B. E. MECHANICAL ENGINEERING FOURTH YEAR SECOND SEMESTER EXAMINATION, 2022

Design of Thermal Systems

Time: Four hours **Full Marks 70**

All parts of the same question must be answered together. Assume any unfurnished data suitably

Use separate answerscript for each part

Part I

Q:1(a) Consider a constrained optimization problem in which a function $f(x_1, x_2, x_3, \dots, x_n)$ is to be minimized subject to m constraints:

$$g_1(x_1, x_2, x_3, \dots, x_n) = 0$$
$$g_2(x_1, x_2, x_3, \dots, x_n) = 0$$
$$\dots$$
$$g_m(x_1, x_2, x_3, \dots, x_n) = 0$$

Here $x_1, x_2, x_3, \dots, x_n$ are the n design variables. Explain how the optimization problem can be solved using Lagrange Multiplier method. What is the significance of Lagrange Multipliers? 8+2

(b) Explain uniform exhaustive search method of optimization. For a heating system, the objective function $U(x)$ is the heat delivered per unit energy consumed. The independent variable x represents the temperature setting and has an initial range of 0 to 8. A maximum in U is desired to operate the system most efficiently. The objective function is given as

$$U(x) = 7 + 17x - 2x^2$$

Obtain the optimum using uniform exhaustive search method. Take 4 intermediate points. 10

OR

Q:1(a) In a system for providing hot water for industrial use, the heating unit has a power input of 150 kW and a thermal efficiency of $100(0.2 + 0.045T^{0.5})$, in percent, where T is the operating temperature in degrees centigrade. The rate of heat loss to the environment, in kW, is represented by the expression $0.12T^{1.25}$. Formulate the optimization problem to maximize the rate of energy supplied to the industry and obtain the optimum by using geometric programming. 15

(b) Explain lattice search method of optimization. 5

Q:2 Consider a hot water tank of volume V. Water at a temperature T_i (varies with time t) is entering the water heater at a mass flow rate $\dot{m}_i$. Water is heated by an electric heater with constant power Q. A stirrer in the tank ensures uniform temperature. The exit flow rate is equal to inlet flow rate and is kept constant and the exit temperature of water is equal to the water temperature in the tank, given by T.

i. Develop a state space model for the dynamics of the process. 4

ii. Convert the state space model into an input-output model in terms of perturbation quantities. 3

iii. Develop a transfer function considering inlet water temperature as input and outlet water temperature as output. 4

iv. Determine the response of the system to unit step function as input perturbation. 4

OR

Q:2. Consider a lumped parameter object of volume V and surface area A heated electrically. The object is losing heat to an ambient at a constant temperature T_a by convection with a constant heat transfer coefficient h. The heater power Q can vary with time.

i. Develop a state space model for the temperature of the object. 4

ii. Convert the state space model into an input-output model in terms of perturbation quantities. 3

iii. Develop a transfer function for the model considering electric heater power Q as input and the temperature of the object T as input. 4

iv. Determine the response of the heater to a step change in the heater power. 4

Part II

Answer question number 3 and any one from Q: 4 – Q:6

Q:3 Answer any four from the following: 20

a) What is the difference between design and analysis? Give suitable example to differentiate.

b) Draw a flowchart to explain design as a part of engineering enterprise.

c) Explain the following terms: Design requirements, operating conditions and constraints.

d) Explain any one method to solve nonlinear algebraic equation.

e) An air conditioning system is to be designed for a residential building. The interior of the building is to be maintained at $22 \pm 5^0 C$. The ambient temperature can go as high as 38^0C. The rate of heat dissipation is 2 kW. The location, geometry and the dimensions are given. Formulate the design problem.

f) A geyser (water heater) is to be designed to supply water during winter. Formulate the design problem.

Q:4 The temperature T of a small copper sphere cooling in air is measured as a function of time t to yield the following data:

t (s)	0.2	0.6	1.0	1.8	2.0	3.0	5.0	6.0	8.0
T (^{0}C)	146.0	129.5	114.8	90.3	85.1	63.0	34.6	25.6	14.1

An exponential decrease in temperature is expected from lumped mass modeling. Obtain a best fit to represent these data. 15

Q:5 There are some vertically mounted fins attached in an electronic circuit board. The heat is transferred to the surrounding air through natural convection. Formulate the problem as two extreme cases(small spacing and large spacing channels). Hence,find the optimum channel spacing between two successive fins for maximum heat transfer. 15

Q:6. The effectiveness ε of a cross-flow heat exchanger is given by the equation:

$$\varepsilon = 1 - \exp\left[\frac{1}{C_r}(N)^{0.22}\left\{\exp\left[-C_r(N)^{0.78}\right]-1\right\}\right]$$

Where N is the number of transfer units and C_r is the ratio of heat capacities of the two fluids. Determine the value of N of the heat exchanger which has an effectiveness of 0.7with C_r=0.8. 15