Name:

Enrolment No:

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES

End Semester Examination, December 2021

Programme Name: B.Tech Mechanical **Semester : V**
Course Name : Heat Transfer **Time : 03 hrs**
Course Code : MECH3008 **Max. Marks : 100**

Instructions:

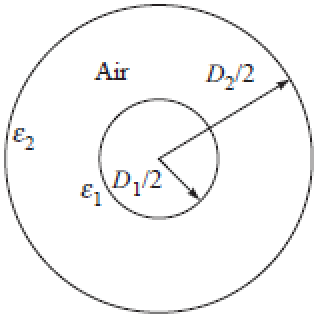
- Section A constitutes of 20 Marks (5 questions x 4 marks); Attempt All.
- Section B constitutes of 40 Marks (4 questions x 10 marks). Attempt All (One choice question).
- Section C constitutes of 40 Marks (2 questions x 20 marks). Attempt All (One choice question).
- Question #8 and Question#10 have options. Please answer only one of the options.

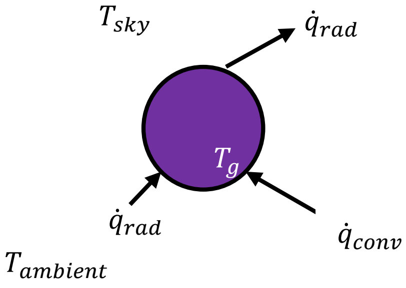
SECTION A

SN		**Marks**	**CO**
Q1	Robert Barker, FRS in a letter to Dr. Brocklesby describes the process of making ice in the East Indies. Published in the *Philosophical Transactions of the Royal Society* (65), pp. 252-257, this 1775 report leaves no iota of doubt about the existence of ice factories in the Pre-British India. At other places in the British archives, there are reports of an ice factory at Prayagraj, Uttar Pradesh. Answer these questions relating to the ingenious Indians who mastered this art without the usage of electricity-consuming refrigerators: 1) What are the different factors that led to this natural technological breakthrough? 2) Can you guess certain weather situations when the ice may not be produced?	**4**	**CO1**
Q 2	If heat transfer is directly proportional to temperature difference, and since it is known that film boiling occurs at a larger temperature difference between fluid and the solid surface, why is it that under some cases, the heat transfer in film boiling may be less than that of Nucleate boiling? Explain.	**4**	**CO1**
Q 3	a) What are rotary enthalpy wheels and how is the heat exchange effected in them? b) Is the heat pipe a biomimetic design? Comment.	**4**	**CO1**
Q 4	A plane wall of thickness 2L, has a volumetric heat source q (W/m^3). It is exposed to local ambient temperature $T\infty$ at both the (x= ±L). Derive an expression for the surface temperature Ts of the wall under steady state condition (where h and e their usual meaning).	**4**	**CO2**
Q5	A large concrete slab 1 m thick has one-dimensional temperature distribution: $$T = 4 - 10x + 20x^2 + 10x^3$$ where T is temperature and x is distance from a face towards other face of wall. If the slab material has thermal diffusivity of 2 x $10^{-3} m^2$/h, what the rate of change of temperature at the other face of the wall?	**4**	**CO3**

SECTION B

Q 6	In the final stages of production, a pharmaceutical is sterilized by heating it from 25 to 75 ⁰C as it moves at 0.2 m/s through a straight thin-walled stainless steel tube of 12.7-mm diameter. A uniform heat flux is maintained by an electric resistance heater wrapped around the outer surface of the tube. If the tube is 10 m long, what is the required heat	**10**	**CO1**

	flux? If fluid enters the tube with a fully developed velocity profile and a uniform temperature profile, what is the surface temperature at the tube exit and at a distance of 0.5 m from the entrance? Fluid properties may be approximated as C_p = 4000 J/kg K, μ = 2x10^3 kg/m-s, ρ = 1000 kg/m^3, k = 0.8 W/mK. OR Cooling water flows through the 25.4-mm-diameter thin-walled tubes of a steam condenser at 1 m/s, and a surface temperature of 350 K is maintained by the condensing steam. The water inlet temperature is 290 K, and the tubes are 5 m long. (a) What is the water outlet temperature? Evaluate water properties at an assumed average mean temperature. Was the assumed value reasonable? Comment. (b) A range of tube lengths from 4 to 7 m is available to the engineer designing this condenser. Generate a **rough** plot to show what coolant mean velocities are possible if the water outlet temperature is to remain at the value found for part (a). All other conditions remain the same.		
Q 7	Two concentric spheres of diameters $D1$ = 0. 5 m and $D2$ = 1 m are separated by an air space as shown in Figure below and have surface temperatures of 400 K and 300 K respectively.  (a) If the surfaces are black, what is the net rate of radiation exchange between the spheres? (b) What is the net rate of radiation exchange between the surfaces if they are diffuse and gray with e1 = 0. 5 and e2 = 0. 5? (c) What error would be introduced by assuming blackbody behaviour for the outer surface (e2 = 1) with all other conditions remaining the same?	**10**	**CO2**
Q 8	 An ice rink is a public skating place typically meant for recreation. A square ice rink of 500 m^2 in surface area has a surface temperature of -3ºC. The ambient air temperature in	**10**	**CO2**

	the rink is 18ºC. Determine the cooling load on the refrigeration system holding the ice rink to its steady state condition. Neglect radiation. Assume that there are no sideboards. Use the properties for air below.		
Q 9	 A grape of diameter ***d*** is heated by a mild breeze of ambient air and by radiation from its near surroundings at the ambient temperature (assume that this is over the grape lower hemisphere and from that surface, the view factor is 1). The grape is cooled by radiation to a cloudless night sky (assume that this is over the grape upper hemisphere and from that surface, the view factor is 1). Assume: The grape temperature is uniform. Known about the grape are the values of k, ρ, c and α. Also known are the convective heat transfer coefficient, h, and the temperatures T_{sky}, and $T_{ambient}$. Develop an equation that gives the grape steady state temperature T_g. Note that T_g should remain as the only undefined term, written in terms of the problem values given herein.	**10**	**CO4**
	SECTION C		
Q 10	Air is forced through a long tube of 0.1 m diameter at a bulk velocity of 6 cm/s. The inlet temperature is 30ºC and the wall temperature is 150ºC. Begin by basing the fluid properties on 30ºC temperature and 2.0 atmospheres pressure. a) After the flow has become fully-developed, hydrodynamically and thermally, and the bulk temperature has reached 100ºC, what is the value of dT_b/dx at this point? Note, T_b is the bulk temperature and x is distance in the streamwise direction. Begin by establishing whether the flow is laminar or turbulent. **Justify your answer.** b) What length of tube from the entrance is needed to establish fully-developed conditions?	**20**	**CO3**
Q 11	Suppose we have air at 1.0 atmosphere pressure on the shell side of a shell and tube heat exchanger (single pass for the fluid on this shell side). On the tube side, which has two passes, we have water entering at 50ºC. The overall heat transfer coefficient, U_0, is 100 W/m^{2}K (U_0, based on the tube outside area). What is the total tube length? The air is flowing at 0.1 kg/sec and is being heated from 10ºC to 40ºC. The water flow rate is 0.1 kg/sec. What is the heat exchanger size, given as A_0, the tube total outside area? **OR** We know this about our heat exchanger: Fluid A: Air at 1.0 atmosphere $\dot{m}$ = 0.1 kg/sec $T_{A,in}$ = 20ºC Fluid B: Water at 1.0 atmosphere pressure $\dot{m}$ = 0.1 kg/sec $T_{A,in}$ = 100ºC	**20**	**CO4**

	The arrangement is cross-flow, both fluids are unmixed, U_0A_0 for the exchanger is 400 W/K. What are the exit temperatures [ºC]? Assume constant properties taken at the respective inlet temperatures of each of the two fluids.		

Appendix

Heat exchanger type	*Effectiveness relation*
1 *Double pipe:*	
Parallel flow	$\varepsilon = \dfrac{1-\exp[-\mathrm{NTU}(1+C)]}{1+C}$
Counterflow	$\varepsilon = \dfrac{1-\exp[-\mathrm{NTU}(1-C)]}{1-C\exp[-\mathrm{NTU}(1-C)]}$
2 *Shell and tube:* One-shall pass 2, 4,... tube passes	$\varepsilon = 2\left\{1+C+\sqrt{1+C^2}\,\dfrac{1+\exp[-\mathrm{NTU}\sqrt{1+C^2}]}{1-C\exp[-\mathrm{NTU}\sqrt{1+C^2}]}\right\}^{-1}$
3 *Cross-flow:* (*single-pass*)	
Both fluids unmixed	$\varepsilon = 1-\exp\left\{\dfrac{\mathrm{NTU}^{0.22}}{C}[\exp(-C\,\mathrm{NTU}^{0.78})-1]\right\}$
$C_{\max}$ mixed, $C_{\min}$ unmixed	$\varepsilon = \dfrac{1}{C}(1-\exp\{1-C[1-\exp(-\mathrm{NTU})]\})$
$C_{\min}$ mixed, $C_{\max}$ unmixed	$\varepsilon = 1-\exp\left\{-\dfrac{1}{C}[1-\exp(-C\,\mathrm{NTU})]\right\}$
4 All heat exchangers with $C = 0$	$\varepsilon = 1-\exp(-\mathrm{NTU})$

Heat exchanger type	NTU *relation*
1 *Double pipe:*	
Parallel flow	$\mathrm{NTU} = -\dfrac{\ln[1-\varepsilon(1+C)]}{1+C}$
Counterflow	$\mathrm{NTU} = \dfrac{1}{C-1}\ln\left(\dfrac{\varepsilon-1}{\varepsilon C-1}\right)$
2 *Shell and tube:* One-shall pass 2, 4,... tube passes	$\mathrm{NTU} = -\dfrac{1}{\sqrt{1+C^2}}\ln\left(\dfrac{2/\varepsilon-1-C-\sqrt{1+C^2}}{2/\varepsilon-1-C+\sqrt{1+C^2}}\right)$
3 *Cross-flow:* (*single-pass*)	
$C_{\max}$ mixed, $C_{\min}$ unmixed	$\mathrm{NTU} = -\ln\left[1+\dfrac{\ln(1-\varepsilon C)}{C}\right]$
$C_{\min}$ mixed, $C_{\max}$ unmixed	$\mathrm{NTU} = -\dfrac{\ln(C\ln(1-\varepsilon)+1)}{C}$
4 All heat exchangers with $C = 0$	$\mathrm{NTU} = -\ln(1-\varepsilon)$

Other fluid properties may be provided during the exam or assume approximate values.