National Program on Technology Enhanced Learning
IIT MADRAS

Design and Optimization of Energy Systems

Self Assessment Test 2

Duration: 50 min

Max. Marks: 40

1. Make suitable assumptions wherever required with justification
2. Make reasonable assumptions of any missing data

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(1) Consider the cooling of an aluminum plate of dimensions 150 x 150 x 3 (all in mm). The plate loses heat by convection from all its faces to still air. Radiation from the plate can be neglected. The plate can be assumed to be spatially isothermal. The ambient temperature is constant at T_∞=30°C. The temperature time response of the plate, based on experiments is given below.

S.No	Time, t, s	Temperature, T, °C
1	10	98.5
2	40	96.1
3	80	90.2
4	120	85.9
5	180	82.8
6	240	75.1

The temperature excess, $\theta = T-T_\infty$ is known to vary as $\theta / \theta_i = \exp(-t/\tau)$ where θ_i is the initial temperature excess given by (T_i-T_∞) and $\tau = mC_P/hA$, the time constant.

(a) With the data given above, perform a linear least squares regression and obtain estimates of θ_i and τ. Also, determine the correlation coefficient.

(12)

(b) Given C_p= 940 J/kg K and ρ= 2700 kg/m^3 for aluminum, from the results obtained in part (i) determine the heat transfer coefficient (h) for the situation.

(2)

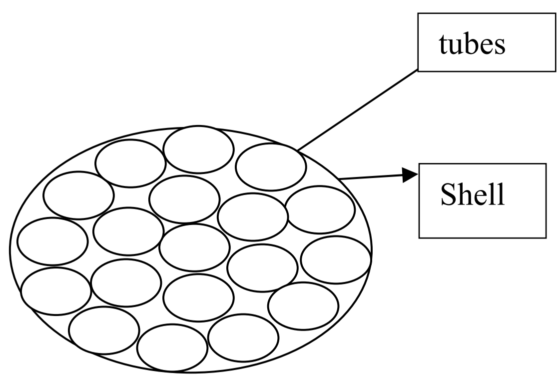
(2) A shell and tube heat exchanger (shown below) is to be designed for minimum total cost. The shell diameter D, the length of the tubes, L (which is also the length of the shell, approximately) and the number of tubes "n" have to be designed to minimize the total cost. The tubes are all 1 inch (d=0.0025 m) in diameter and have a single pass. The cost of the shell (in lakhs of rupees) is given by 50 $D^{1.5}$ $L^{1.25}$. The cost of each tube is 0.4 $L^{0.5}$ again in lakhs.

There are a few constraints in the problem

(a)The total tube surface area needs to be 47 m^2.
(b) The packing density of the tubes (total tube volume/shell volume) shall not exceed 50% to allow for shell side fluid movement.
(c) The length of any tube (all tubes are of same length) shall not exceed 10m for ease of maintenance and replacement (*Note: D and L are in m*)

Set up the optimization problem for minimizing the total cost of the exchanger and solve it as a constrained optimization problem using the Lagrange multiplier method to determine the optimal solution. You may use constraint (b) as an equality to reduce the number of variables (n, D and L) to 2. This way you can solve this as a 2 variable, 1 constraint optimization problem by substituting for one of the variables from either constraint (a) or (b) into the objective function.

Furthermore, you may ignore constraint #(c) and check if it is violated after obtaining the optimum.



(16)

(3) The cost of engines plus fuel for a cargo ship (in lakhs of rupees per year for 100 tons of cargo carried) varies with speed and is given by 0.2 x^2 where x is the speed of the ship in m/s. The fixed costs of hull and crew (again in the same units) are given by 450/x. Using the Golden Section method, determine the operating speed of the ship for minimum total cost. Start with an original interval of uncertainty of $4 \leq x \leq 16$ m/s and carry out evaluations to reduce the final uncertainty to 0.26 m or less. (10)