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EXAM PREP

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UPSC

Engineering Services Exam

ESE (Mains) Examination 2021

Mechanical Engineering Paper-I

Question Paper

MECHANICAL ENGINEERING

Paper-I

SECTION-'A'

1(a). What is Laminar sublayer? For the velocity profiles given below, stare whether the boundary layer has separated or separation or will remain attached with the surface:

(i) $\frac{u}{U} = 2\left(\frac{y}{\delta}\right) - \left(\frac{y}{\delta}\right)^2$

(ii) $\frac{u}{U} = -2\left(\frac{y}{\delta}\right) + \left(\frac{y}{\delta}\right)^2$

(iii) $\frac{u}{U} = \frac{3}{2}\left(\frac{y}{\delta}\right)^2 + \frac{1}{2}\left(\frac{y}{\delta}\right)^3$

The symbols have their usual meaning.

(b) A heat engine receives reversibly 420 kJ/cycle of heat from a source at 327°C and rejects heat reversibly to a sink at 27°C. There are no other heat transfers. For each of the three hypothetical amounts of heat rejected in (i), (ii) and (iii) below, compute the cyclic integral of $\oint \frac{dQ}{T}$.

From these results, show which case is irreversible, which is reversible and which is impossible:

(i) 210 kJ/cycle rejected

(ii) 105 kJ/cycle rejected

(iii) 315 kJ/cycle rejected

(c) Deduce an expression for the shape factor of a hemispherical cavity within itself.

(d) What is negative slip in a reciprocating pump?

The suction lift is 4 m, length of suction pipe 6.5 m, diameter of suction pipe 100 mm, diameter of piston 150 mm and length of stroke is 0.45 m. Assume simple harmonic motion, atmospheric pressure head as 10.3 m of water and separation occurs at 2.6 m of water absolute.

Determine the maximum speed at which a double acting reciprocating pump can be operated if fitted with an air vessel on the suction side close to the pump. Darcy's f = 0.024.

(e) Flue gas analysis using Orsat apparatus provides the following data for combustion of an unknown hydrocarbon :

CO_2 = 12.0%

CO = 0.8%

O_2 = 3.1%

N_2 = 84.1%

Determine air-fuel ratio, fuel composition on mass basis, stoichiometric air-fuel ratio and percentage of excess air.

2(a). A four cylinder, four stroke square engine having a bore of 100 mm operating at 4000 rpm has a compression ratio 7.

If the relative efficiency is 60% when the specific fuel consumption is 250 gm/kWh, estimate (i) how many times the spark will trigger in one minute per cylinder, (ii) number of thermodynamic cycles per cylinder per second, (iii) calorific value of the fuel, and (iv) corresponding fuel consumption in kg/hr, given that the mean effective pressure is 8.5 bar.

(b) An infinite slab of thickness "L" (m) is having thermal conductivity "K" $\left(\frac{W}{mK}\right)$. It is generating heat at a uniform rate of "q" $\left(\frac{W}{m^3}\right)$. One of the sides of the slab is perfectly insulated and the other side is maintained at a constant temperature of "T_W" (°C). Deduce an expression for the temperature distribution within the slab. Also find out the position of maximum temperature in the slab.

(c) A solid cylinder of 15 cm diameter and 60 cm length, consists of two parts made of different materials. The first part at base is 1.2 cm long and has specific gravity of 5.0. The other part of the cylinder is made of material having specific gravity of 0.6. Determine whether it can float vertically or not in water.

3.(a) An all glass body air-conditioned bus is having height of 3 m, width of 3 m and length of 10 m. Inside surfaces of the glass are maintained at 20°C. The bus is moving at a speed of 60 kmph. Atmospheric temperature is 34°C. Neglecting the conduction resistance of the glass and assuming walls and roof are perfectly flat, find the following:

(i) Heat gained by the bus from the roof and side walls. (Neglect Laminar Region).

(ii) Capacity of Air Conditioner Unit required in tonnes of refrigeration (TR) to remove the heat gained as given in (i).

(iii) Power required to run the air-conditioning unit if the COP is 4.

Take the properties of the air as given below :

Density = 1.1774 kg/m^3

Kinematic viscosity = 1.569×10^{-5} m^2/s.

Thermal conductivity = $0.02624 \frac{W}{mK}$

Pr = 0.708

For turbulent flow $\overline{Nu_L} = 0.036\ Re_L^{0.8}\ Pr^{0.33}$.

(b) (i) (I) For a given thermodynamic system while considering control volume approach, what is the significance of flow work ? Is flow work a path function or point function ?

(II) With a neat sketch apply steady flow energy equation to a system handling incompressible fluid (like pump) and a system handling compressible fluid flow (like compressor). Draw important inferences from the steady flow energy equations of pump and compressor.

(ii) (I) Show that COP of a heat pump is greater than COP of a refrigerator.

(II) A housewife keeps the door of a refrigerator open in order to beat the heat of summer by closing the door and window of a kitchen. However the cooling effect wears out with the passage of time and she feels uncomfortable with the rise of temperature. Assume the room plaster is well insulated with no heat exchange to the surroundings. How will you evaluate this case in the context of first law of thermodynamics?

(c) A vertical cylindrical rod of 1 m length is maintained at a temperature of 120°C. Diameter of the rod is 5 cm. It is exposed to a very large room having surrounding air and wall temperature at 34°C. It has surface emissivity of 0·7.

Find the following:

(i) Heat lost by the rod by convection.

(ii) Heat lost by the rod by radiation.

(iii) Total heat loss by the rod.

(iv) Percentage of convection and radiation heat loss.

(v) Is it correct to neglect the radiation heat loss for this situation?

Take the property values of air as given below :

Density = 0.998 kg/m^3

Kinematic viscosity = $2.076 \times 10^{-5} m^2/s$

Thermal conductivity = $0.03 \frac{W}{mK}$

Pr = 0.697

Stefan's Constant = $5.67 \times 10^{-8} \frac{W}{m^2K^4}$

Use correction

$\overline{Nu_L} = 0.1[Gr_L \, Pr]^{0.33}$

Neglect heat loss from the ends.

4.(a) A circular pipe of length 500 m and diameter 400 mm is connected with a reservoir at one end and to the atmosphere at the other end. The pipe has rounded entrance (K = 0·15), sudden contraction to 400 mm (K = 0.25), sharp bend (K = 0.18), gate valve full open (K = 8) and sudden expansion to 500 mm pipe. Assuming pipe friction loss coefficient as 0.012, determine discharge for head of 50 m at entrance. K is the head loss coefficient.

(b) In a double pipe, parallel flow heat exchanger, hot fluid enters at 120°C and leaves at 80°C. Cold fluid enters at 20°C and leaves at 50°C. If inlet temperatures, overall heat transfer coefficient and flow rate of the fluids remain same, find the exit temperatures of the fluids if counter flow arrangement is used. Use effectiveness method.

Effectiveness of parallel flow heat exchanger = $\frac{1-e^{[-N(1+C)]}}{1+C}$

Effectiveness of counter flow heat exchanger = $\frac{1-e^{[-N(1-C)]}}{1+Ce^{[-N(1-C)]}}$

Where N = NTU, C = $\frac{C_{min}}{C_{max}}$.

(c) Explain variation in specific heat of gases and its influence on engine performance. Also explain how actual cycle differs from air fuel cycle. Explain exhaust blow-down loss for SI engine.

5(a). A compound parabolic collector, 2 m long (L), has an acceptance angle (2θa) of 30°. The absorber surface of the collector is flat and has a width (b) of 20 cm. Calculate the concentration ratio (C), the aperture width (W), the height (H), and the surface area (A_{con}) of the concentrator.

(b) In the context of engine components, answer the following:

(i) Why are there multiple intake and multiple exhaust valves nowadays in modern engines ? How will you identify inlet valve from exhaust valve through visual inspection?

(ii) Why are pistons made tapered ? How will you identify a piston of a two-stroke engine from the piston of a four-stroke engine through visual inspection assuming same engine capacity?

(c) In an air-conditioning unit, 10 m^3/min of air from atmospheric condition of DBT 40°C and Relative humidity 70 % is adiabatically mixed with 90 m^3/min of recirculation air coming from the air-conditioned chamber. Condition of the recirculation air is DBT 25°C and WBT 20°. Find the Enthalpy, Specific humidity, Relative humidity and WBT of the air after mixing.

Also draw the process in a skeleton Psychrometric chart. [Psychrometric chart is attached.]

(d) With the help of diagram, show the placing of evaporator, superheater, reheater and economiser in the boiler. Also justify the placement at specific location.

(e) Explain the effect of the following on the COP of Vapour Compression refrigeration cycle with suitable P-h diagram:

(i) Subcooling of the liquid in condenser.

(ii) Decrease of Evaporator temperature.

(iii) Wet Compression

6(a). Show that a Pelton turbine with coefficient of velocity C_v and blade friction coefficient K can have a maximum hydraulic efficiency :

$$(\eta_H)_{max} = \frac{1}{2} C_v^2(1 + K\cos\beta')$$

where β' = (180 - blade angle).

A double overhang Pelton wheel unit is coupled to a generator producing 30,000 kW under an effective head of 300 m at the base of the nozzle. Find the size of the jet, mean diameter of runner, synchronous speed and specific speed of each wheel. Assume generator efficiency as 93 %, overall efficiency of turbine as 85 %, coefficient of nozzle velocity as 0.97, speed ratio as 0.46, frequency of generator as 50 cycles per second, pair of poles as 16 and the jet ratio as 12. Also take ρ_{water} = 1000 kg/m^3.

(b) (i) What are the major sources of air leakage in the condenser of a power plant ? Write the effect of pressure of air on the performance of the plant. Also discuss working of air ejector.

(ii) In a typical power plant, steam at 35°C goes to the condenser. Steam flow is 650 T/hr. Moisture in steam at inlet of condenser is 12%. Condenser pressure is maintained at 0.075 bar. Cooling water enters at 23°C and leaves condenser at 33°C. Find rate of cooling water flow and rate of air leak in the condenser. Take the following data at 0.075 bar:

h_f, specific enthalpy of saturated water = 146.7 kJ/kg

h_{fg}, specific enthalpy of conversion from saturated liquid to dry vapour = 2418.6 kJ/kg

v_f, specific volume of saturated water = 0.001006 m^3/kg

v_{fg}, specific volume of conversion from saturated liquid to dry vapour = 25.22 m^3/kg

Specific heat of water = 4.187 k/kg K

R = 0.287 kJ/kg K

(c) What do you understand by biomass gasification ? How are gasifiers classified ? Describe with a schematic diagram the working of a downdraft gasifier.

7(a). What is meant by volumetric efficiency of a reciprocating compressor ? How is it affected by

(i) Speed of the compressor,

(ii) Throttling across valves, and

(iii) Delivery pressure?

It is desired to compress air at 1 bar and 25°C and deliver it at 160 bar using multi-stage compression and intercoolers. The maximum temperature during compression must not exceed 125°C and cooling in the intercooler is done so as not to drop the temperature below 30°C. The law of compression followed is $PV^{1.25}$ = constant for all stages. Calculate:

(i) Number of stages required,

(ii) Work input per kg of air, and

(iii) Heat rejected in the intercoolers.

Take R = 0.287 kJ/kg K

C_v = 0.71 kJ/kg K

(b) Explain why ideal regenerative feed water heating is not used in practice. Derive expression of optimum regeneration to get maximum efficiency with one regenerative feed water heater.

(c) (i) What is the consideration while deciding number of blades for a horizontal axis wind turbine ? State the significance of optimal tip-speed ratio and comment what will happen if the tip-speed ratio is very high or very low.

(ii) A 3-bladed rotor of horizontal axis wind turbine having blade length of 40 m is installed at a location where free wind velocity of 20 m/sec is available. What shall be the ideal rotor speed that can be maintained for optimal energy extraction ?

8(a). Prove that the efficiency corresponding to the maximum work done in a Brayton cycle is given by the relation

$$\eta_{w\,max} = 1 - \frac{1}{\sqrt{t}}$$

where t is the ratio of the maximum and minimum temperatures of the cycle.

An ideal open-cycle gas turbine plant using air operates in an overall pressure ratio of 4 and between temperature limits of 300 K and 1200 K. Assuming the constant value of specific heat C_p = 1 kJ/kg K and C_v = 0.717 kJ/kg K, evaluate the specific work output and thermal efficiency for:

(i) basic cycle with regenerator (heat exchanger), and

(ii) basic cycle with regenerator (heat exchanger) and two-stage intercooled compressor.

Assume optimum stage pressure ratios, perfect intercooling and perfect regeneration.

(b) The velocity of steam entering in a simple impulse turbine is 800 m/s and nozzle angle is 22°. The mean peripheral velocity of blades is 300 m/s and blades are symmetrical. Calculate the following for steam flow of 2 kg/sec:

(i) Blade angles for entry without shock

(ii) Tangential thrust

(iii) Diagram power

(iv) Diagram efficiency

(v) Axial thrust

(c) (i) Why are solar PV panels placed inclined due south in Indian context ? What is the basis of deciding the slope of such solar panels?

(ii) A solar PV panel feeds a dc motor to produce 1 hp of power at shaft output. The motor efficiency is 80 %. Each module has multicrystalline silicon solar cells arranged in 9 × 4 matrix. The cell is 125 mm × 125 mm and cell efficiency is 15 %. Calculate the number of modules requirement in the array. Assume global radiations incident normally to the panel as 1000 W/m^2.

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