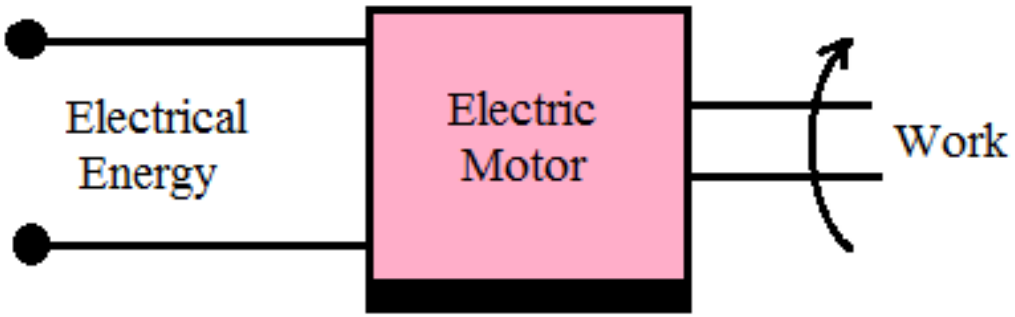


Production of Mechanical Energy

6. Wind Turbine:



7. Electric Motor:



Mathematical Problem

Calculate the amount of heat required to produce 2 kg of 130 ^{0}C steam from -20 ^{0}C ice. Also calculate the required amount of coal to produce that 2 kg of steam. Heating value of coal is 20 MJ/kg.

Solution:

Here, mass, m=2 kg

Required heat, Q =

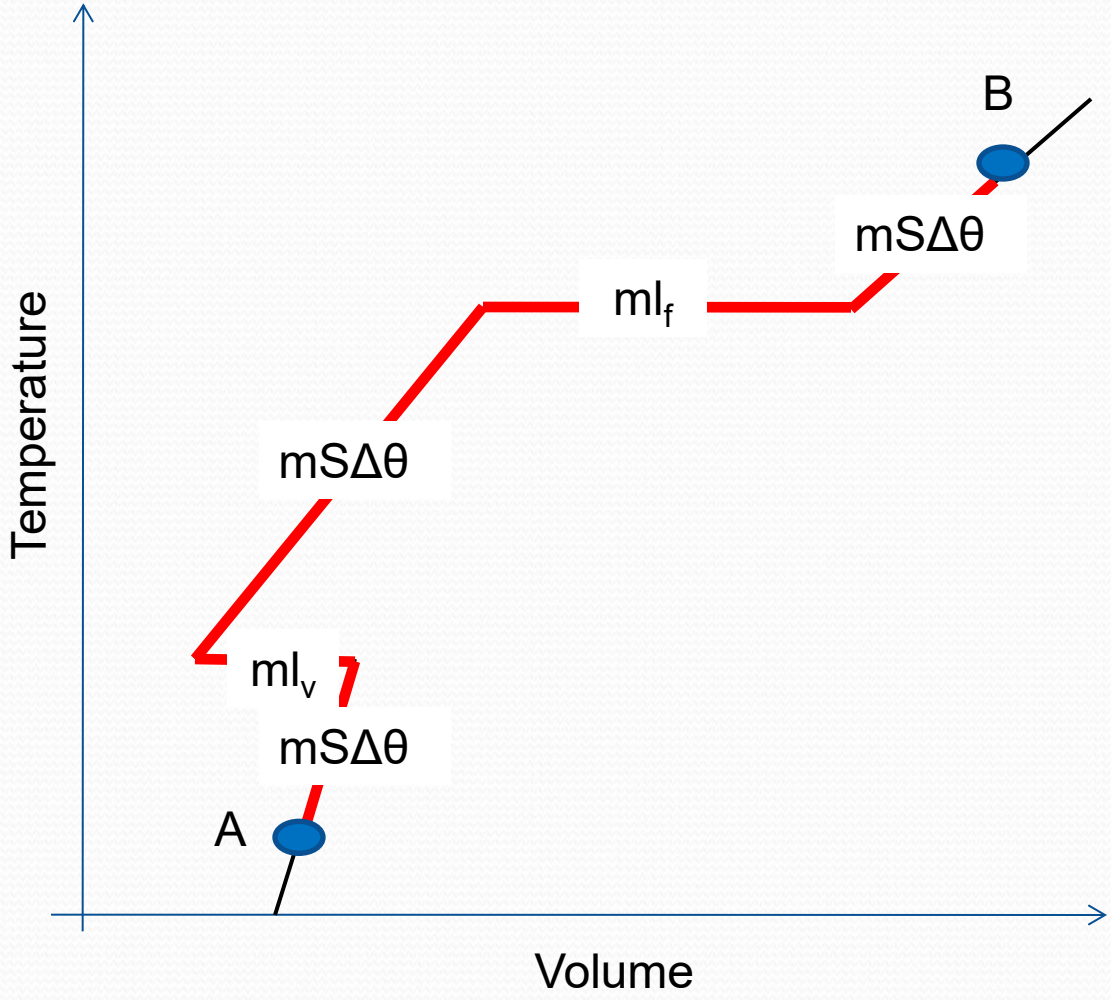
$(mS\,\Delta\theta)_{ice}$ +

$(ml_v)_{ice\text{-}water}$ +

$(mS\,\Delta\theta)_{water}$ +

$(ml_f)_{water\text{-}steam}$ +

$(mS\Delta\theta)_{steam}$



$$Q = (mS\Delta\theta)_{ice} + (ml_v)_{ice\text{-}water} + (mS\Delta\theta)_{water}$$

$$+ (ml_f)_{water\text{-}steam} + (mS\Delta\theta)_{steam}$$

$$Q = 2\times\underline{2100}\times[0-(-20)] + 2\times\underline{336000} + 2\times\underline{4200}\times(100-0)$$
$$+ 2\times\underline{2260000} + 2\times\underline{2100}\times(130-100)$$

$$= 6242000\ J = 6.242\ MJ \qquad \text{(Ans)}$$

Data required: ***(To be memorized)***

Specific Heat of ice	2100 J/kgK
Latent heat of melting of ice	336000 j/kg
Specific heat of water	4200 J/kgK
Latent heat of evaporation of water	2260000 J/kg
Specific heat of steam	2100 J/kgK

Again:

$$Q = mf \times HV$$

so, $$mf = Q/HV$$

$$= 6.242/20$$

$$= 0.3121 \text{ kg}$$

$$= 31.21 \text{ g} \qquad \text{(Ans)}$$

Mf = Fuel Burnt (kg)
HV = Heating Value (MJ/kg)

Heating Value: Amount of heat produced by burning 1 kg of fuel.

ME 201

Mechanical Engineering Fundamentals

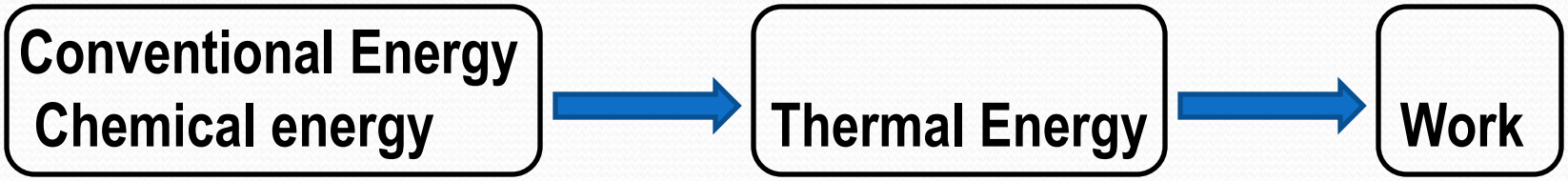
Internal Combustion Engine(ICE)

Md. Abdul Hamid

Engine and Machine

Engine:

Extract work from conventional form of energy



Engines are 2 types:

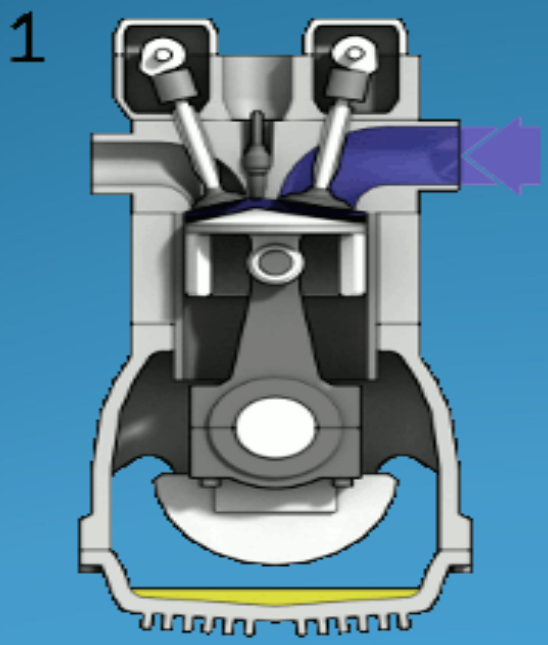
1. ***External combustion engines.***
2. ***Internal combustion engines.***

Machine:

Converts energy from one form to another

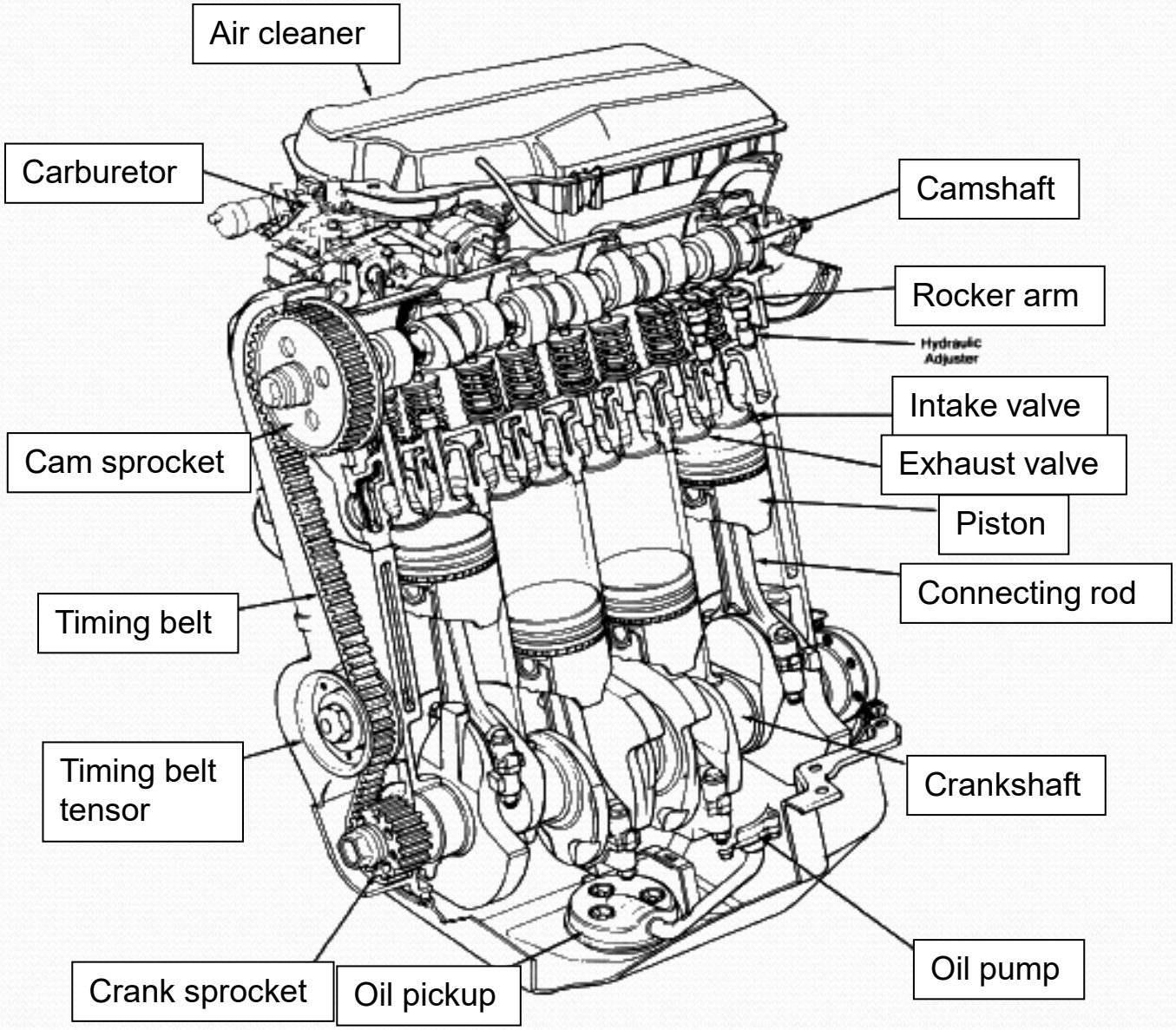
Lathe machine, Shaper machine, Transformer etc

Internal Combustion Engine Operation (Strokes)

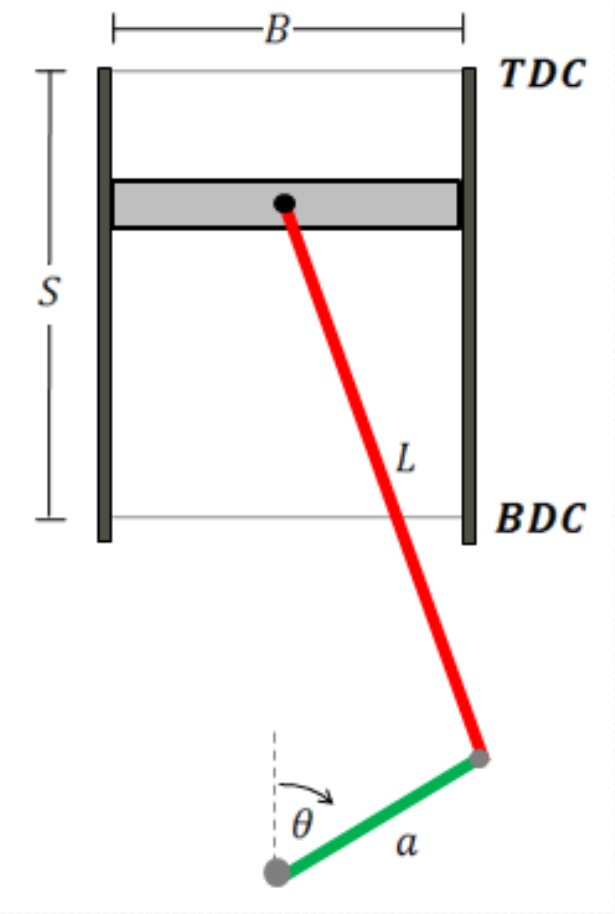


1. Suction
2. Compression
3. Power
4. Exhaust

Engine Anatomy



Some Specification:



TDC = Top Dead Center

BDC = Bottom Dead Center

B = Bore (Diameter of Cylinder)

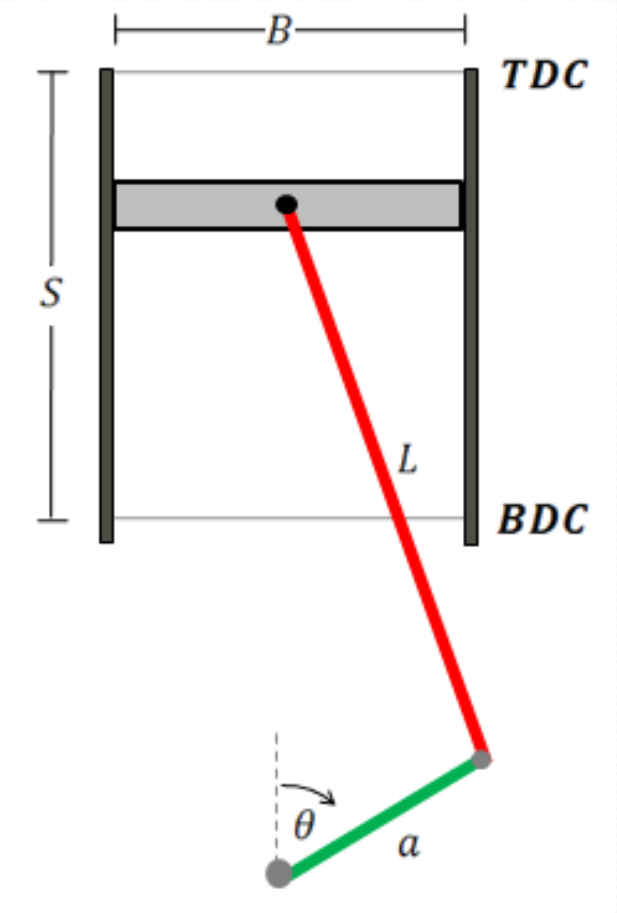
S = Stroke length (TDC - BDC)

L = Connecting Rod

a = crank

θ = Crank Angle

Some Specification:



CC: Total engine volume

$$CC = \mathbf{N} \times \left[\frac{\pi \times B^2}{4}\right] \times S$$

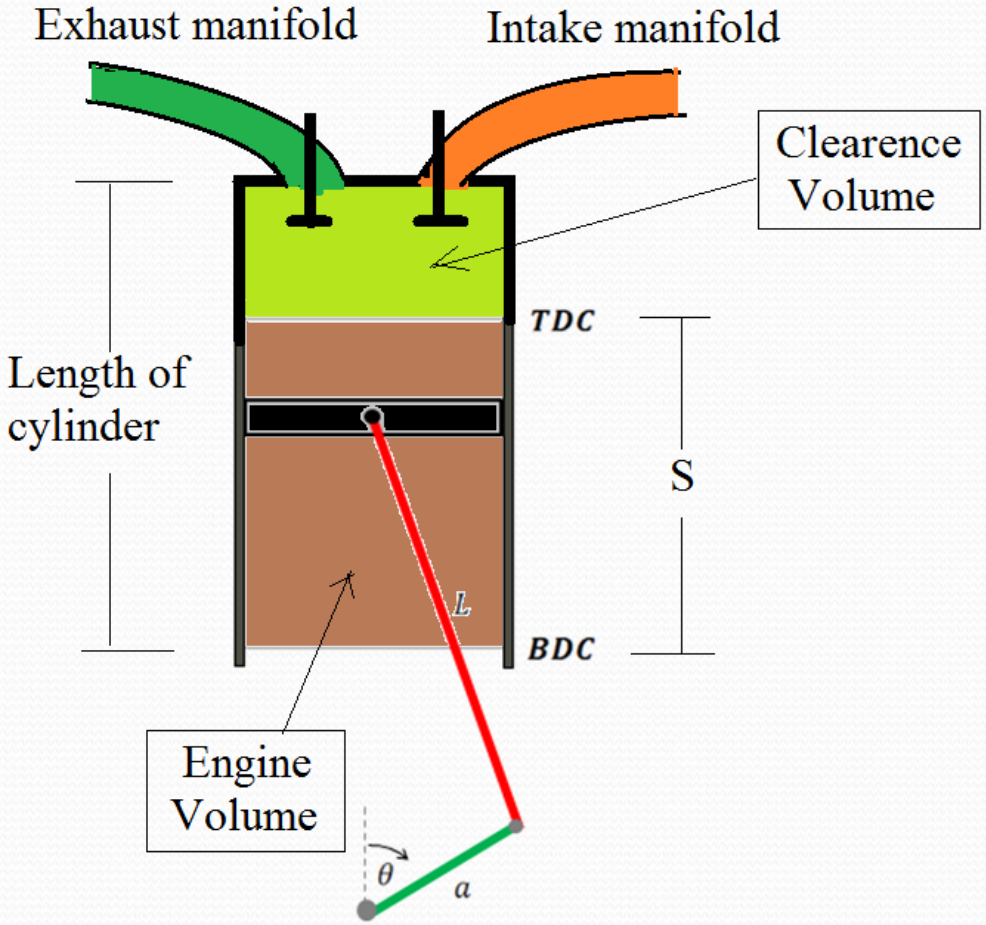
B = Bore in cm

S = Stroke length in cm

N = No of Cylinder

CC = Total volume in cm^3

Some Specification:



Cylinder volume = engine volume + clearence volume

Compression Ratio (CR):

$$CR = \frac{\text{Cylinder volume}}{\text{Clearance Volume}}$$

$$= \frac{\text{length of cylinder (Lc)}}{\text{length of cylinder (Lc) - length of stroke (S)}}$$

$$= \frac{Lc}{(Lc - S)}$$

(For flat faced cylinder and piston)

Math: A 4 cylinder engine has a bore of 0.05 m and stroke of 0.1 m with flat piston and cylinder face. If the length of the cylinder is 0.105 m, then find-

(a) The CC of the engine and

(b) Compression Ratio

Ans: Here d = 0.05 m = 5 cm; S = 0.1 m = 10 cm

Lc = 0.105 m = 10.5 cm

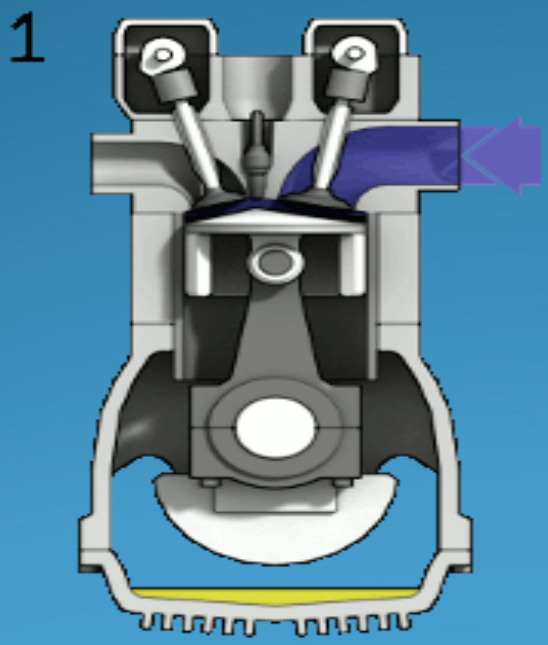
(a) CC = 4*(3.1416*5*5/4)*10

= 785.4 cc (Ans)

(b) CR = 10.5/(10.5-10)

= 21 (Ans)

Internal Combustion Engine Operation (Strokes)



1. Suction
2. Compression
3. Power
4. Exhaust

Four Strokes

1. Intake/Suction Stroke:

a. Piston moves from TDC to BDC.
b. Inlet Valve is open
c. Exhaust valve is closed
d. Intake of combustible fuel.

2. Compression Stroke:

a. Piston moves from BDC to TDC.
b. Inlet Valve is Closed
c. Exhaust valve is closed
d. Fuel is compressed.

3. Power Stroke:

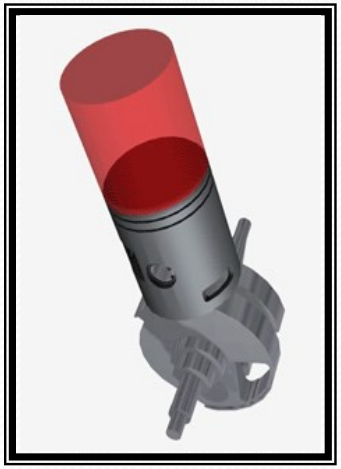
a. Piston moves from TDC to BDC.
b. Inlet Valve is closed
c. Exhaust valve is closed
d. Power is produced.

4. Exhaust Stroke:

a. Piston moves from BDC to TDC.
b. Inlet Valve is closed
c. Exhaust valve is open
d. Product of combustion is exhausted.

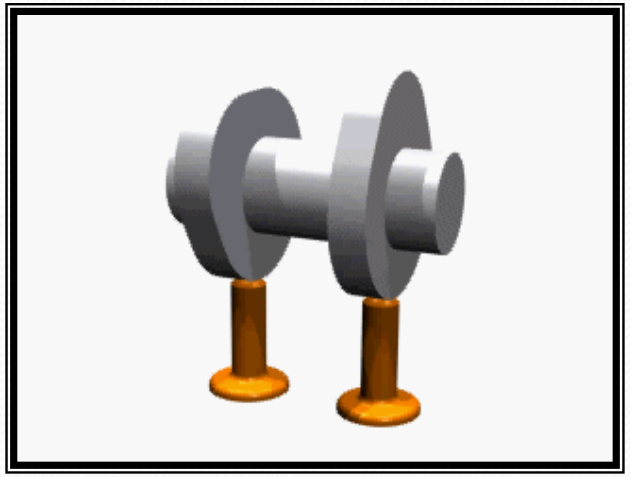
Valve opening Mechanism

PISTON

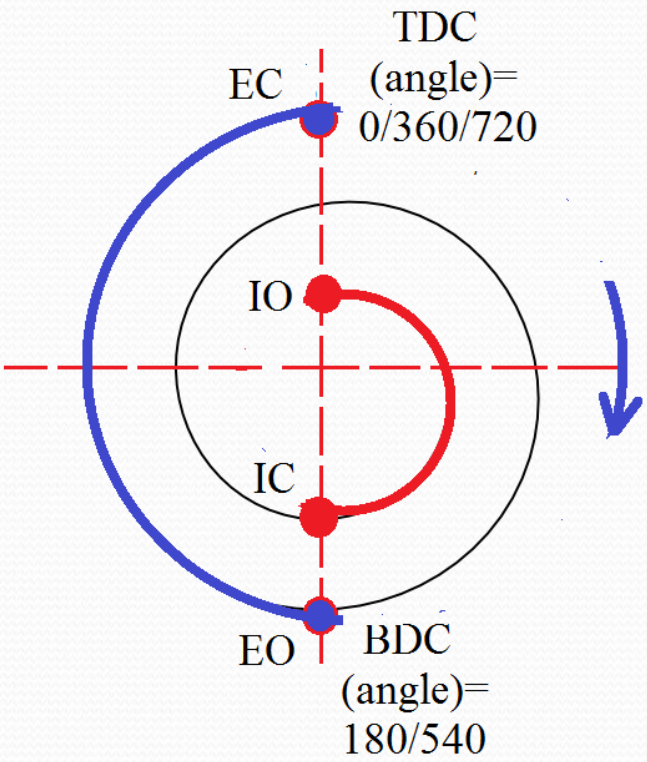


VALVE

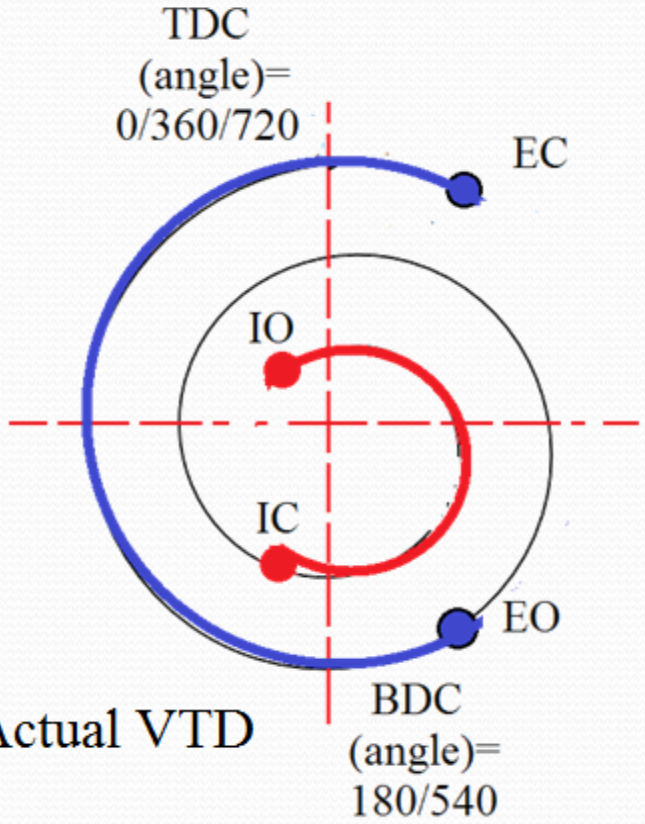
CAM SHAFT



Valve Timing Diagram:



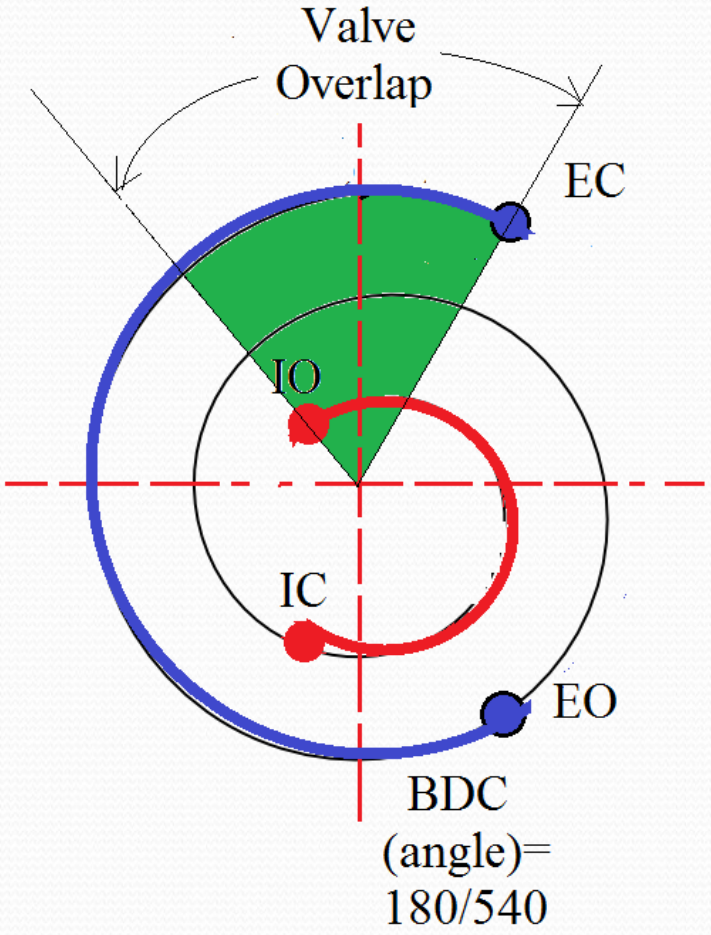
Ideal VTD



Actual VTD

- TDC = Top dead centre
- BDC = Bottom dead centre
- IO = Inlet valve opens
- IC = Inlet valve closes
- EO = Exhaust valve opens
- EC = Exhaust valve closes

Valve Timing Diagram:



Valve Overlap:

1. Both valve is open at the same time
2. Starts at the end of exhaust stroke and ends at the beginning of the suction stroke
3. Causes more pollution

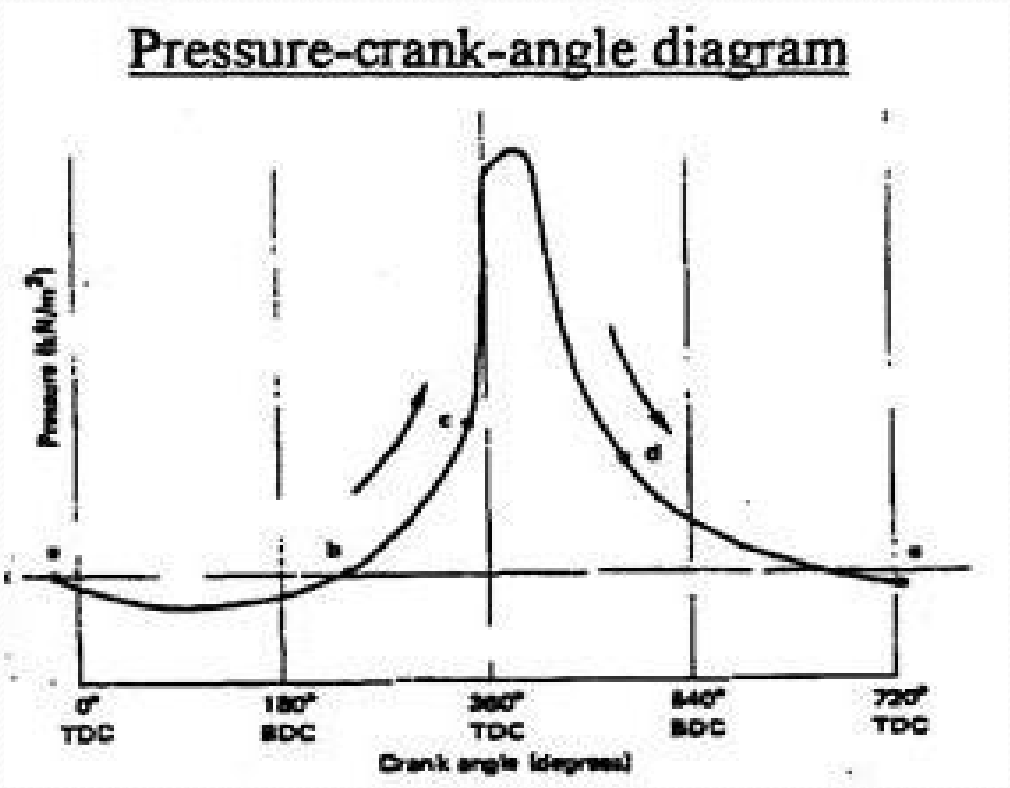
A motorcycle at high speed causes low pollution

Engines with Single cylinder:

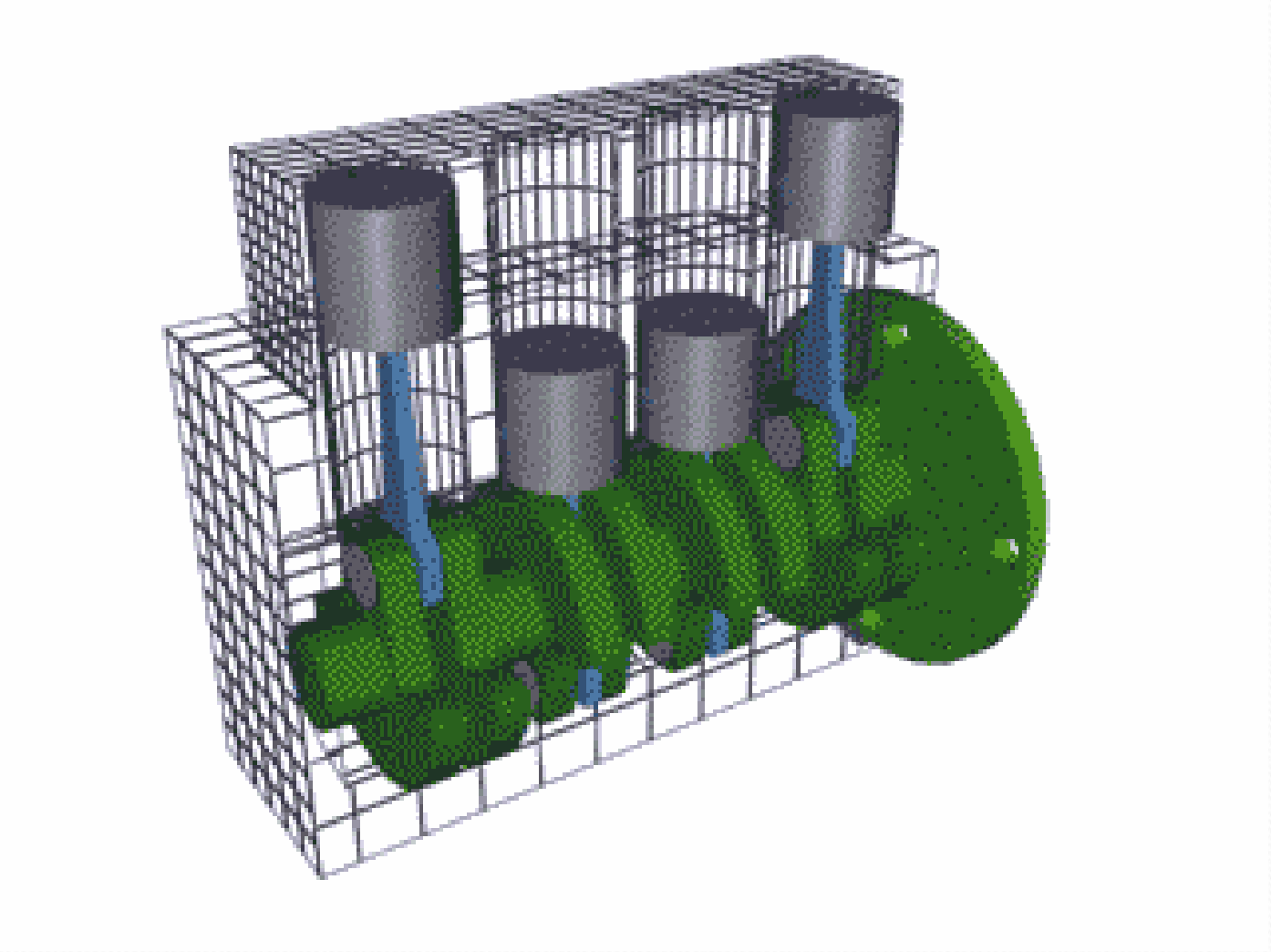
Single Cylinder Engine

1. Pressure Fluctuation is higher.
2. Need larger Flywheel.
3. Fatigue on shaft is higher.

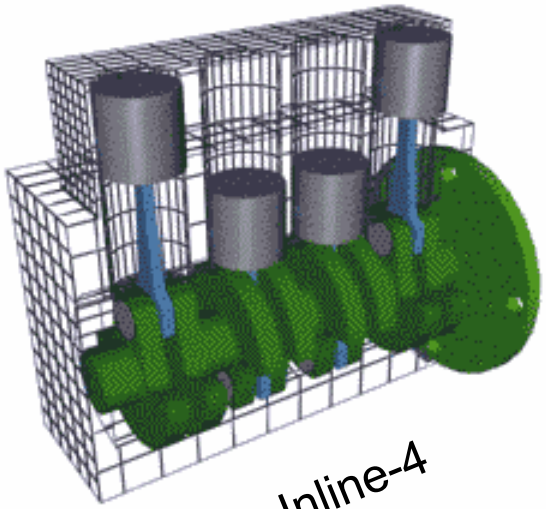
Multiple Cylinder Engines Reduce these problems.



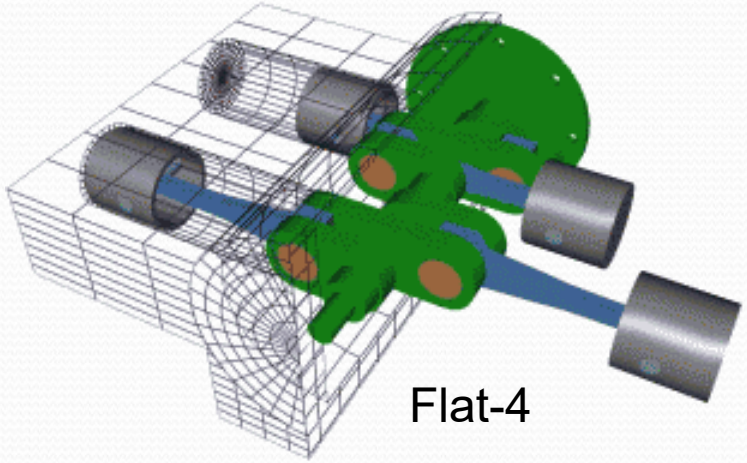
Multi-cylinder Engines



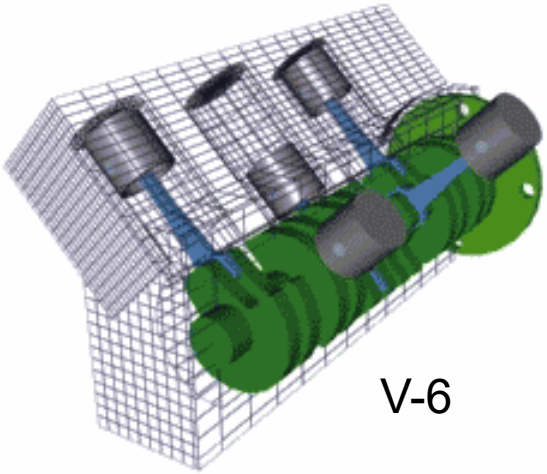
Cylinder Arrangement



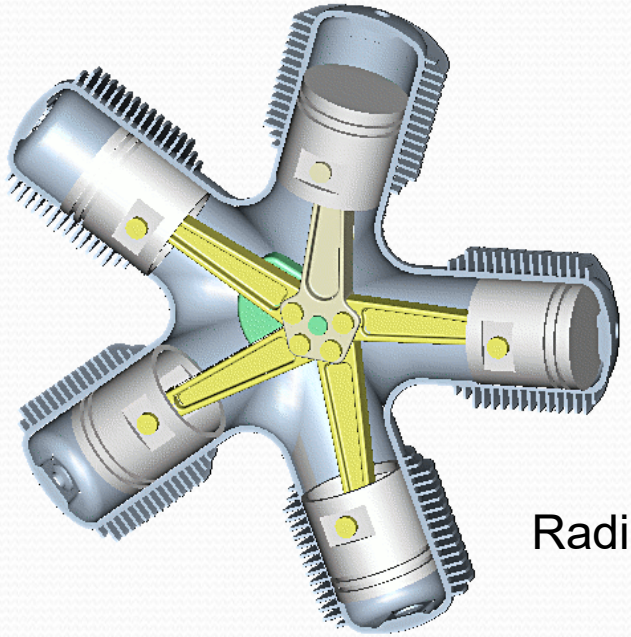
Inline-4



Flat-4



V-6



Radial

Major classifications

Based on Application:

- Stationary Engine
- Mobile Engine

Based on No of Strokes:

- Four stroke engine.
- Two Stroke engine.

Based on Ignition Types:

- Spark Ignition engines (SI engine).
- Compression Ignition engines (CI engine).

Based on cycle:

- Otto cycle
- Diesel cycle
- Dual cycle

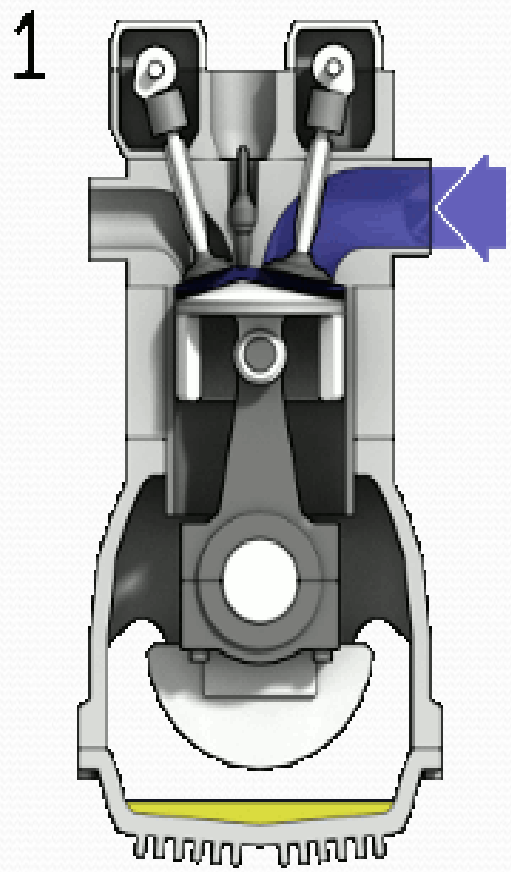
Based on fuel used:

- Petrol engine (otto cycle)
- Diesel engine (diesel cycle)
- Gas engine (otto cycle)
- Dual engine (duel cycle)
- Bi-fuel engine (otto/diesel cycle)

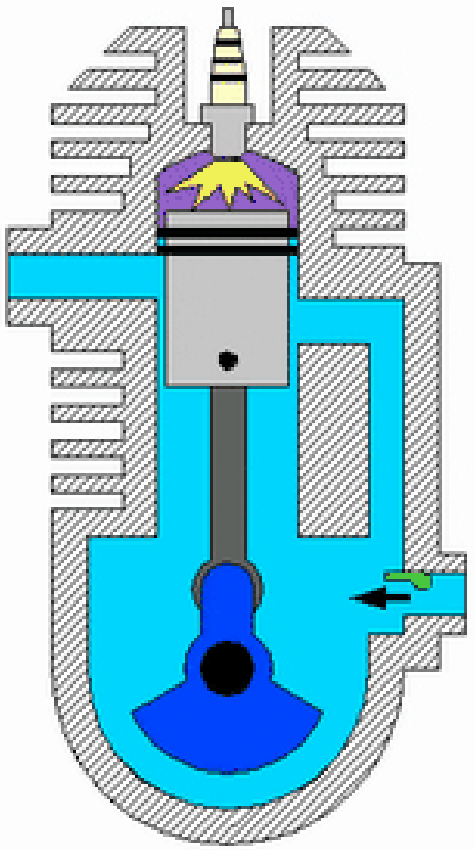
Based on cooling system:

- Water cooled.
- Air cooled.

Four Stroke Engine



Two Stroke Engine



Comparison of Two-stroke and Four-stroke Engine

Advantages of Two stroke Engine

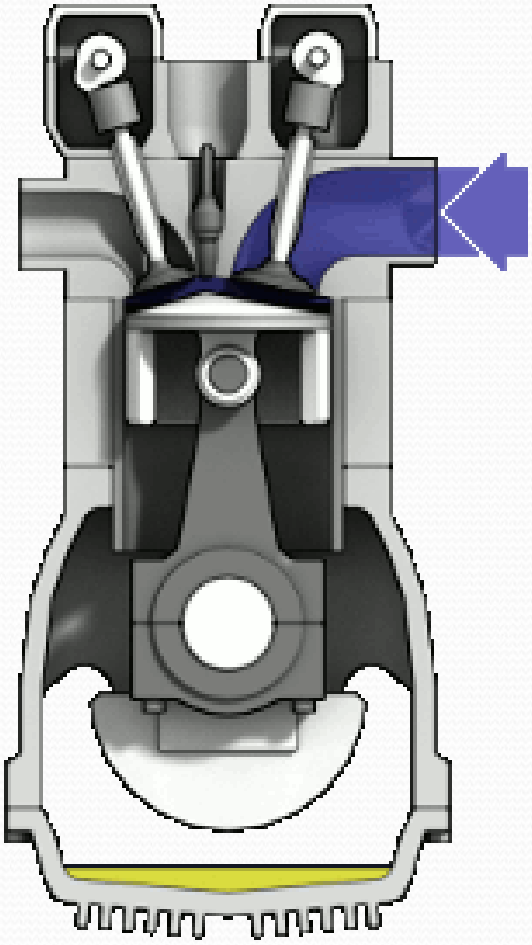
1. Double Power stroke.
2. Lighter, Smaller (Same power developed).
3. Turning moment is more uniform.

Disadvantages of Two stroke Engine:

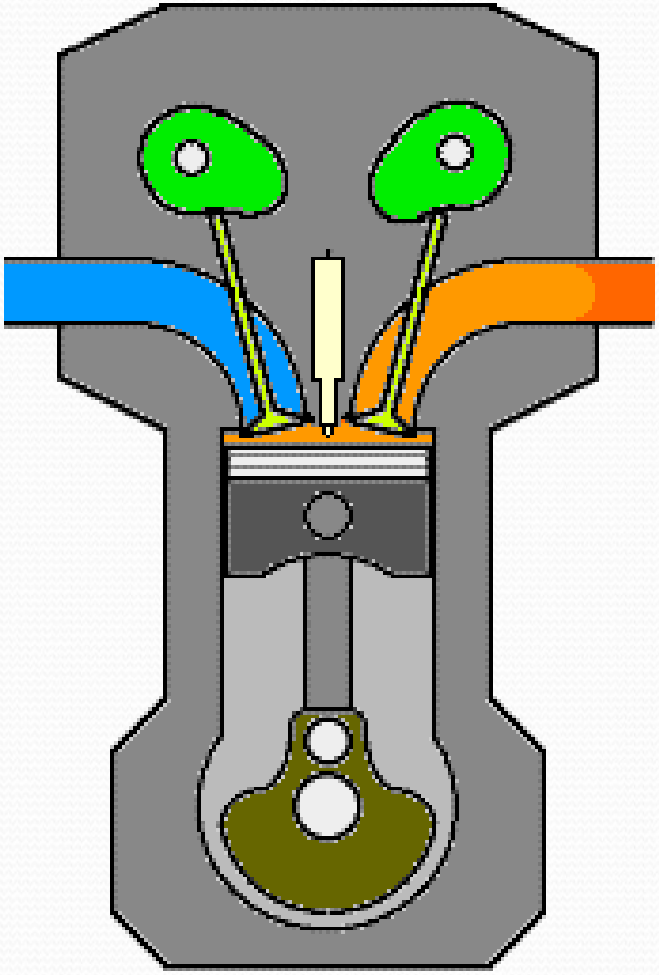
1. Both inlet and exhaust ports are open for sometime.
2. Cooling is Costly.
3. Air Pollution.

SI Engine (Petrol Engine)

1

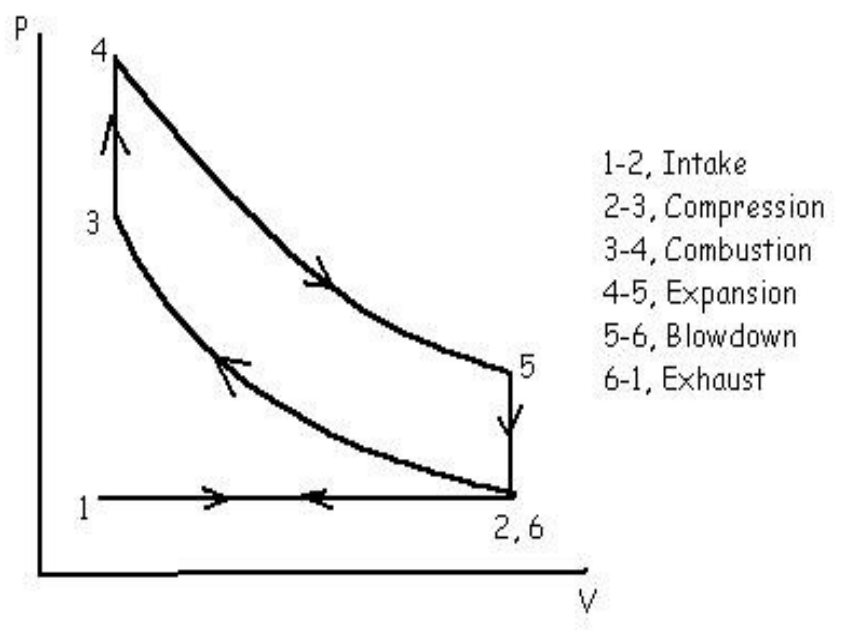


CI Engine (Diesel Engine)



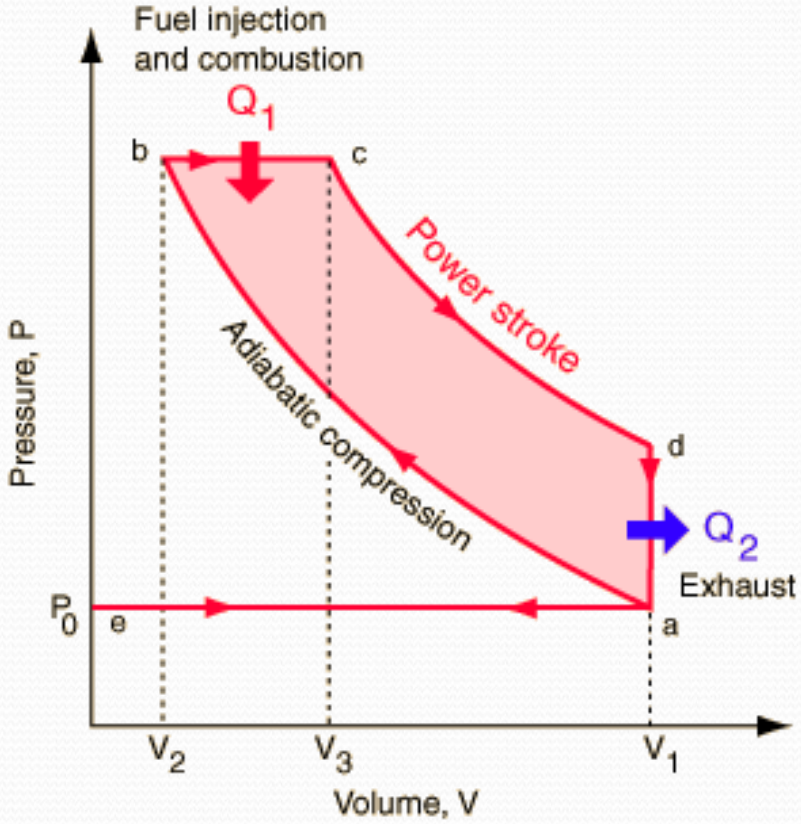
SI Engine (Petrol Engine)

Ignition is done by Spark Plug

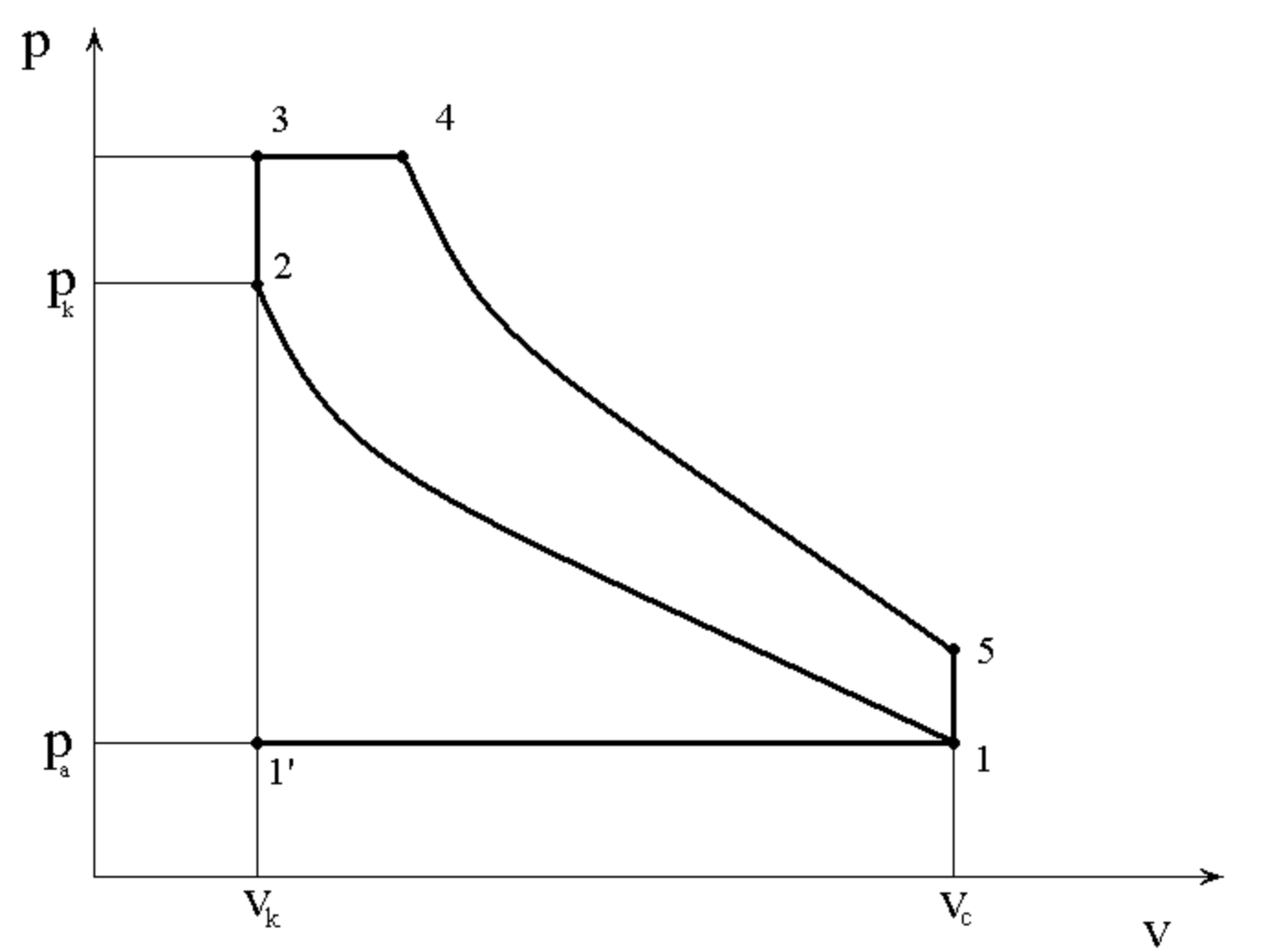


CI Engine (Diesel Engine)

Ignition is done by Fuel Injection



Dual Engine



Comparison of Petrol and Diesel Engines

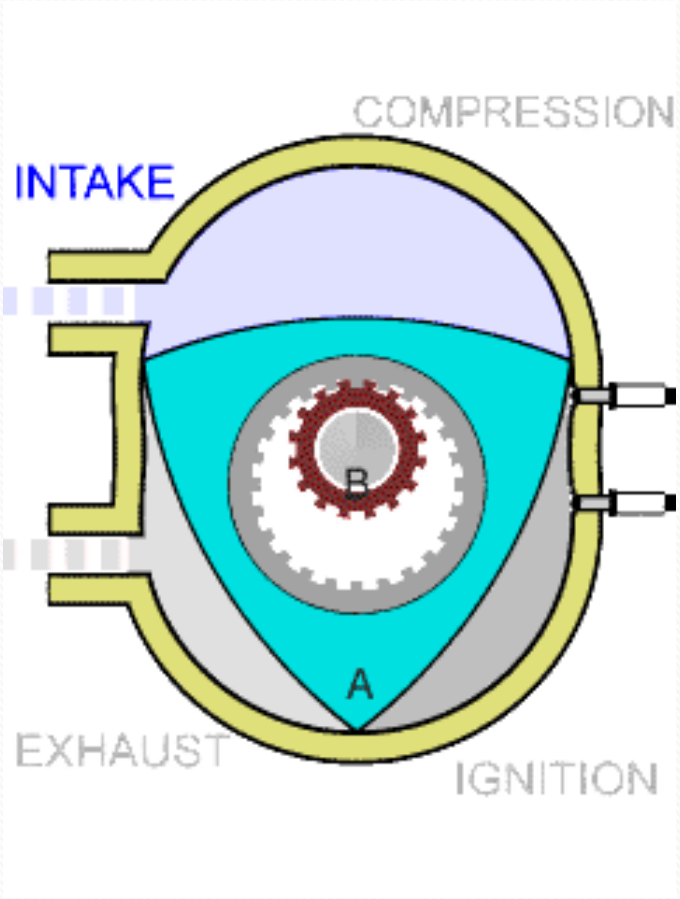
	Petrol Engines	Diesel Engines
1.	Draws a **mixture** of petrol and air.	Draws only air during suction stroke.
2.	The **Carburettor** is employed to mix air and petrol in the required proportion.	The injector or atomiser is employed to inject the fuel.
3.	**Pressure at the end** of comp: stroke is about 10 bar.	Pressure at the end of compression is about 35 bar.
4.	The charge (i.e. petrol and air mixture) is ignited with the help of **spark plug.**	The fuel is injected in the form of fine spray..

Comparison of Petrol and Diesel Engines

5.	The combustion of the fuel takes place at **constant volume**. It works on Otto cycle.	The combustion of the fuel takes place at constant pressure. It works on Diesel cycle.
6.	A petrol engine has **compression ratio** from 6 to 10.	A diesel engine has compression ratio from 15 to 25.
7.	The **starting is easy** due to low compression ratio.	The starting is difficult due to high compression ratio.
8.	As the compression ratio is low, the petrol engines are **lighter and cheaper**.	As the compression ratio is high, the diesel engines are heavier and costlier.

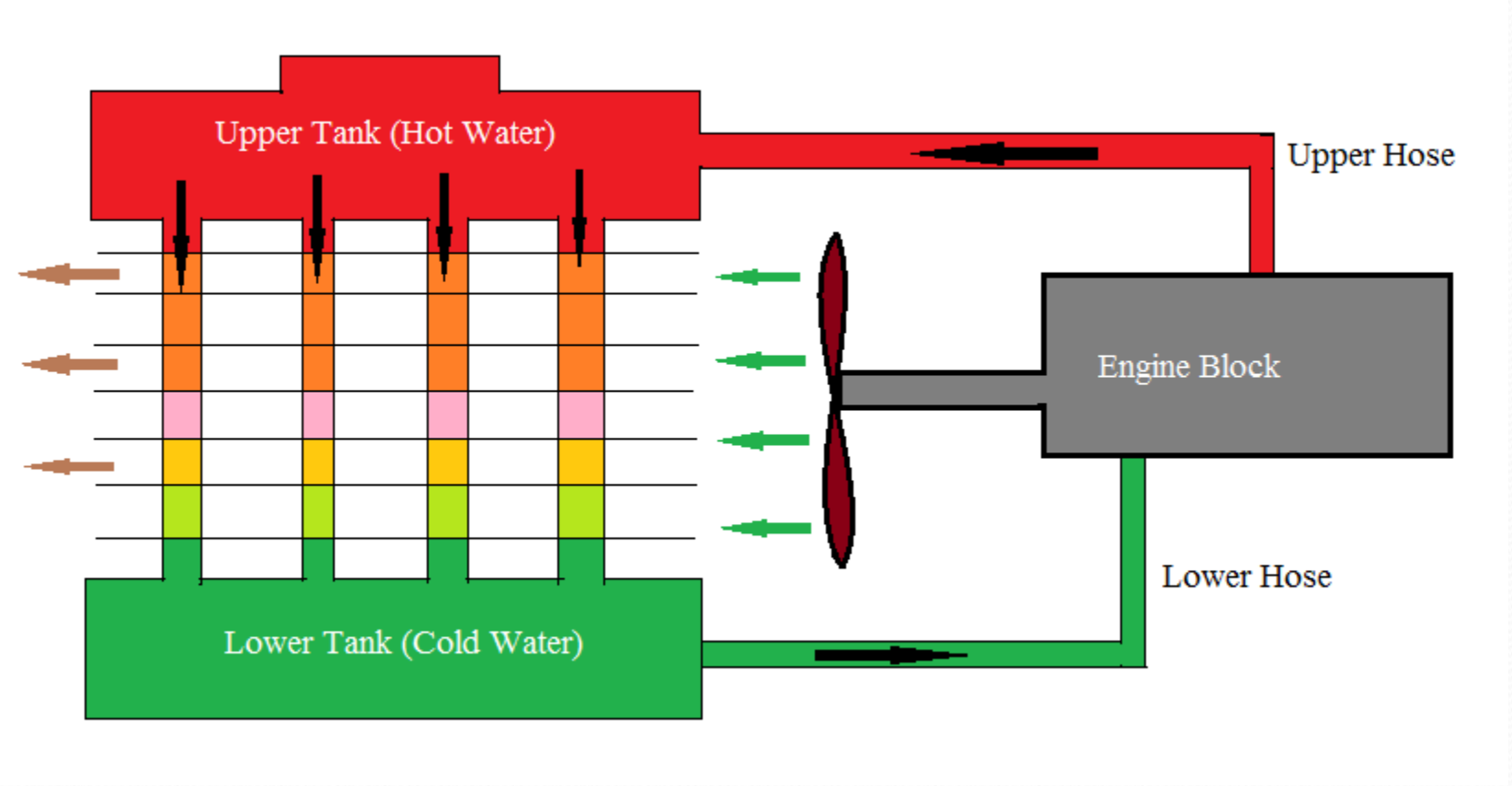
Other Type of ICEs

Wankel Engine (Rotary Engine)



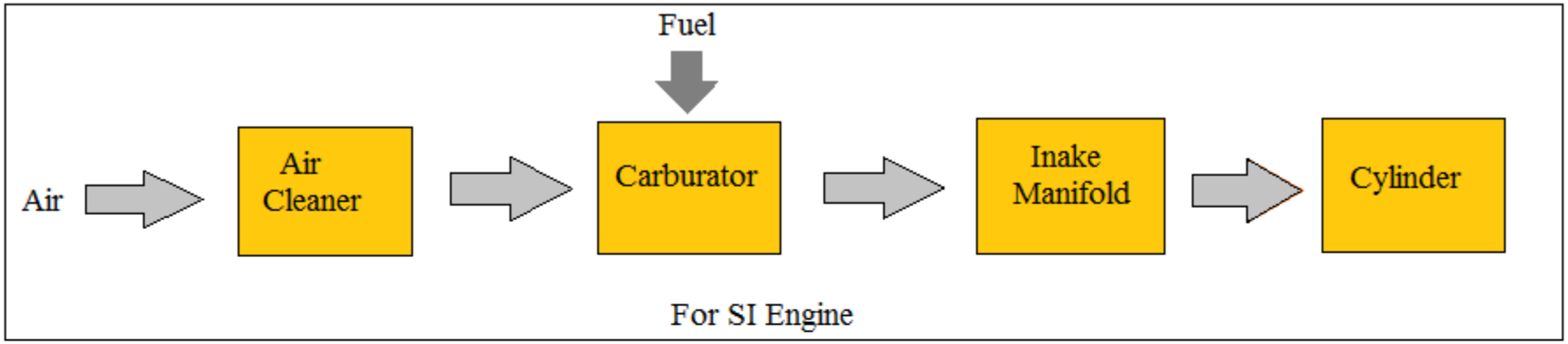
Various Systems Associated with SI and CI Engine

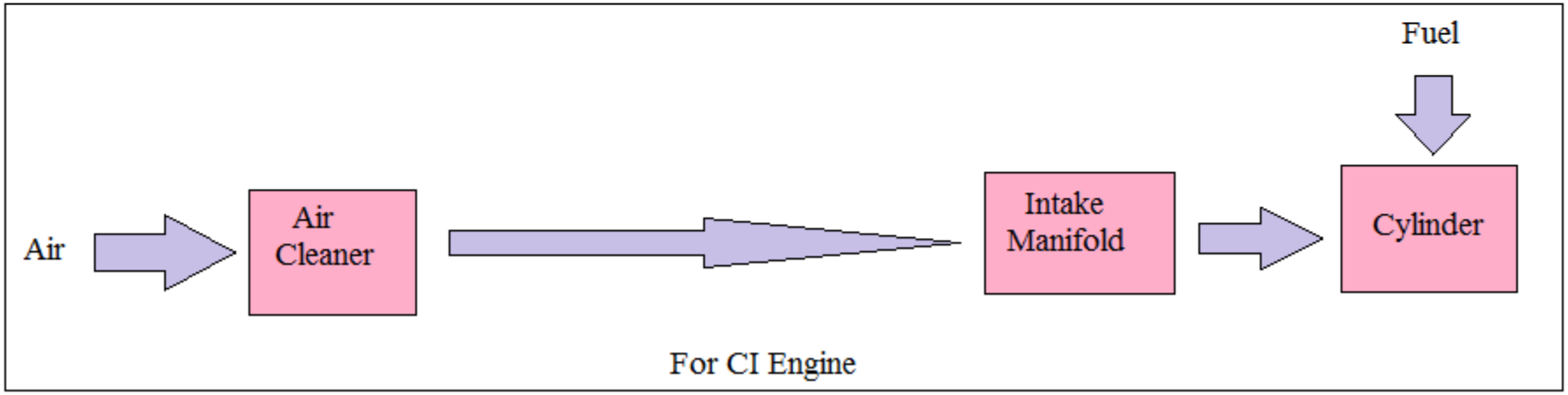
Water cooling System:



Various Systems Associated with SI and CI Engine

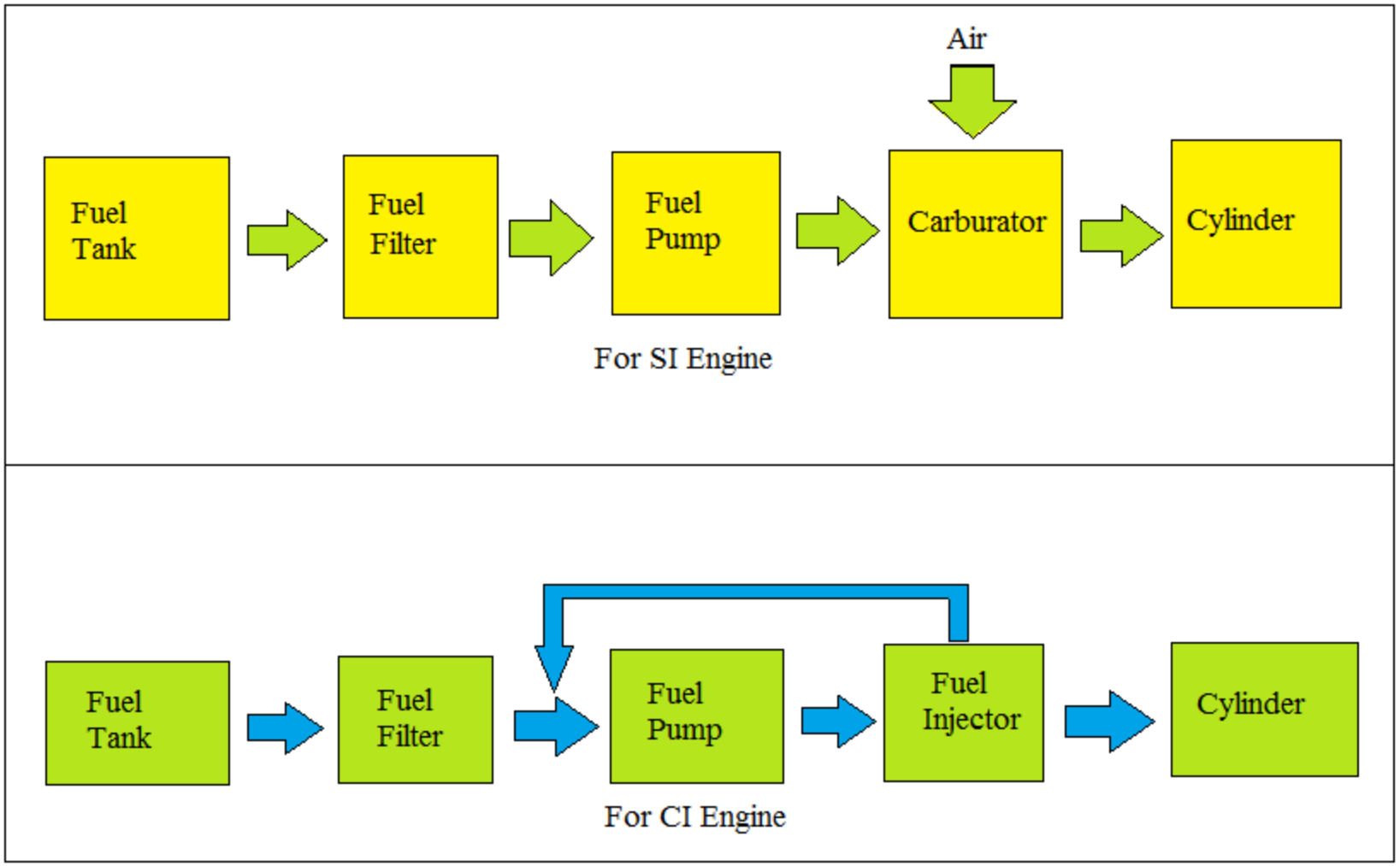
Air Intake System:





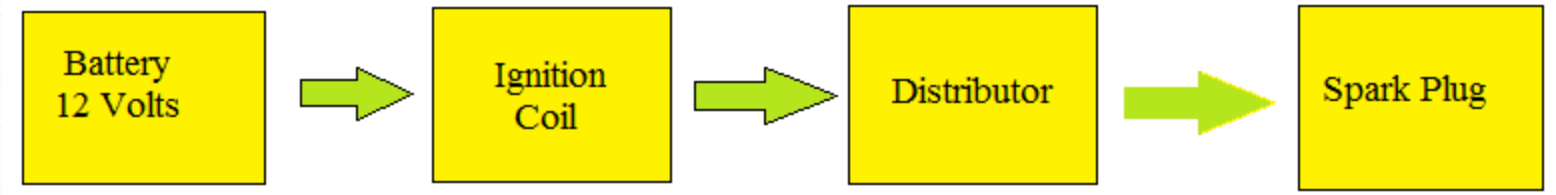
Various Systems Associated with SI and CI Engine

Fuel Supply System:

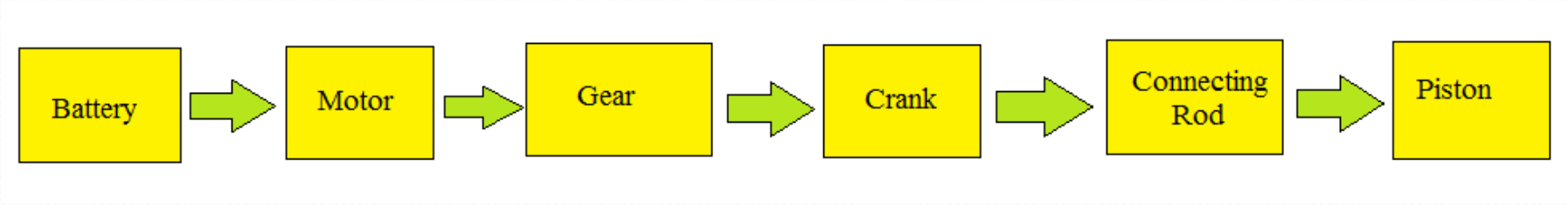


Various Systems Associated with SI and CI Engine

Ignition System: (Only Needed in SI Engine)

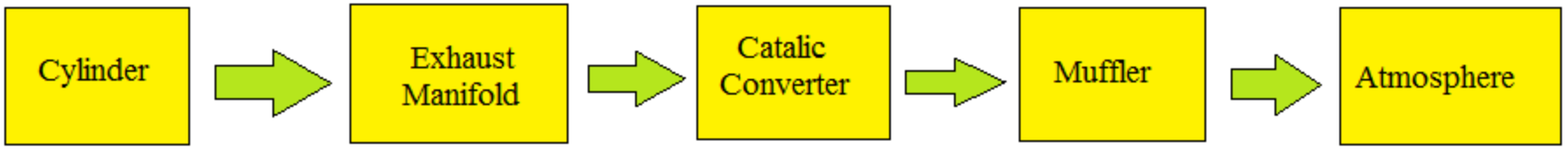


Starting System: (Same for SI and CI Engine)

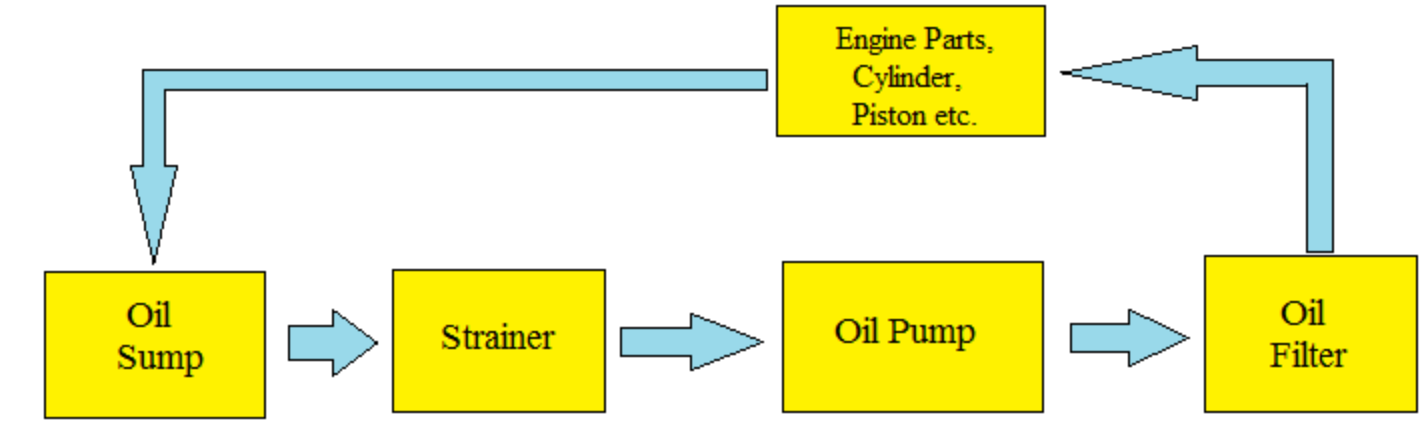


Various Systems Associated with SI and CI Engine

Exhaust System: (Same for SI and CI Engine)

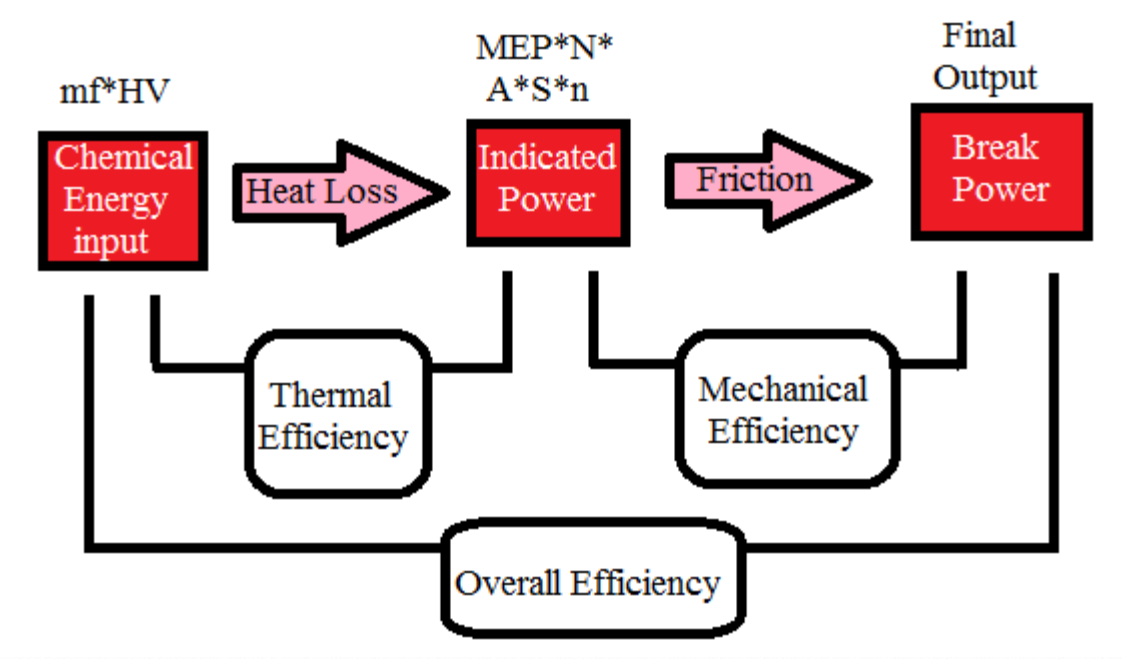


Forced Lubrication System: (Same for SI and CI Engine)



Some Terminology

1. Mean Effective Pressure (MEP): [unit: Pa or N/m^2]
   The average pressure inside the cylinder
2. Fuel consumption rate (mf): [unit: kg/sec]
   kg of fuel consumed per second.



Power Stages of an IC Engine

Expression for indicated Power (IP)

1. Indicated Power (IP): Immediately produced in the engine

IP = Power produced in the engine

= (Work done on piston in one power stroke)*(No of power stroke in 1 sec)

= (*Force on piston*)*(Displacement of piston)*(No of power stroke in 1 sec)

= (*Average Pressure on piston)*(**Total Piston area**)*(Displacement of piston)*(No of power stroke in 1 sec)

= (Average pressure on piston)*(**No of total cylinder**)*(**Area of single piston**)*(Displacement of piston)*(No of power stroke in 1 sec)

= (MEP)*(N)*(A)*(S)*(n)

= MEP*N*A*S*n

n = rpm/(2*60),
for four stroke engine
n = rpm/(60),
for two stroke engine

Performance calculation of ICE

1. Indicated Power (IP): Immediately produced in the engine
   IP = MEP*No of cylinder(N)*Area(A)*Stroke(S)*
   No of power stroke(n)
   = MEP*N*A*S*n
2. Friction Power (FP): Power losses due to friction.
3. Brake Power (BP): Rest of power after all kind of frictional losses
   = IP - FP
4. Thermal efficiency:
   = (IP)/(mf*Heating Value)
5. Mechanical efficiency:
   = (BP)/(IP)
6. Overall efficiency:
   = Thermal efficiency*Mechanical efficiency

Mathematical Problem

A four cylinder four stroke petrol engine have a cylinder of diameter 15 cm and stroke of 25 cm. The mean effective pressure (MEP) upon the piston is 700 kN/m^2 and the crank shaft rotates at 500 rpm.

a) Find the indicated power of the engine.

b) If the frictional power loss is 5 kw, then find the brake power and mechanical efficiency.

c) If the fuel consumption rate of the engine is 18 kg/hour (Heating value = 40 MJ/kg) then find the thermal efficiency of the engine.

d) What will be the overall efficiency?

Solution:

a) Indicated Power: (IP)

$$IP = \boxed{MEP\ (N/m^2)} * \boxed{N} * \boxed{A\ (m^2)} * \boxed{S\ (m)} * \boxed{n\ (sec^{-1})}$$

$$= (700 * 10^3) * 4 * [(3.1416 * 0.15^2)/4] * 0.25 * [500/(2*60)]$$

$$= 51542\ W$$

$$= 51.54\ kW \qquad \text{(Ans)}$$

b) Break Power: (BP)

$$BP = IP - \text{Frictional power loss}$$

$$= 51.54 - 5$$

$$= 46.45\ kW \qquad \text{(Ans)}$$

Mechanical Efficiency = break power/indicated power

= 46.45/51.54

= 0.9

= 90% (Ans)

c) Thermal Efficiency = IP/(mf*Heating Value)

= (51.54*1000)/[(18/3600)*(40*1000000)]

= 0.26

= 26% (Ans)

d) Overall Efficiency = Mechanical efficiency *Thermal efficiency

= 0.90*0.26

= 0.234

= 23.4% (Ans)

Pollution from ICE

U.S. Environmental Protection Agency estimates of average passenger car emissions in the United States for July 2000[9]

Component	Emission Rate	Annual pollution emitted
Hydrocarbons	2.80 grams/mile (1.75 g/Km)	77.1 pounds (35.0 kg)
Carbon monoxide	20.9 grams/mile (13.06 g/Km)	575 pounds (261 kg)
NO_x	1.39 grams/mile (0.87 g/Km)	38.2 pounds (17.3 kg)
Carbon dioxide - greenhouse gas	0.916 pounds per mile (258 g/km)	11,450 pounds (5,190 kg)

Global Warming Potential of Primary Greenhouse Gases

Greenhouse Gas	Chemical formula	Global Warming Potential [Time Horizon] 20 years	100 years
Carbon Dioxide	CO_2	1	1
Methane	CH_4	42-70	16-26
Nitrous Oxide	N_2O	280	310
Hydrofluorocarbons	HFCs	460 - 9,100	140-11,700
Perfluorocarbon	PFCs	4,400-6,200	6,500-23,900
Sulphur Hexafluoride	SF_6	16,300	23,900

Global Worming Potential:

1. Represents pollution capability.
2. Base is CO2.
3. Impact on green house effect.

ME 201

Mechanical Engineering Fundamentals

Boilers Steam generators and Steam turbine

Md. Abdul Hamid

Boilers

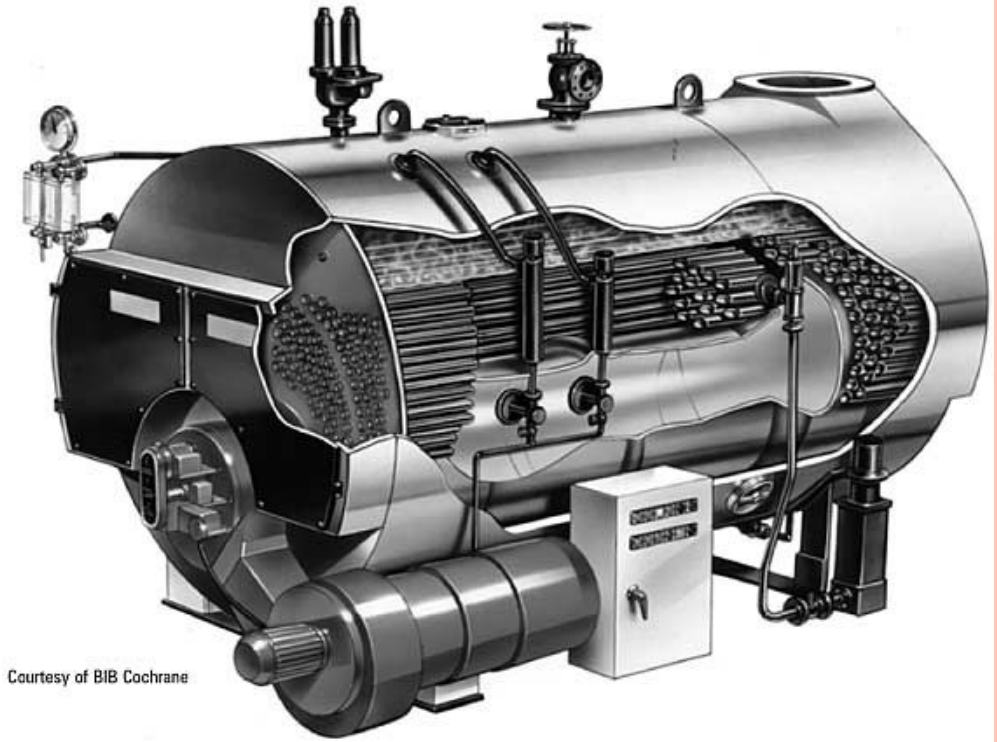
Objectives:

1. To describe and explain the boiler's function.
2. Describe main types of boilers.
3. Describe boiler accessories and mountings.
4. Analyze boiler performances.

What is Boiler:

- A closed vessel, that produce steam.
- What is the difference from a kettle?

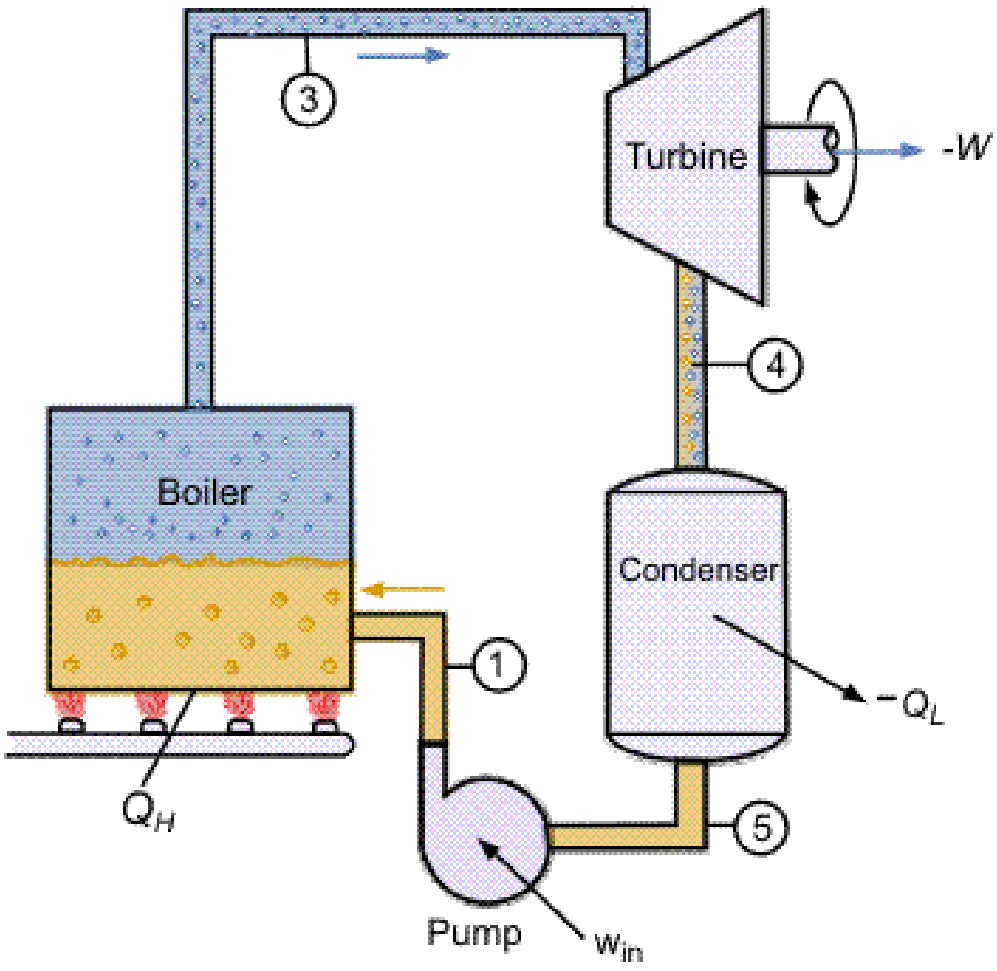
Kettle



Boiler

- Both provide steam.
- Boiler can control **pressure, temperature** and flow rate of the steam

Function of boiler:



Known as Rankine Cycle
(Steam power plant)

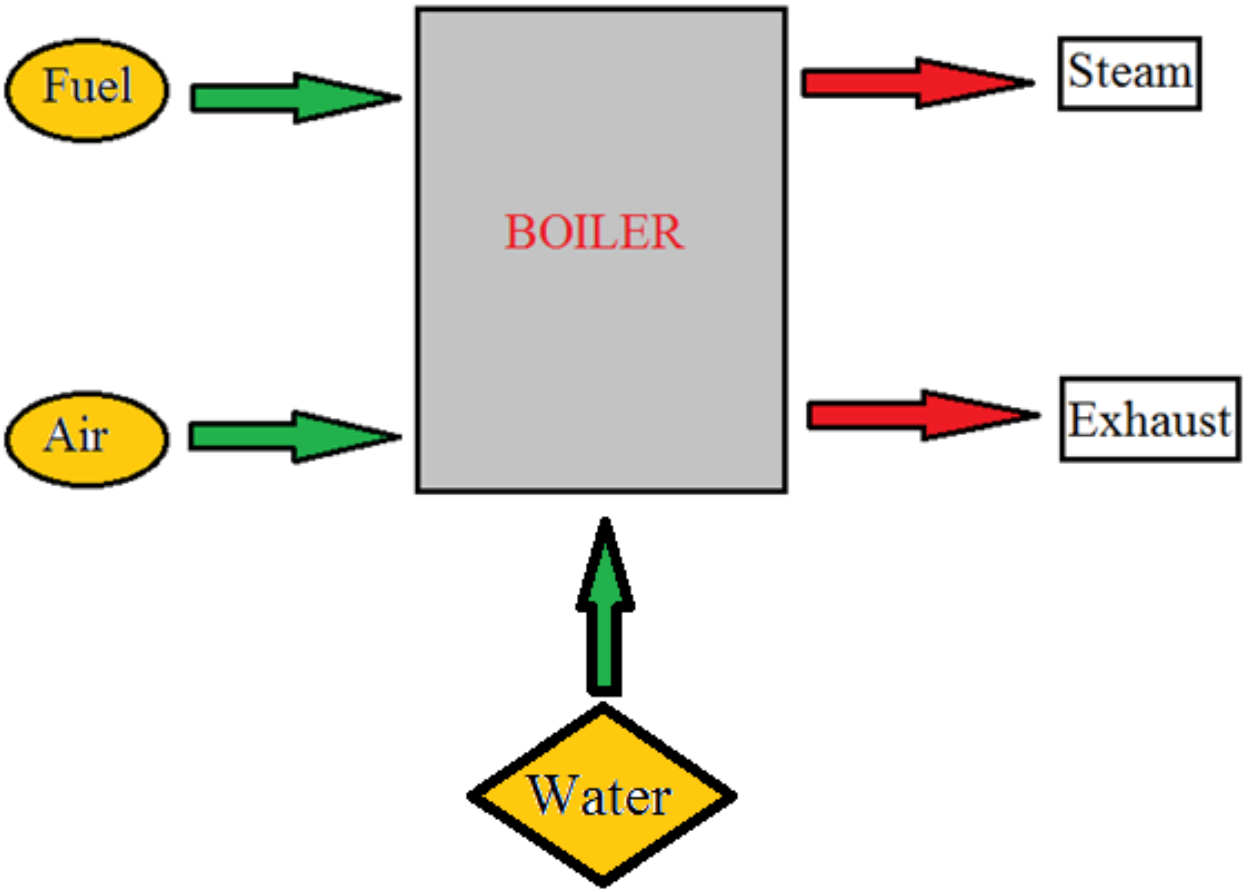
Boiler produces and supplies steam which can be used for

* Power generation

* Industrial purposes like:

1. Sugar Mills
2. Tannery Industries
3. Food Industries
4. Textile Industries

Boiler Operation:



Feed water has to be soft water

Types of Boilers:

1. Based on content in tube:
   a) Fire tube boiler
   b) Water tube boiler

2. Based on position of furnace:
   a) Internally fired
   b) Externally fired

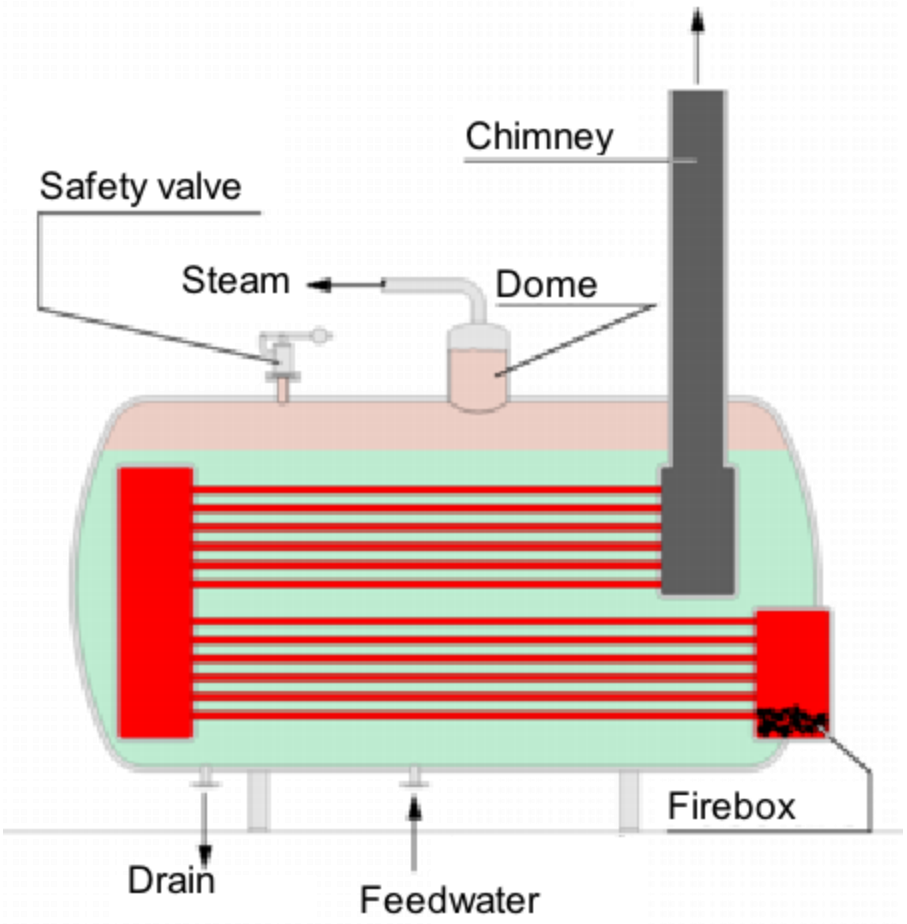
3. Based on Number of Tubes:
   a) Single tube
   b) Multi tube

4. Based axis of shell:
   a) Vertical
   b) Horizontal

5. Based on circulation:
   a) Natural circulation
   b) Forced circulation

6. Based on installation:
   a) Stationary boiler
   b) Mobile boiler

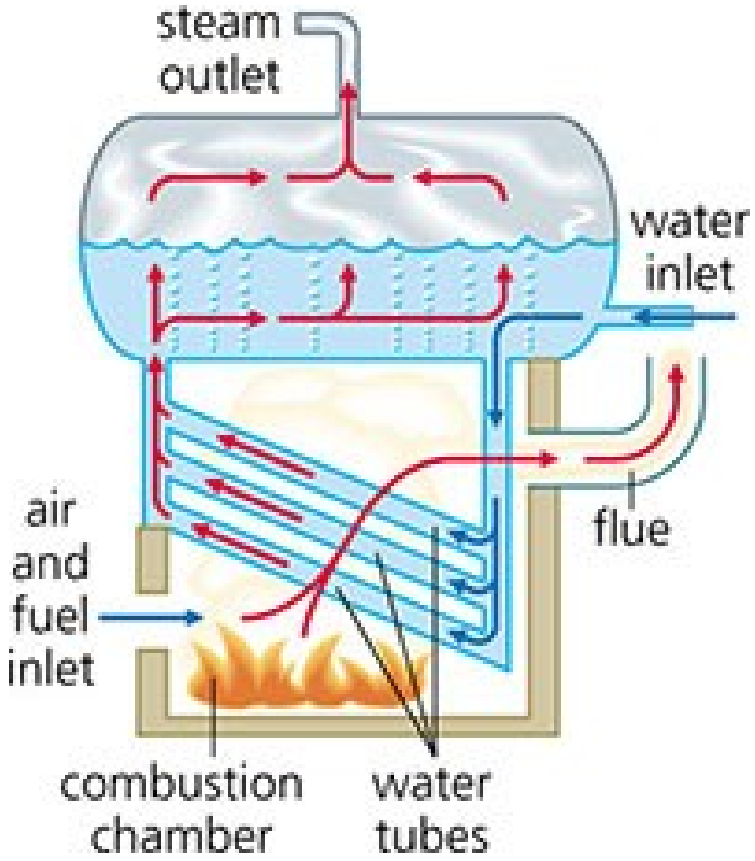
Fire Tube Boiler:



Examples:

1. Cochran boiler,
2. Lancashire Boiler,
3. Cornish Boiler,
4. Scotch Marine Boiler,
5. Locomotive Boiler,
6. Velcon Boiler

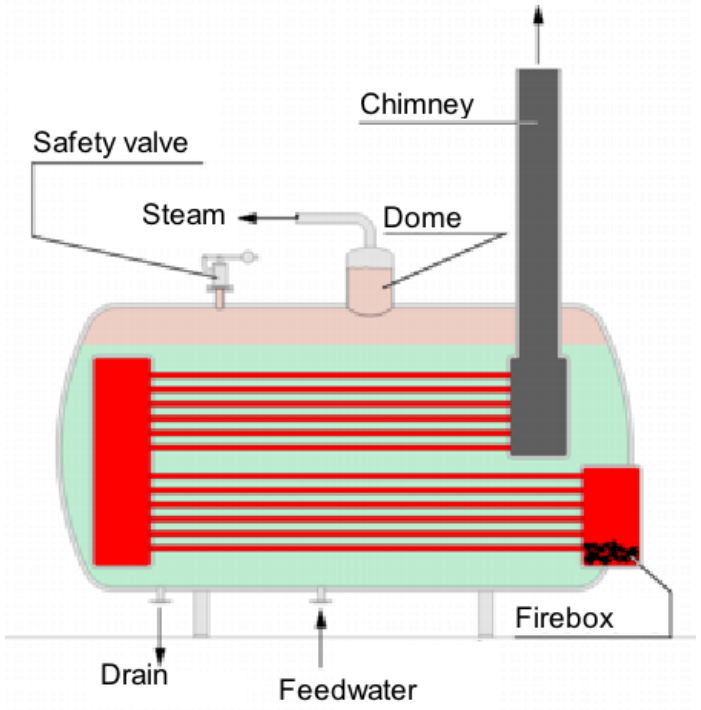
WATER TUBE BOILER



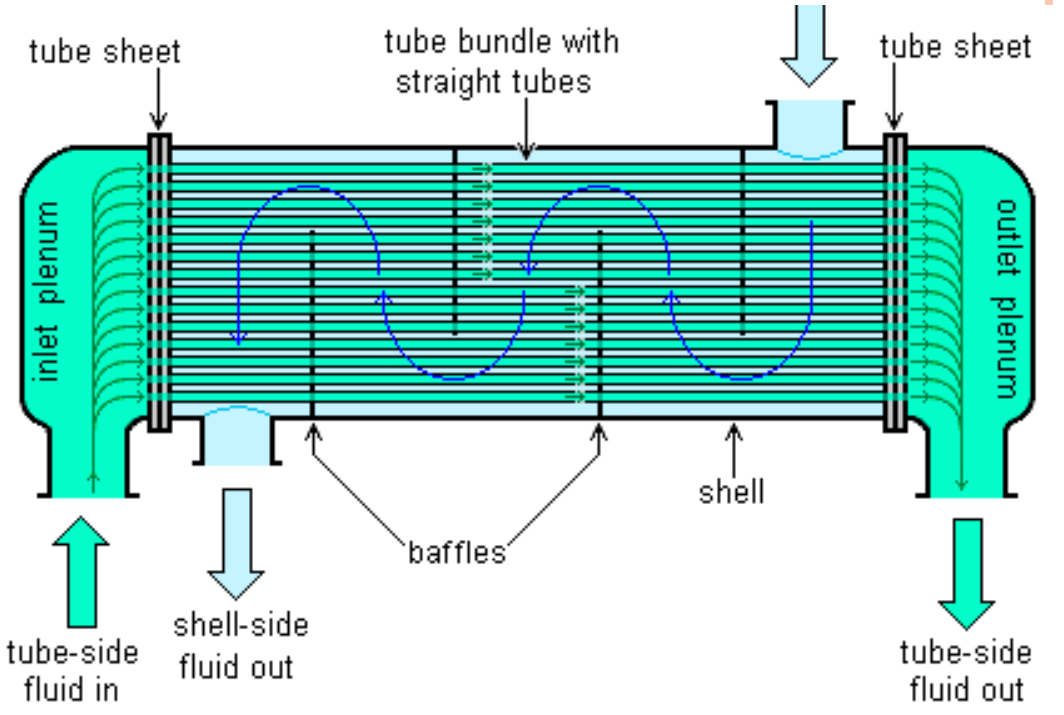
Examples:

1. Babcock and Wilcox Boiler
2. Stirling Boiler
3. La-Mont Boiler
4. Benson Boiler
5. Yarrow Boiler
6. Loeffler Boiler

Boiler tube and pass



6 tube, 2 (tube) pass boiler



14 tube, 5 (shell) pass boiler

Components of Boilers:

Three types:

1. Main body parts

   Needed for:

   a) construction and
   b) functioning.

2. Mountings

   Needed for

   a) safety and
   b) proper functioning

3. Accessories

   Needed for

   a) performance enhancement
   b) better efficiency

Components of Boilers:

1. Main body parts:

   Shell, Tubes, Furnace etc.

2. Boiler Mountings and Accessories

Mountings:

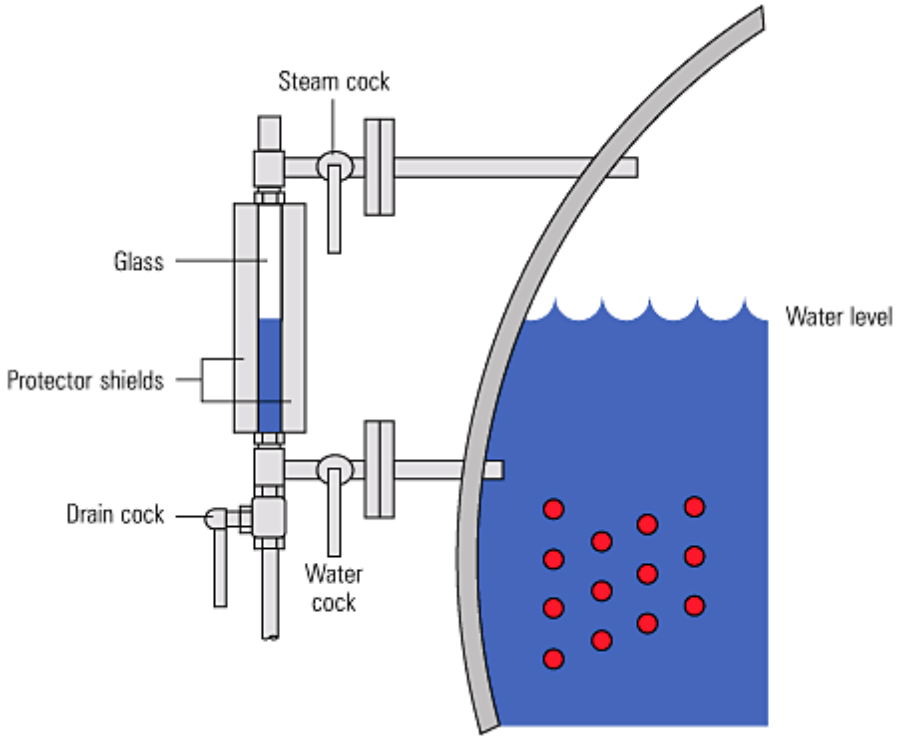
1. Water Level Indicator
2. Pressure gauge
3. Safety valves
4. Steam stop valve
5. Blow off cock
6. Fusible plug
7. Feed Check valve

Accessories

1. Superheater
2. Economiser
3. Air preheater
4. Reheater
5. Feed Pump
6. Draught Production Equipments

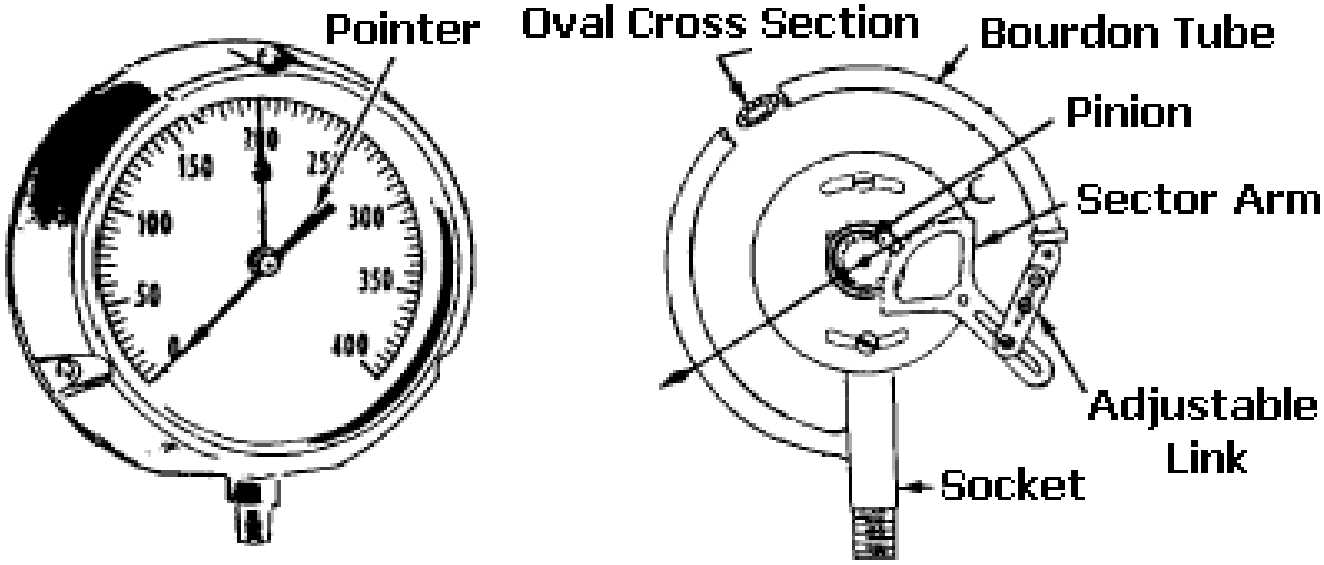
1. Water Level indicator:

1. At least two
2. Shows the water level in boiler shell.
3. Made of transparent materials.
4. Alarm is attached to buzz when the water level falls lower then a predetermined level



If the boiler shell is empty heating causes access rise in temperature and mechanical failure takes place

2. Pressure gauge

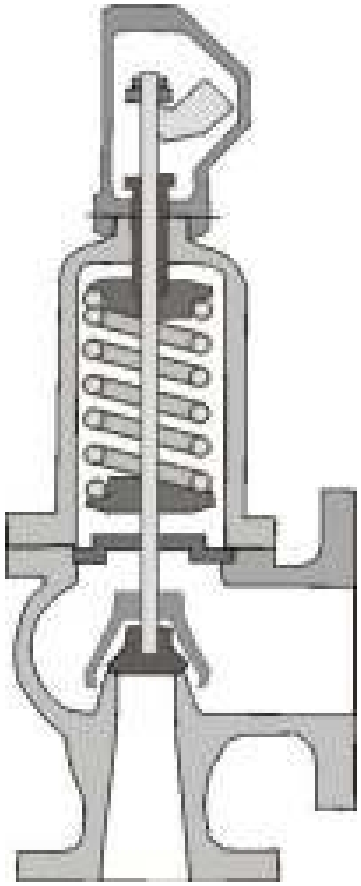


Pressure gauge always shows the difference of Measured pressure and atmospheric pressure

So, Absolute Pressure = Gauge Pressure + Atmospheric Pressure

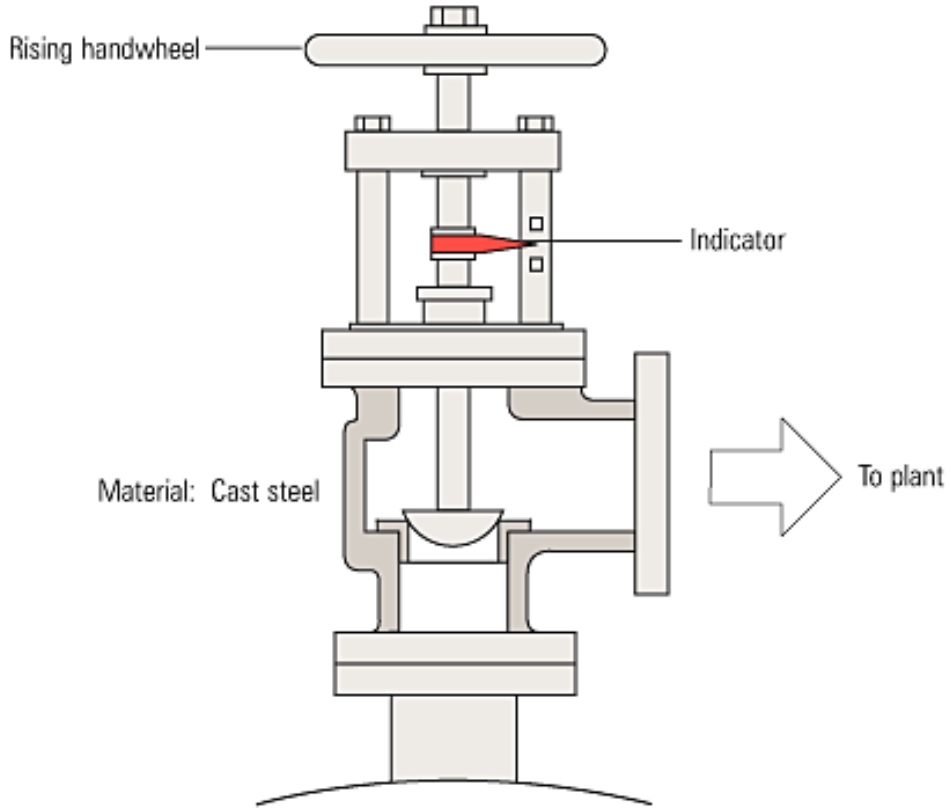
Absolute pressure can never be negative but the gauge pressure can be negative.

3. Safety Valve



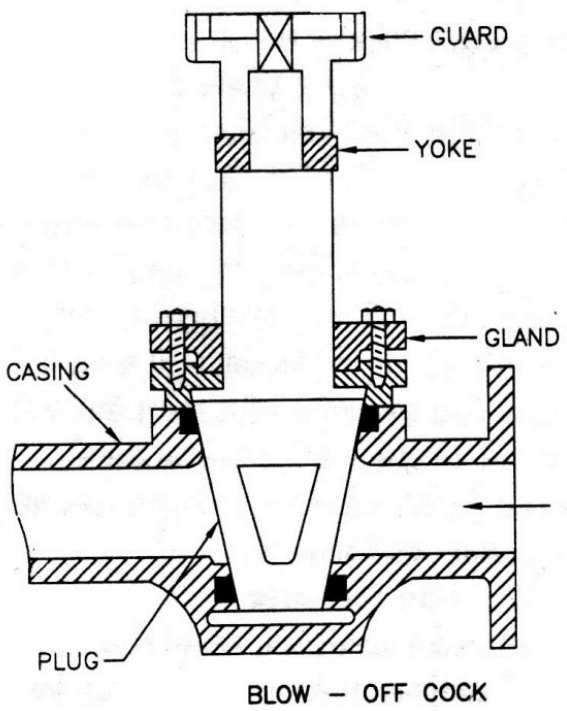
- Prevent pressure rise above a pre-determined maximum pressure.
- Spring loaded, dead weight lever type valve.
- Release some steam automatically.
- At least 2 valves are mounted on the top of the shell.

4. Steam Stop Valve



- Shut off the steam flow completely.
- Control the flow of steam.
- Mounted on top of the shell.

5. Blow Off cock



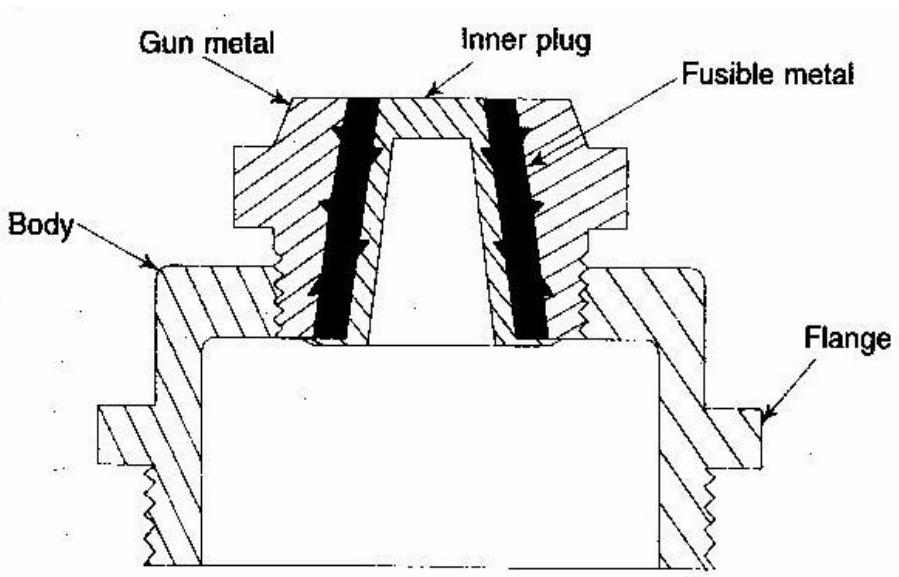
- Used to remove mud, scale or sediments.
- Also it is used to empty the boiler when required.
- Mounted at the bottom of the shell

6. Fusible Plug

- Used to put off the fire in the furnace

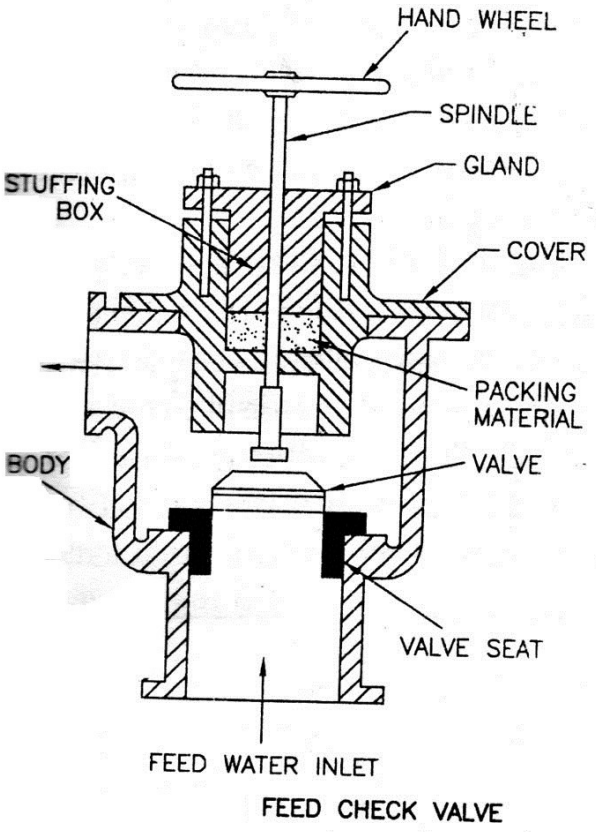
- If the level of water falls to an unsafe limit excess temperature rises.

- The fusible metal fuses and stop the furnace



- Mounted over the furnace - inside the shell

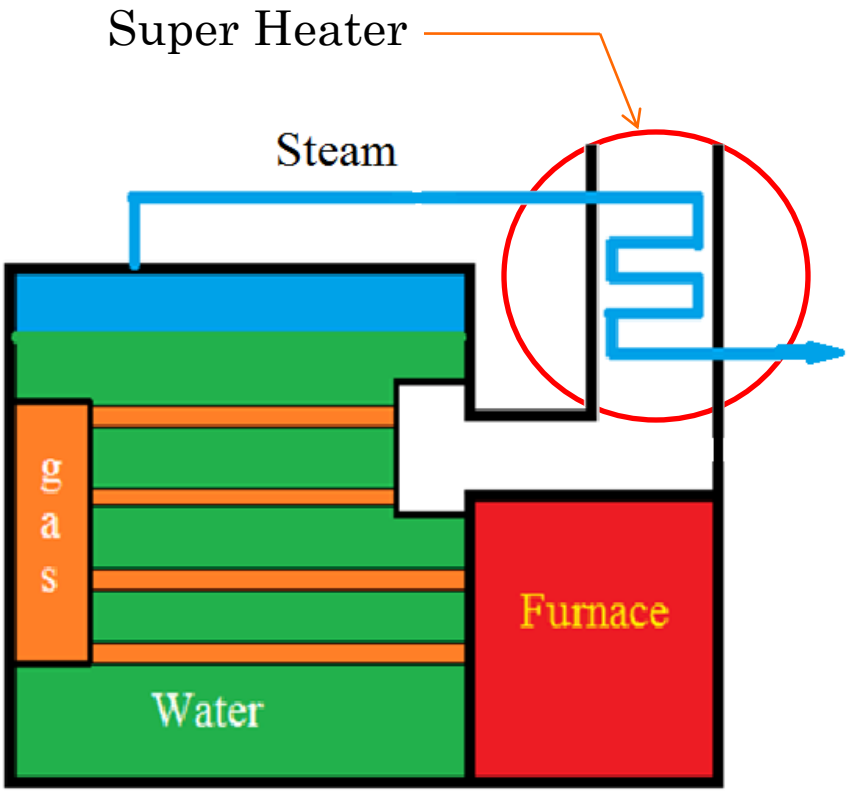
7. Feed check valve



FEED CHECK VALVE

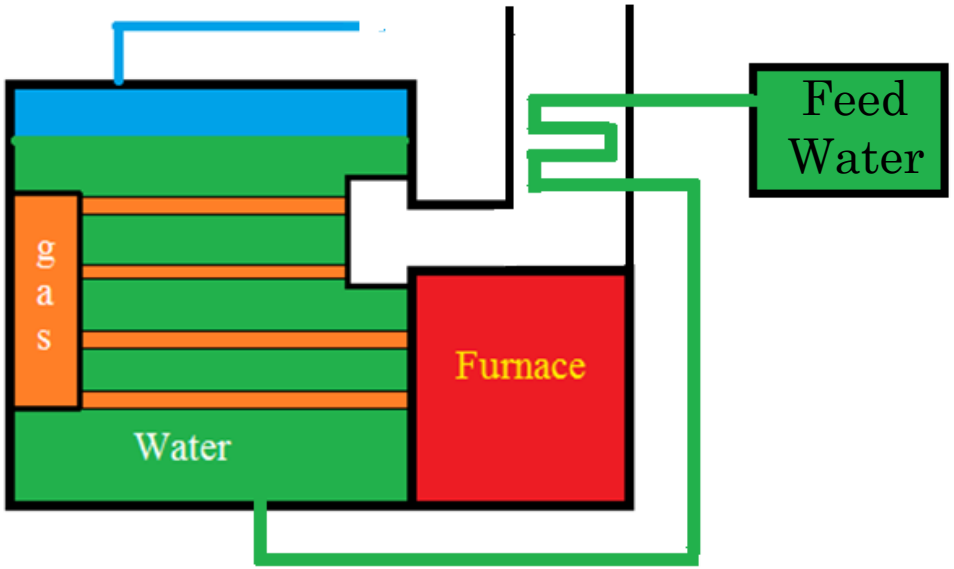
- Control the supply of water into the boiler.
- It does not allow any water to flow back from the boiler
- It is fitted over the shell slightly below the normal water level of the boiler.

Super Heater:



1. Super heats the final steam.
2. Do not change pressure.
3. Use energy from flue gas.
4. Usually inherently installed.
5. Some times external super heater is installed.

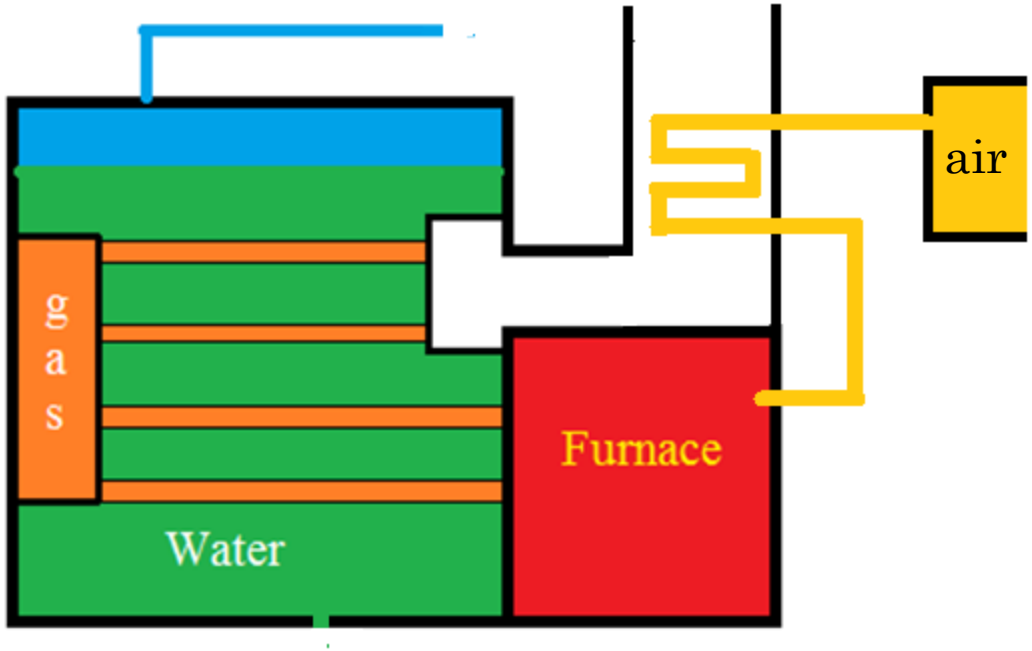
ECONOMIZER



1. Heat up the feed water.
2. Do not change pressure.
3. Use energy from flue gas.
4. 15% - 20% cost saving.
5. Shorten the time required.
6. Reduce scaling in boiler.
7. Reduce thermal fatigue.

Economizer is the most effective accessories among all others

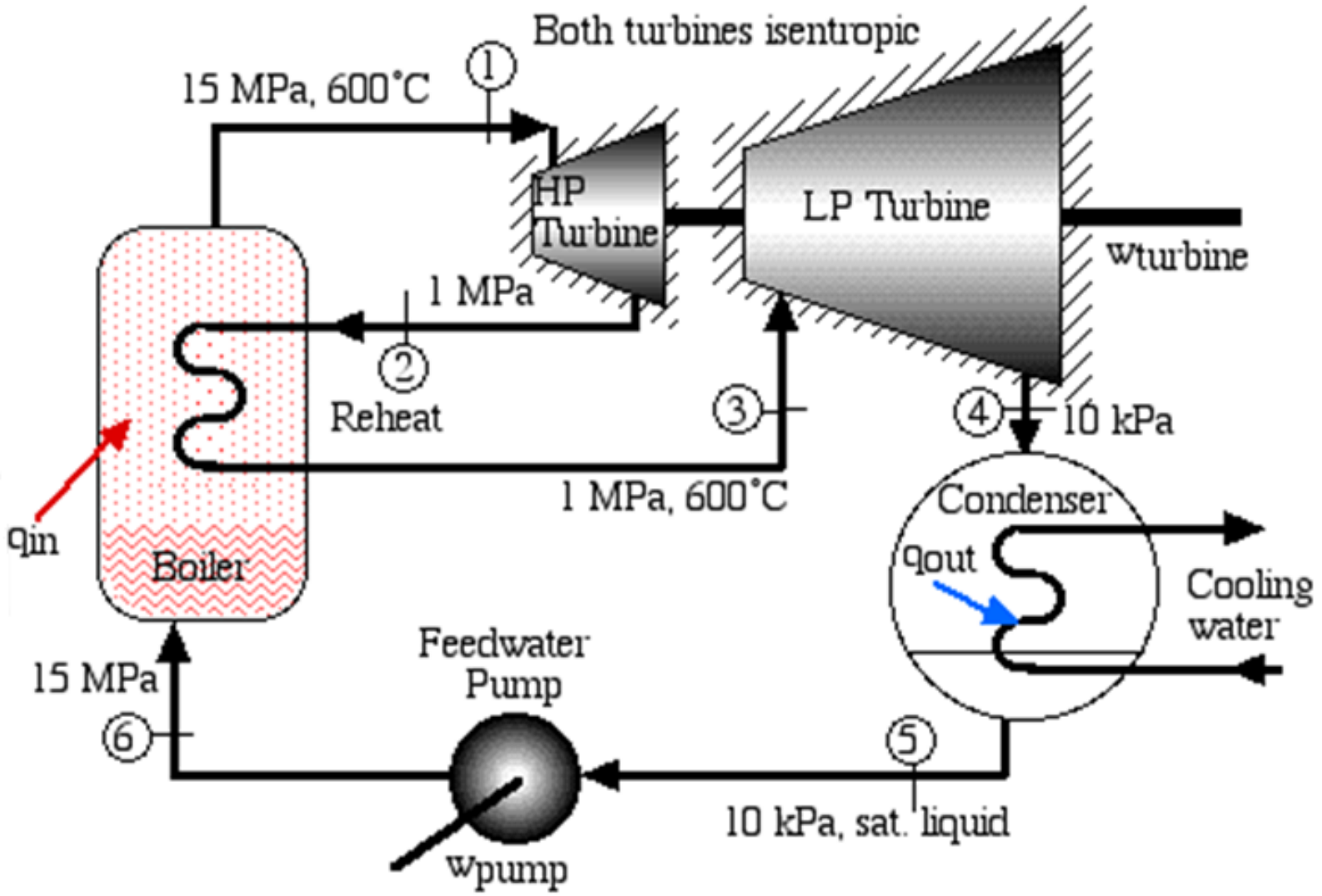
Air Pre-heater



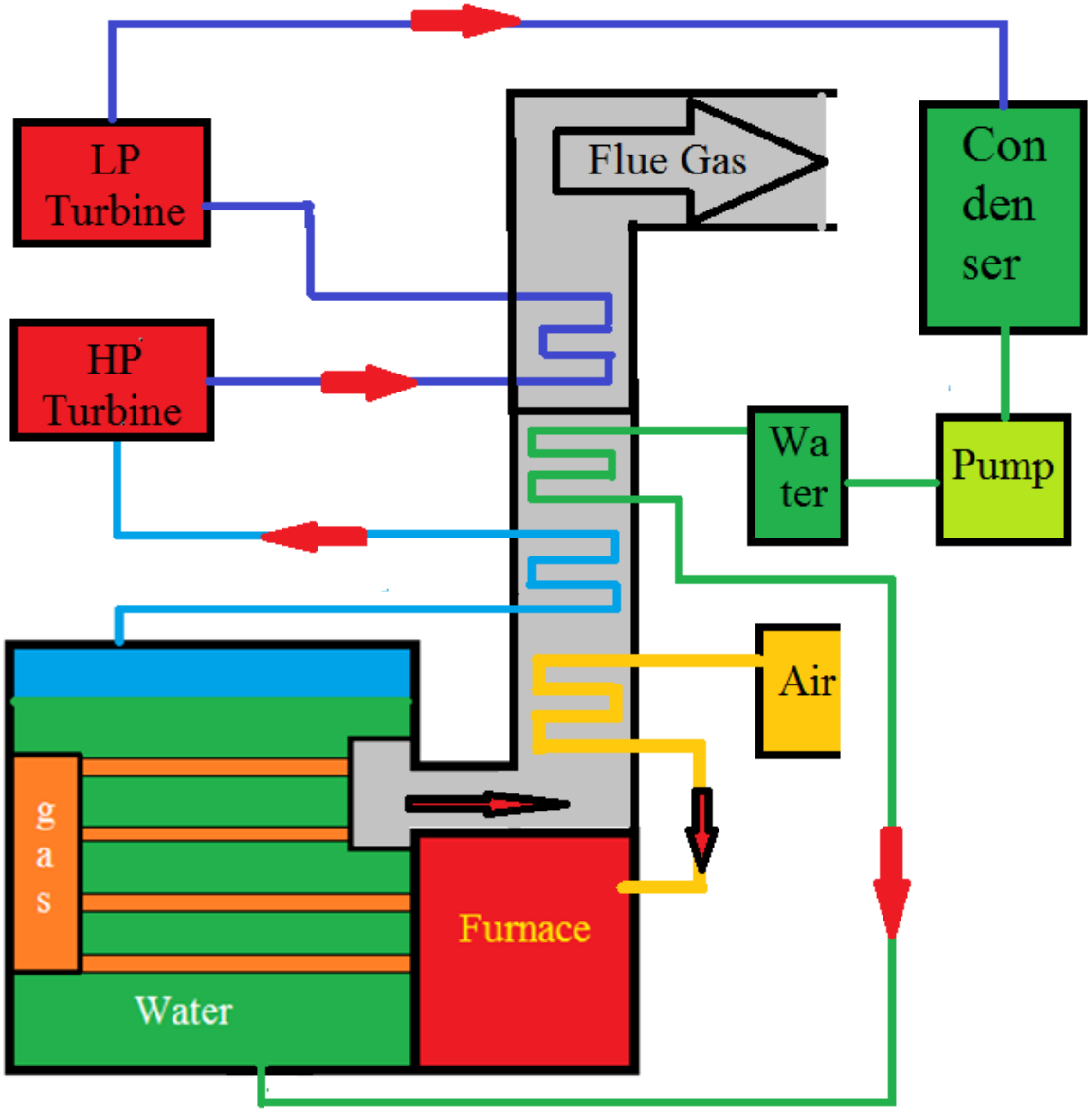
1. Heat up the air.
2. Do not change pressure.
3. Use energy from flue gas.
4. Provide higher furnace temperature.
5. About 2% increase in efficiency, per 35^0 rise in temperature.

6. Better combustion with low soot, smoke and ash
7. Enables low grade fuel to be used

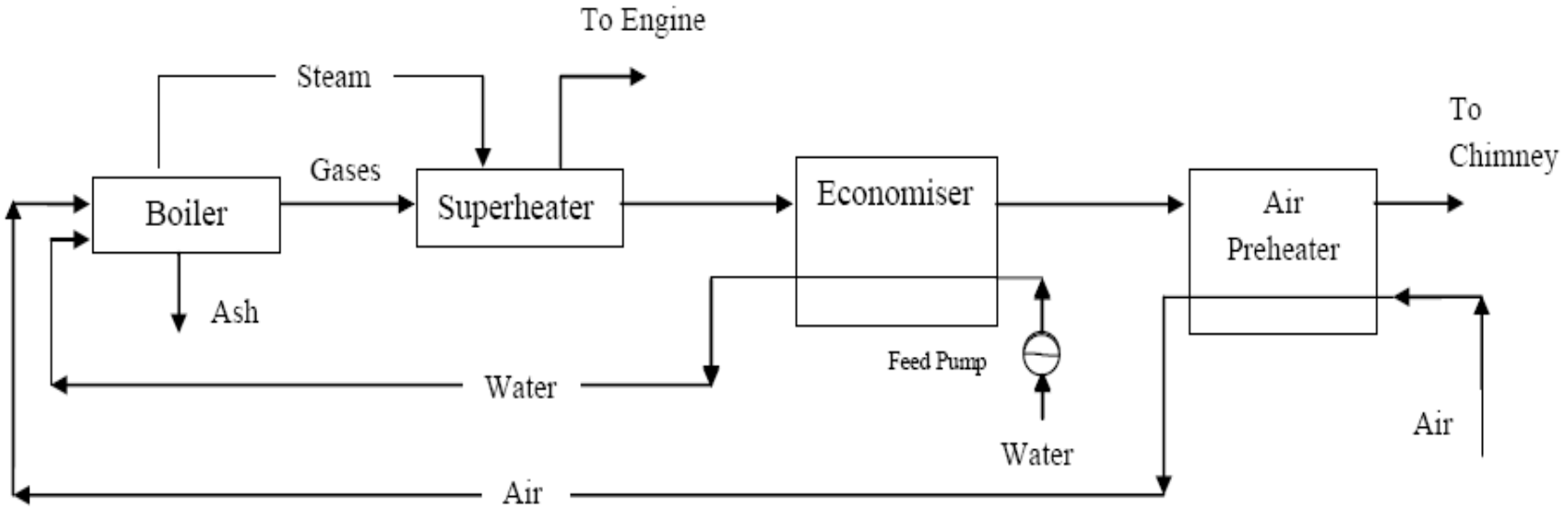
Reheater:


Both turbines isentropic
15 MPa, 600°C
1
HP Turbine
LP Turbine
Wturbine
1 MPa
2
Reheat
3
4
10 kPa
1 MPa, 600°C
Condenser
qin
Boiler
qout
Cooling water
15 MPa
6
Feedwater Pump
5
10 kPa, sat. liquid
wpump

An operative efficient boiler



SCHEMATIC BLOCK DIAGRAM



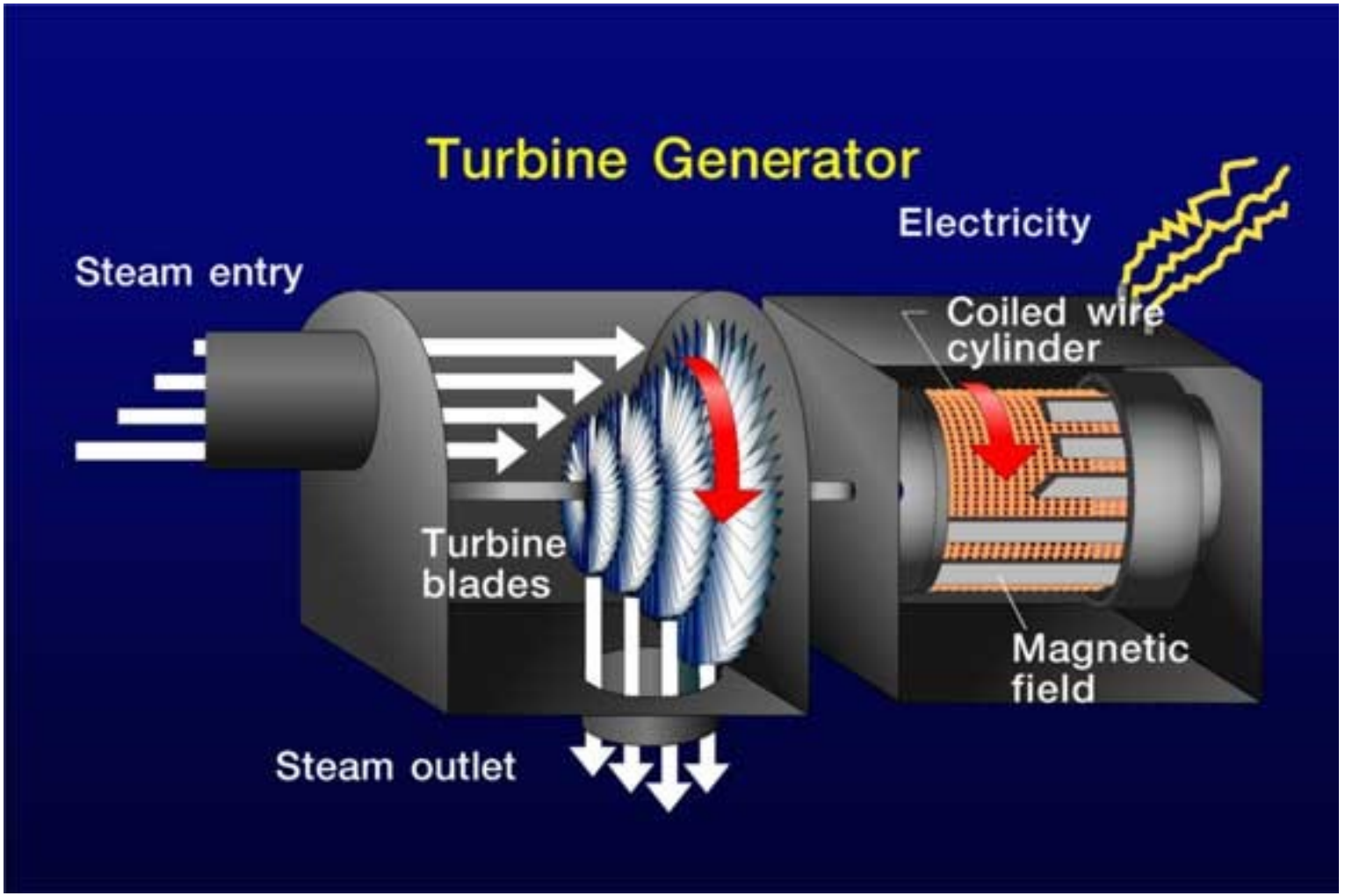
This block diagram is with:

1. Super-heater
2. Economizer (Feed water heater)
3. Air pre-heater
4. Feed pump

Reheater is absent

Steam Turbine

Device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft.

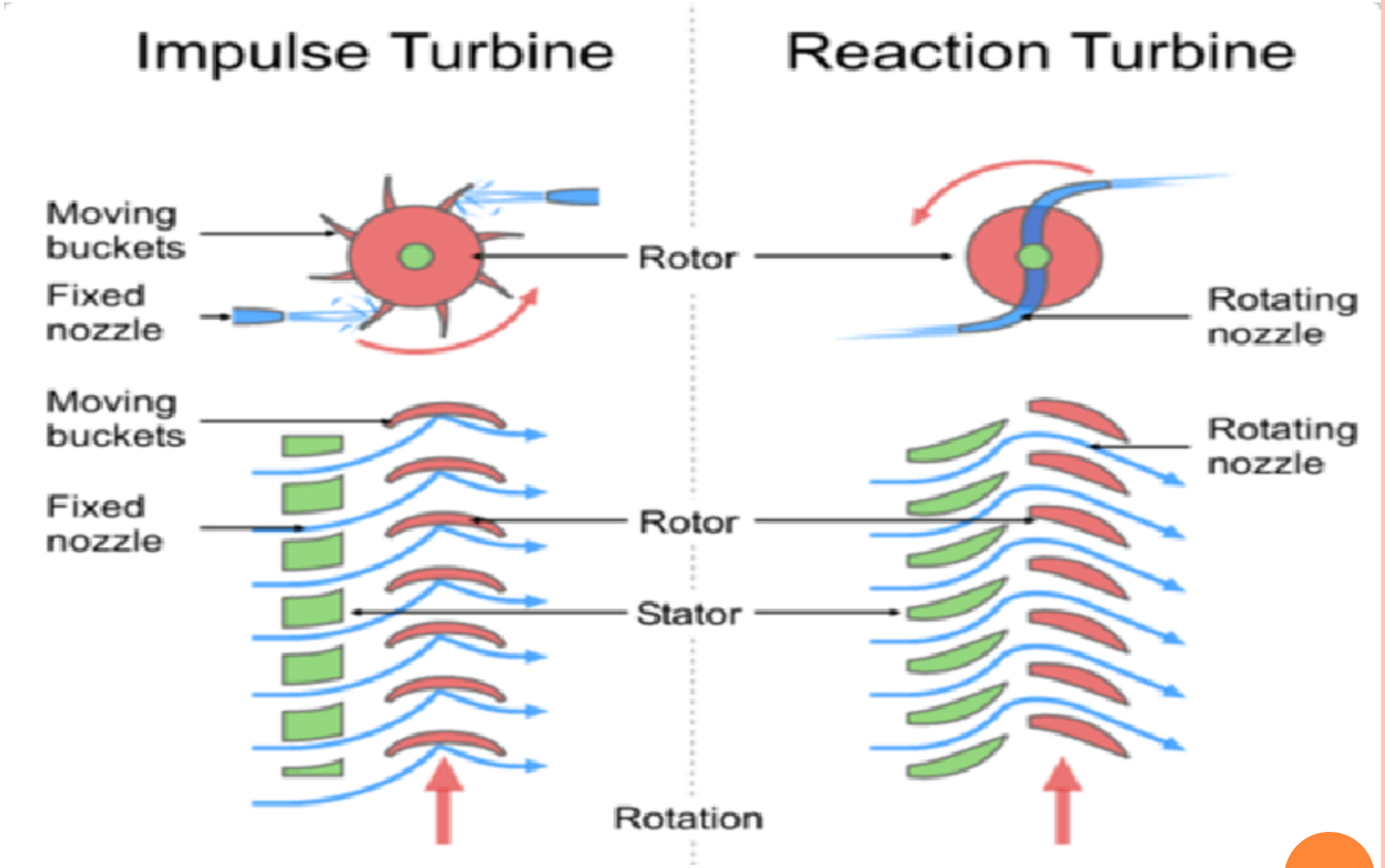


Types of turbines

Turbines are mainly of two types:

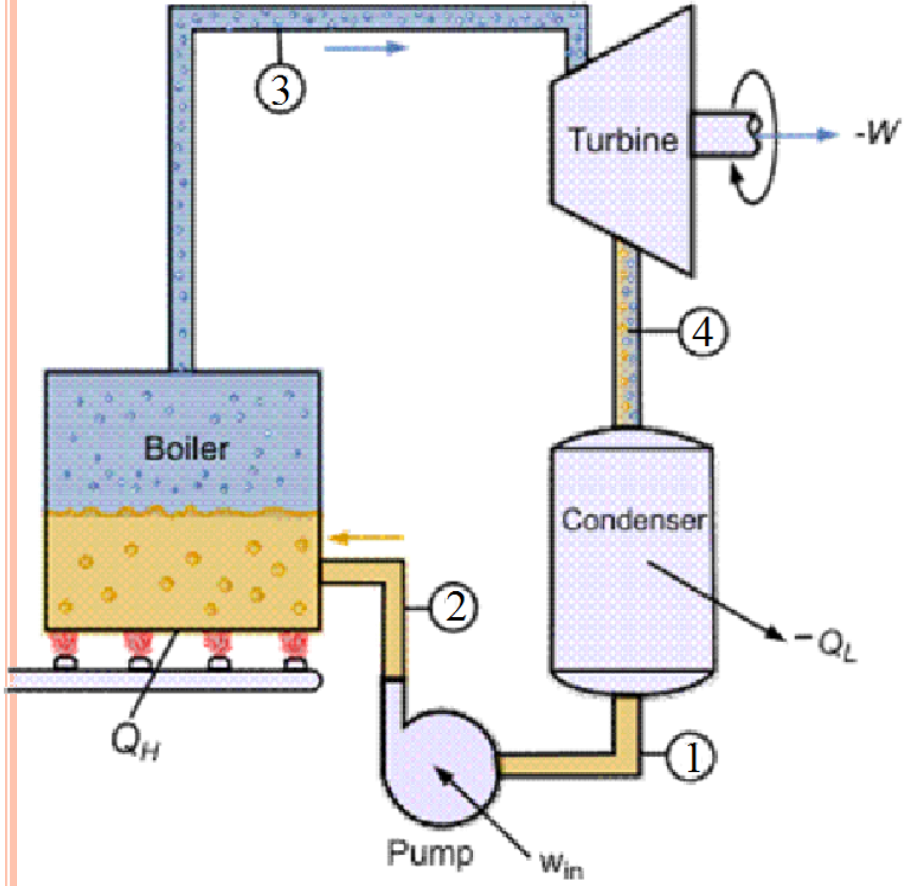
1. Impulse Turbine
2. Reaction Turbine

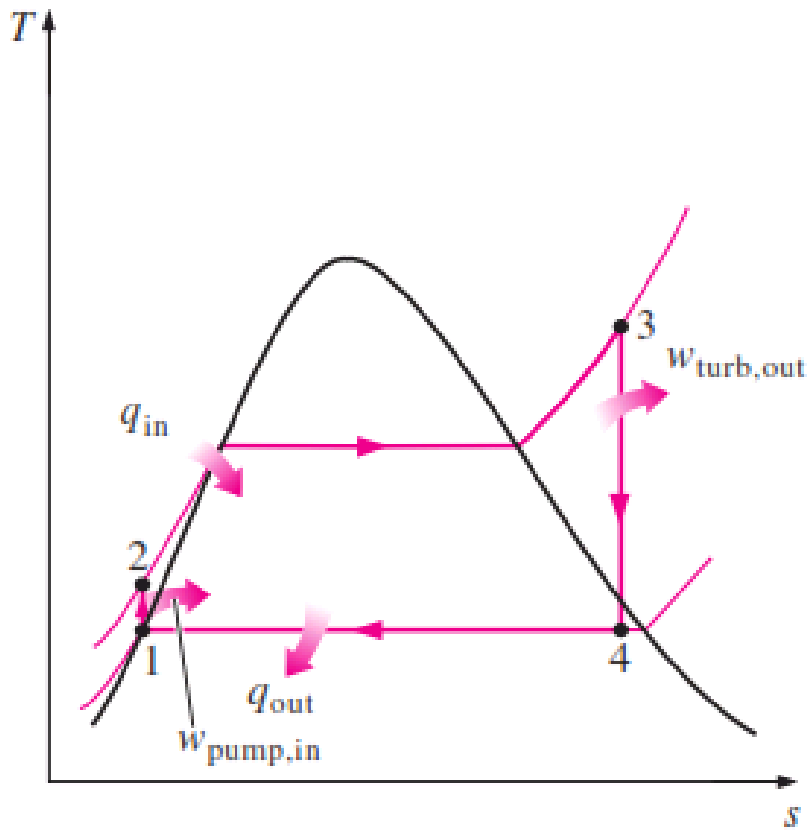
Most steam turbines use a mixture of the reaction and impulse designs. Typically, higher pressure sections are impulse type and lower pressure stages are reaction type.


Impulse Turbine
Reaction Turbine
Moving buckets
Fixed nozzle
Rotor
Rotating nozzle
Moving buckets
Fixed nozzle
Rotor
Stator
Rotating nozzle
Rotation

Thermodynamic Processes and Cycles

Rankine cycle





Rankine cycle

Description of Process:

1---2 : (Compression in Pump)

a) Isentropic compression (S const, P increase, T increase)

2---3 : (Heating of water + Evaporation of water + Heating of steam in Boiler)

a) Isobaric heat addition (S increase, P const, T **varies + const**)

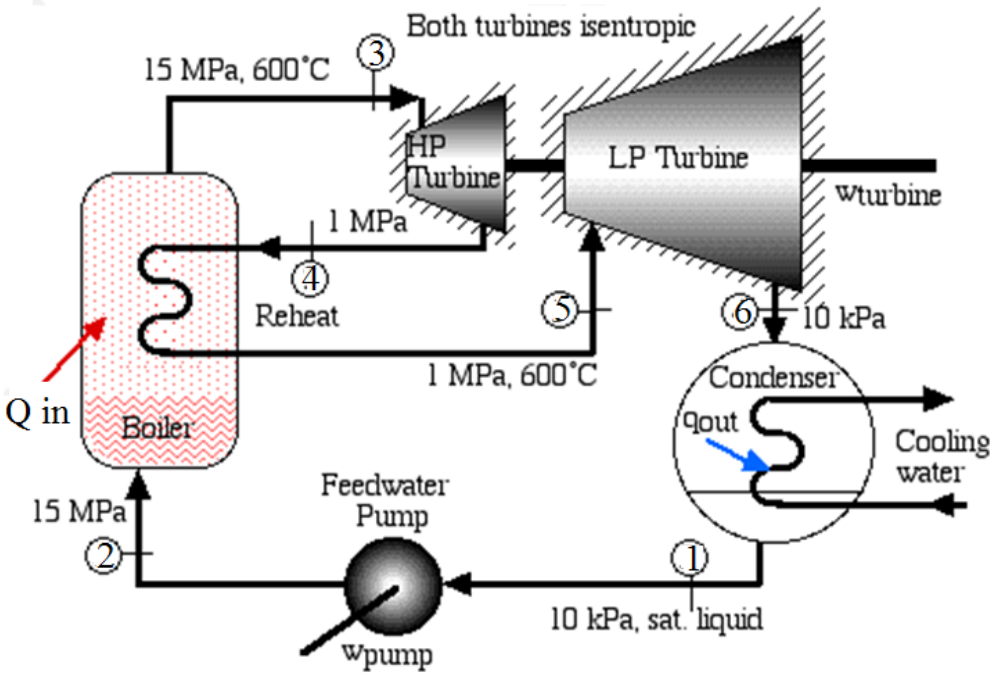
3---4 : (Expansion in Turbine)

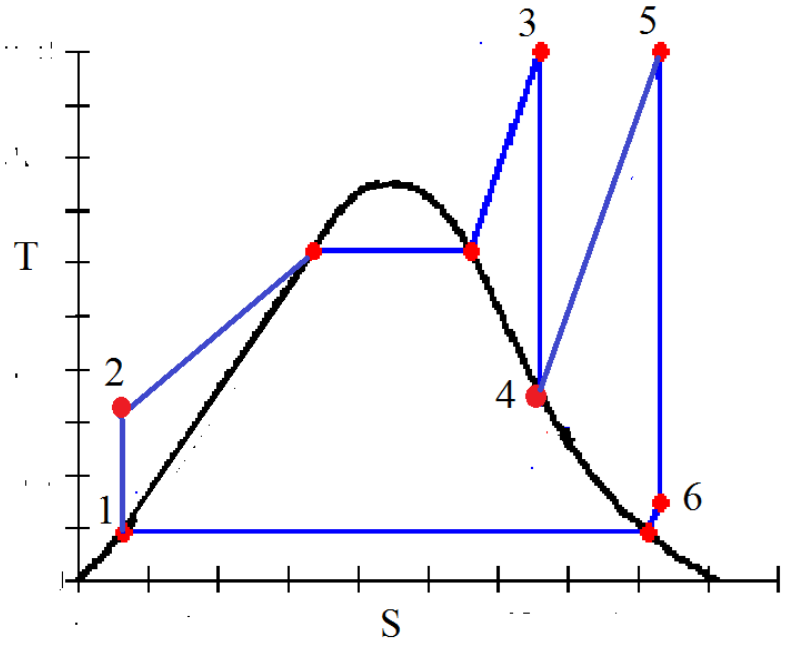
a) isentropic expansion (S const, P decrease, T decrease)

4---1 : (Condensation of vapor)

a) Isobaric heat rejection (S decrease, P const, T **const + varies**)

Rankine cycle with Reheat





Processes involved:

1—2: Pump

2—3: Boiler

3—4: HP Turbine

4—5: Reheater

5—6: LP Turbine

6—1: Condenser

Linear Interpolation and Steam Table

Mathematical problem

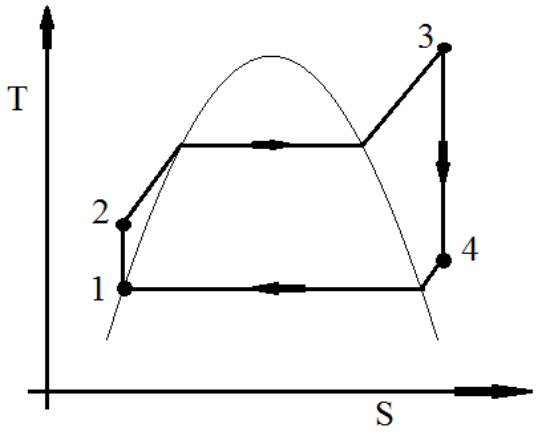
Problem: In a power plant the turbine is run by a boiler that consumes 0.12 kg of natural gas (HV = 50 MJ/kg) and produce 2 kg of super heated steam per second. The boiler supply's steam at 5 MPa and 460^0 C which enters a steam turbine. The outlet of the turbine is at a pressure of 0.7 MPa superheated steam. Then the steam is condensed and pumped into the boiler again. Determine:

a. Work input to the pump.
b. Heat input to the boiler.
c. Out put work of the turbine.
d. Heat rejected to the condenser.
e. Thermal efficiency of boiler.
f. Efficiency of the cycle considering pump work.
g. Efficiency of the cycle neglecting pump work.

Solution:
Parameters: T, P, s, h

Step 1: Draw the T-S diagram:

1—2 : Work input to pump
2—3 : Heat input to boiler
3—4 : Work output from turbine
4—1 : Heat rejection to condenser



Step 2: Finding well defined point:

Point	T	P	s	h	Fluid Condition
1	Unknown	0.7 MPa	Unknown	Unknown	Saturated Liquid
2	Unknown	5 MPa	Unknown	Unknown	Compressed Liquid
3	460^0 C	5 MPa	Unknown	Unknown	Superheated Steam
4	Unknown	0.7 MPa	Unknown	Unknown	Superheated Steam

Step 3: Point analysis

Point 3: T3 = 460^0 C, P3 = 5 MPa (Superheated Steam)

h3 = Superheated Steam table (5 MPa)

s3 = Superheated Steam table (5 MPa)

Now,

$$h3 = 3316.34 + \frac{(3432.63 - 3316.34)}{(500 - 450)} (460\text{-}450)$$

$$= 3339.60 \text{ kJ/kg}$$

T (^{0} C)	h (kJ/kg)
450	3316.34
460	3339.60
500	3432.63

$$s3 = 6.8190 + \frac{(6.9745 - 6.8190)}{(500 - 450)} (460 - 450)$$

$$= 6.8501 \text{ kJ/kgK}$$

T (^{0} C)	s (kJ/kgK)
450	6.8190
460	6.8501
500	6.9745

Step 3: Point analysis

Point 4: P4 = 0.7 MPa (Superheated Steam)

s4 = s3 = 6.8501 kJ/kgK

T4 = Superheated steam table (0.7 MPa)

h4 = Superheated Steam table (0.7 MPa)

Now,

$$T4 = 164.95 + \frac{(200 - 164.95)}{(6.8867 - 6.7050)} (6.8501\text{-}6.7050)$$

$$= 192.25 \text{ kJ/kg}$$

s (kJ/kgK)	T (^{0} C)
6.7050	164.95
6.8501	192.25
6.8867	200

$$h4 = 2762.13 + \frac{(2844.77 - 2762.13)}{(200 - 164.95)} (192.25 - 164.95)$$

$$= 2826.50 \text{ kJ/kg}$$

T (^{0} C)	h (kJ/kg)
164.95	2762.13
192.25	2826.50
200	2844.77

Step 3: Point analysis

Point 1:

P1 = 0.7 MPa (Superheated Steam)

T1 = Saturated liquid table (0.7 MPa)

s1 = Saturated liquid table (0.7 MPa)

h1 = Superheated Steam table (0.7 MPa)

P (MPa)	T (^{0} C)
0.683477	164
0.7	164.95
0.718210	166

Now,

$$T1 = 164 + \frac{(166 - 164)}{(0.718210 - 0.683477)} (0.7 - 0.683477)$$

$$= 164.95^0 \text{ C}$$

T (^{0} C)	h (kJ/kg)
164	692.546
164.95	696.7
166	701.271

$$h1 = 692.546 + \frac{(701.271 - 692.546)}{(166 - 164)} (164.95 - 164)$$

$$= 696.7 \text{ kJ/kg}$$

T (^{0} C)	s (kJ/kgK)
164	1.9802
164.95	1.9896
166	2.0000

$$s1 = 1.9802 + \frac{(2.0000 - 1.9802)}{(166 - 164)} (164.95 - 164)$$

$$= 1.9896 \text{ kJ/kgK}$$

Step 3: Point analysis

Point 2: P2 = 5 MPa (Compressed liquid)
T2 = Compressed liquid table (5 MPa)
s2 = s1 = 1.9896 kJ/kgK
h2 = Compressed liquid table (5 MPa)

Now,

$$T2 = 160 + \frac{(180 - 160)}{(2.1299 - 1.9342)}(1.9896 - 1.9342)$$

$$= 165.66^0 \text{ C}$$

s (Kj/kgK)	T (^{0} C)
1.9342	160
1.9896	165.66
2.1299	180

$$h2 = 677.72 + \frac{(764.80 - 677.72)}{(180 - 160)}(165.66 - 160)$$

$$= 702.36 \text{ kJ/kg}$$

T (^{0} C)	h (kJ/kg)
160	677.72
165.66	702.36
180	764.80

Step 4: Completing the property table

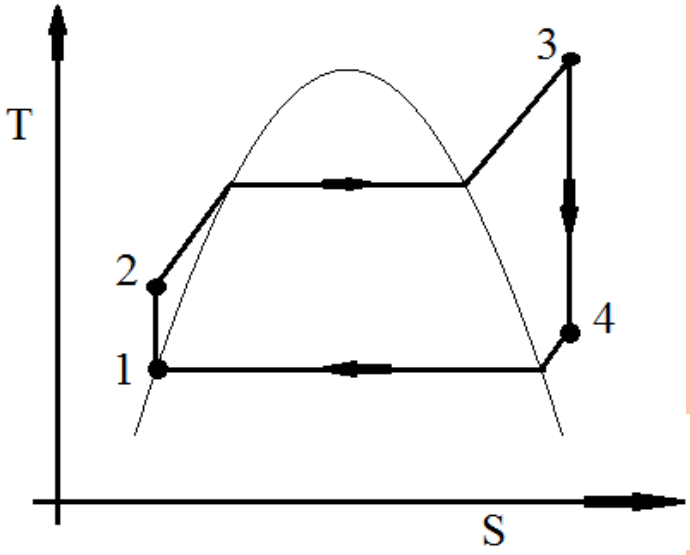
Point	T (^{0} C)	P (MPa)	S (kJ/kgK)	h (kJ/kg)	Fluid Condition
1	164.95	0.7	1.9896	696.70	Saturated Liquid
2	165.66	5.0	1.9896	702.36	Compressed Liquid
3	460.00	5.0	6.8501	3339.60	Superheated Steam
4	192.25	0.7	6.8501	2826.50	Superheated Steam

1. Work input (pump) : Wp = m (h2 - h1)

2. Heat input (boiler) : Qb = m (h3 – h2)

3. Work output (turbine) : Wt = m (h3 – h4)

4. Heat rejection (condenser) : Qc = m (h4 – h1)



Step 5: Calculation of desired parameters

a. Work input (pump) : $W_p = m (h_2 - h_1) = 2 * (702.36 – 696.7)$
$= 11.32$ kW $= 0.0113$ MW

b. Heat input (boiler) : $Q_b = m (h_3 – h_2) = 2 * (3339.60 – 702.36)$
$= 5274.48$ kW $= 5.274$ MW

c. Work output (turbine) : $W_t = m (h_3 – h_4) = 2 * (3339.60 – 2826.50)$
$= 1026.20$ kW $= 1.026$ MW

d. Heat rejection (cond) : $Q_c = m (h_4 – h_1) = 2 * (2826.50 – 696.70)$
$= 4259.60$ kW $= 4.259$ MW

e. Thermal efficiency of boiler: $Q_b/(m_f*HV) = 5.274/(0.12*50)$
$= 87.9\%$

f. Cycle efficiency including Wp: $(W_t - W_p)/(Q_b) = (1.026 – 0.0113)/5.247$
$= 19.3\ \%$

g. Cycle efficiency excluding Wp: $(W_t)/(Q_b) = (1.026)/5.247$
$= 19.6\ \%$

Assignment: 1

Problem1: In a power plant the turbine is run by a boiler that consumes 0.12 kg of natural gas (HV = 50 MJ/kg) and produce 2 kg of super heated steam per second. The boiler supply's steam at 5 MPa and 460^0 C which enters a steam turbine. The outlet of the turbine is saturated steam which is condensed and pumped into the boiler again. Determine:

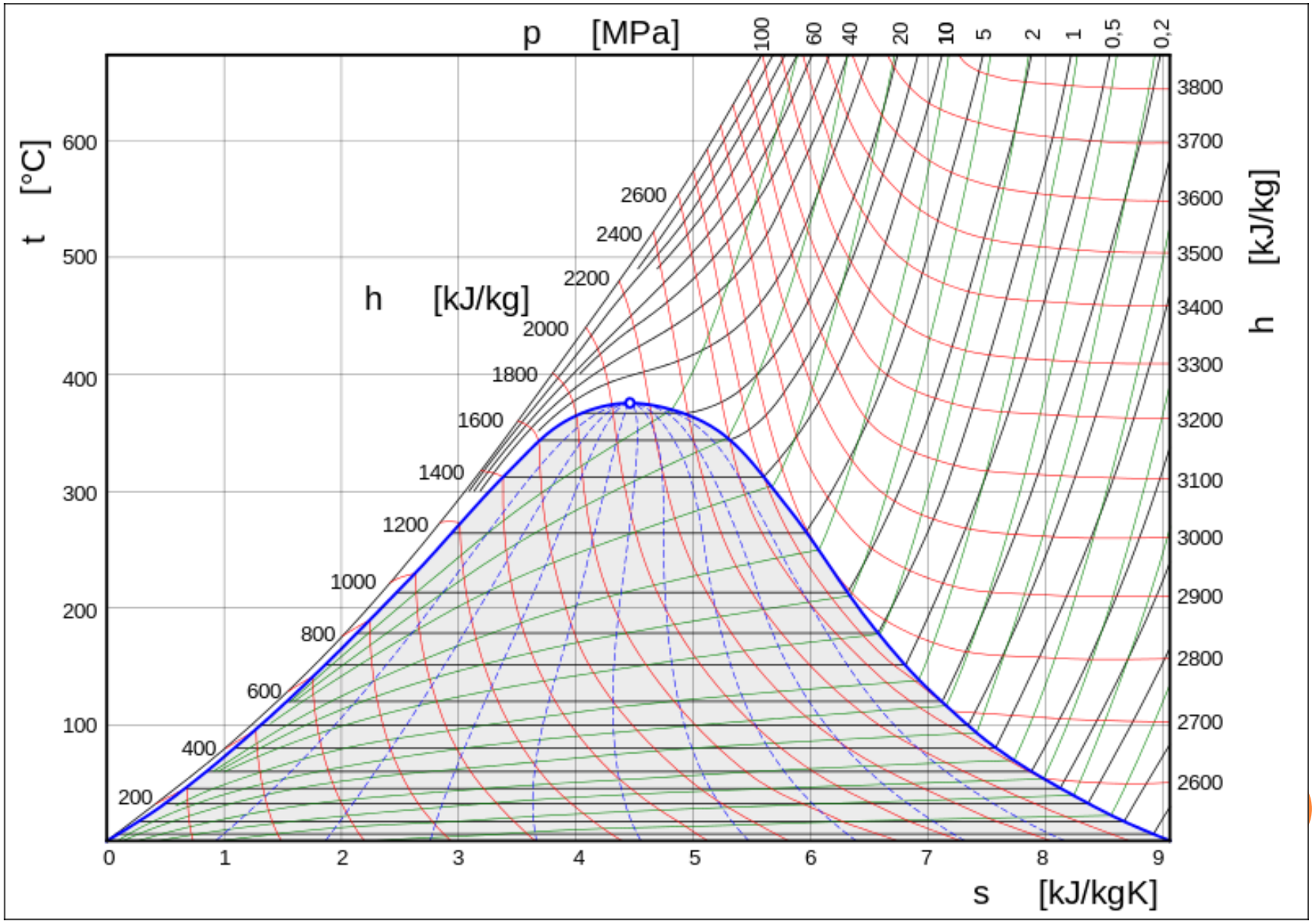
a. Work input to the pump.
b. Heat input to the boiler.
c. Out put work of the turbine.
d. Heat rejected to the condenser.
e. Thermal efficiency of boiler.
f. Efficiency of the cycle considering pump work.
g. Efficiency of the cycle neglecting pump work.

Assignment: 1

Problem 2: In a power plant the turbine is run by a boiler that consumes 0.12 kg of natural gas (HV = 50 MJ/kg) and produce 2 kg of super heated steam per second. The boiler supply's steam at 5 MPa and 460^0 C which enters the HP steam turbine. The outlet of the HP turbine is superheated steam of 2 MPa which is reheated to 350^0 C and then enter into the LP turbine. The outlet of the LP turbine is saturated steam which is condensed and pumped into the boiler again. Determine:

a. Work input to the pump.
b. Heat input to the boiler.
c. Out put work of the HP turbine.
d. Output work of LP turbine.
e. Heat rejected to the condenser.
f. Thermal efficiency of boiler.
g. Efficiency of the cycle considering pump work.
h. Efficiency of the cycle neglecting pump work.

T—S Diagram for steam



ME 201

Mechanical Engineering Fundamentals

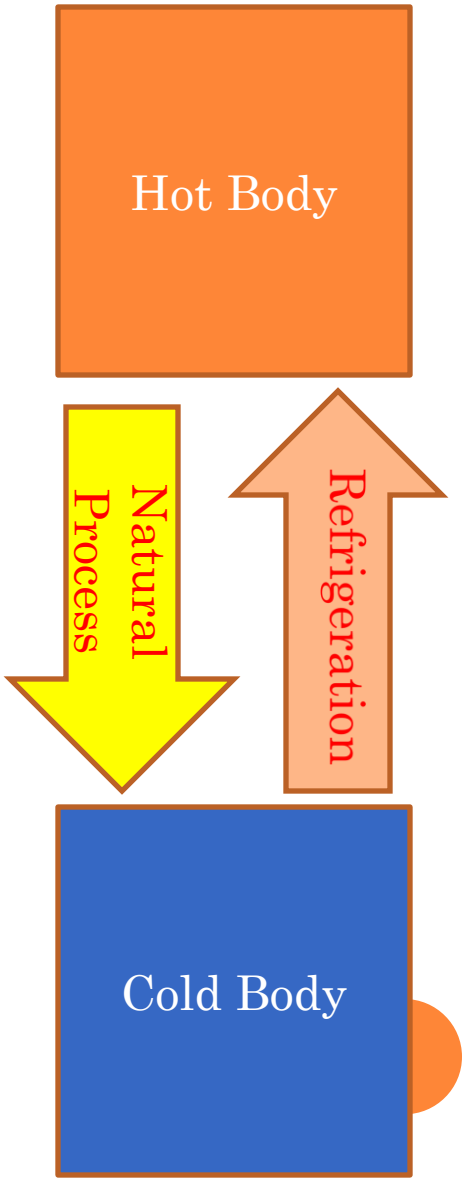
REFRIGERATION & AIR CONDITIONING

Md. Abdul Hamid

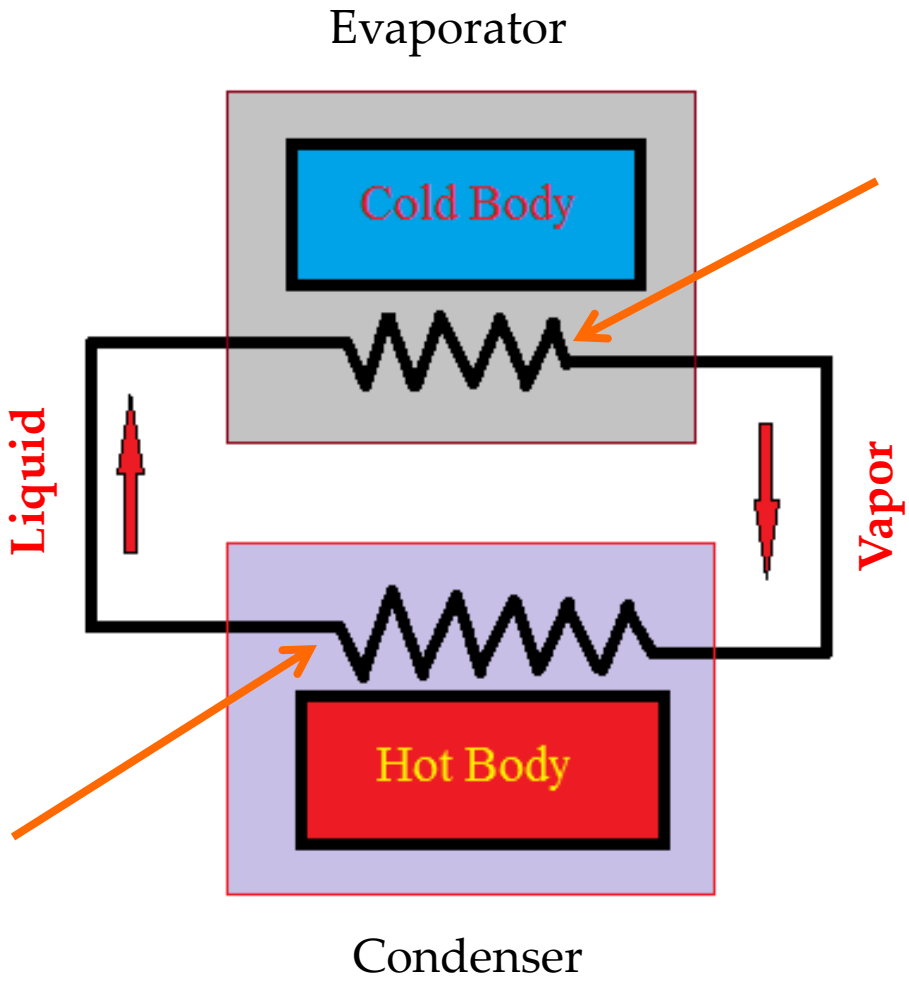
WHAT IS REFRIGERATION ?

- Ans: Removal of heat

  (Forced heat transfer):
- Heat going from hot body to cold body is a natural process.
- Heat sending from cold body to hot body is called forced heat transfer or Refrigeration.
- According to laws of thermo - dynamics Refrigeration is impossible without any work input.
- Some times heat is forced to move to the cold body at a faster rate then natural process (Heat Pump), this is also a subject of refrigeration.



How Does Refrigeration Work



How Does Refrigeration Work ?

Difficulties:

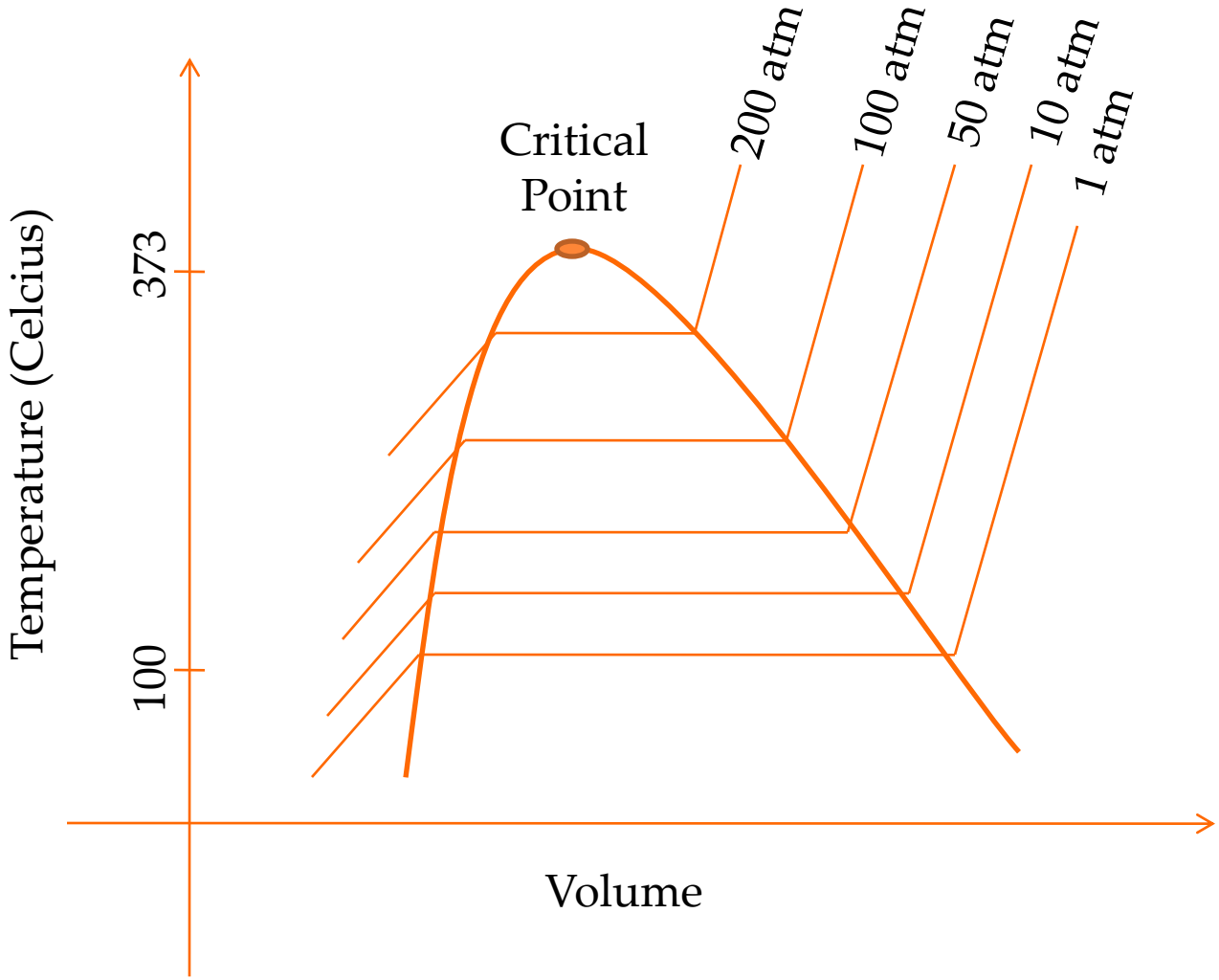
1. Finding Working Fluid ?

No fluid evaporate at low temperature and condense at high temperature

Solution?
Pressure

The evaporation temperature is a function of pressure. So it is very much possible to evaporate a fluid at lower temperature and condense at higher temperature by creating low and high pressure side

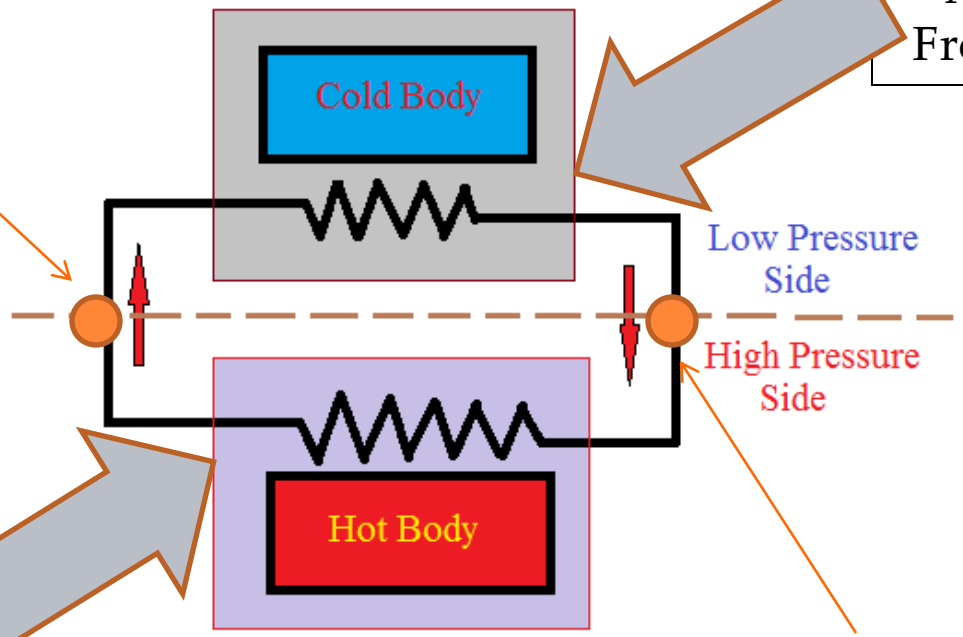
Temperature Vs Volume plot for Water



Solution:

Pressure reducing device (Turbine)

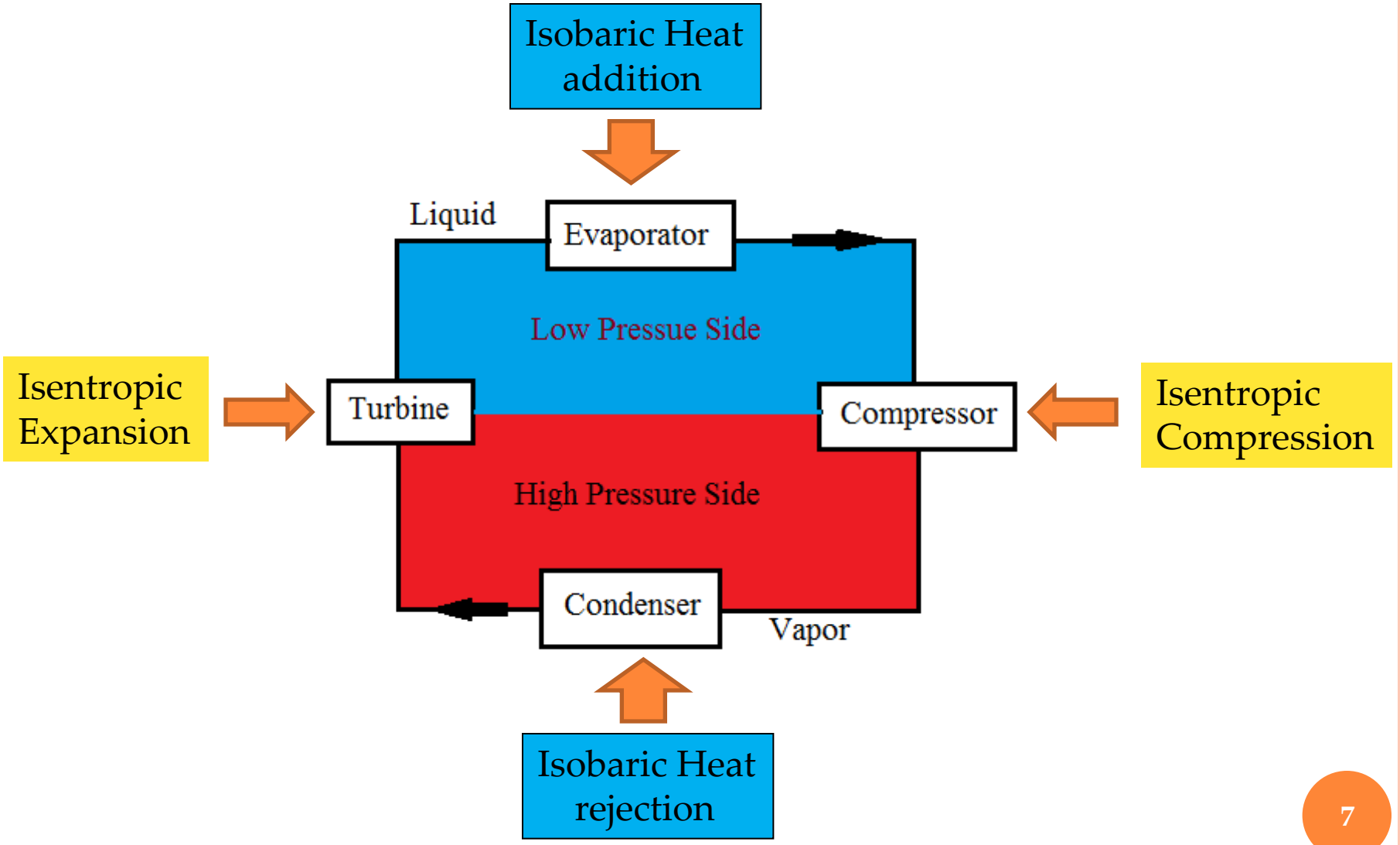
Liquid Evaporates at low pressure And extract heat From the cold body



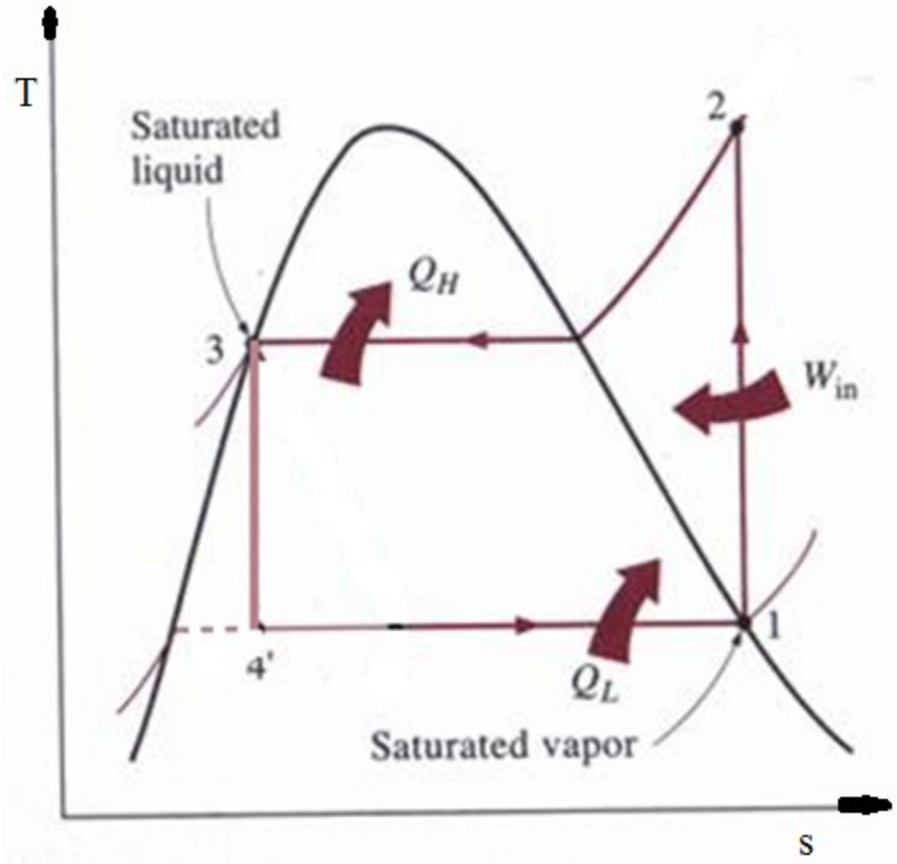
Vapor condense at high pressure And release heat to the hot body

Pressure increasing device (Compressor)

Refrigeration Cycle



T-S Diagram



1—2: Work input in Compressor (Isentropic Process)

2—3: Heat rejection in Condenser (Iso-baric Process)

3—4: Work output in Turbine (Isentropic Process)

4—1: Heat addition in Evaporator (Iso-baric Process)

Disadvantages of using turbine:

1. Power output from turbine is negligible.
2. Installation of turbine is costly
3. Turbine handle two phase mixture

So, turbine is replaced by throttling device.

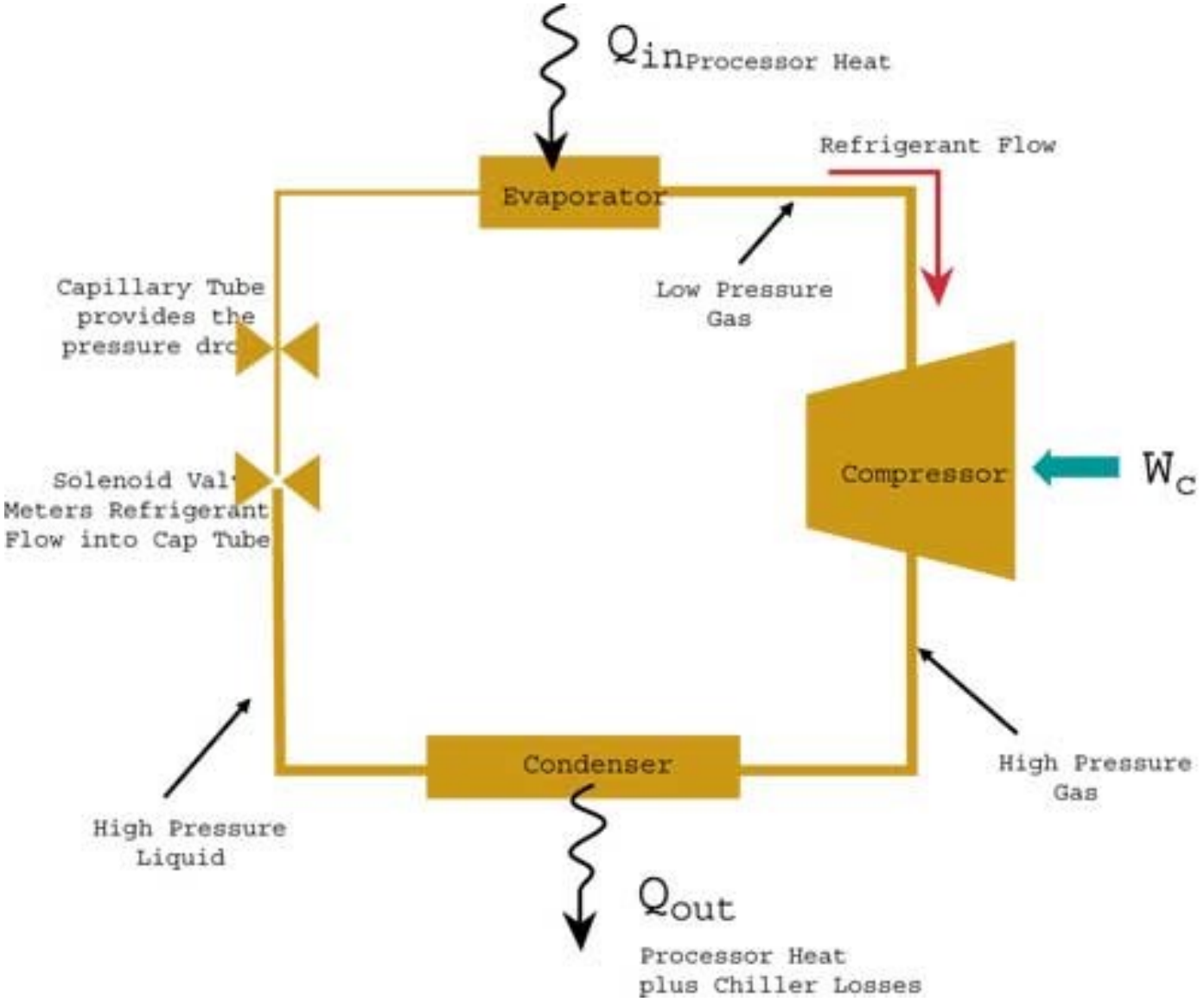
1. No work output from throttle valve.
2. Low cost of installation.
3. Iso - enthalpic process.

So actual refrigeration cycle consists of :

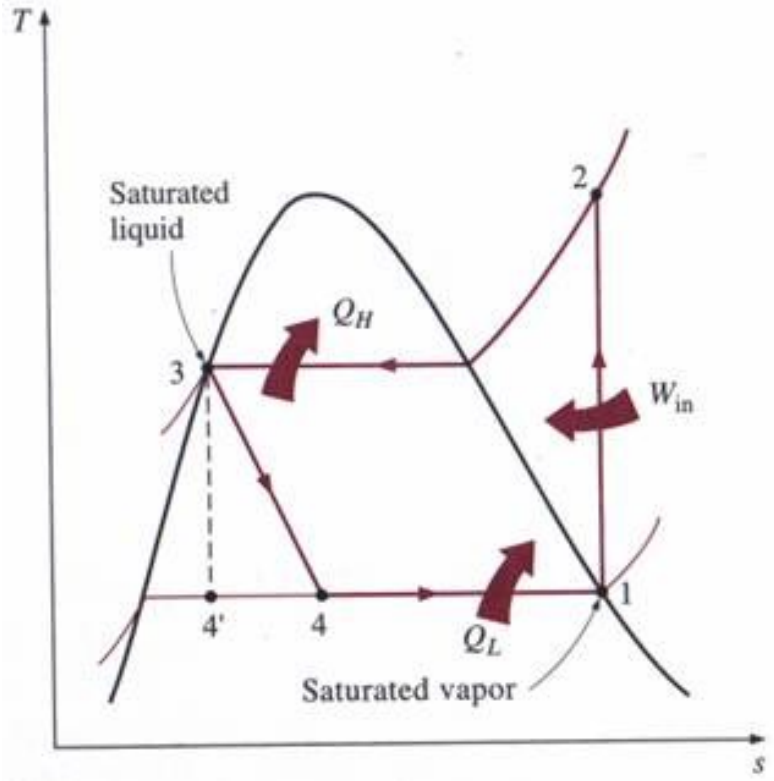
i) Compressor ii) Condenser

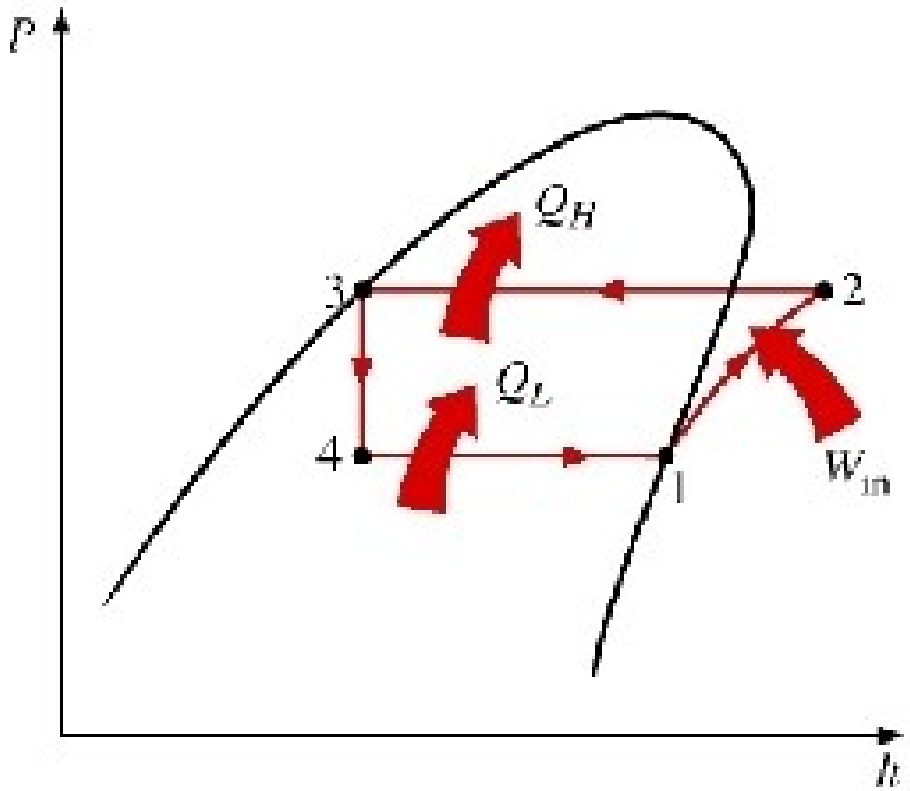
iii) Throttle valve iv) Evaporator

Actual Refrigeration Cycle Block Diagram



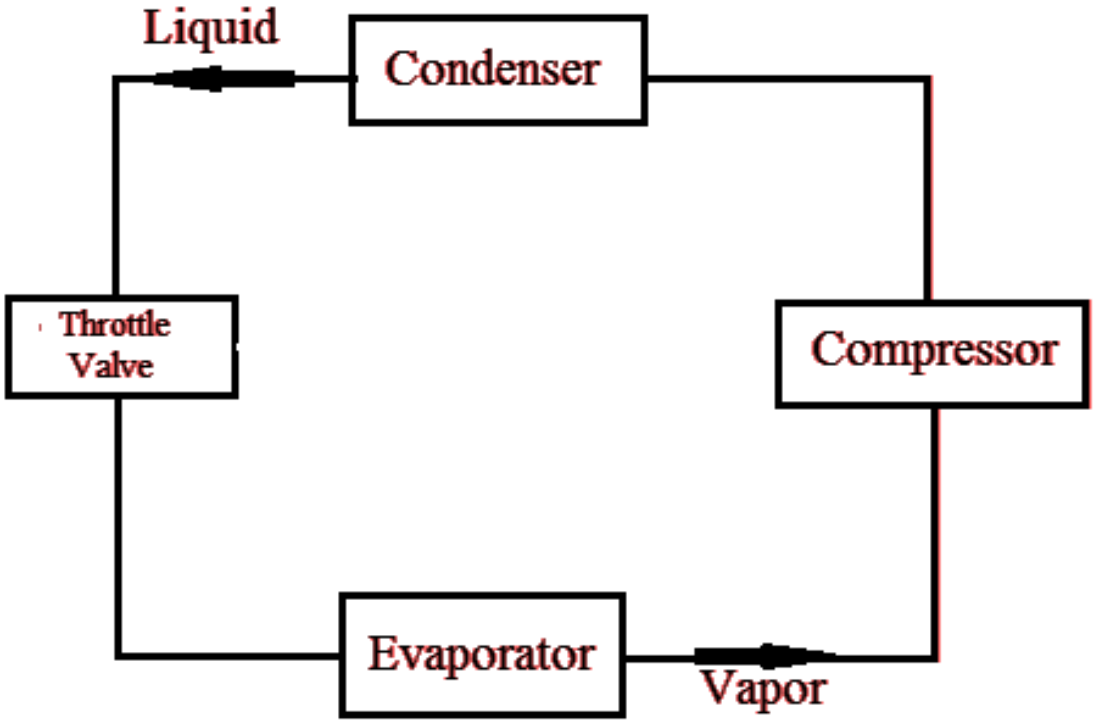
T-S and P-H Diagram of an actual Refrigeration Cycle





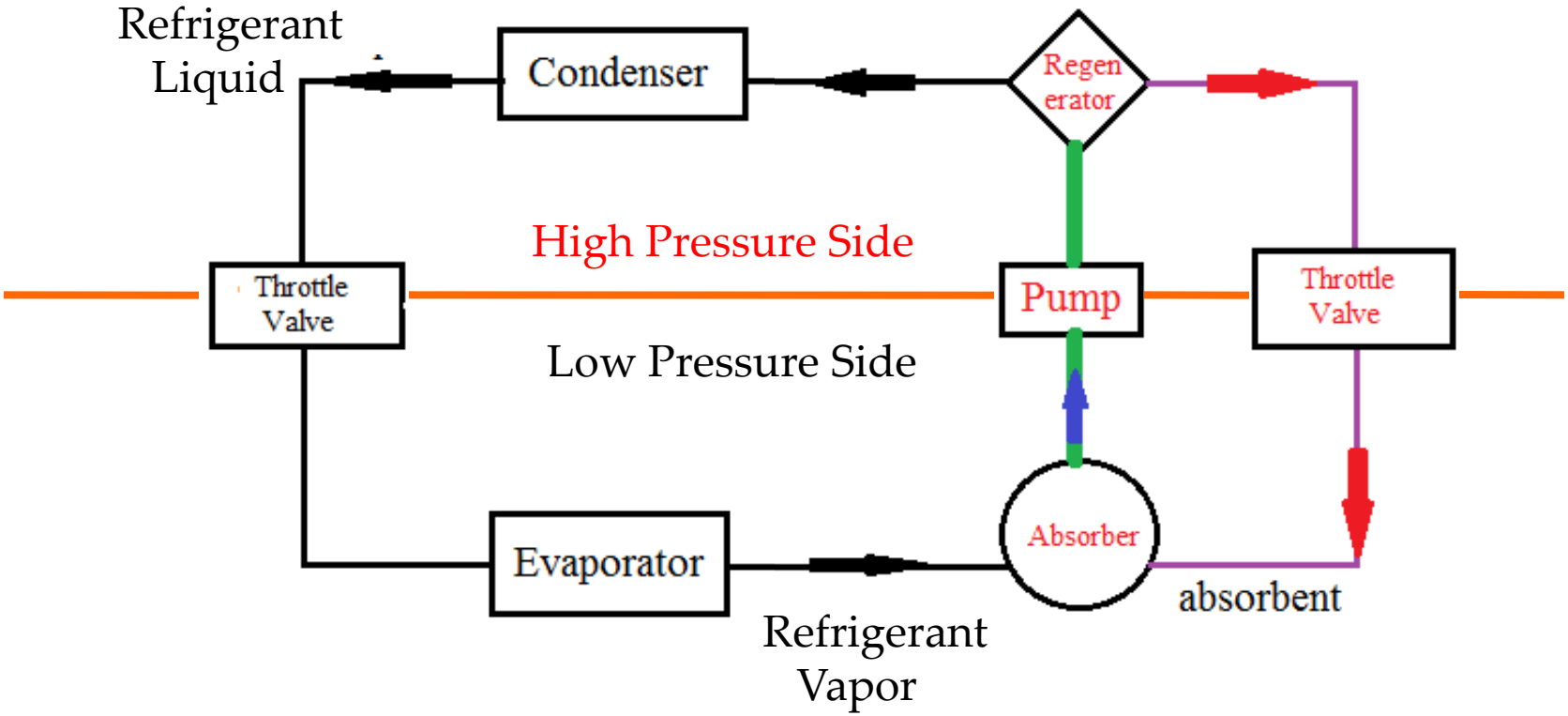
Classification of Refrigeration

1. Vapor compression Refrigeration Cycle
2. Vapor absorption refrigeration cycle



Vapor compression Refrigeration Cycle

Vapor Absorption Refrigeration Cycle



Commonly Used Absorbent And Refrigerant:
Water-ammonia, Water-LiBr

Vapor Absorption Refrigeration Cycle

Advantages:

1. Compressor is replaced by a set of
    a) Absorber ……(No energy input)
    b) Pump …… (Negligible energy input)
    c) Regenerator ..... (Thermal energy input)
    d) Throttle valve… (No energy input)

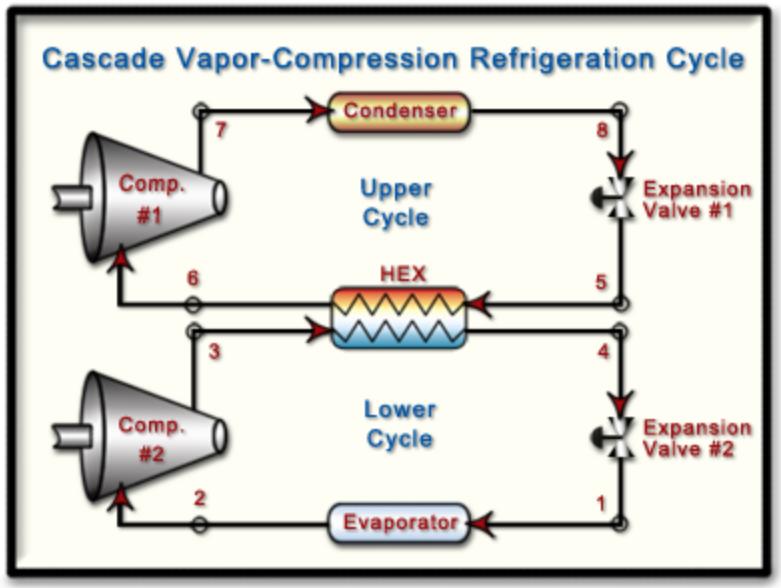
2. If the energy input is calculated as the sum of work input in pump and the heat input in the regenerator then there is no savings of energy.

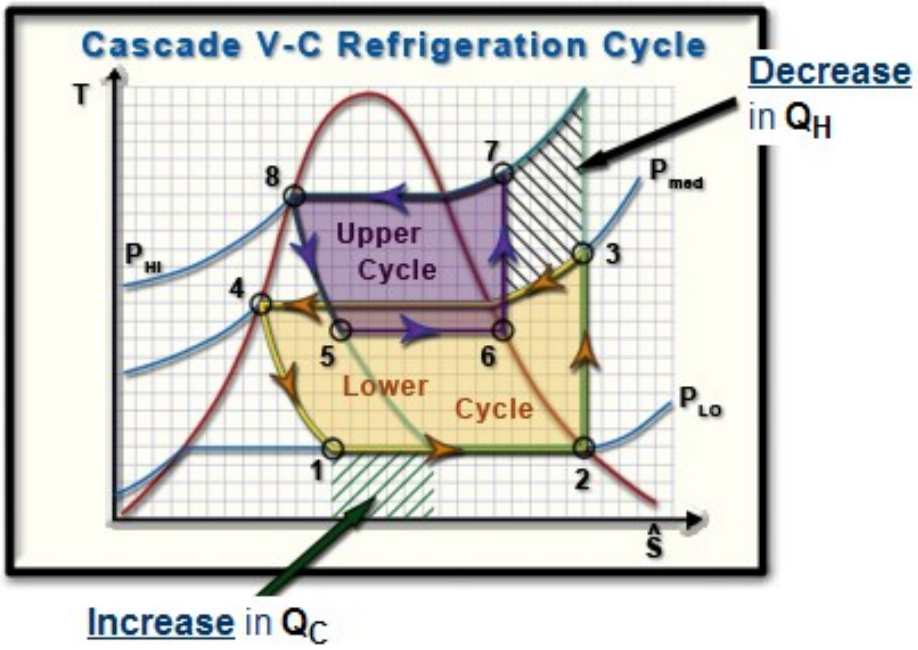
3. But the heat required to the generator is readily available in the factories.

4. That's why Vapor Absorption Refrigeration is only used in industrial (Factory) uses.

Cascade Refrigeration cycle

1. Two refrigeration cycles that use two different refrigerants are linked by a heat exchanger.
2. The lower cycle is colder and it absorbs heat from the refrigerated space.
3. The lower cycle rejects heat into the upper cycle through the heat exchanger.
4. The upper cycle is hotter and can reject heat to a very hot reservoir.

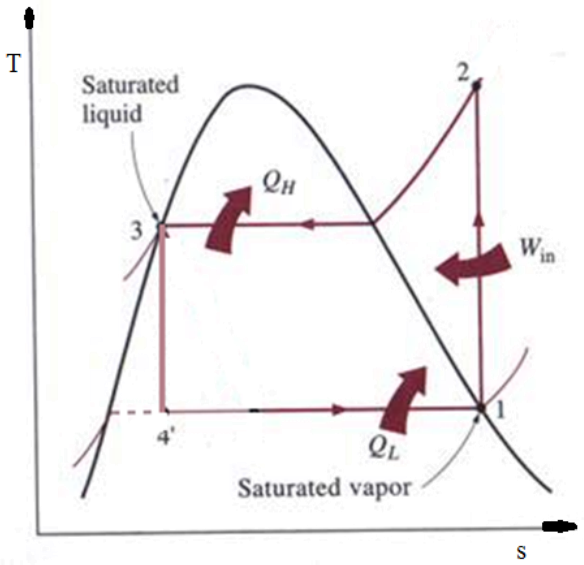




Some Terminology

COP: Ratio of Removed Heat to New work done

$$\text{COP} = \frac{Ql}{Win} = \frac{m(h1 - h4)}{m(h2 - h1)}$$

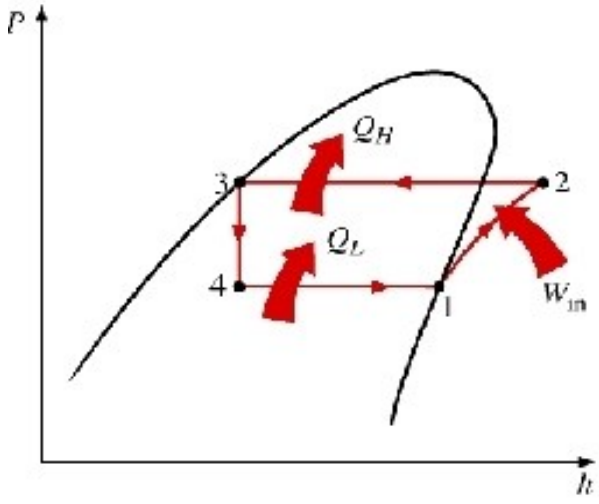


Capacity: (Tonage): 1 short Ton (2000 lb) ice from zero degree water per day.

** 1 Ton = (mh_v/t)

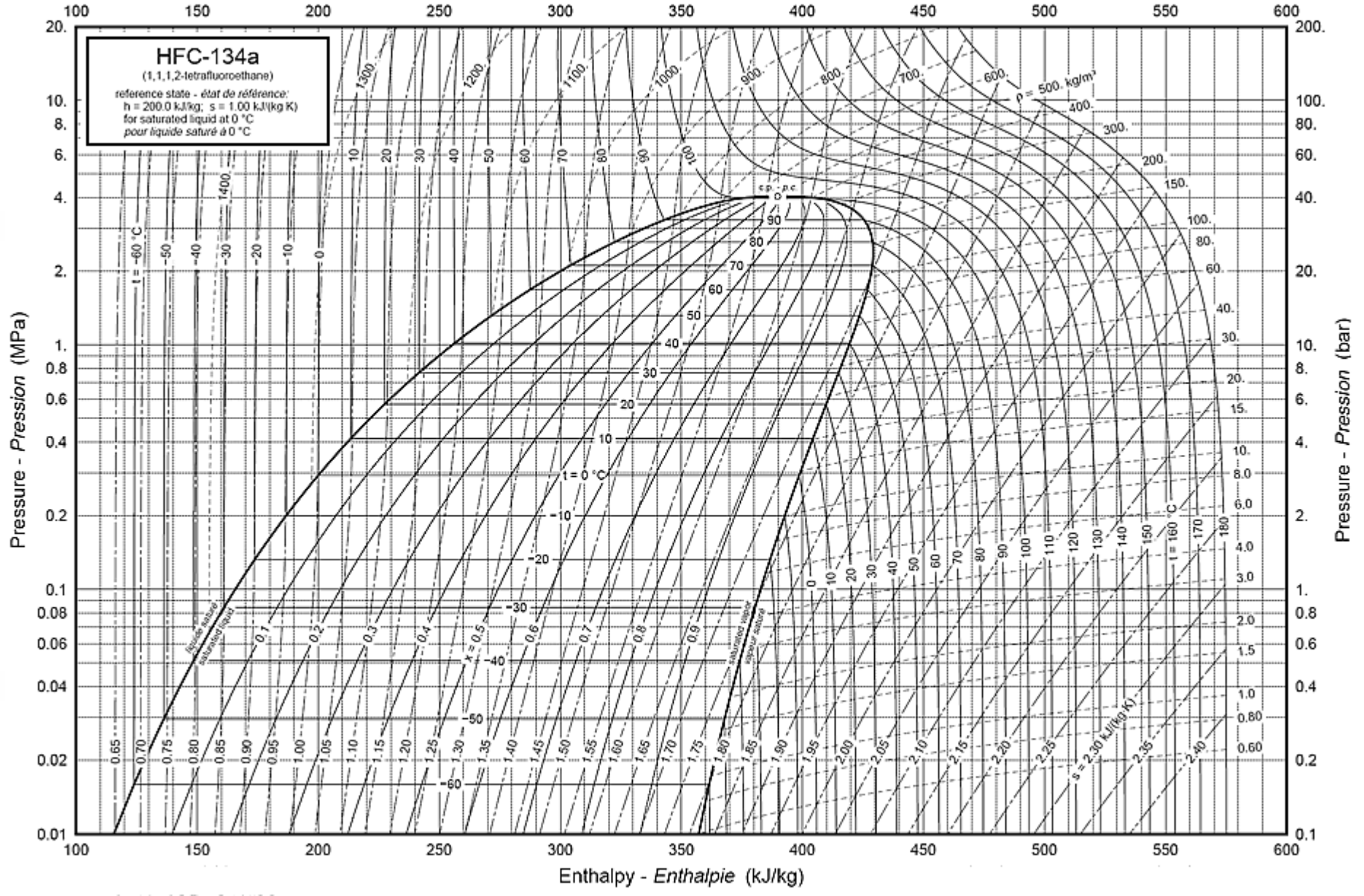
= (0.907×1000)×(334000)/(24×60×60)

= 3.51 kW



COP must be greater than 1 for economic uses. Usually COP >=2.5

P—H Diagram for Ra 134a Refrigerant



Refrigerant

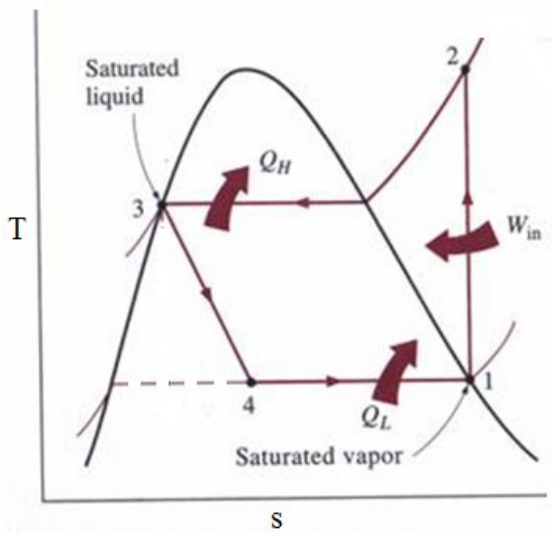
- Desirable properties:
  - High latent heat (Less refrigerant)
  - Non-toxicity
  - Desirable saturation temp (low temperature)
  - Chemical stability (non-flammable/non-explosive)
  - Ease of leak detection
  - Low cost
  - Readily available
- Commonly use FREON (R-12, R-114, etc.)

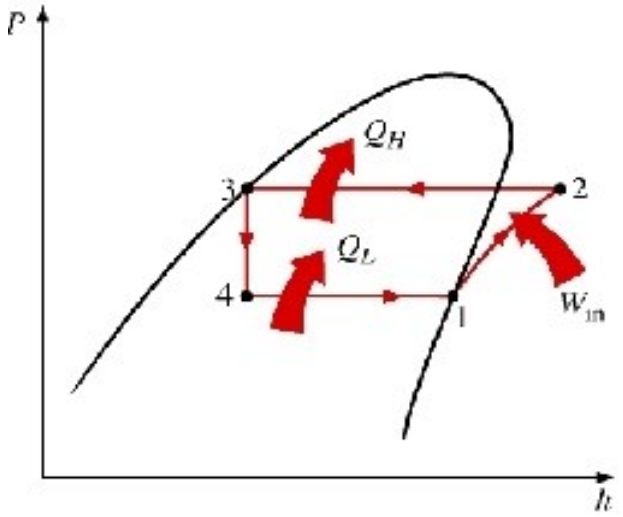
Mathematical Problem

A refrigeration cycle operates with condenser and evaporator pressure of 1 MPa and 0.15 MPa respectively. The working fluid is Ra-134a which flows at a rate of 0.05 kg/s. Find the followings:

a) rate of heat removal from the refrigerated space.
b) rate of work input to the compressor.
c) rate of heat rejected in the condenser.
d) cope of the refrigerator.
e) tonnage of the refrigeration cycle.

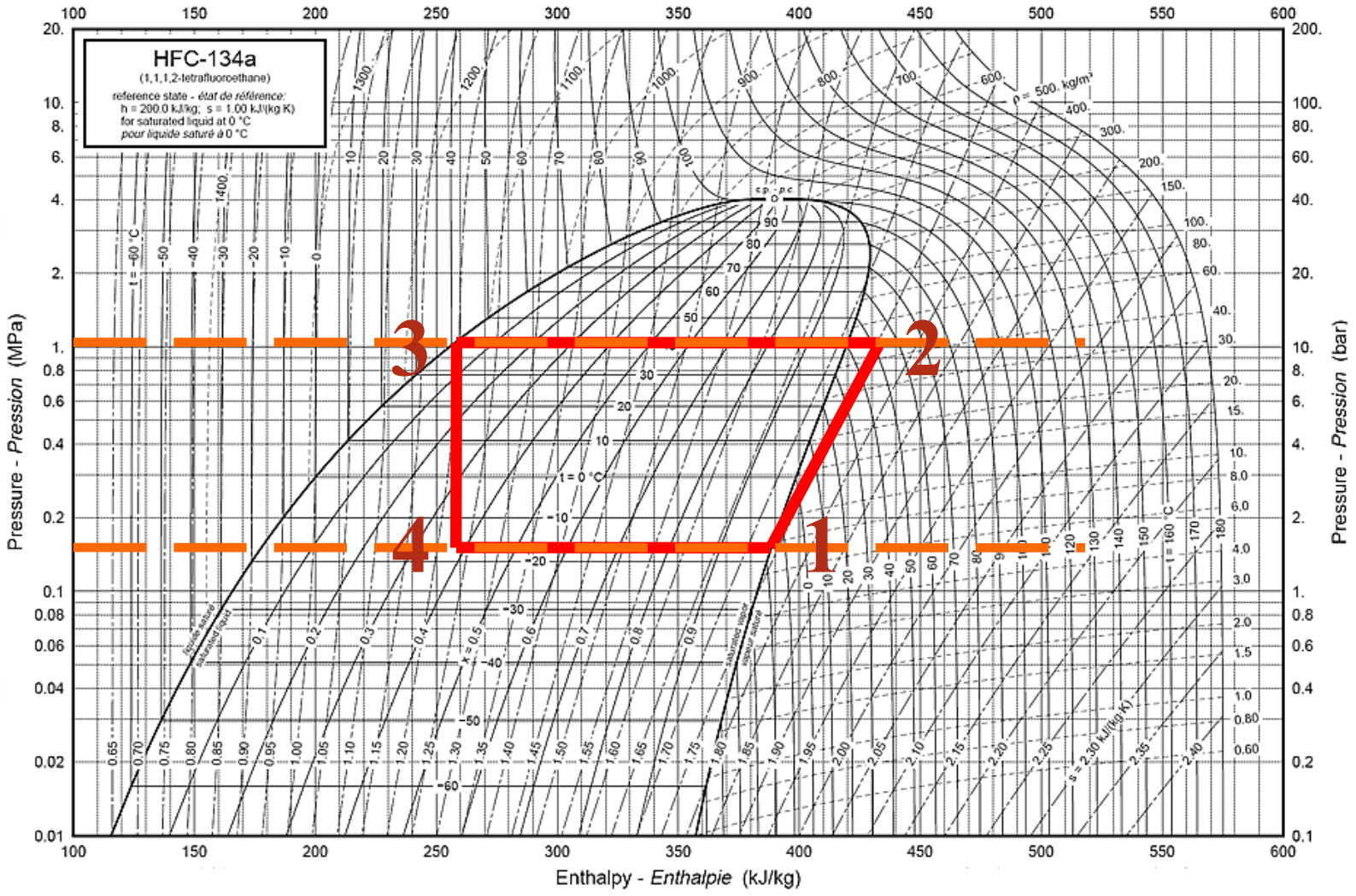
Solusion:
Step 1: draw the T—s and P—h diagram using hand.





Mathematical Problem

Step 2: Drawing the P—h diagram on scale.



Mathematical Problem

Step 3: Completing the enthalpy table.

Point	1	2	3	4
Enthalpy (h) kJ/kg	390	440	260	260

Stem 4: Calculation of desired parameters.

Given: m = 0.05 kg/s

a) Rate of heat removal:

$Ql = m\,(h1 - h4)$

$= 0.05*(390 - 260)$

$= 6.5$ kW

b) Rate of work input:

$Win = m\,(h2 - h1)$

$= 0.05*(440 - 390)$

$= 2.5$ kW

c) Rate of heat rejection:

$Qh = m\,(h2 - h3)$

$= 0.05*(440 - 260)$

$= 9$ kW

d) Coefficient of performance

$COP = (Ql/Win)$

$= (6.5/2.5)$

$= 2.6$

e) Tonnage of the cycle:

$TON = (Ql/3.51) = (6.5/3.51) = 1.85$ TON

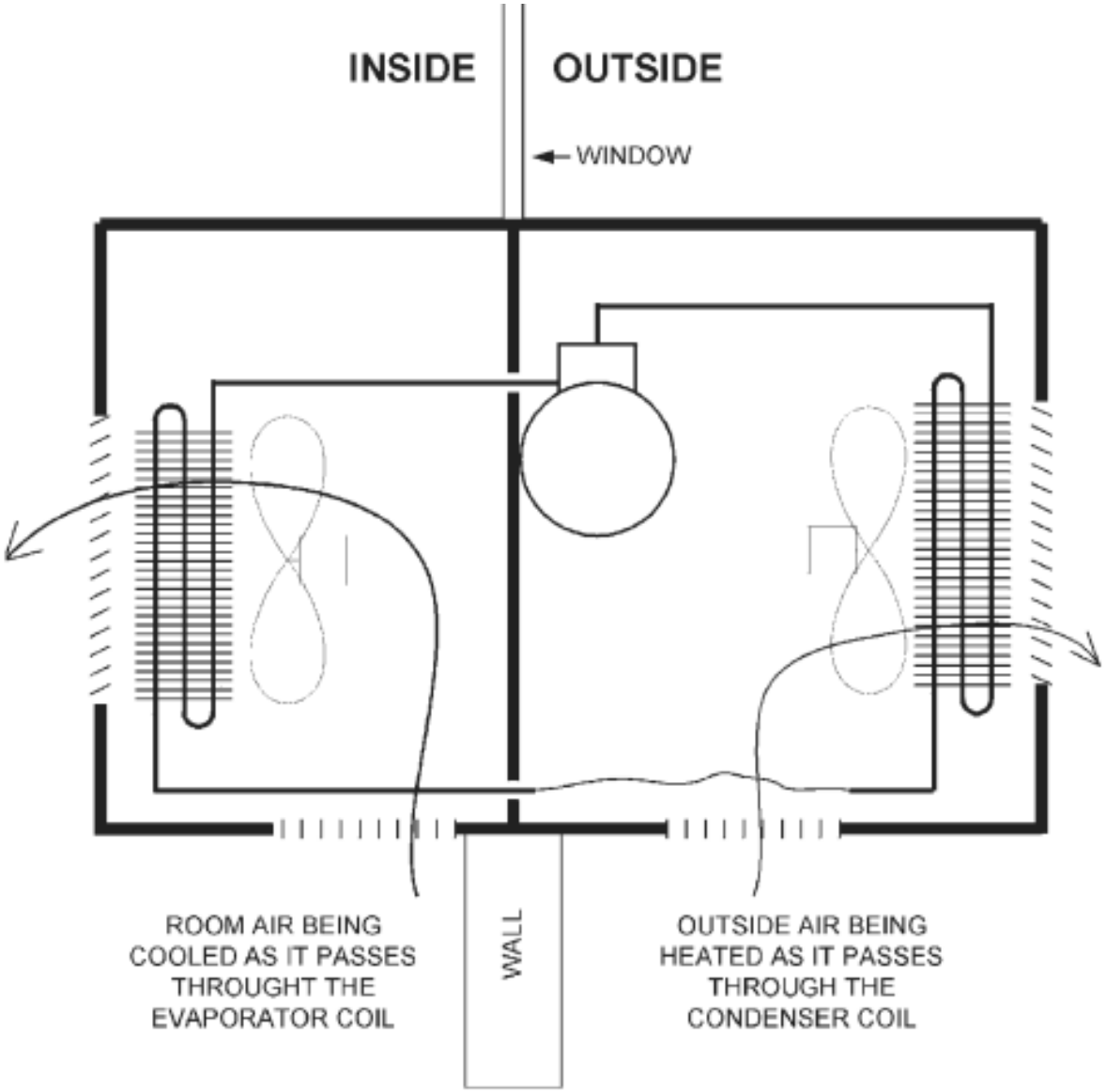
AIR CONDITIONING

*Not just cooling (For lives)

**Controlling & maintaining temperature
and humidity (Freshness)

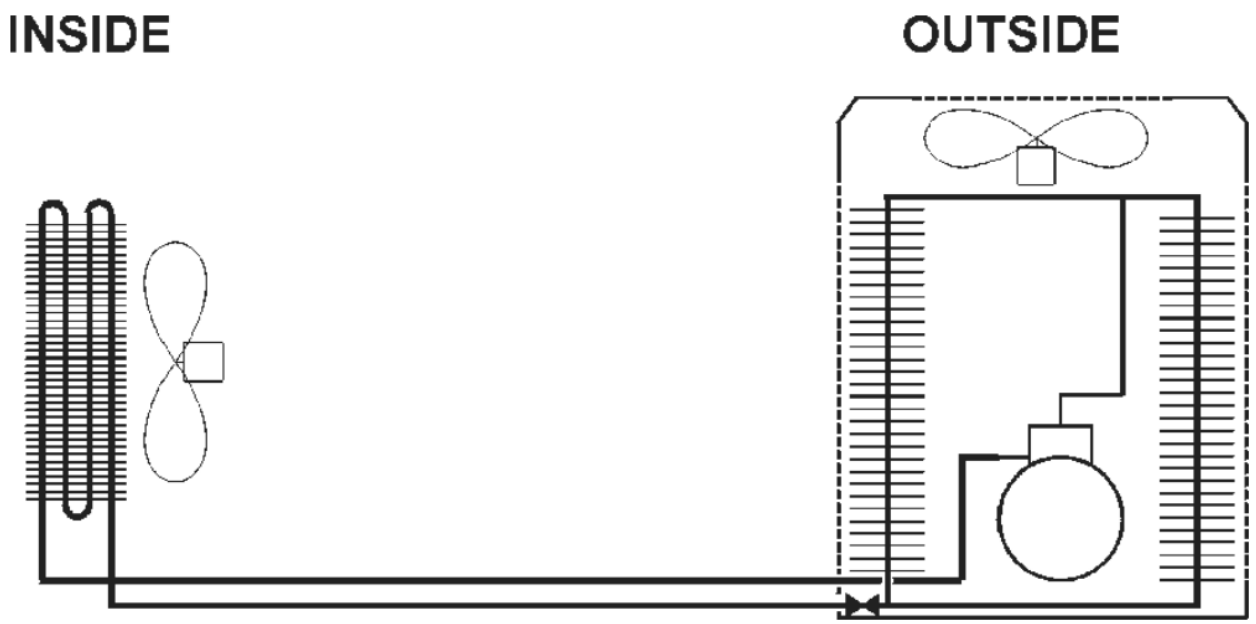
HVAC = Heating, Ventilation and Air Conditioning

Window Type Air Conditioner



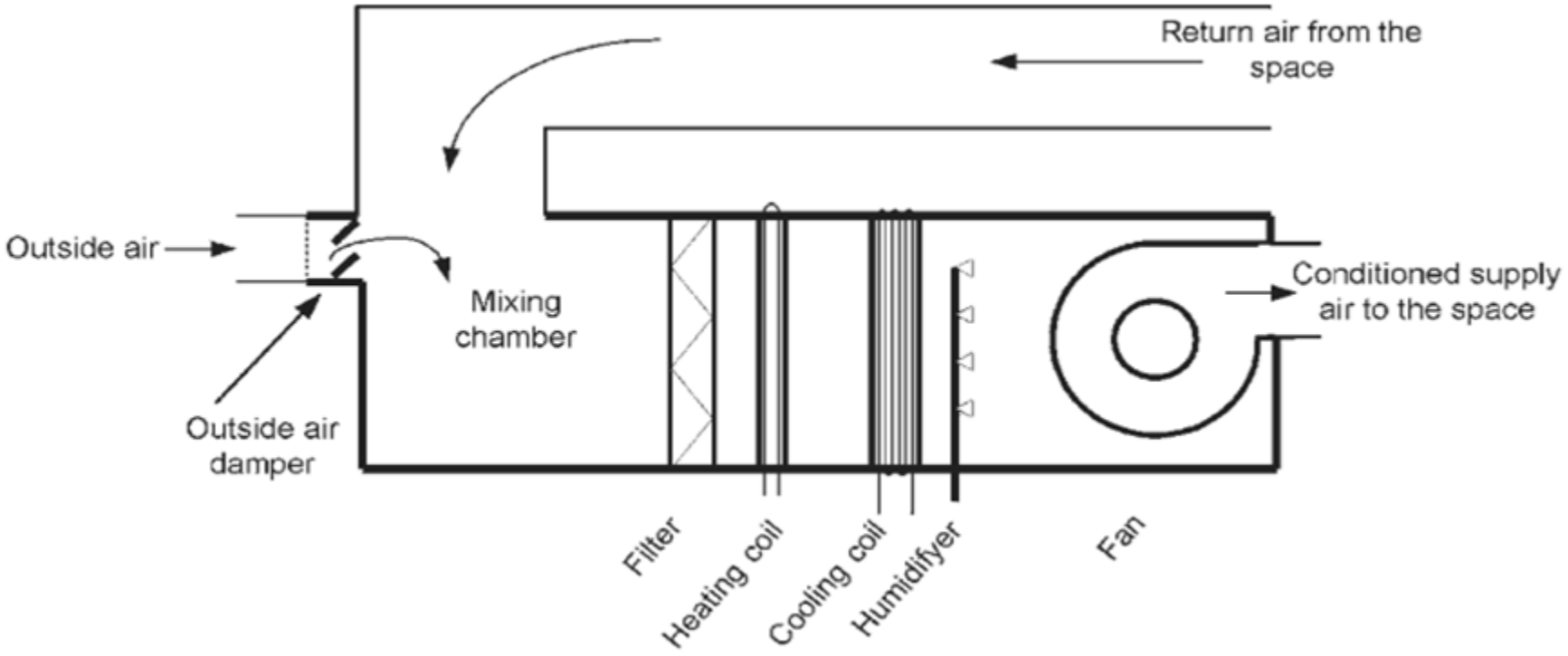
Split System

Condenser separates from the evaporator.

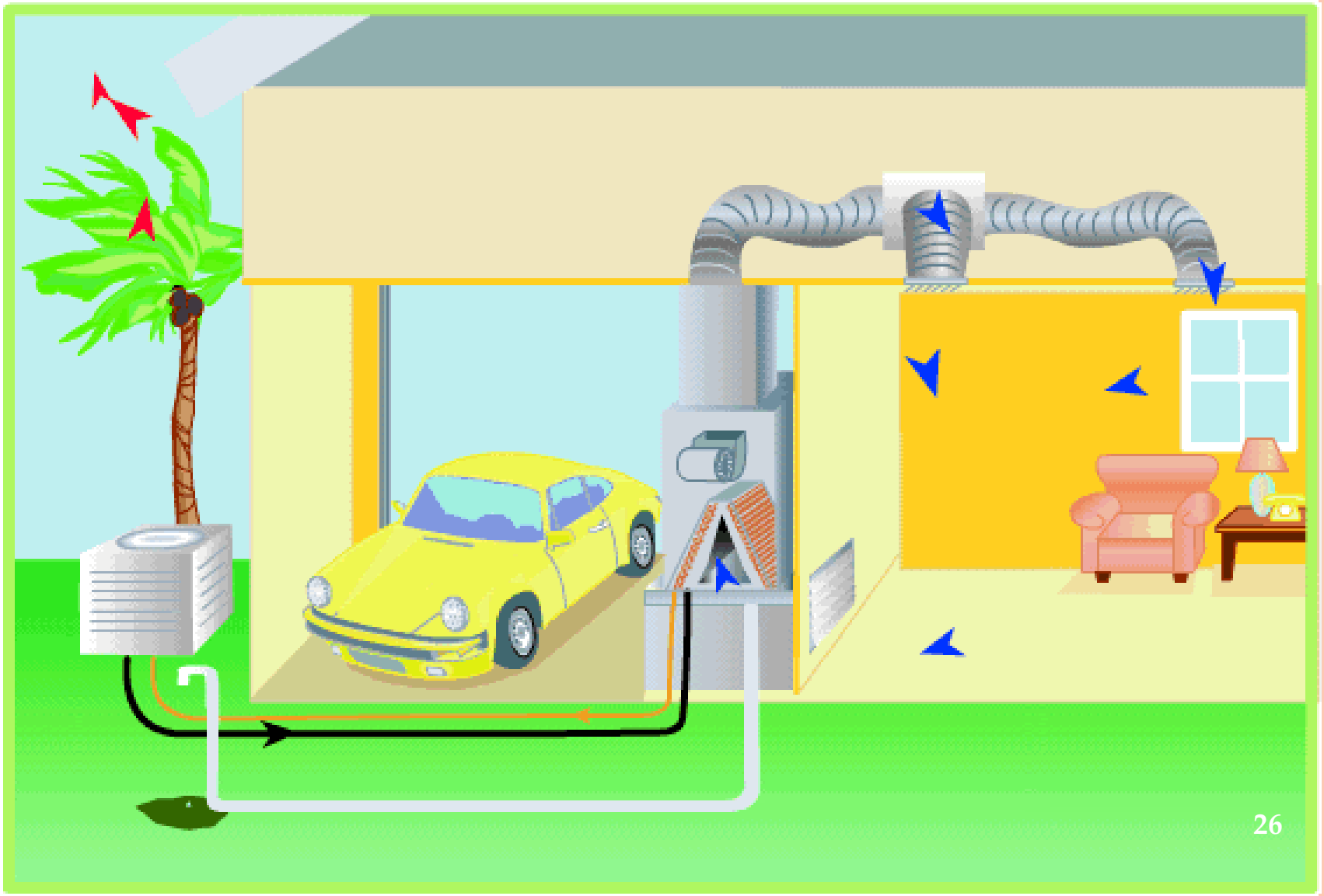


It enables to locate the condenser elsewhere.

Basic Air Conditioning System



HVAC Components



AIR CONDITIONING LOAD

There are two types of cooling load:

(i) Sensible cooling load
(ii) Latent cooling load

Factors that influence the sensible cooling load:

1. Glass windows or doors
2. Sunlight striking windows, skylights, or glass doors and heating the room
3. Exterior walls and partitions (that separate spaces of different temperatures)
4. Ceilings and roofs
5. Floors over an open crawl space
6. People in the building
7. Equipment and appliances operated in the summer
8. Air infiltration through cracks in the building, doors, and windows

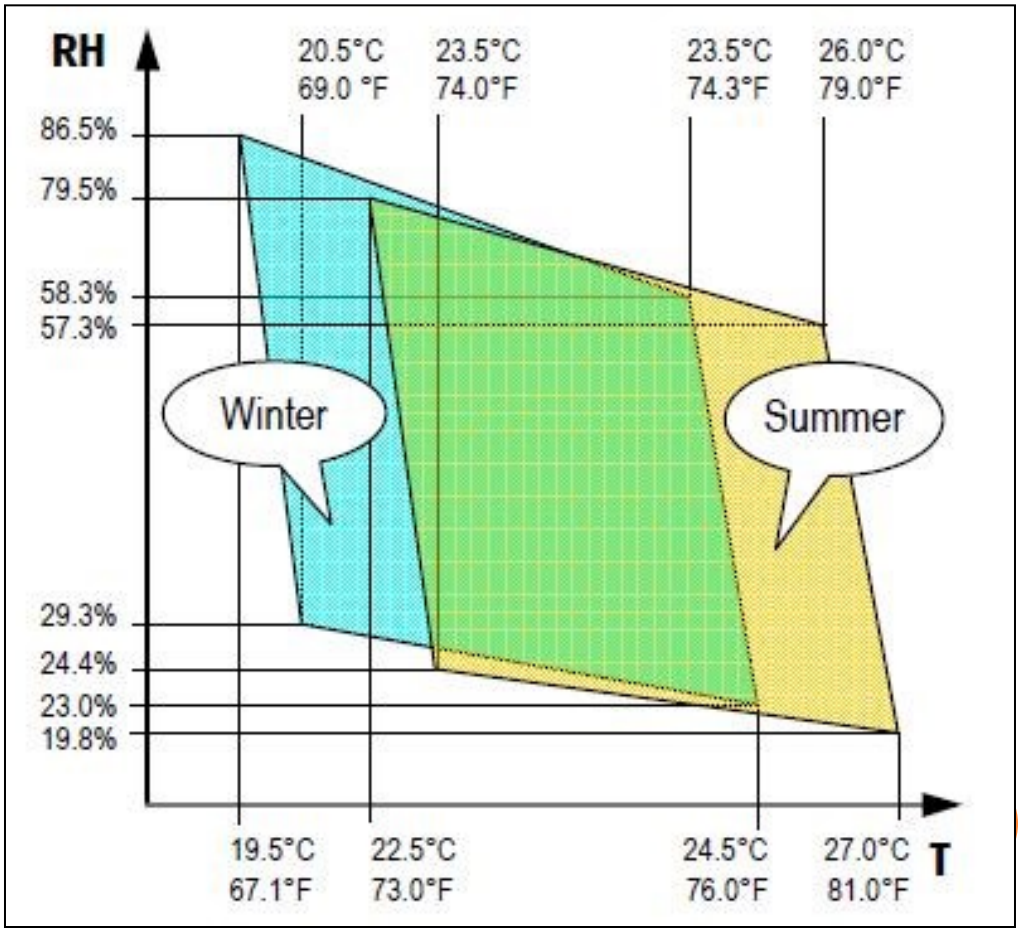
Factors that influence the latent cooling load:

1. People in the building
2. Equipment and appliances
3. Air infiltration through cracks in the building, doors, and windows

HUMAN COMFORT

Human Comfort:

1. There is no fixed **temperature** and **humidity** condition at which everyone is comfortable.
2. People are comfortable at a range of temperatures and humidities.
3. Research conducted over many years on large numbers of people by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASRAE) concluded there is a range of combined temperatures and humidities that provides comfort to most people.



HUMAN COMFORT

There are four factors that affect the human comfort:

(i) Temperature of air
(ii) Humidity of air
(iii) Freshness / purity of air
(iv) motion of air

Humidity:

** Absolute humidity: it is the amount of vapor (kg) present in 1 kg of air.

** Relative humidity: it is the ratio of amount of vapor (kg) present in the air to maximum amount of vapor (kg) that can be present in1 kg of air.

INTRODUCTION TO PSYCHOMETRY

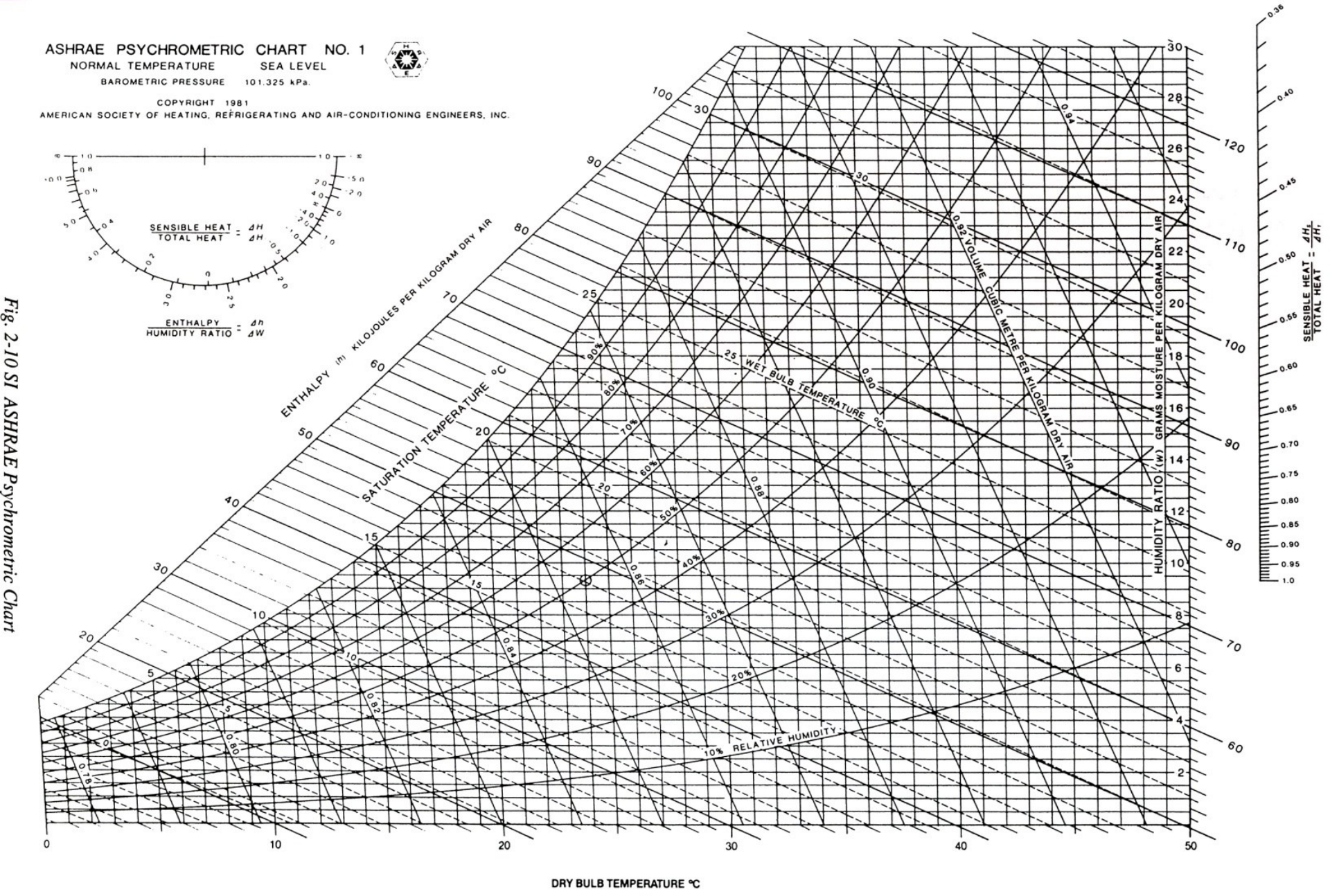


Fig. 2-10 SI ASHRAE Psychrometric Chart

Mathematical Problem

Problem 1:
Find out the point when air has a dry bulb temperature of 30^0 C and wet bulb temperature of 25^0 C.

1. Also find out the relative and absolute humidity of the air.
2. Find out the temperature at which the air will become saturated (dew point).
3. Also find out the enthalpy of the air per kg.

Problem 2: ***(Assignment 2)***
A room consist of 25^0 C 70% humid air. Find out the point and:

1. Also find out the absolute and relative humidity of the air.
2. Find out the temperature at which the air will become saturated (dew point).
3. Also find out the enthalpy of the air per kg.

PROBLEM 1

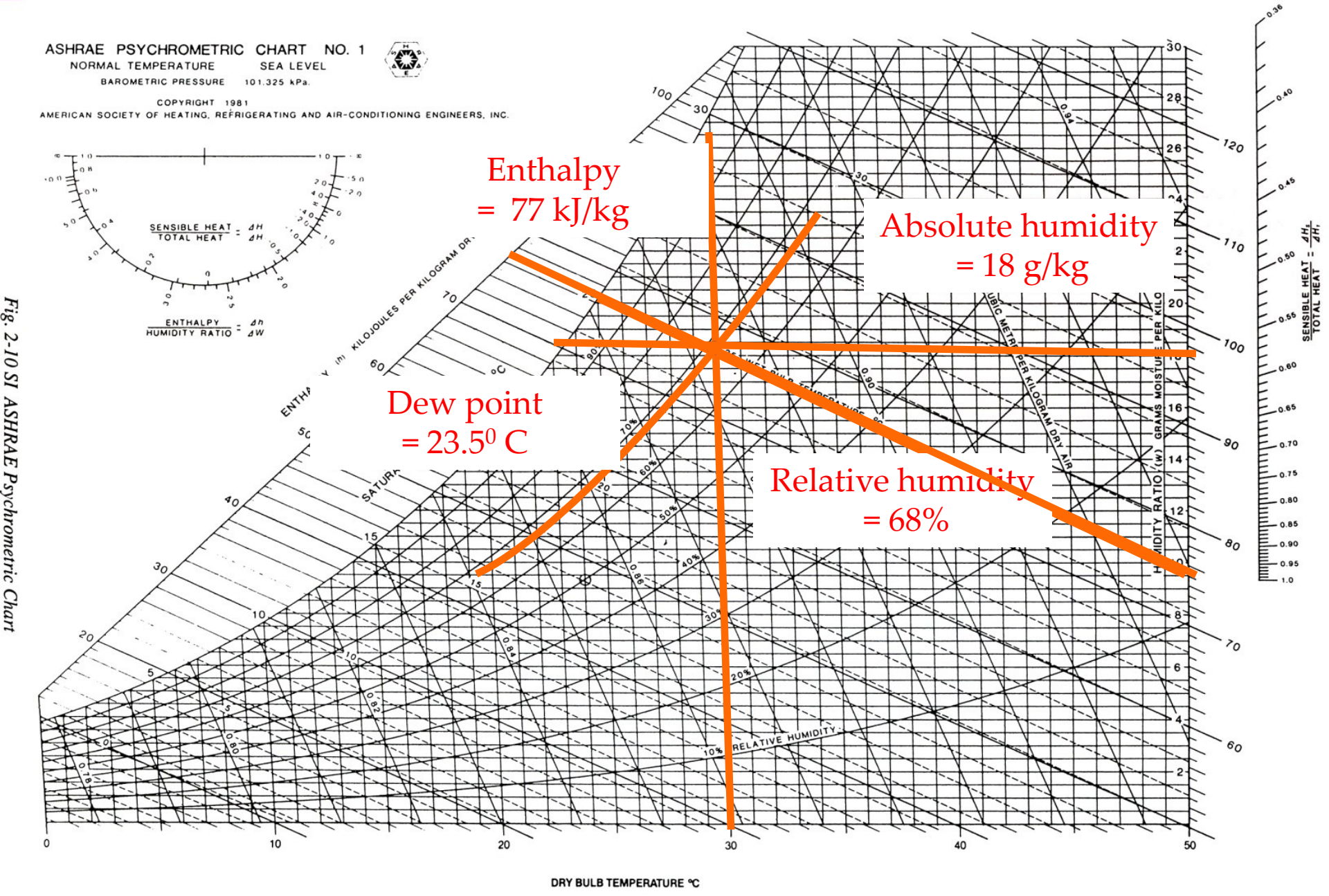


Fig. 2-10 SI ASHRAE Psychrometric Chart

Mathematical Problem

Problem 3:
A room consists of air of 30^0 C dry bulb and 28^0 C wet bulb temperature. If any one wants to make the room at 27^0 C and 70% relative humidity then find the amount of moisture (g) required to remove per kg of air.

Solution:

Form Psychometric chart: (next slide)

w1 = 23.5 g/kg of air
w2 = 15.5 g/kg of air

So, required amount of moisture to be removed is
23.5 – 15..5 = 8 g/kg of air.

*** *Note: All the charts/diagrams used must be attached with the answer script with sketch.*

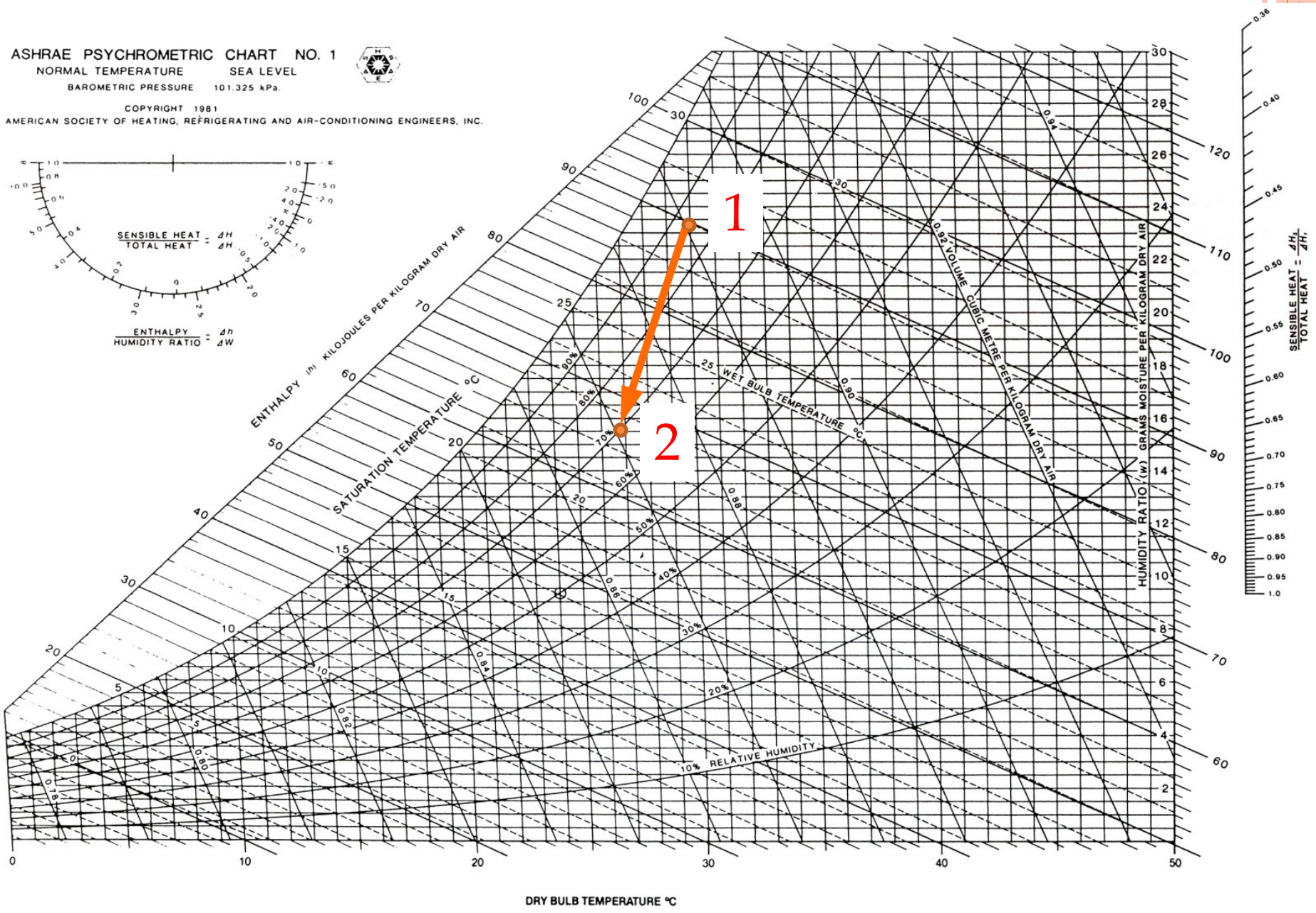


Fig. 2-10 SI ASHRAE Psychrometric Chart

ME 201

Mechanical Engineering Fundamentals

Pumps, compressors and turbines

Md. Abdul Hamid

Hydraulic Machines

- These are machines, Not Engines.
- Either their input/output/through (Via) is hydraulic energy.

- Hydraulic energy:

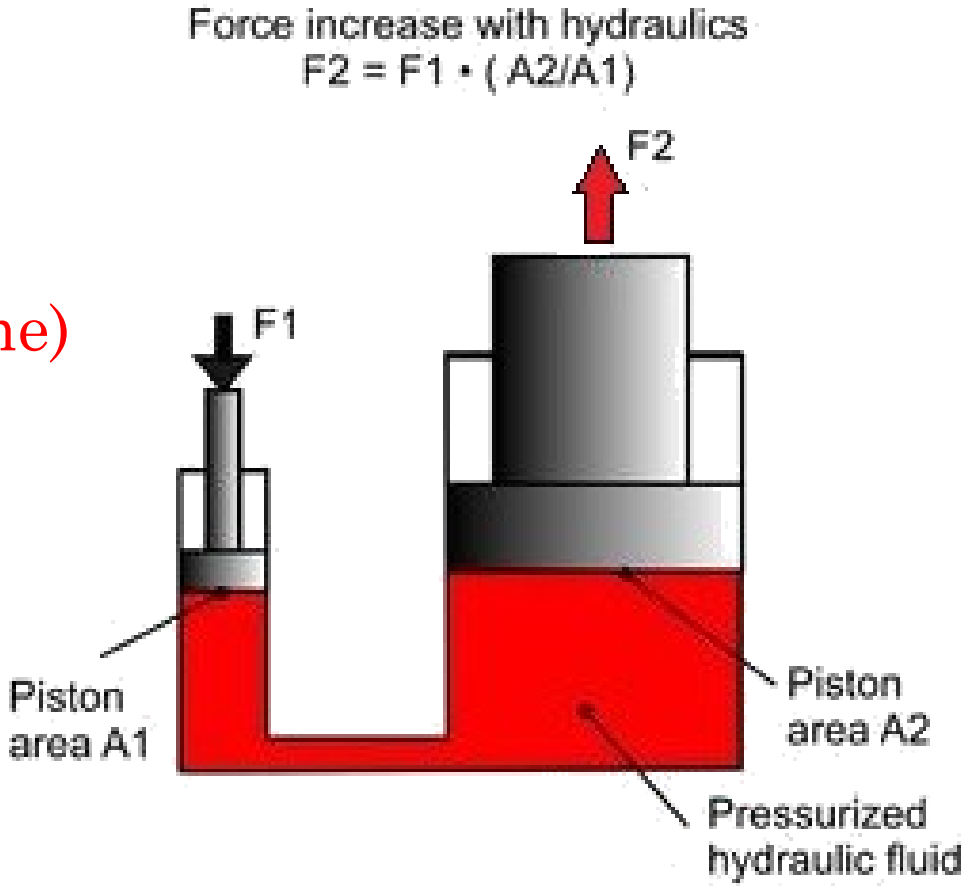
  Energy due to 1. Pressure, 2. Velocity,
  3. Elevation 4. Temperature

Application:

1. Irrigation, 2. Power Generation, 3. Automobiles,
4. Domestic Purpose (Tube Well, Drinking Water)

Hydraulic Press

Force can be increased
Not Energy/Work done



P1=P2=P (pressure)
V1=V2=V (displaced volume)

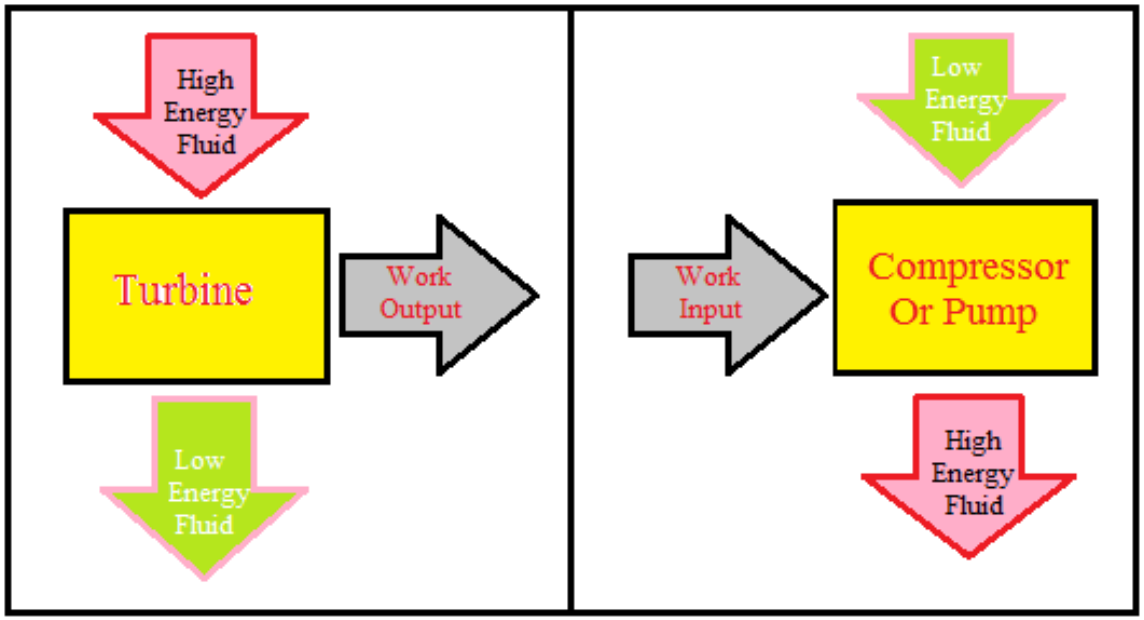
$W1 = F1*x1 = F1*V1/A1$
$= (F1/A1)*V1 = P*V$

$W2 = F2*x2 = F2*V2/A2$
$= (F2/A2)*V2 = P*V$

Works on Pascal's Law

Turbo Machinery

- Dynamic fluid machines (extract energy/add energy)



For turbine:

Efficiency=(Work output/Input hydraulic energy)

For Pump/Compressor:

Efficiency=(Output hydraulic energy/Input work)

Add Energy to Fluid

Based on type of fluid handled:

1. Incompressible fluid: E.g. Pumps
2. Compressible fluid: E.g. Compressors

Work: $W = P*V$

So, $\Delta W = P*\Delta V + V*\Delta P$

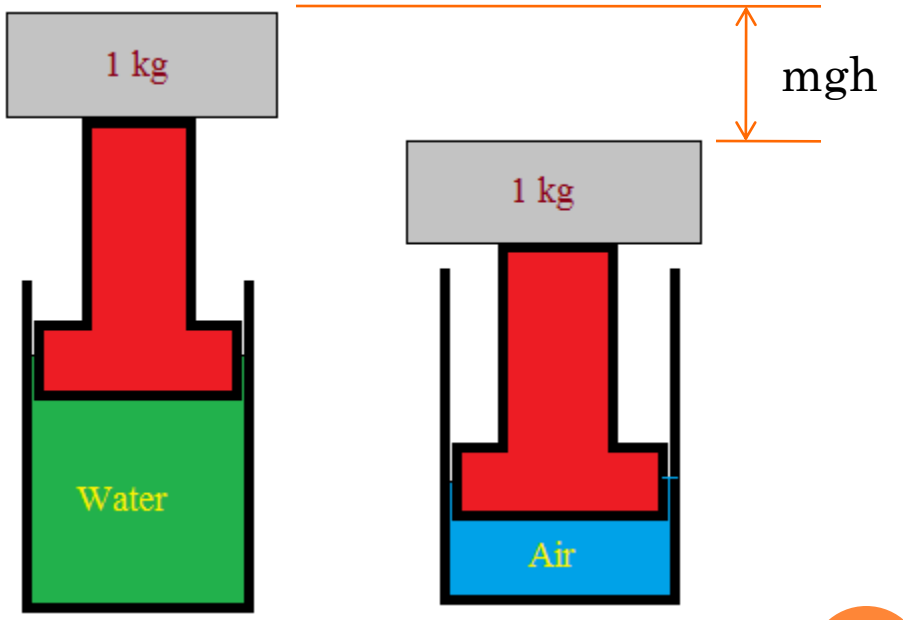
For Pumps: $\Delta V = 0$

so, $\Delta Wp = V*\Delta P$

For Compressor:

$\Delta Wc = P*\Delta V + V*\Delta P$

So, $\Delta Wc = P*\Delta V + \Delta Wp$

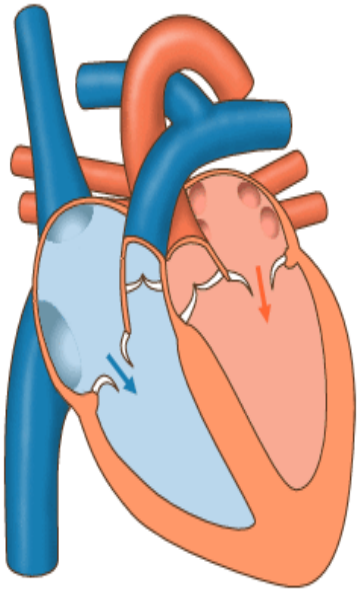


Compressors consume more power than pumps for same pressure rise

COMPARISON OF PUMP AND COMPRESSOR

1. Both impart energy into the fluid
2. Basically pumps and compressors work in same way

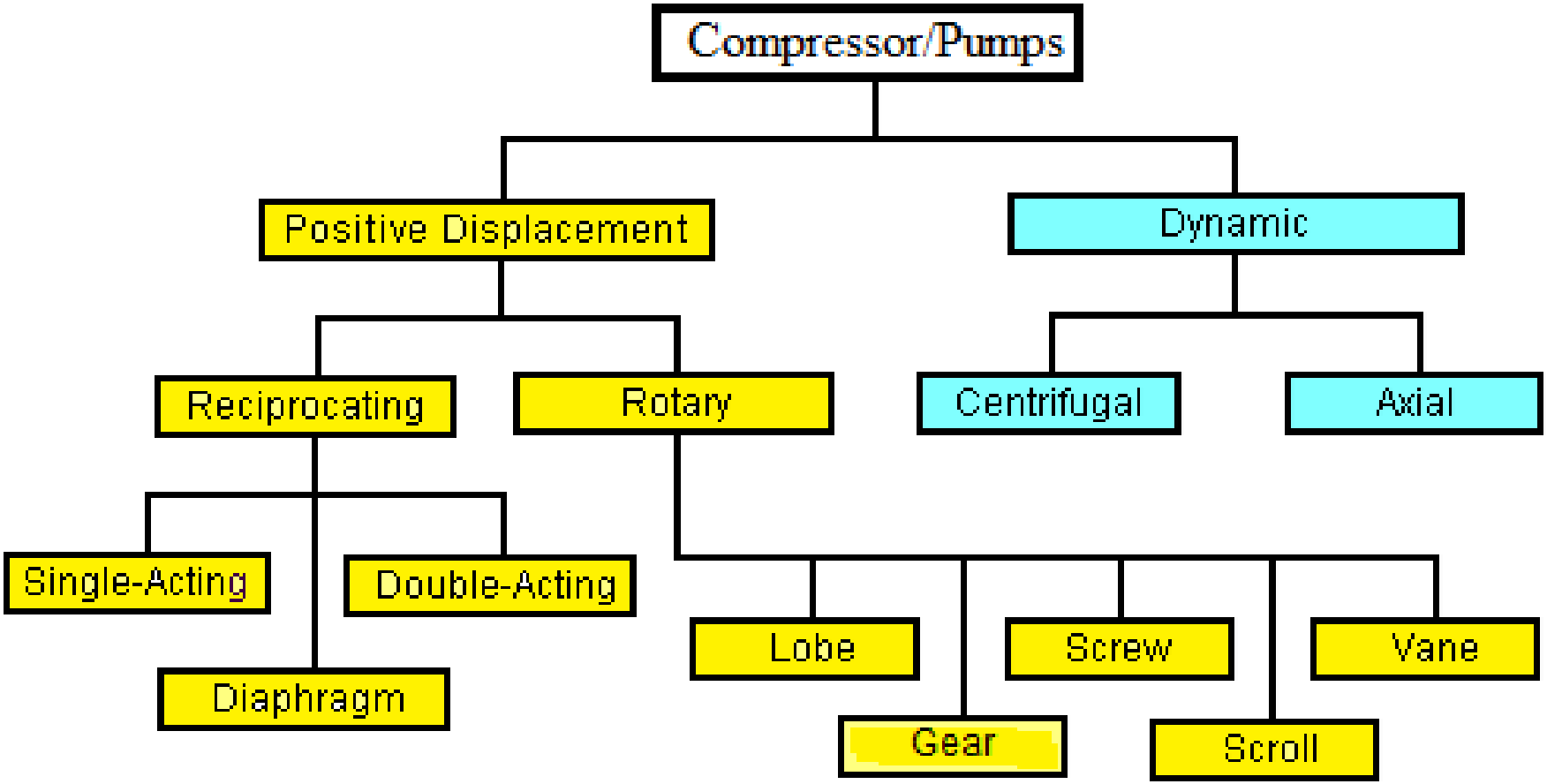
Pump



Heart

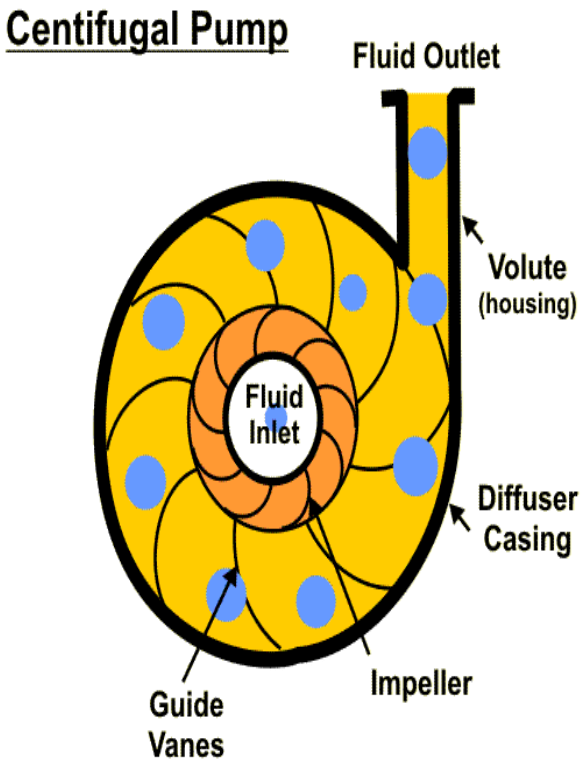
Compressor

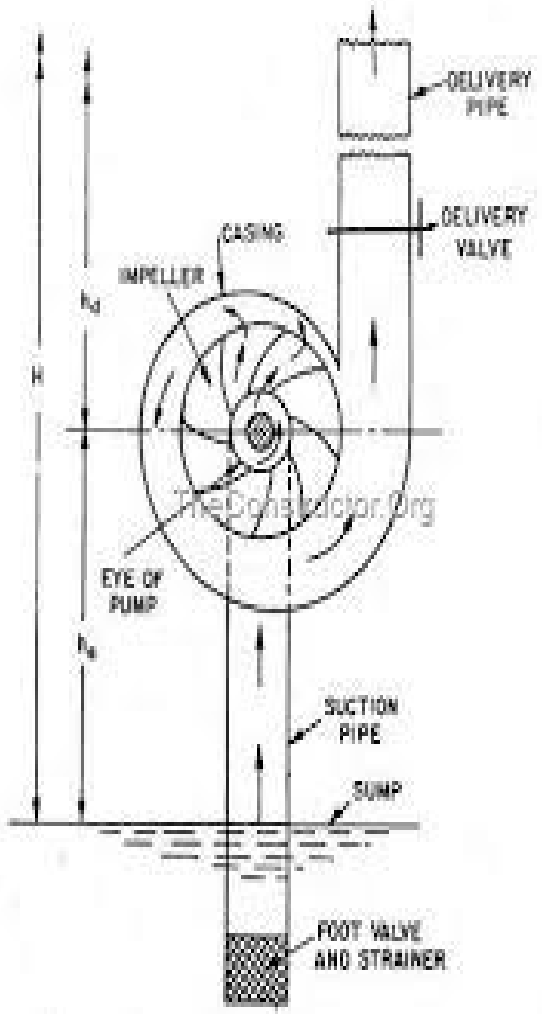
Classification of Pumps/Compressors

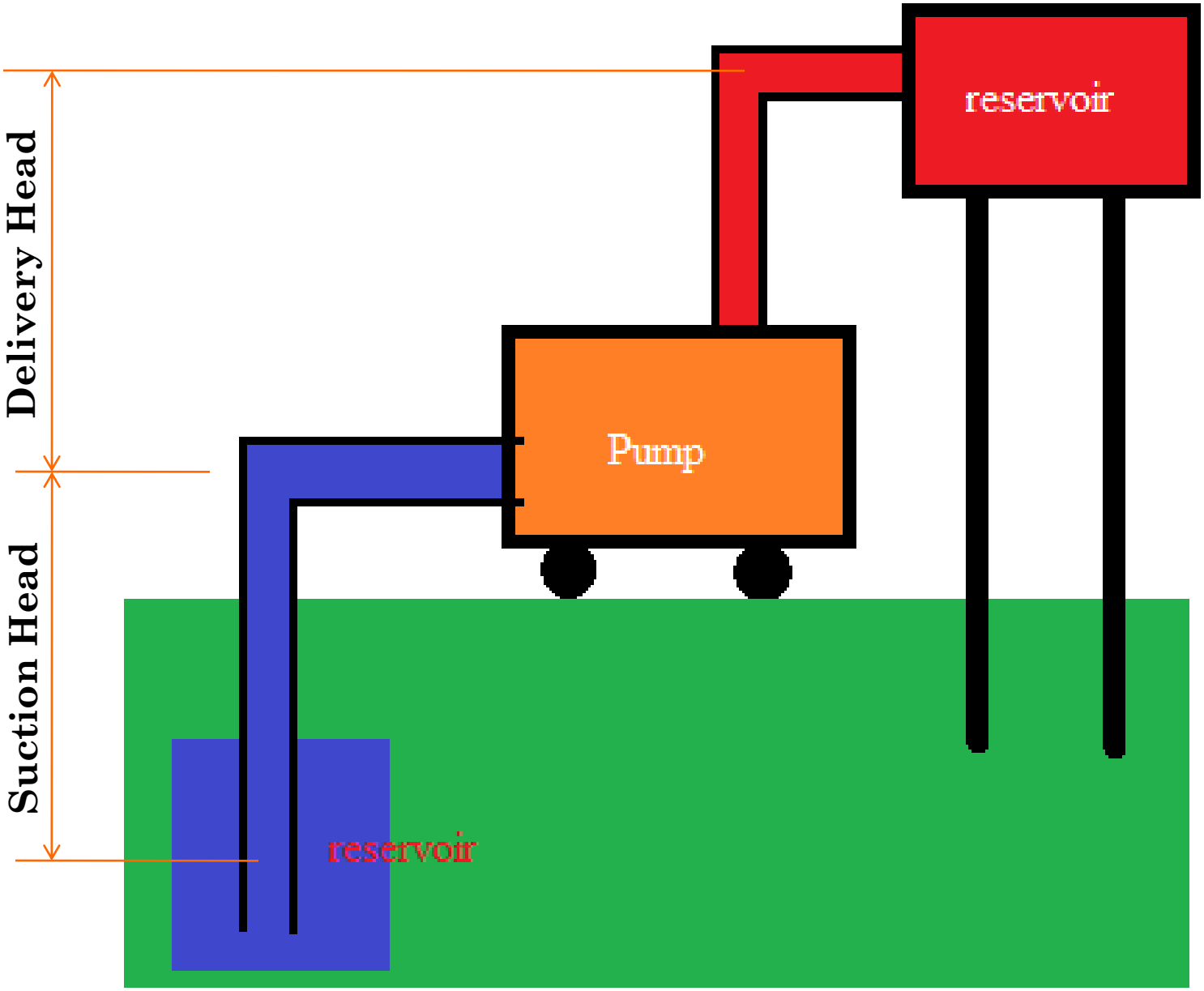


Centrifugal Pumps

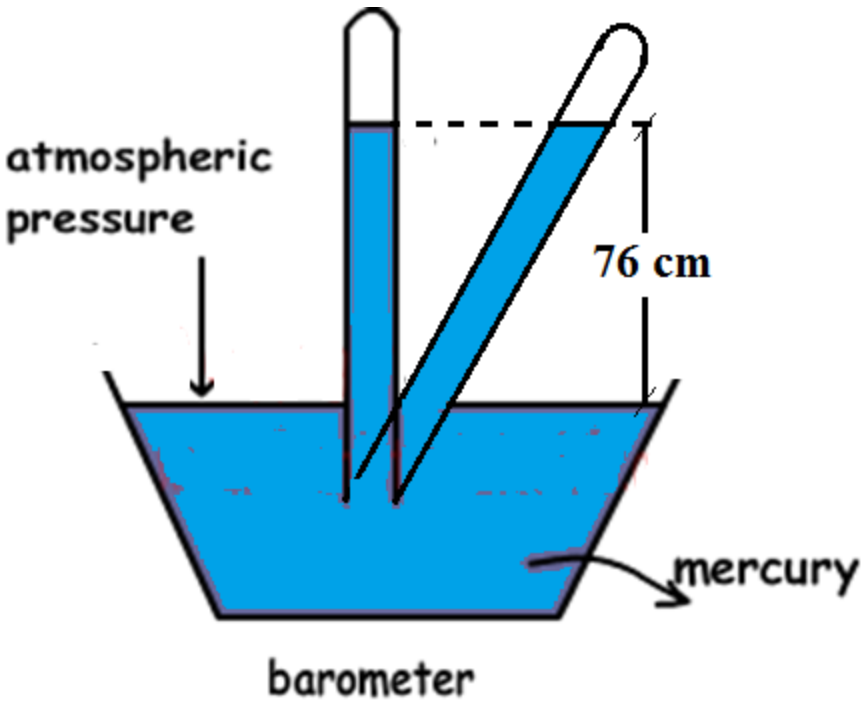
- Work due to centrifugal action.
- Velocity is increased first.
- Diffuser then increase pressure.
- Casing (Volute) act like diffuser

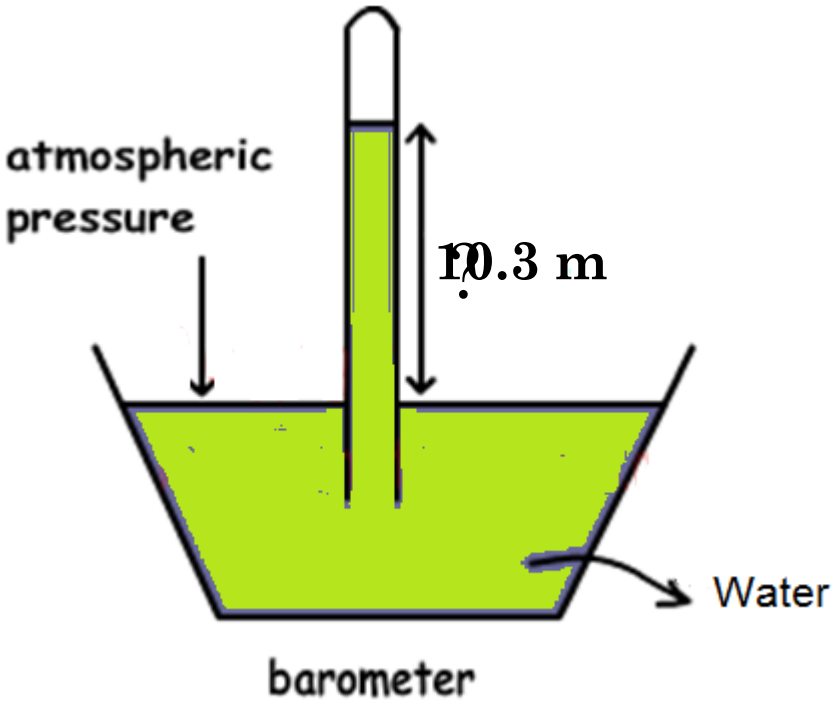





Delivery Head
Suction Head
reservoir
Pump
reservoir

Net Positive Suction Head





$$NPSH = [(Pop)/(\rho g)] - [Pv/(\rho g)] - Hf$$

Priming is necessary

Mathematical Problem:

Problem 1: Find the NPSH of a pump that operates at room condition and the frictional loss in suction pipe is 1.5 m of water.

Solution:

$$NPSH = [(Pop)/(\rho g)] - [Pv/(\rho g)] - Hf$$

$$= (101325 - 3200)/(1000*9.8) - Hf$$

$$= 10.01 - 1.5$$

$$= 8.51 \text{ m}$$

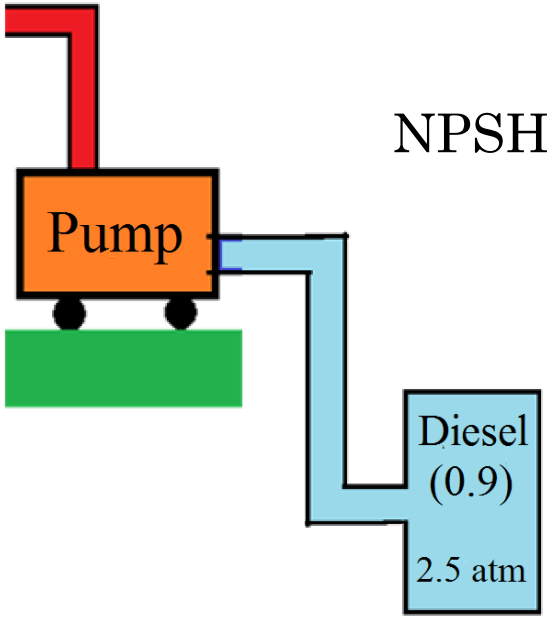
So, the pump can be installed maximum 8.51 m above the water level.

Mathematical Problem:

Problem 2: Find the NPSH of a pump that operates at room condition and the frictional loss in suction pipe is 2 m of water. Vapor pressure of diesel at room temperature is 4000 Pa

Solution: $0.9*1000*9.81*(Hf)d = 1000*9.81(Hf)w$

$(Hf)d = 2.22$ m of Diesel



$NPSH = [(Pop)/(\rho g)] - [Pv/(\rho g)] - Hf$

$= (2.5*101325-4000)/(0.9*1000*9.8) - Hf$

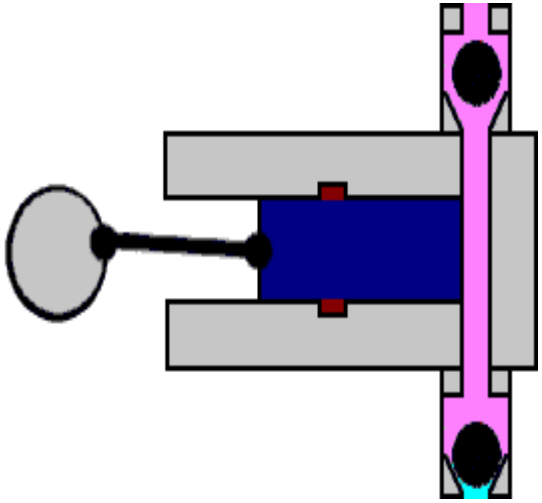
$= 28.24 - 2.22$

$= 26.02$ m

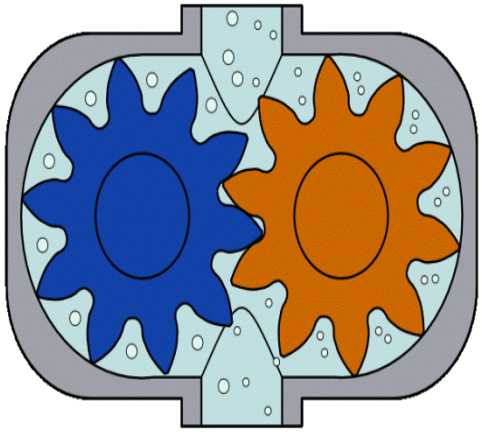
So, the pump can be installed maximum 8.51 m above the water level.

Positive Displacement Pumps

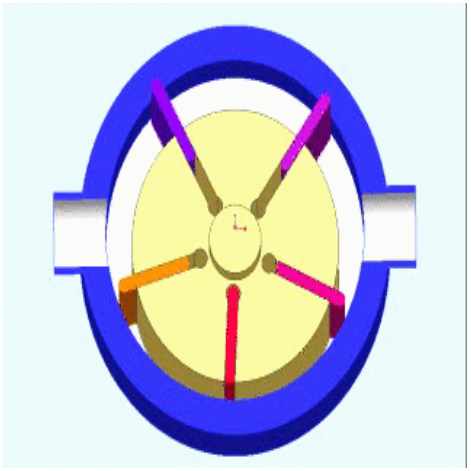
1. Trap a fixed volume and force into the discharge pipe.
2. The volume is constant through each cycle of operation.



Piston pump

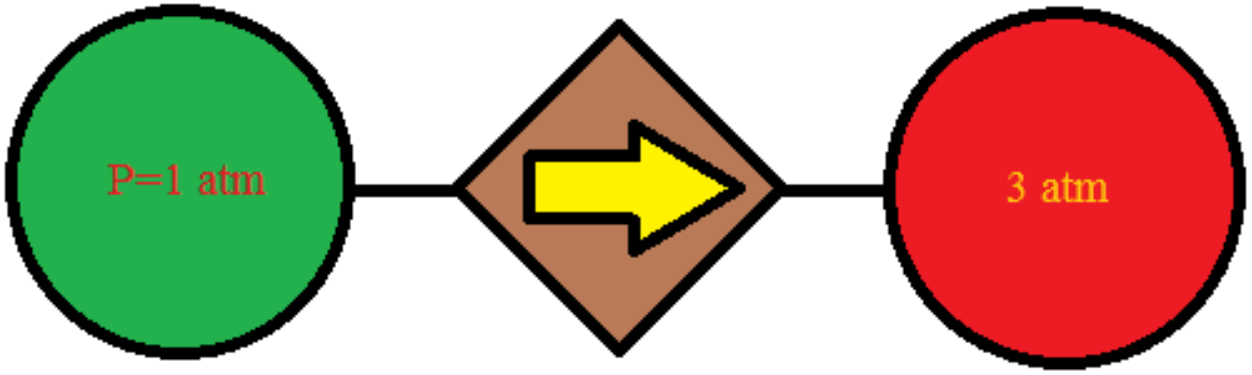


Gear pump



Vane pump

Centrifugal Pumps and Positive Displacement Pump



Positive displacement Pump Rota dynamic Pump

Positive displacement pump: Blind Pump

Performance depends only on rpm and displacement volume

Rotadynamic Pump: Sense input and output pressure

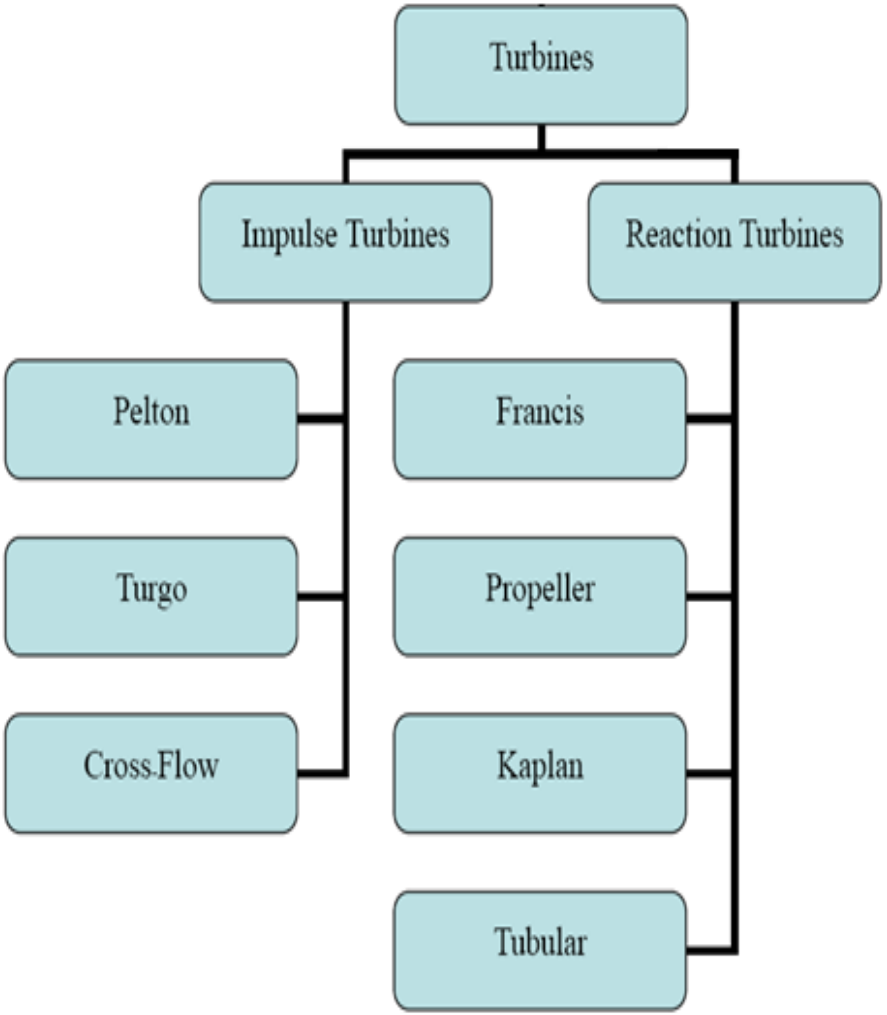
Performance depends on input and output pressure

Where to use reciprocating pumps?

1. Give **constant flow** rate (speed regulated flow)
2. Independent of tank **pressure**.
3. High efficient for high **viscous fluids**.
4. No easy **access of human** (specially children)
5. No possibility of **closed delivery valve**
6. No need to **empty the pipelines**.

Lubrication of automobiles, Flow meters etc

Extracting energy from Fluid

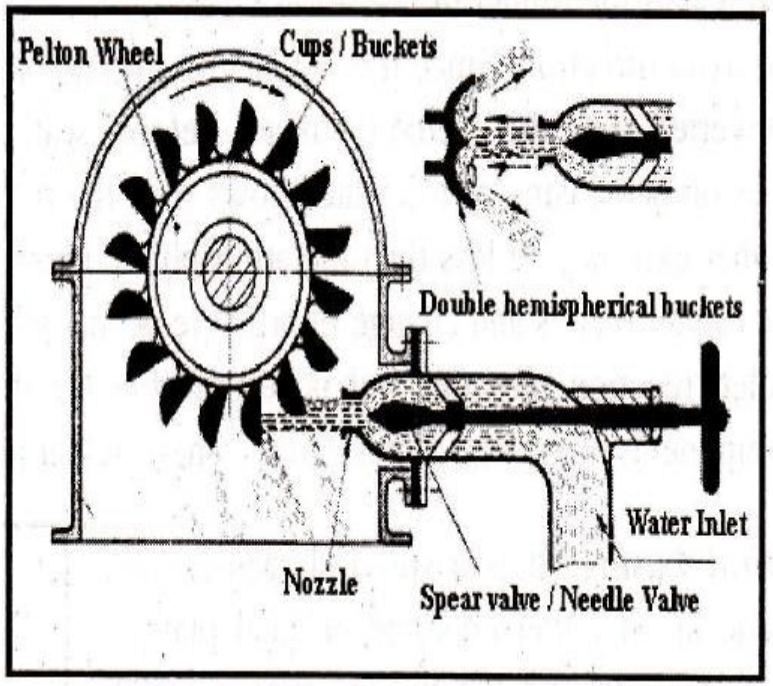


Based on direction of fluid flow:

1. Axial Flow:
   E.g. Kaplan Turbine
2. Radial Flow:
   E.g. Pelton Wheel
3. Mixed Flow:
   E.g. Francis Turbine

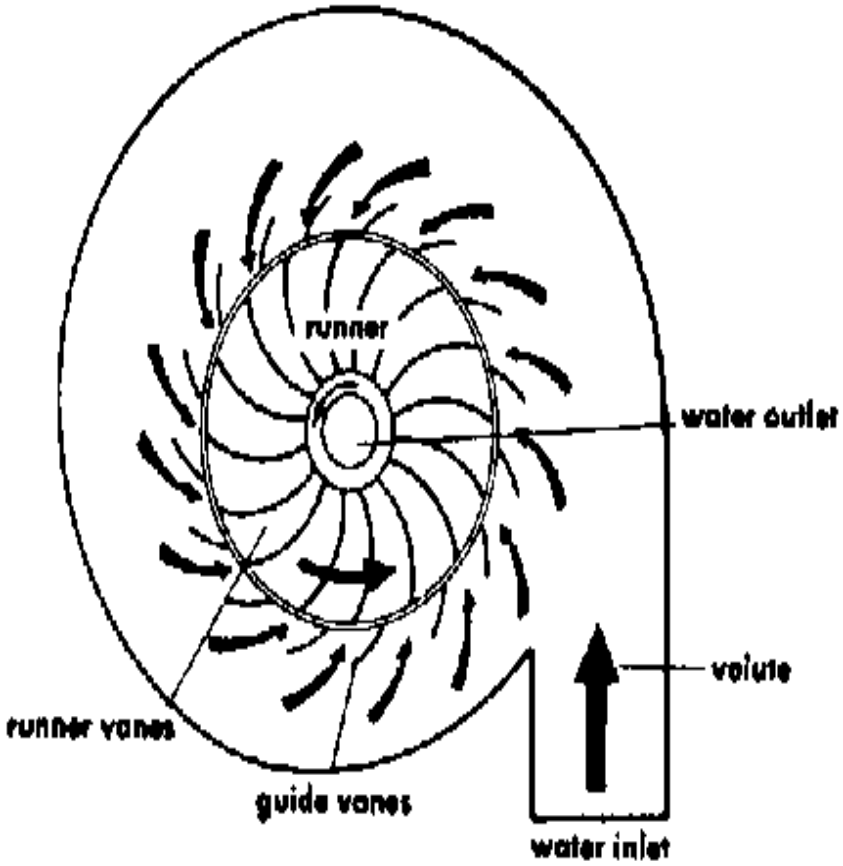
Pelton Wheel

- Impulse Turbine
- Used for high head (15–2000 ~ m)
- Low flow rate



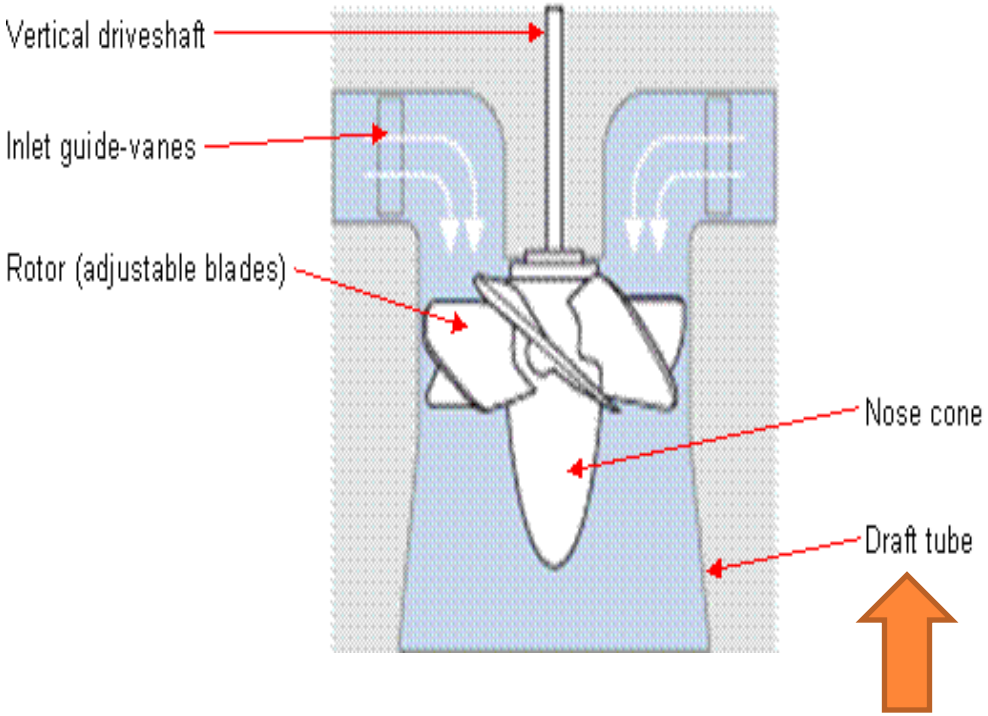
Francis Turbine

- Inward-flow (Mixed flow) reaction turbine
- Medium head (40 to 600 m)
- Medium flow rates.



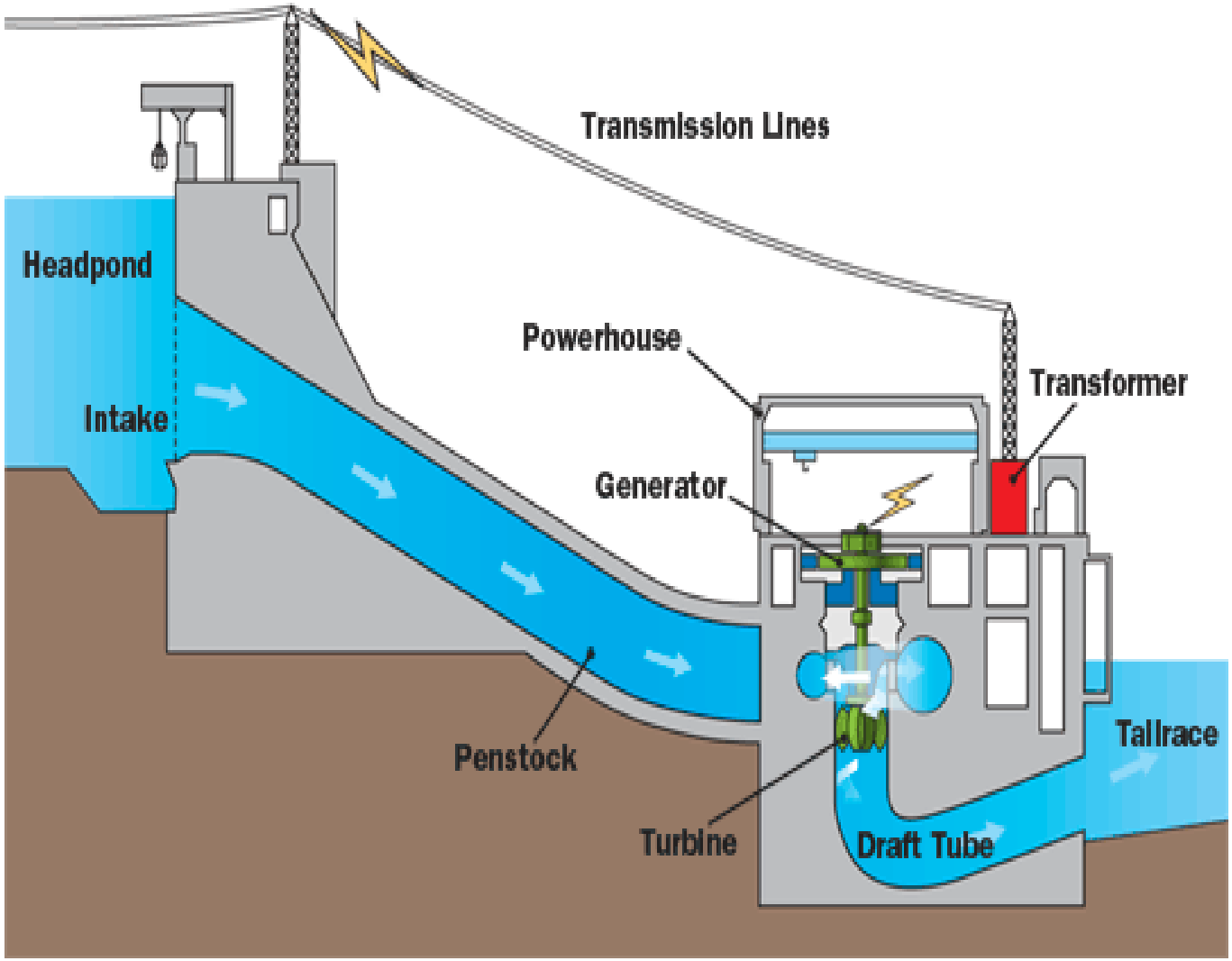
KAPLAN TURBINE

- Evolution of the Francis Turbine
- Adjustable blades
- Low heads (10 – 70m)
- High flow rates.



NP: Draft tube is installed at the exit

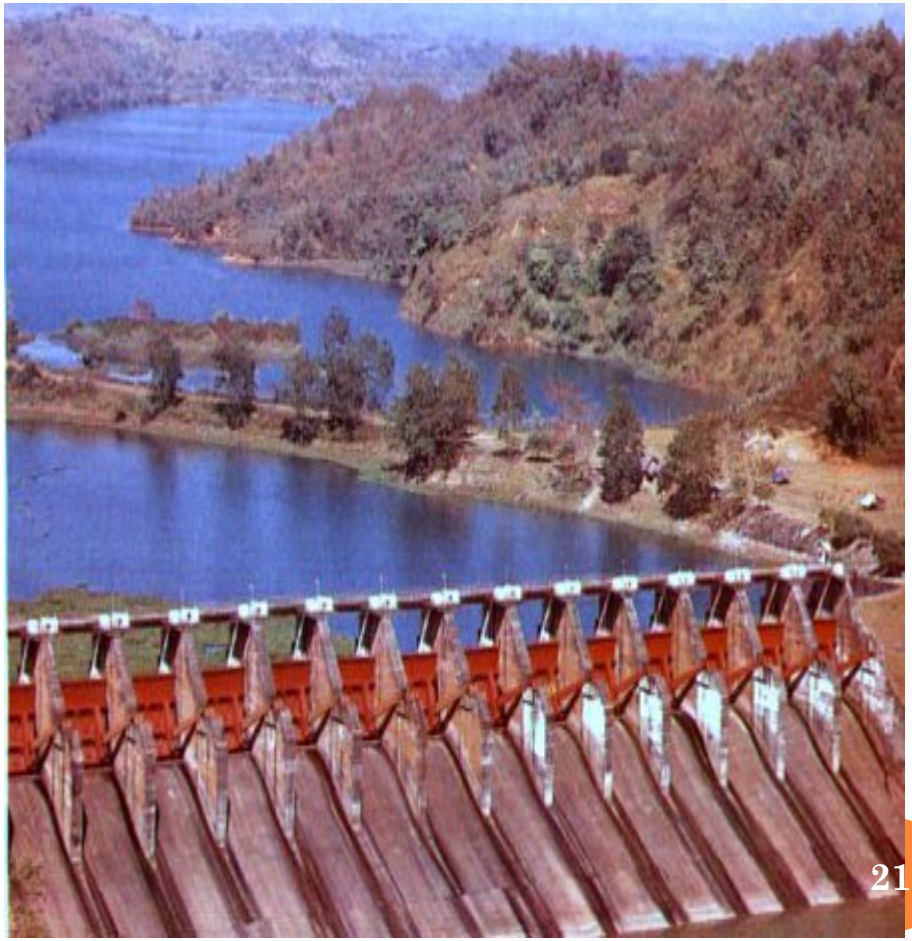
Hydroelectric power plant



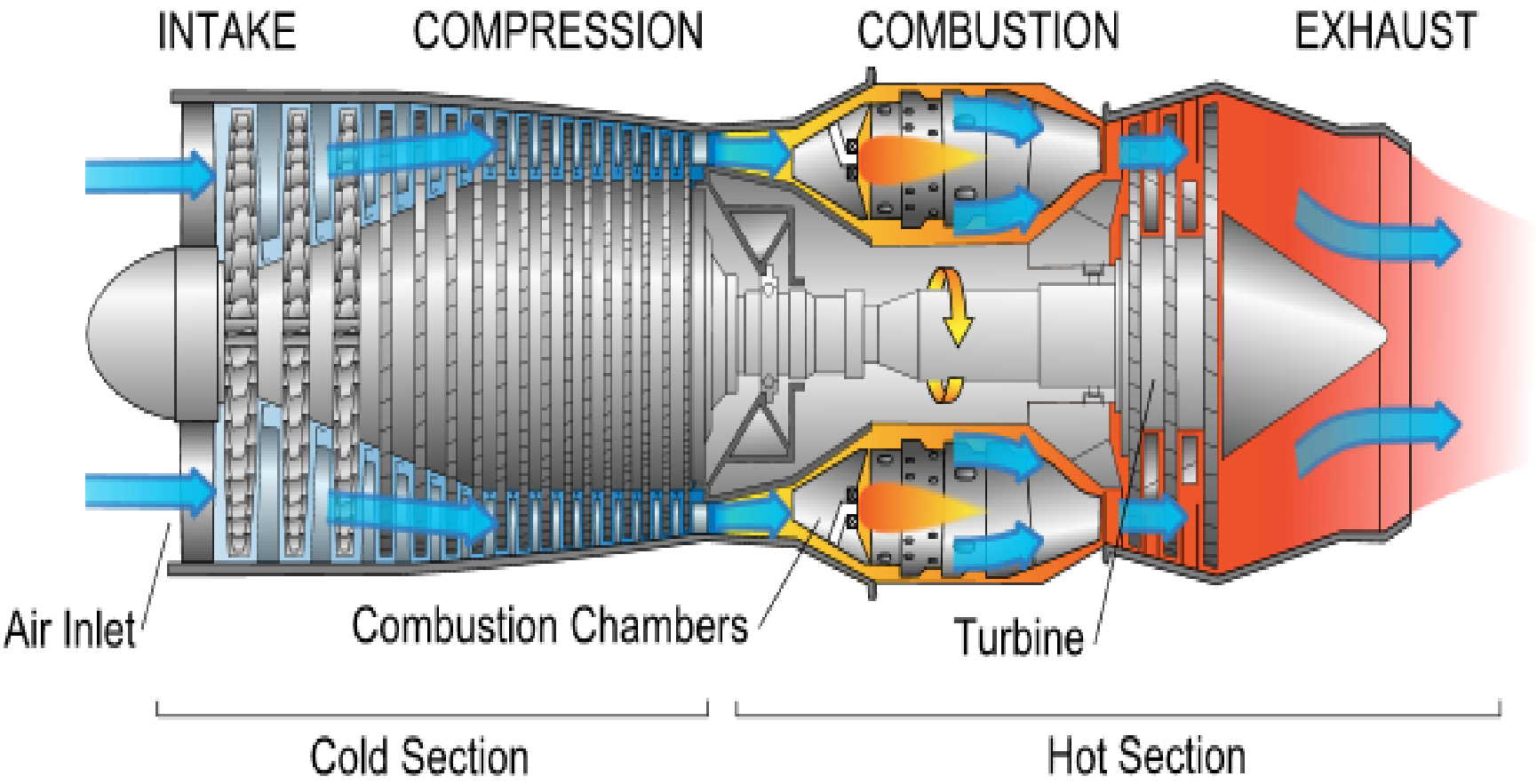
Karnafuli Hydroelectric power plant

Generation capacity = 230MW

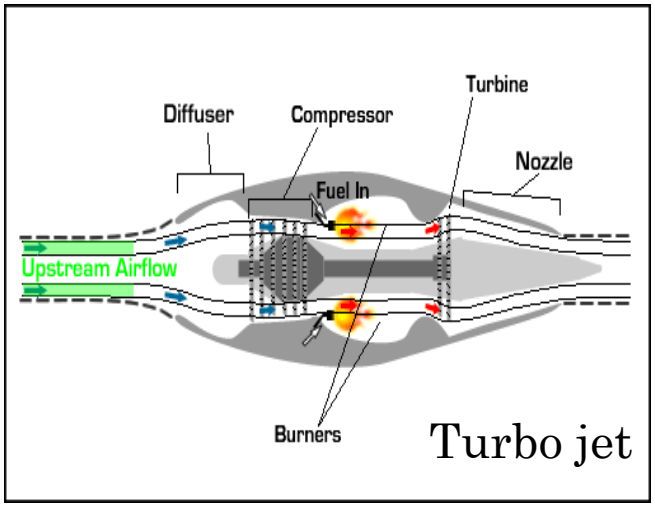
Reservoir size = 777 sq. km

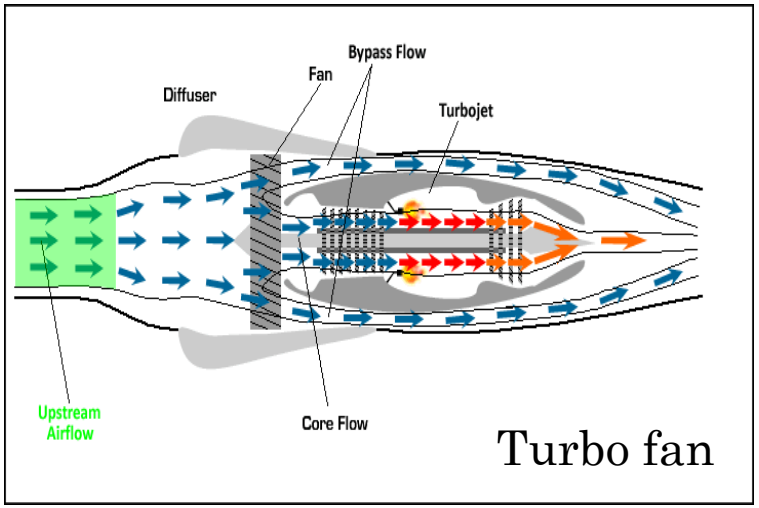


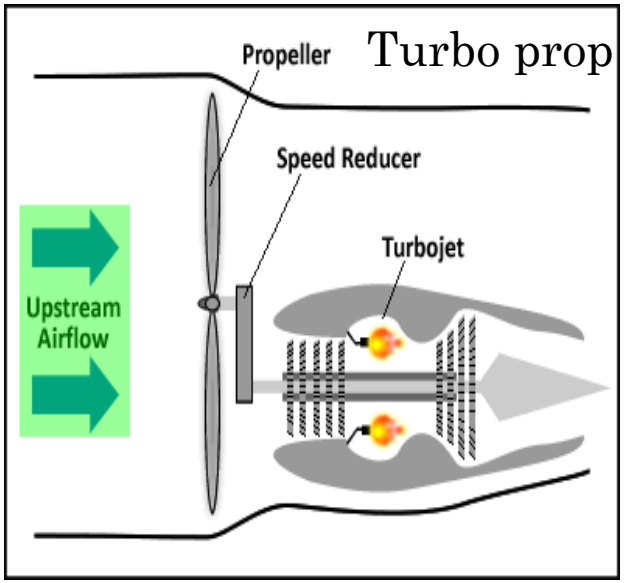
Gas Turbine


INTAKE
COMPRESSION
COMBUSTION
EXHAUST
Air Inlet
Combustion Chambers
Turbine
Cold Section
Hot Section

Jet Engine


Diffuser
Compressor
Turbine
Nozzle
Fuel In
Upstream Airflow
Burners
Turbo jet

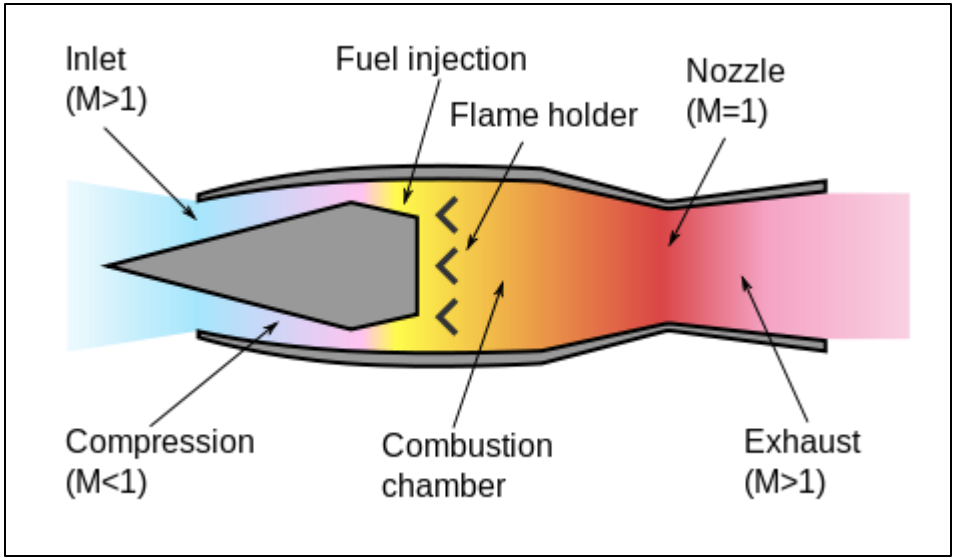

Bypass Flow
Fan
Diffuser
Turbojet
Upstream Airflow
Core Flow
Turbo fan

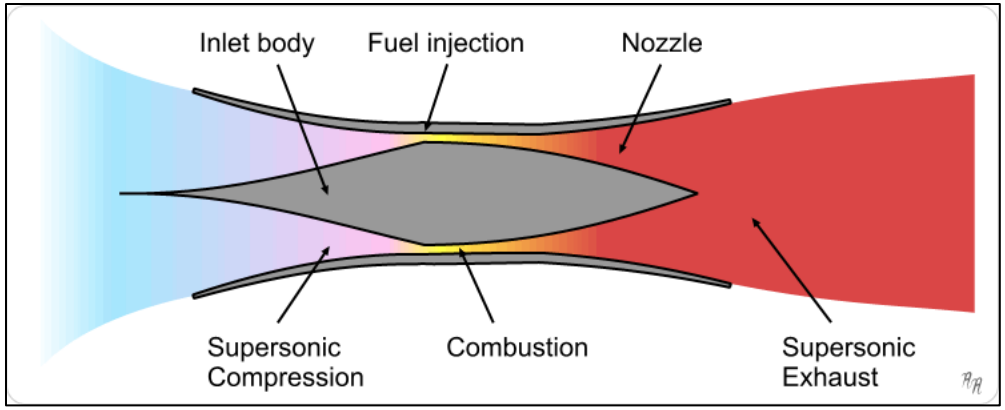

Propeller
Turbo prop
Speed Reducer
Turbojet
Upstream Airflow

Other jet Engines

Ram Jet:

- Between Mach 3 ~ 6
- Flying 'Stove Pipe'
- Can't move from standstill
- Missile, Mortar etc





Scram Jet:

- Between Mach 12 ~ 24
- Still in progress
- Almost costless

ME 201
Mechanical Engineering Fundamentals

Fluid Mechanics

Md. Abdul Hamid

What is Fluid?

Fluid is some thing that can not withstand shear stress no matter how small the stress is.

The shear stress in fluid is measured by Newton's law of viscosity:

$$\tau = \mu \, (\partial v / \partial y) = \mu \, (\Delta v / \Delta y)$$

$$\Rightarrow F/A = \mu \, (\Delta v / \Delta y)$$

Here, τ = Shear stress (Pa or N/m^2)

μ = Viscosity of fluid (Ns/m^2)

v = Velocity of fluid (m/s)

y = Distance perpendicular to the velocity (m)

F = Force (N)

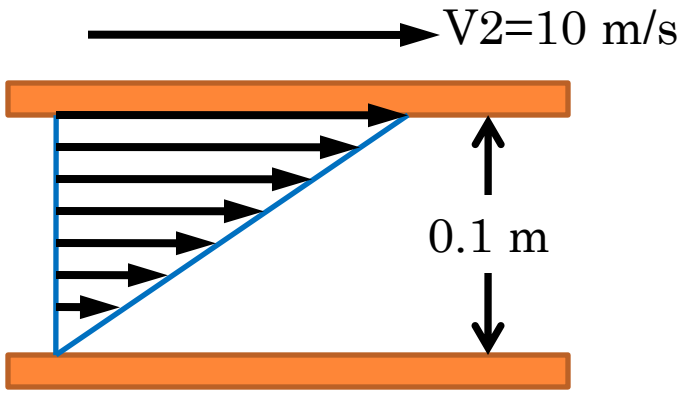
A = Area (m^2)

$\partial, \Delta \longrightarrow$ denotes change

Mathematical Problem

Problem 1: Two parallel plates of 0.5 m length and 0.2 m width are 0.1 m apart from each other. The interior space is filled by oil of viscosity 15 Ns/m. find the force required to move the upper plate at a velocity of 10 m/s.

Solution:



Here, $A = 0.5*0.2\ m^2$

$\mu = 15$ Ns/m

$v1 = 0$ m/s, $v2 = 10$ m/s

$\Delta y = 0.1$ m

Newton's law of viscosity: $F/A = \mu\ (\Delta v/\Delta y)$

So, $F = A^*\ \mu\ (\Delta v/\Delta y) = A^*\ \mu\ \{(v2-v1)/(\Delta y)\}$

$= (0.5*0.2)*15*(10-0)/(0.1)$

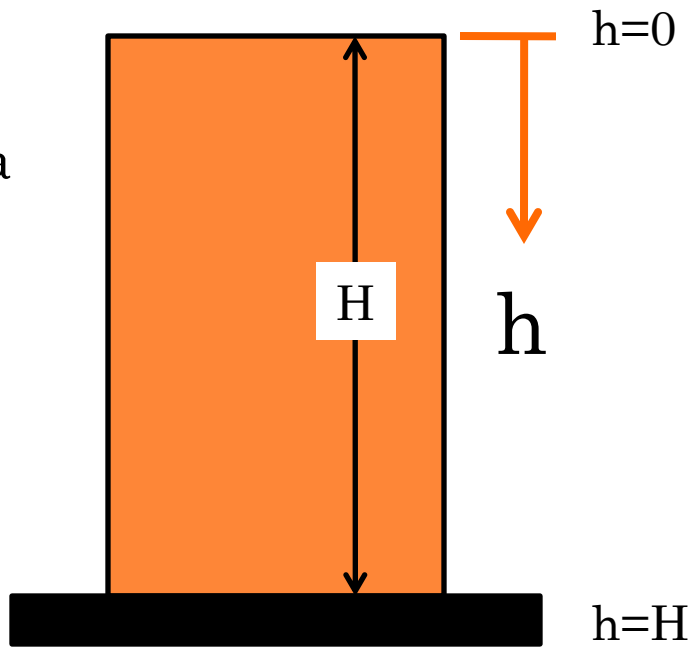
$= 150$ N (Ans)

Pressure of Fluid

Fluid creates pressure at its bottom due to is own weight.

Pressure = Force/Area
= (Mass*g)/Area
= (Density*Volume*g)/Area
= (Density*Depth*Area*g)/Area
= (Density*Depth*g)
= ρgh

$$P = \rho g h$$



Here, P = Pressure (Pa or N/m^2)
ρ = Density (kg/ m^3)
g = 9.81 (m/s^2)
h = Depth (m)

Mathematical Problem

Problem 2: Find the pressure at the bottom and at point A.

The Tank is filled with oil of density 900 kg/m^3.

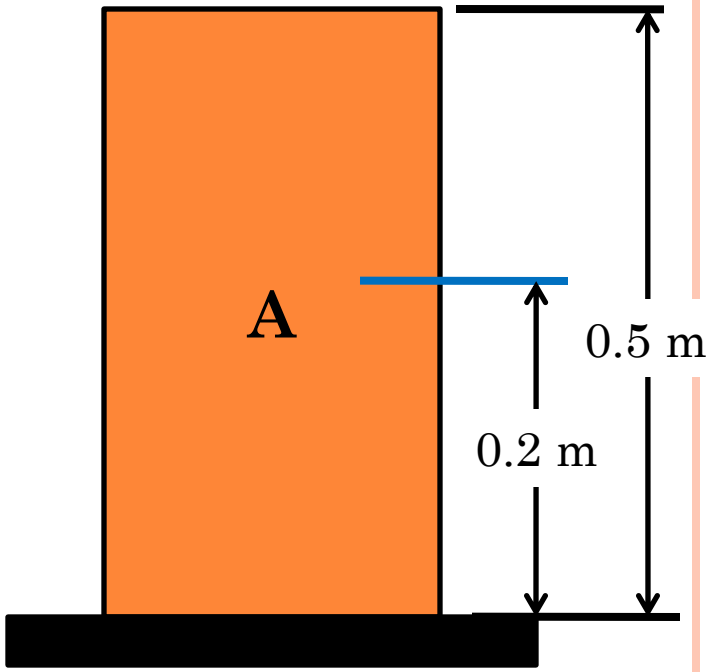
Solution:

Pressure at bottom:

$$P_b = (\rho g h)_{bottom}$$
$$= 900*9.81*0.5$$
$$= 4414.5 \text{ Pa}$$
$$= 4.4145 \text{ kPa} \qquad \text{(Ans)}$$

Pressure at point A:

$$P_a = (\rho g h)_a$$
$$= 900*9.81*(0.5 - 0.2)$$
$$= 2648.7 \text{ Pa}$$
$$= 2.648.7 \text{ kPa} \qquad \text{(Ans)}$$



Mathematical Problem

Problem 3: Find the pressure at points A, B and C. The tank is filled with water.

Solution: Pressure at A = 1000*9.81*(0.5-0.2) = 2943 Pa

Pressure at B = 1000*9.81*(0.5-0.05) = 4414.5 Pa

Pressure at C = 1000*9.81*(0.5-0.2) = 2943 Pa

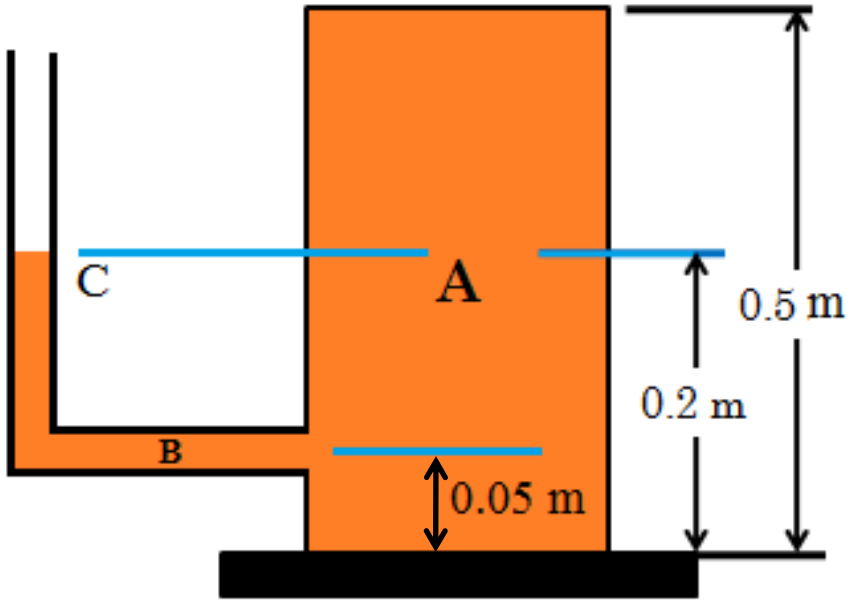
Pressure at C:

Pc = Pa (Same Elevation)

= Pb – 1000*9.81*(0.2-0.05)

= 4414.5 – 1471.5

= 2943 Pa



Introduction to Mannometry

Density (ρ): Mass of 1 m^3 of substance (kg/m^3)

Specific Weight (w): Weight of 1 m^3 of substance (N/m^3)

$$w = \rho * g$$

Specific Gravity (s.g.): Ratio of density of substance to density of water.

$$s.g. = (\rho/\rho_w)$$

So, Density = (s.g.)*(1000)

Density of water = 1000 kg/m^3

s.g. of Hg = 13.6 **(To be memorized)**

Introduction to Mannometry

Problem 4: Find the pressure in tank B if the pressure in tank A is 0.7 atm.

Solution: Given, Pa = 0.7*101325 = 70927.5 Pa

$$Pa = Pb + (0.85*1000)*(9.81)*(0.07) - (13.6*1000)*(9.81)*(0.02) + (0.9*1000)*(9.81)*(0.015)$$

$\Rightarrow$ Pa = Pb – 1952.19

$\Rightarrow$ Pb = Pa + 1952.19
= 70927.5 + 1952.19
= 72879.69 Pa

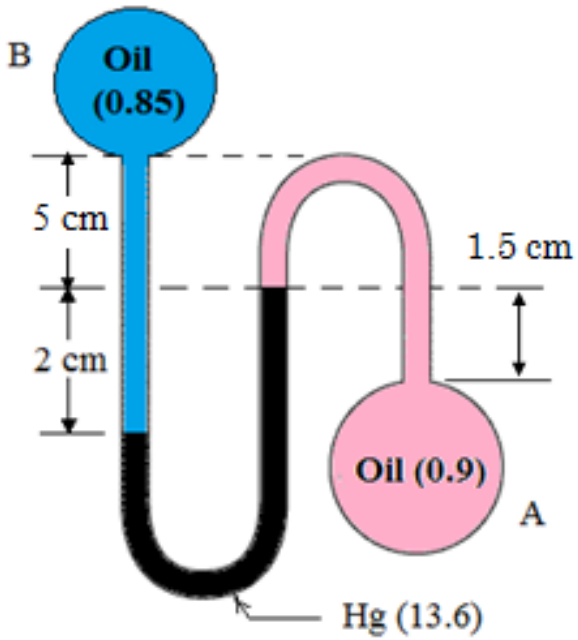
(Ans)

Again (Alternate Method):

$$Pb = Pa - (0.9*1000)*(9.81)*(0.015) + (13.6*1000)*(9.81)*(0.02) - (0.85*1000)*(9.81)*(0.07)$$

$\Rightarrow$ Pb = Pa + 19572.19

= 72879.69 Pa (Ans)



Introduction to Mannometry

Problem 5: Find 'h' if the pressure in tank A and B are 1.5 atm and 1.1 atm respectively.

Solution: Pa = 1.5*101325 = 151987.5 Pa; Pb = 1.1*101325 = 111457.5 Pa

Pb = Pa+(0.75*1000*9.81*0.05)-(13.6*1000*9.81*h)-(0.9*1000*9.81*0.1)
+(0.8*1000*9.81*0.15)+(0.95*1000*9.81*0.04)

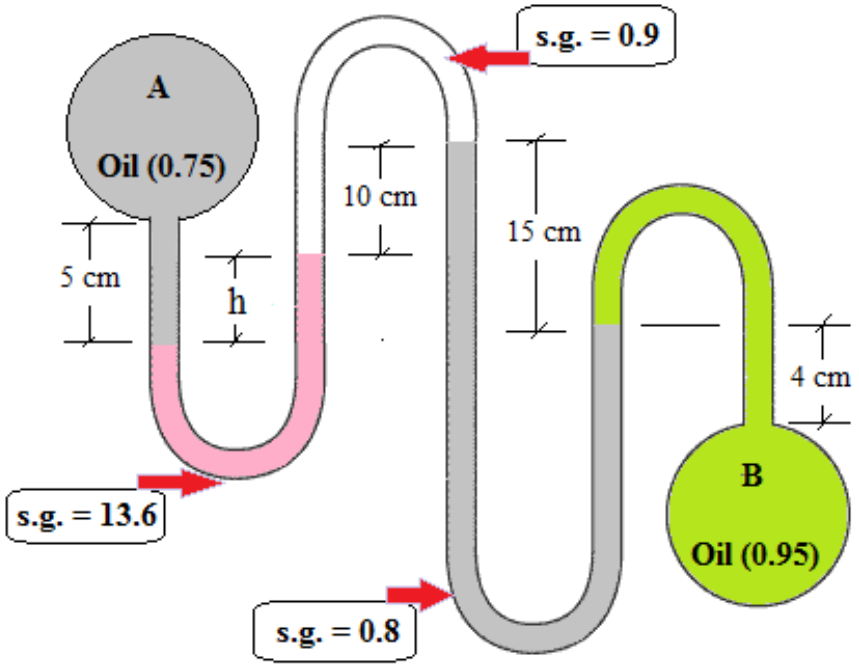
⇨ Pb = Pa+1034.96-(133416*h)

⇨ 133416*h = (Pa-Pb)+1034.96

⇨ 133416*h = (151987.5-111457.5)
+1034.96

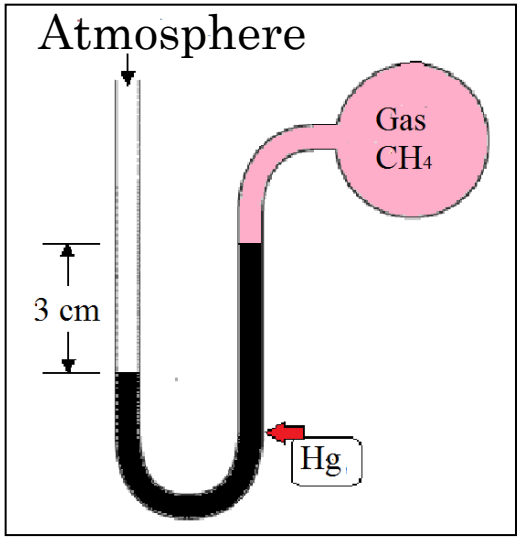
⇨ 133416*h = 41564.96

⇨ h = 41564.96/133416
= 0.31 m
= 31 cm (Ans)



Introduction to Mannometry

Problem 6: Find Pressure in the tank



Solution:

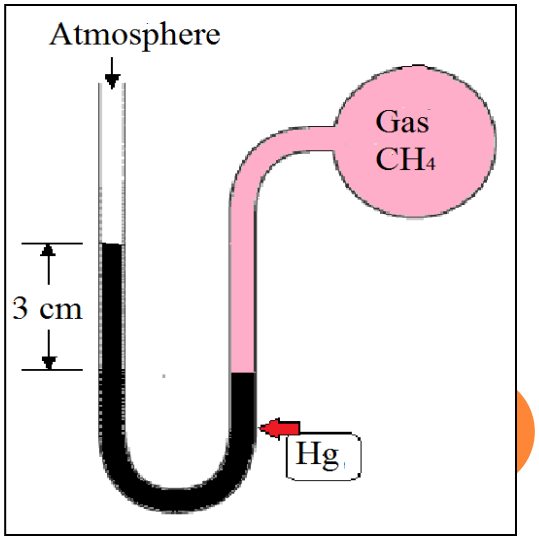
P = Patm - (13.6*1000*9.81*0.03)

⇨ P = Patm – 4002.5

= 101325 – 4002.5

= 97322.5 Pa (Ans)

Problem 7: Find Pressure in the tank



Solution:

P = Patm + (13.6*1000*9.81*0.03)

⇨ P = Patm + 4002.5

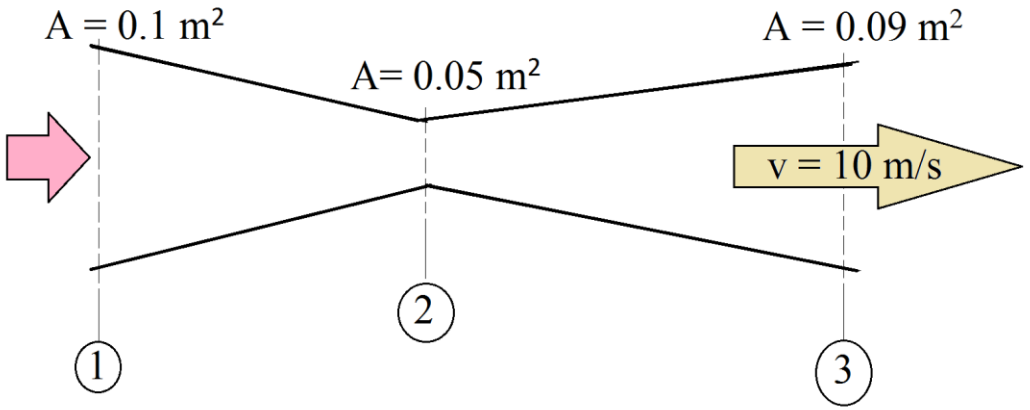
= 101325 + 4002.5

= 105327.5 Pa (Ans)

Introduction to Fluid Mechanics

Assumption:

1. Incompressible Flow
2. In-viscous Flow
3. Ir-rotational Flow
4. Steady Flow



Basic Equations:

1. Continuity Equation

Deals with Conservation of mass.

$$A_1 v_1 = A_2 v_2 = A_3 v_3 = - - - = A_n v_n$$

2. Momentum Equation

Deals with Conservation of momentum

$$\frac{P_1}{\rho} + \frac{{v_1}^2}{2} + g z_1 = \frac{P_2}{\rho} + \frac{{v_2}^2}{2} + g z_2$$

(Known as Bernouli's Equation)

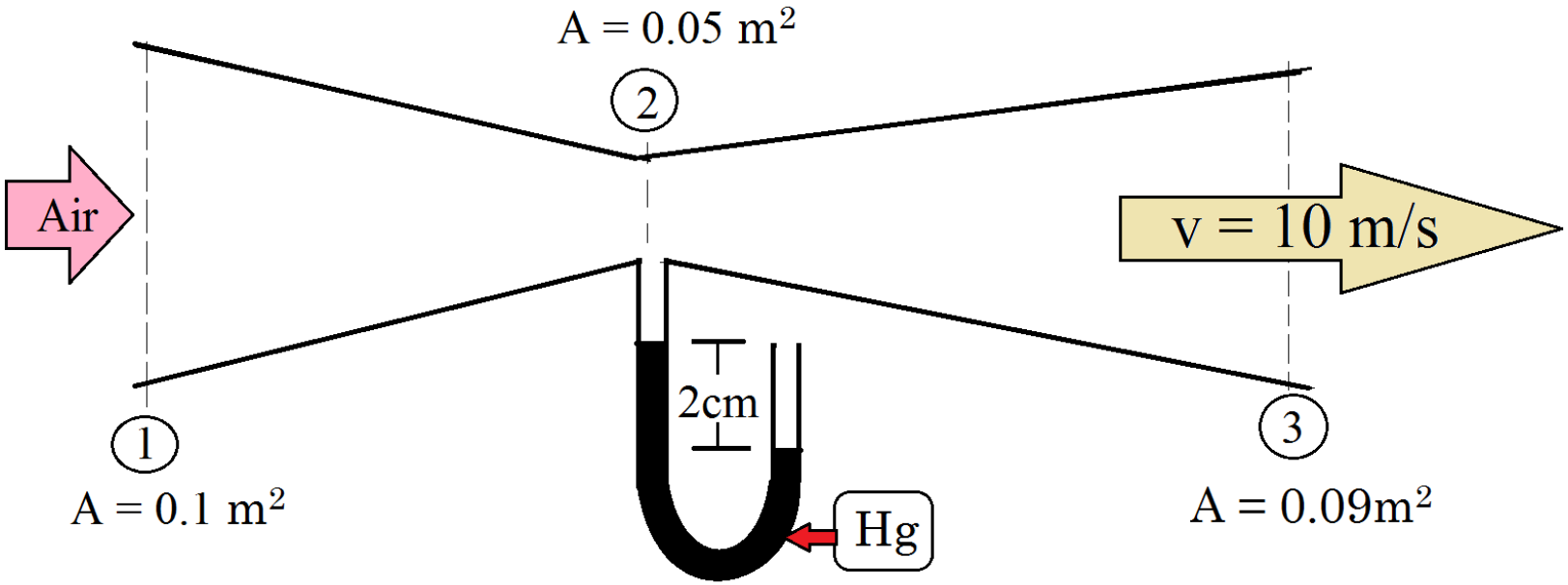
Mathematical Problem

Problem 8: Find the all the unknown velocities and pressures in the following figure.

Ans:

Velocity: A1*v1 = A3*v3 ; v1 = (0.09*10)/0.1 = 9 m/s

Similarly: A2*v2 = A3*v3 ; v2 = (0.09*10)/0.05 = 18 m/s



Mathematical Problem

Here,

$$P2 = 101325 - (13.6*1000*9.81*0.02) = 98656.7 \text{ Pa}$$

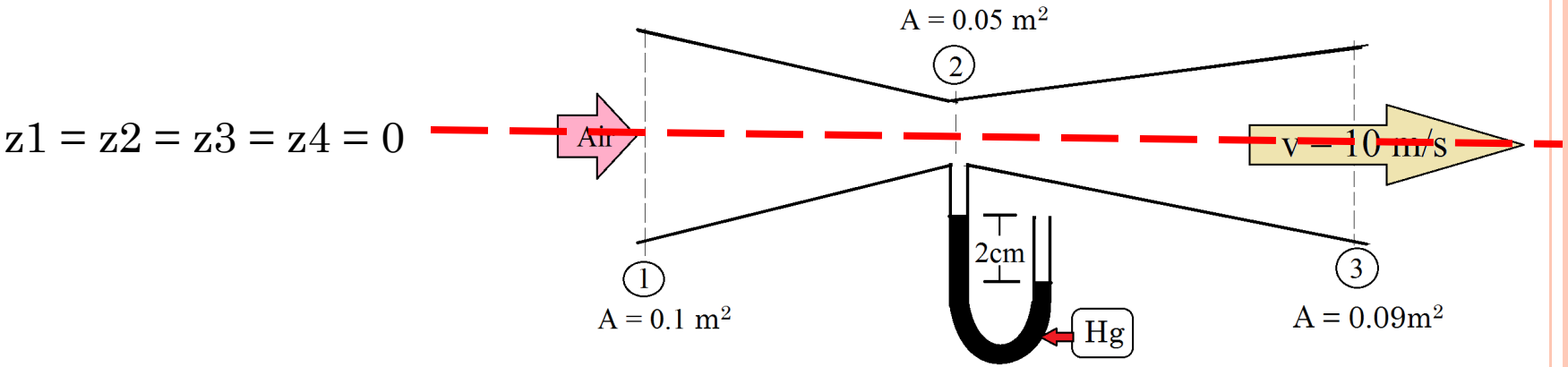
$$(P1/1000)+(9*9/2)+0 = (98656.7/1000)+(18*18/2)+0$$

$$P1 = 220156.7 \text{ Pa}$$

Similarly,

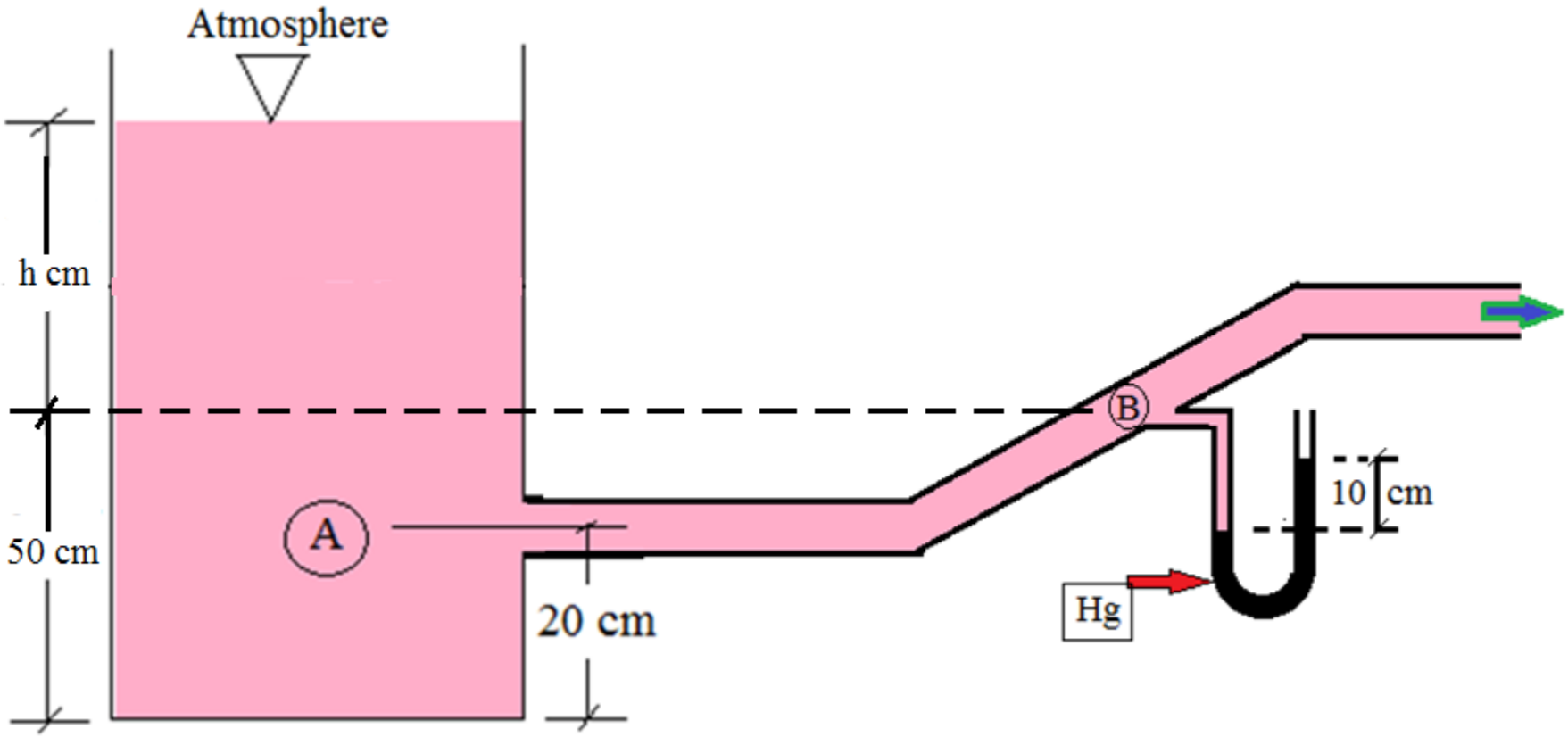
$$(P3/1000)+(10*10/2)+0 = (98656.7/1000)+(18*18/2)+0$$

$$P3 = 210656.7 \text{ Pa}$$



Mathematical Problem

Problem 9: Find the value of 'h' that will cause velocity of 10 m/s at point B. The flowing fluid is Water and the mannometric fluid is Hg.



Mathematical Problem

Here,

$P_b = 101325 + (13.6*1000*9.81*0.1) = 1146666$ Pa

$v_b = 10$ m/s ; $z_b = 50$ cm $= 0.5$ m

$P_a = 101325 + [1000*9.81*\{h + (0.5 - 0.2)\}] = 9810*h + 104268$ Pa

$v_a = 0$ m/s ; $z_a = 20$ cm $= 0.2$ m

Now Bernoulie's equation:

$(9810*h+104268)/1000+(0*0)/2+(0.2*9.81)=(1146666)/1000+(10*10)/2+(0.5*9.81)$

- $9.81*h+104.268+1.962 = 1146.666+50+4.905$
- $9.81*h = 1196.7$
- $h = 111.9$ m (Ans)