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2 Marks

Q.1

Sol. **Load Duration Curve:** The load Curve gives the variations of load. But in the Load Duration Curve, all the loads are arranged in descending order of magnitudes from the greatest load on the left and the least loads on the extreme right.

Q.2

Sol. Answer (Exam-Oriented):

Fourier's law is called a phenomenological law because it is based on experimental observation of heat flow behavior, not derived from first principles. It states that heat flows in the direction of negative temperature gradient:

$$q = -kA \frac{dT}{dx}$$

Here, the constant k (thermal conductivity) is obtained experimentally, so the law describes the observed phenomenon rather than explaining its microscopic cause.

Q.3

Sol. The critical radius of insulation depends on geometry:

- For a cylinder:

$$r_c = \frac{k}{h}$$

- For a sphere:

$$r_c = \frac{2k}{h}$$



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Since the critical radius of a sphere is twice that of a cylinder, it is greater.

Reason: In a sphere, the heat transfer area increases more rapidly with radius compared to a cylinder, so a larger radius is required before the increase in surface area overcomes the added conduction resistance.

Q.4

Sol. Fin efficiency is maximum when the temperature of the entire fin is nearly equal to the base temperature,

i.e., when:

- Thermal conductivity of fin material is very high, and
- Fin length is small or heat transfer coefficient is low.

In other words, when temperature drop along the fin is negligible, fin efficiency approaches 100%.

Q.5

Sol. Because momentum diffusion and heat diffusion occur at different rates in a fluid.

- Velocity boundary layer develops due to viscosity (momentum diffusion).
- Thermal boundary layer develops due to thermal conductivity (heat diffusion).

Their relative thickness depends on the Prandtl number:

$$Pr = \frac{\nu}{\alpha}$$

- If $Pr > 1$ (oils, water): thermal BL is thinner than velocity BL ($\delta_t < \delta$)
- If $Pr < 1$ (liquid metals): thermal BL is thicker ($\delta_t > \delta$)

So: Different diffusivities different boundary layer thickness.



Q.6

- Sol. It requires very large specific volume and very high vacuum, so equipment size becomes large.
- Refrigerant → Water
 - Principle → Evaporation under vacuum
 - Main drawback → Large volume & high vacuum required

Q.7

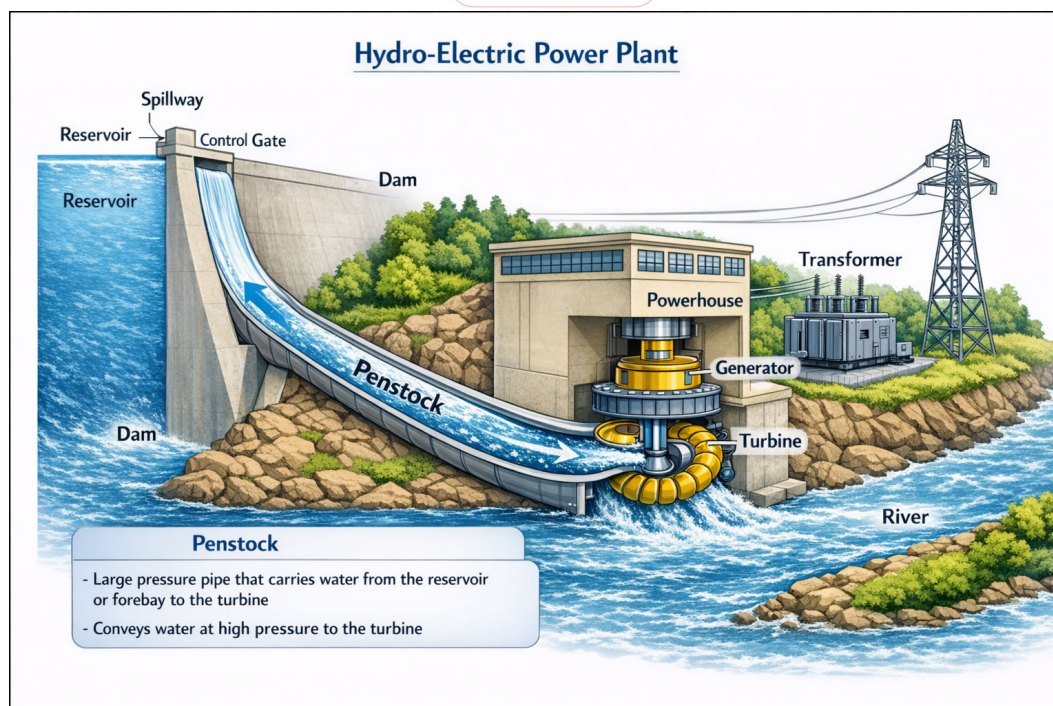
- Sol. The compression ratio of a C.I. (Diesel) engine is higher because:
1. Self-ignition requirement: In a C.I. engine, fuel must auto-ignite due to high temperature and pressure, so a high compression ratio (14:1 to 25:1) is necessary.
 2. No knocking limitation like S.I. engine: An S.I. engine uses spark ignition and cannot use high compression ratio due to knocking, whereas C.I. engine does not suffer from pre-ignition in the same way.
- Therefore, C.I. engines operate with much higher compression ratios than S.I. engines.

Q.8

- Sol. • Excessive turbulence improves combustion because it enhances air-fuel mixing and increases flame propagation speed, resulting in faster and more complete combustion.
- However, it increases heat loss because the hot gases come into more intense contact with cylinder walls, increasing convective heat transfer to the walls.
- Thus, turbulence speeds up combustion but also increases heat loss to engine walls.

Q.9

- Sol. A penstock is a large pressure pipe which carries water from the reservoir or forebay to the turbine. Its main function is to convey water at high pressure and high velocity to the turbine for power generation.



Q.10

- Sol. Control rods are used to control the rate of nuclear fission reaction in a reactor. They absorb excess neutrons and thus regulate or stop the chain reaction to keep the reactor operating safely at the desired power level.

Q.11

Sol. Hazen-Williams formula is an empirical equation used to calculate head loss due to friction in water pipes (especially for turbulent flow in large diameter pipes).
It is given by:

$$h_f = 10.67 \frac{LQ^{1.852}}{C^{1.852} D^{4.87}}$$

Where:

- h_f = head loss due to friction (m)
- L = length of pipe (m)
- Q = discharge (m^3/s)
- D = diameter of pipe (m)
- C = Hazen-Williams coefficient

Q.12

Sol. The deflector in a Pelton turbine is used to temporarily divert the jet of water away from the buckets when the load on the turbine suddenly decreases, so as to prevent overspeeding of the runner. It helps in smooth control of speed without immediately closing the nozzle.

Q.13

Sol. Divergence of velocity is a measure of the rate at which fluid is expanding or compressing at a point in the flow field.

Mathematically, it is given by:

$$\Delta \cdot \vec{V} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}$$

Where u, v, w are velocity components in x, y, z directions.

KEY POINT:

- Divergence of velocity represents the rate of expansion or compression of fluid at a point in the flow field.
- For incompressible flow, divergence of velocity = 0.

Q.14

Sol. The main components of a vapour compression refrigeration system (VCRS) are:

1. Compressor
2. Condenser
3. Expansion device (Capillary tube / Expansion valve)
4. Evaporator

Q.15

Sol. • Azeotropic refrigerant is a mixture of two or more refrigerants that behaves like a single substance and boils/condenses at a constant temperature without change in composition.

Example: R-502

- Zeotropic refrigerant is a mixture of refrigerants that boils/condenses over a range of temperatures and its composition changes during phase change.

Example: R-404A, R-407C

Q.16

Sol. **Control Mass (Closed System):**

A control mass is a fixed quantity of matter in which no mass crosses the system boundary, though energy (heat or work) may cross the boundary.

Control Volume (Open System):

A control volume is a fixed region in space through which both mass and energy can cross the system boundary.

Example:

- **Control Mass:** Gas in a sealed piston-cylinder
- **Control Volume:** Turbine, pump, compressor



Q.17

Sol. Intensive Properties:

These properties are independent of the mass of the system.

Examples: Temperature (T), Pressure (P), Density (ρ)

Extensive Properties:

These properties depend on the mass of the system.

Examples: Mass (m), Volume (V), Internal Energy (U)

Note: Extensive properties per unit mass become intensive properties.

Q.18

Sol. The dead state is the condition at which a system is in complete thermodynamic equilibrium with its surroundings, and hence no useful work can be obtained from the system.

Key Point:

At the dead state, the system has zero availability (exergy = 0) since $T = T_0$, $P = P_0$, and chemical equilibrium exists with surroundings.

Q.19

Sol. A binary vapour power cycle is preferred for low-temperature heat sources because it uses a secondary working fluid with a low boiling point, which can efficiently utilize low-grade heat that cannot be effectively used in a conventional steam Rankine cycle.

Key Point:

This improves overall thermal efficiency and energy recovery from sources like geothermal or waste heat.

Q.20

Sol. Kinematic viscosity is defined as the ratio of dynamic viscosity to density of the fluid.

$$\nu = \frac{\mu}{\rho}$$

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Key point:

Unit: m^2/s

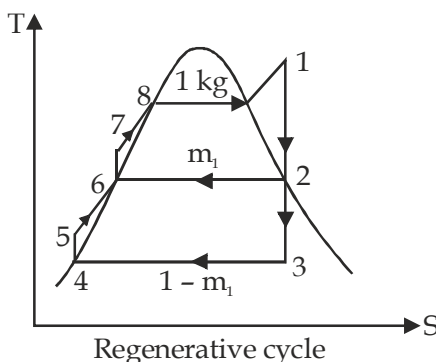
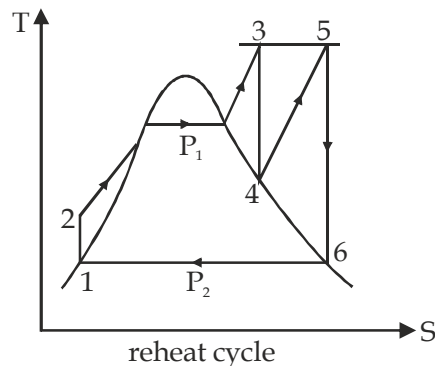
Meaning: It represents the resistance to flow under gravity.

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5 Marks

Q.21

Sol.



Significance of Reheat: The reheat cycle has been developed to take advantage of the increased efficiency with higher pressure but the chief advantage is in decreasing to a safe value the mixture content in the low-pressure stages of the turbine.



Significance of Regenerative cycle:

- Average temperature of heat addition is increased.
- Heating process in the boiler tends to become reversible.
- less amount of steam is passed through the low pressure stages so blade height will be less resulting in low cost of L.P. turbine.

Q.22

Sol. (1) Basic Assumptions (Prandtl Boundary Layer Theory)

For steady, 2-D, incompressible, laminar flow over a flat plate:

- Flow is steady, two-dimensional
- Fluid is incompressible and Newtonian
- Boundary layer thickness is very small compared to plate length ($\delta \ll L$)
- Velocity component $u \gg v$
- Pressure across boundary layer is constant and equal to free stream pressure.

(2) Governing Equations (from Navier-Stokes)

(a) Continuity equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

(b) x-momentum equation:

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \frac{\partial^2 u}{\partial y^2}$$

(c) y-momentum equation:

$$\frac{\partial p}{\partial y} = 0$$

Since pressure in boundary layer equals free stream pressure and for a flat plate:

$$\frac{dp}{dx} = 0$$

So the boundary layer equation becomes:

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \nu \frac{\partial^2 u}{\partial y^2}$$

(3) Boundary Conditions

At plate surface ($y = 0$):

$$u = 0, v = 0$$

At edge of boundary layer ($y \rightarrow \infty$):

$$u = U_{\infty}$$

(4) Blasius Solution (Similarity Solution)

Blasius solved this equation by introducing a similarity variable:

$$\eta = y \sqrt{\frac{U_{\infty}}{\nu x}}$$

He introduced a stream function:

$$\psi = \sqrt{\nu U_{\infty} x} f(\eta)$$

Which reduces PDE into ODE:

$$f''' + \frac{1}{2} f f'' = 0$$



With boundary conditions:

$$f(0) = 0, \quad f'(0) = 0, \quad f'(\infty) = 1$$

Key Point:

(5) Important Results from Blasius Solution (Very Important for Exams)

1. Boundary layer thickness:

$$\delta = \frac{5x}{\sqrt{Re_x}}$$

2. Wall shear stress:

$$T_w = 0.332\rho U_\infty^2 \frac{1}{\sqrt{Re_x}}$$

3. Local skin friction coefficient:

$$C_f = \frac{0.664}{\sqrt{Re_x}}$$

4. Average skin friction coefficient:

$$C_f = \frac{1.328}{\sqrt{Re_L}}$$

Q.23

Sol. Radiation properties (for a surface):

1. Absorptivity (α)

Fraction of incident radiation absorbed by the surface.

$$\alpha = \frac{E_{abs}}{E_{inc}}$$

2. Reflectivity (ρ)

Fraction of incident radiation reflected by the surface.

$$\rho = \frac{E_{ref}}{E_{inc}}$$

3. Transmissivity (T)

Fraction of incident radiation transmitted through the material.

$$T = \frac{E_{trans}}{E_{inc}}$$

4. Emissivity (ε)

Ratio of radiation emitted by a real surface to that emitted by a black body at the same temperature.

$$\varepsilon = \frac{E}{E_b}$$

Proof of $\alpha + \rho + T = 1$

Let incident radiation on a surface be E_{inc} .

It gets split into three parts:

- absorbed: E_{abs}
- reflected: E_{ref}
- transmitted: E_{trans}

Energy conservation gives:

$$E_{inc} = E_{abs} + E_{ref} + E_{trans}$$



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Divide by E_{inc} :

$$1 = \frac{E_{abs}}{E_{inc}} + \frac{E_{ref}}{E_{inc}} + \frac{E_{trans}}{E_{inc}}$$

Using definitions:

$$1 = \alpha + \rho + T$$

Hence proved.

Key Point:

Special Cases (1-line add-on, very scoring)

- Opaque surface: $T = 0 \Rightarrow \alpha + \rho = 1$
- Black body: $\alpha = 1, \rho = 0, T = 0$
- Perfect reflector: $\rho = 1, \alpha = 0, T = 0$

Q.24

Sol. (1) Sensible Heat and Latent Heat (One line revision)

- Sensible heat $\rightarrow$ Heat which changes temperature
- Latent heat $\rightarrow$ Heat which changes moisture content (humidity)

In air-conditioning, total heat load = Sensible + Latent

(2) Room Sensible Heat Factor (RSHF)

Definition:

$$RSHF = \frac{\text{Room Sensible Heat (RSH)}}{\text{Room Sensible Heat (RSH) + Room Latent Heat (RLH)}}$$

Meaning:

RSHF is the ratio of sensible heat to total room heat load.

Physical significance:

- Shows the nature of room load:
 - $RSHF \approx 1 \rightarrow$ Mostly sensible load (dry areas)
 - $RSHF$ small $\rightarrow$ More latent load (humid areas, halls, kitchens)

(3) Effective Room Sensible Heat Factor (ERSHF)

Definition:

$$ERSHF = \frac{\text{Room Sensible Heat}}{\text{Room Sensible Heat + Room Latent Heat + Bypass/system heat effects}}$$

Meaning:

ERSHF is the corrected RSHF which includes the effect of air leakage, coil bypass factor and system losses.

Why it is used:

- Actual air supplied does not behave ideally
- So ERSHF is used instead of RSHF for accurate apparatus (cooling coil) selection

(4) Grand Sensible Heat Factor (GSHF)

Definition:

$$GSHF = \frac{\text{Total Sensible Heat (Room + System)}}{\text{Total Heat (Room + System Sensible + Latent)}}$$

Meaning:

GSHF considers:

- Room sensible heat
- Room latent heat
- System sensible heat (fan heat, duct heat, motor heat, etc.)

So, GSHF represents the overall heat factor of the complete A/C system.

Importance of RSHF, ERSHF and GSHF

1. Used to plot condition lines on psychrometric chart
2. Used for selection of cooling coil/apparatus
3. Help in deciding:
 - Amount of dehumidification required
 - Cooling capacity of the system
4. Used in proper design of year-round air-conditioning system
5. Help to determine supply air condition

Comparison in One Look

Factor	Considers	Used for
RSHF	Only room load	Basic room analysis
ERSHF	Room load + system effects	Actual apparatus selection
GSHF	Room + system total load	Overall system design

Q.25

Sol.

1. Introduction

Internal combustion engines emit harmful pollutants due to incomplete combustion and high temperature reactions. These emissions cause air pollution, health hazards and global warming, hence emission control is necessary.

2. Major Engine Pollutants and Their Formation

(a) Carbon Monoxide (CO)

- Formed due to incomplete combustion of fuel.
- Occurs mainly in rich air-fuel mixtures.

(b) Unburnt Hydrocarbons (HC)

- Caused due to misfiring, flame quenching near walls and crevice volumes.
- More in S.I. engines.

(c) Oxides of Nitrogen (NO_x)

- Formed at high combustion temperature (>1800 K) due to reaction of N₂ and O₂ in air.
- More in high compression and high load conditions.

(d) Particulate Matter (PM/Smoke)

- Found mainly in C.I. engines due to incomplete combustion of fuel droplets.

3. Methods of Emission Control

(A) In-Cylinder Control Methods

1. Proper air-fuel ratio control
2. Improved fuel injection system
3. Better combustion chamber design
4. Exhaust Gas Recirculation (EGR) → reduces NO_x by lowering combustion temperature

(B) Exhaust After-Treatment Methods

1. Catalytic Converter (S.I. engines)

- Converts:

- CO → CO₂
- HC → CO₂ + H₂O
- NO_x → N₂ + O₂

2. Diesel Particulate Filter (DPF)

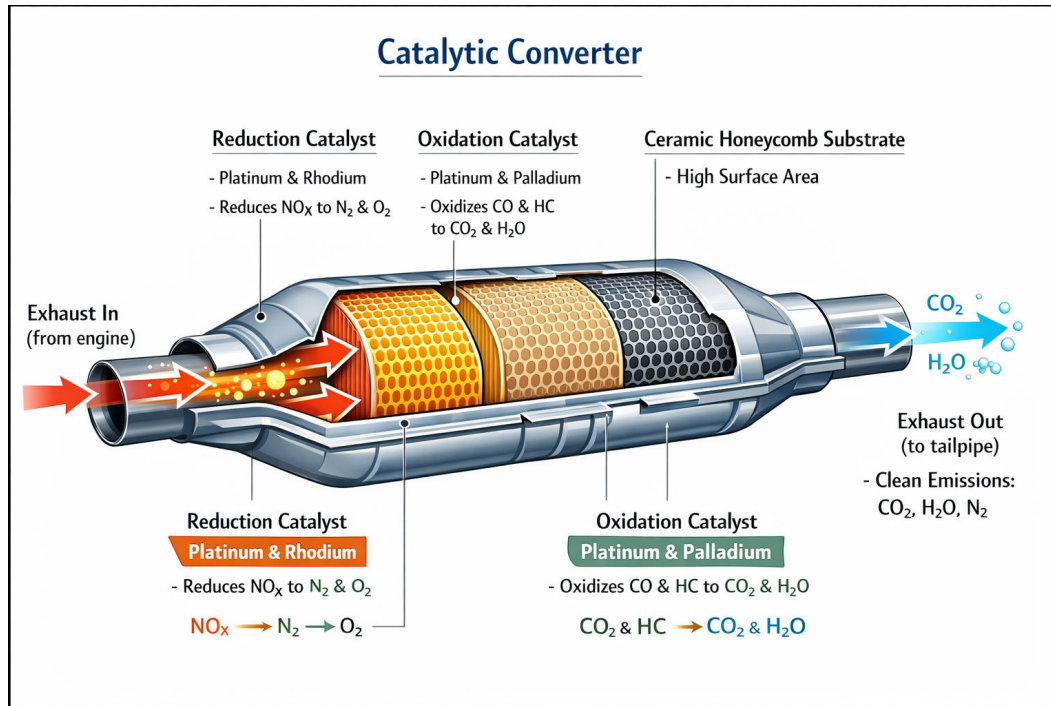
- Traps soot and smoke particles in diesel engines.

3. Selective Catalytic Reduction (SCR)

- Uses urea injection to convert NO_x into N₂ and H₂O.

4. Conclusion

By using proper combustion control and exhaust treatment devices, harmful emissions from I.C. engines can be effectively reduced to meet pollution norms.



Q.26

Sol. No. of atoms in 235 gm $\text{U}_{235} = 6.02 \times 10^{23}$
 Given; Power output = $5 \times 10^6 \text{ W}$
 $\therefore$ Power produced = $\frac{5 \times 10^6}{0.3} \text{ W} = 16.67 \times 10^6 \text{ W}$
 or Power produce = $16.67 \times 10^6 \times 6.241 \times 10^{12} = 1.04 \times 10^{20} \text{ MeV}$
 No. of atoms required to produce this much of energy

$$N = \frac{1.04 \times 10^{20}}{190} \text{ MeV} = 5.47 \times 10^{17}$$

$$\text{Mass of } \text{U}^{235} \text{ required} = \frac{5.47 \times 10^{17}}{6.02 \times 10^{23}} \times 235 = 213.53 \times 10^{-6} \text{ gm}$$

Q.27

Sol. Given: $H_m = 16 \text{ m}$, $D_2 = 400 \text{ mm}$, $D_1 = 200 \text{ mm}$
 For the minimum speed for starting the pump, condition is

$$\frac{u_2^2}{2g} - \frac{u_1^2}{2g} \geq H_m$$

$$\therefore u_2 = \frac{\pi D_2 N}{60}, \quad u_1 = \frac{\pi D_1 N}{60}$$

$$\therefore D_2 = 2D_1, \quad \therefore u_2 = 2u_1$$

$$\therefore \frac{(2u_1)^2}{2g} - \frac{u_1^2}{2g} \geq H_m$$

$$\Rightarrow \frac{3u_1^2}{2g} \geq H_m$$

$$\frac{3u_1^2}{2 \times 9.81} \geq 16$$

$$u_1 \geq 10.229$$

$$\therefore \frac{\pi D_1 N}{60} \geq 10.229$$

$$\therefore \frac{\pi \times 0.2 \times N}{60} \geq 10.229$$

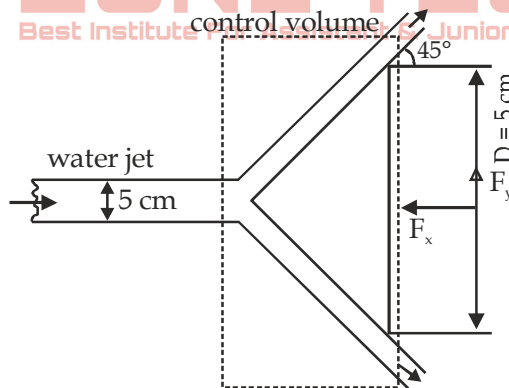
$$\therefore N \geq 976.83 \text{ rpm}$$

Minimum speed to start the pump is 976.83 rpm

Q.28

Sol. **Assumptions:**

- (i) Flow is steady and incompressible.
- (ii) Atmospheric pressure over the cone and jet
- (iii) Gravitational effects are neglected
- (iv) Jet flow is uniform and thus the momentum flux correction factor can be taken as unity.



$$m = \rho V = \rho A v = 100 \times \frac{\pi}{4} \times 0.05^2 \times 30 = 58.90 \text{ kg / s}$$

Momentum equation for steady flow

$$\sum \vec{F} = mV_2 \cos \theta - mV_1 = mv(\cos \theta - 1)$$

$$F_y = 0 \text{ because of symmetry about 'x' axis:}$$

$$F_x = 58.90 \times 30 (\cos 45^\circ - 1) = -517.59 \text{ N}$$

Here negative sign indicates that a force of 517.59 N must be applied to the cone in the opposite direction of the flow to hold it in place.

Q.29

Sol. Given: COP = 0.1; Volume = $0.35 \times 10^{-3} \text{ m}^3$; $\Delta T = 20 - 4 = 16^\circ\text{C}$;
 $t = 30 \text{ minutes}$; $p = 1000 \text{ kg/m}^3$; $c_p = 4.18 \text{ kJ/kg-K}$

$$\text{Refrigeration capacity} = \frac{mc_p \Delta T}{t} = \frac{10^3 \times 0.35 \times 10^{-3} \times 4.18 \times 16}{30 \times 60} = 0.013 \text{ kW}$$

$$\text{COP} = \frac{\text{Refrigeration capacity}}{\text{Power input}}$$

$$\text{Power input} = \frac{0.013}{0.1} = 0.13 \text{ kW}$$

Q.30

Sol. Given:

- Isentropic enthalpy drop, $\Delta h_{is} = 1200 \text{ kJ/kg}$
- Sum of actual enthalpy drops in reheat stages, $\Sigma \Delta h_{\text{actual}} = 1320 \text{ kJ/kg}$

Formula (Reheat Factor):

$$\text{Reheat Factor (RF)} = \frac{\Sigma \Delta h_{\text{actual}}}{\Delta h_{is}}$$

Substitute values:

$$\text{RF} = \frac{1320}{1200} = 1.10$$

Physical significance of reheat factor (RF) in the performance of a turbine

- It indicates the increase in total heat drop due to reheating during expansion.
- It increase the work output of a multistage turbine.
- Typical value: Reheat Factor = 1.03 to 1.05

Q.31

Sol. Brayton (gas turbine) cycle performance can be improved by the following modifications:

(1) Intercooling (during compression):

What it is: Compression is done in two stages, and air is cooled in between using an intercooler.

Effect:

- Intercooling reduces compressor work (because cooler air needs less work to compress).
- Hence net work output increases.

Note: If used alone, it can reduce thermal efficiency because more heat is required in the combustor to reach the same T_{max} .

(2) Reheating (during expansion):

What it is: Expansion is done in two turbine stages, and heat is added between them in a reheater/ combustor.

Effect:

- Reheating increases turbine work (because expansion happens with higher average temperature).
- Hence net work output increases.

Note: If used alone, it generally reduces thermal efficiency because extra heat is supplied.

(3) Regeneration (heat recovery):

What it is: A regenerator (heat exchanger) transfers heat from hot turbine exhaust to the compressed air before combustion.

Effect:

- Heat added in combustor decreases (fuel saving).
- Hence thermal efficiency increases.

Best condition: Regeneration is effective when

$$T_{\text{turbine exhaust}} > T_{\text{compressor outlet}}$$



Q.32

Sol. Given: Flow through a straight circular pipe of Length L , diameter D , mean velocity V , density ρ

Derivation

Consider steady incompressible flow through a pipe. Head loss due to friction = h_f

Using force balance on a length L of pipe:

(1) Pressure force causing flow

$$\Delta p \cdot A$$

where $A = \frac{\pi D^2}{4}$

(2) Friction resisting force at pipe wall

Shear force:

$$\tau_0 \times (\text{wetted area}) = \tau_0 (\pi DL)$$

Equating pressure force to friction force:

$$\Delta p \cdot \frac{\pi D^2}{4} = \tau_0 (\pi DL)$$

$$\Delta p = \frac{4\tau_0 L}{D}$$

Convert pressure drop into head loss:

$$h_f = \frac{\Delta p}{\rho g} = \frac{4\tau_0 L}{\rho g D}$$

Now define Darcy friction factor f as:

$$\tau_0 = \frac{f}{8} \rho V^2$$

Substitute in h_f :

$$h_f = \frac{4L}{\rho g D} \left(\frac{f}{8} \rho V^2 \right)$$

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

This is the Darcy-Weisbach equation.

Meaning of Terms

- h_f = head loss due to friction (m)
- f = Darcy friction factor (dimensionless)
- L = length of pipe (m)
- D = diameter of pipe (m)
- V = mean velocity (m/s)
- g = acceleration due to gravity (m/s²)

Key point:

Factors Affecting Friction Loss

From $h_f = f \frac{L}{D} \frac{V^2}{2g}$ friction loss increases with:

1. Pipe length L (directly proportional)
2. Velocity V (proportional to V^2)
3. Smaller diameter D (inversely proportional)
4. Higher friction factor f (depends on Reynolds number and pipe roughness)



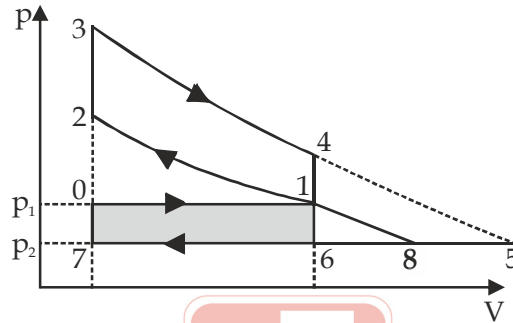
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Q.33

Sol. Supercharging: The power output of an engine depends upon the amount of air inducted per unit time, the degree of utilization of this air and the thermal efficiency of the engine. The amount of air inducted per unit time can be increased by increasing the density of air at intake. The method of increasing inlet air density, called supercharging, is usually employed to increase the power output of engine.



Above figure shows p-V diagram for an ideal Otto cycle super charged engine.

P_1 : Supercharging pressure

P_5 : Exhaust pressure

Processes:

- (i) 0-1-Admission of air at supercharging pressure (which is greater than atmospheric pressure)
- (ii) 1-2-Isentropic compression
- (iii) 2-3- Heat addition at constant volume.
- (iv) 3-4-Isentropic expansion

4-1-6-Heat rejection at constant volume

(blowdown to atmospheric pressure)

6-7-Driving out exhaust at constant atmospheric pressure

For supercharger

- (i) 7-6-8-Admission of air at atmospheric pressure
- (ii) 8-1-Isentropic compression to pressure p_1 .
- (iii) 1-0-Delivery of supercharged air at a constant pressure p_1 .

The pressure p_1 represents the super charging pressure and p_5 is exhaust pressure. Area 8-6-7-01-8 represents the work done by the supercharger in supplying air at a pressure p_1 while area 1-2-3-4-1 is the output of the engine. Area 0-1-6-7-0 represents gain in work during the gas exchange process due to supercharging. This a part of supercharger work is recovered. However the area 1-6-8-1 cannot be recovered represents a loss of work. C.I. engine is more suitable for supercharging. This is because, due to supercharging, there is an increase in pressure and temperature of intake air, which reduces ignition delay and hence reduces knocking in C.I. engines.

Q.34

Sol. Water-Intensive Nature of Ethanol Production: Ethanol production in India is heavily dependent on sugarcane, which requires enormous water resources, exacerbating water stress in already drought-prone regions.

This raises concerns about unsustainable agricultural practices and groundwater depletion, particularly in states like Maharashtra and Uttar Pradesh.

Alternative feedstocks like maize and sorghum are being promoted, but their adoption remains limited due to lower ethanol yields and farmer preferences.

According to NITI Aayog, sugarcane and paddy combined use 70% of irrigation water of the country, posing risks for long-term sustainability of ethanol.

Impact on Food Security and Inflation: As ethanol demand increases, more food grains like rice and maize are diverted for fuel, potentially driving up food prices and affecting food security.

The use of FCI rice and maize for ethanol production may reduce surplus buffer stocks, limiting government capacity to stabilize food prices during shortages.

This raises ethical concerns about using edible grains for energy when malnutrition remains a challenge in India.

FAO 2023 report warned that biofuel expansion could tighten global food supply chains, impacting vulnerable populations.

Limited Ethanol Production Capacity and Supply Chain Bottlenecks: Despite rapid growth, India's ethanol production and distribution infrastructure remain inadequate to meet the 20% blending target by 2025.

Supply chain inefficiencies, including transport challenges and storage constraints, make uniform ethanol availability difficult across all regions.

Many states lack sufficient distilleries and blending facilities, making them dependent on ethanol imports from other states.

Technological and Vehicle Compatibility Challenges: India's vehicle fleet is largely designed for E10 fuel, and transitioning to E20 and beyond requires modifications in engine design and fuel systems.

- Higher ethanol content can cause corrosion and reduced fuel efficiency, leading to long-term maintenance challenges for consumers.
- Automobile manufacturers are working on E20-compatible engines, but existing vehicles may face performance issues unless retrofitted.

Financial Viability and Price Volatility: Ethanol production is subject to price fluctuations due to variable sugarcane and grain output, impacting industry profitability and investment stability.

- Distilleries depend on government-fixed procurement prices, which may not always align with market dynamics, creating uncertainty for investors.
- The energy content of ethanol is lower than that of gasoline, requiring more fuel for the same mileage, which can offset cost benefits for consumers.

Environmental Concerns in Ethanol Production: While ethanol reduces carbon emissions in vehicles, its production process-especially from sugarcane and molasses-leads to high water usage, deforestation, and industrial waste discharge.

- Ethanol distilleries generate large amounts of waste water. This wastewater, known as vinasse, contains high concentrations of organic matter, residual sugars, and other pollutants.
- If not properly treated, it can pose significant environmental risks, including water pollution and depletion of oxygen in aquatic ecosystems.

Heavy Dependence on Government Subsidies: Ethanol production in India is heavily reliant on government incentives, including interest subvention schemes, differential pricing, and tax exemptions.

- Any policy reversal or reduction in financial support could make ethanol production economically unviable for distillers and farmers.
- The Pradhan Mantri JI-VAN Yojana has been extended until 2028-29 to boost second-generation ethanol, but adoption remains slow due to high capital costs.
- Policy fluctuations in ethanol blending targets, such as the shift from 2030 to 2025, create implementation challenges for industry stakeholders.

Q.35

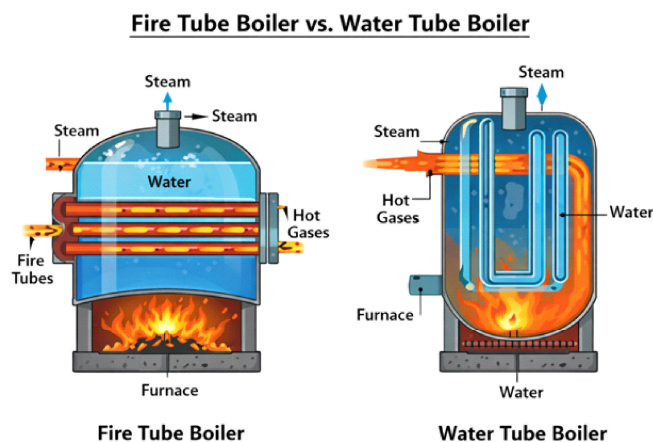
Sol. Differences between fire tube and water tube boilers:

Fire tube and water tube boilers differ fundamentally in their design: in fire tube boilers, hot combustion gases pass through tubes submerged in water, while in water tube boilers, water flows through tubes surrounded by hot gases.

Merits and Demerits:

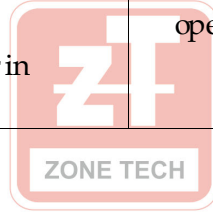
Feature	Fire Tube Boiler	Water Tube Boiler
Operating Principle	Hot gases inside tubes, water outside.	Water inside tubes, hot gases outside.
Operating Pressure	Lower (typically under 2.5 MPa).	Higher (can exceed 2.5 MPa, up to 165+ bar).
Steam Capacity	Lower (usually not exceeding 35 tons/hour).	Higher (can reach 450+ tons/hour).
Efficiency	Lower (approx. 75–85%).	Higher (approx. 85–95%).
Startup Time	Slower (requires longer to heat large water volume).	Faster (less water volume in tubes).
Safety	Higher risk of catastrophic failure due to large water volume.	Lower risk of major explosion; a tube failure is contained.
Applications	Small to medium industrial use, process heating.	Large power plants, high-capacity industrial processes.

Simple Schematic Diagram of fire tube and water tube boiler:



Merits and Demerits of Boilers:

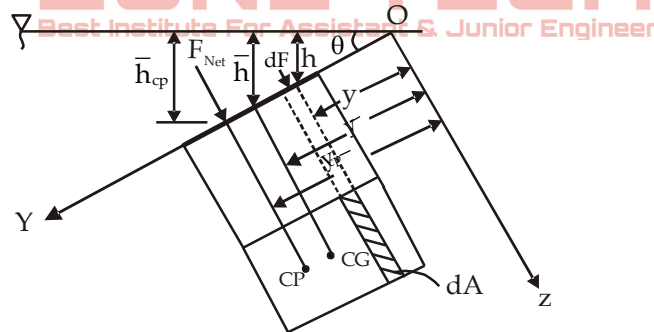
Boiler Type	Merits (Advantages)	Demerits (Disadvantages)
Fire Tube	• Simpler design and construction. • Lower initial and maintenance costs. • Compact size and larger water volume provide good heat retention and handle sudden, short load changes well.	• Lower efficiency and pressure capacity. • Slower steam generation rate and response to sustained load changes. • Requires more floor area for a given output.
Water Tube	• Higher efficiency and can produce very high pressure/temperature steam • Faster steam generation and quicker response to load changes. • Safer due to less water in individual tubes.	• More complex design and higher initial/maintenance costs. • Requires strict water treatment to prevent scaling in small tubes. • Requires more highly skilled operators.



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Q.36

Sol. Pressure force on inclined surface:-



Let us consider a plane surface inclined at an angle θ with the horizontal.

A = Total area of the surface

$\bar{h}$ = Depth of C.G. of inclined area from free surface

h^* or $\bar{h}_{cp}$ = Distance of centre of pressure from free surface of liquid

θ = Angle made by the plane of the surface with free liquid surface

$\bar{y}$ = Distance of C.G. of the inclined surface from O-Z

y^* or $\bar{y}_{cp}$ = Distance of the centre of pressure from O-Z

As we know that

$$P = \rho gh$$

$$dF = PdA$$

$$dF = \rho gh dA$$

Integrate it

$$F = \int \rho gh dA = \rho g \int h dA \quad \left| \because h = y \sin \theta \right.$$

$$= \rho g \int y \sin \theta dA$$

$$F = \rho g \sin \theta \int y dA \quad \left| \because \int y dA = Ay_1 + Ay_2 \dots = A\bar{y} \right.$$

$$F = \rho g \sin \theta \bar{y} A \quad \left| \because \bar{h} = \bar{y} \sin \theta \right.$$

$$F = \rho g \bar{h} A = F_{\text{Net}}$$

Location of Total pressure force:-

Taking moment about O

$$F_{\text{net}} \cdot \bar{y}_{\text{cp}} = \int dF \cdot y$$

$$= \int p dA \cdot y$$

$$= \int \rho gh dA \cdot y$$

$$\rho g \bar{h} A \frac{\bar{h}_{\text{cp}}}{\sin \theta} = \rho g \int y^2 \sin \theta dA \quad \left(\because \bar{y}_{\text{cp}} = \frac{\bar{h}_{\text{cp}}}{\sin \theta} \right)$$

$$\bar{h} A \frac{\bar{h}_{\text{cp}}}{\sin \theta} = \sin \theta \int y^2 dA$$

$$\bar{h}_{\text{cp}} = \frac{\sin^2 \theta}{\bar{h} A} I_{xx}$$

By the theorem of parallel axis, we have

$$I_{xx} = I_{Gxx} + A(\bar{y})^2$$

Where I_{Gxx} = Moment of inertia (M.O.I) of area about an axis passing through the centre of gravity (C.G.) of the area and parallel to the free surface of liquid.

Hence,
$$\bar{h}_{\text{cp}} = \frac{\sin^2 \theta}{\bar{h} A} \left[I_{Gxx} + A(\bar{y})^2 \right]$$

$$\bar{h}_{\text{cp}} = \frac{\sin^2 \theta}{\bar{h} A} \left[I_{Gxx} + A \frac{\bar{h}^2}{\sin^2 \theta} \right] \quad \left(\because \bar{y} = \frac{\bar{h}}{\sin \theta} \right)$$

$$\bar{h}_{\text{cp}} = \frac{I_{Gxx} \times \sin^2 \theta}{\bar{h} A} + \bar{h}$$

As in question asking for force exerted on a sub-merged vertical plane surface i.e. $\theta = 90^\circ$

Hence,

$$\bar{h}_{\text{cp}} = \bar{h} + \frac{I_{Gxx}}{\bar{h} A}$$

Q.37

Sol.

(i) From the definition of entropy,

$$dQ = Tds$$

From the first law of thermodynamics,

$$dW = PdV$$

Therefore,

$$TdS = dU + PdV$$

Or,

$$Tds = du + PdV$$

This is known as the first Tds or, **Gibbs equation**.

The second Tds equation is obtained by eliminating du from the above equation using the definition of enthalpy.

$$h = u + Pv$$

$$dh = du + vdp$$

Therefore,

$$Tds = dh - vdp$$

The two equations can be rearranged as

$$ds = (du/T) + (Pdv/T)$$

$$ds = (dh/T) - (vdp/T)$$

Change of state for an ideal gasIf an ideal gas undergoes a change from P_1, v_1, T_1 to P_2, v_2, T_2 the change in entropy can be calculated by devising a reversible path connecting the two given states.

Let us consider two paths by which a gas can be taken from the initial state, 1 to the final state, 2.

The gas in state 1 is heated at constant pressure till the temperature T_2 is attained and then it is brought reversibly and isothermally to the final pressure P_2 .**Path 1-a:** reversible, constant-pressure process**Path a-2:** reversible, isothermal path

$$\Delta S_{1-a} = \int \frac{dq}{T} = \int C_p \frac{dT}{T} = C_p \ln \left(\frac{T_2}{T_1} \right)$$

$$\Delta S_{a-2} = \int \frac{dq}{T} = \int \frac{(du + pdv)}{T} = \int \frac{(pdv)}{T} = R \ln \left(\frac{v_2}{v_a} \right)$$

(Since $du = 0$ for an isothermal process)

Since

$$P_2 v_2 = P_a v_a = P_1 v_a$$

Or,

$$\frac{v_2}{v_a} = \frac{P_1}{P_2}$$

Or,

$$\Delta S_{a-2} = -R \ln \left(\frac{P_2}{P_1} \right)$$

Therefore,

$$\begin{aligned} Ds &= Ds_{1-a} + Ds_{a-2} \\ &= C_p \ln \left(\frac{T_2}{T_1} \right) - R \ln \left(\frac{P_2}{P_1} \right) \end{aligned}$$

Path 1-b-2: The gas initially in state 1 is heated at constant volume to the final temperature T_2 and then it is reversibly and isothermally changed to the final pressure P_2 .

1-b: reversible, constant volume process

b-2: reversible, isothermal process

$$\Delta S_{1-b} = C_v \ln \left(\frac{T_2}{T_1} \right)$$



$$\Delta S_{b-2} = R \ln \left(\frac{v_2}{v_1} \right)$$

or,

$$\Delta s = C_v \ln \left(\frac{T_2}{T_1} \right) + R \ln \left(\frac{v_2}{v_1} \right)$$

(ii) **Difference between SI Engine and CI Engine:-**

1. The compression ratio for a petrol engine is less. Hence the temperature after compression is much below the self ignition temperature of the fuel. Thus, a spark plug provided for combustion of the fuel in petrol engines.
In diesel engines, the compression ratio is very high. Hence the temperature of air after compression is above the self ignition temperature of the fuel. Due to this reason a spark plug is not necessary for diesel engine.
2. In petrol engines, the air and fuel get mixed in a carburettor before entering the engine cylinder. In diesel engines no mixing takes place between air and fuel before the start of suction stroke. Thus diesel engines do not have a carburettor.
3. For separate entry of fuel at the end of compression stroke, a nozzle (also known as injector) is provided for diesel engines. Petrol engines do not have a nozzle.
4. Heat addition takes place at constant pressure for diesel engines. It takes place at constant volume for petrol engines.
5. For the same compression ratio the efficiency of a petrol engine is higher than that of a diesel engine. But this is theoretical.
6. In actual practice the compression ratio of diesel engine is 1.5 times to 3 times more than that of petrol engine. Hence the efficiency of a diesel engine only is higher than the petrol engine.
7. For a diesel engine $\rightarrow r=16$ to 20
For petrol engine $\rightarrow r=6$ to 10
8. Under cruising condition/speed (Normal speed) the AF ratio for petrol engines is 16 and for diesel engine between 25 to 35.

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