UNIVERSITY OF JOHANESSBURG

Final Exam: May 2019

VENUE: TBD

UNIVERSITY OF JOHANNESBURG

Rethink Education. Reinvent Yourself

COURSE, SUBJECT AND CODE: HEAT TRANSFER WAO 4A11

EXAMINER: JEN, TIEN-CHIEN

MODERATOR: Naeema Kharsany

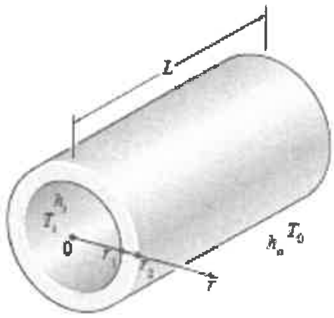
DURATION: 3.0 hours **MARKS:** 100

INSTRUCTION: ATTEMPT ALL QUESTIONS

DEPARTMENT OF MECHANICAL ENGINEERING SCIENCE

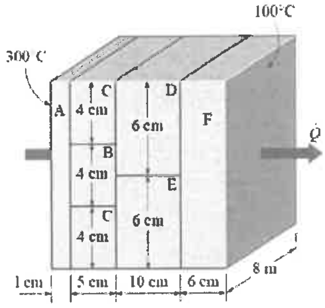
Question 1: (20 Marks)

Consider a steam pipe of length *L,* inner radius r_1, outer radius r_2, and constant thermal conductivity *k.* Steam flows inside the pipe at an average temperature of T_i with a convection heat transfer coefficient of h_i. The outer surface of the pipe is exposed to convection to the surrounding air at a temperature of T_0 with a heat transfer coefficient of h_o. Assuming steady one-dimensional heat conduction through the pipe, (*a*) express the differential equation and the boundary conditions for heat conduction through the pipe material, (*b*) obtain a relation for the variation of temperature in the pipe material by solving the differential equation, and (*c*) obtain a relation for the temperature of the outer surface of the pipe.



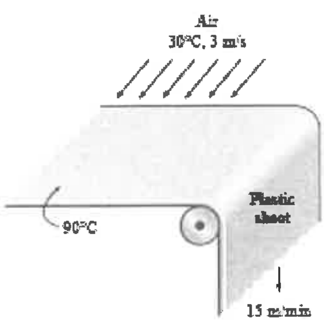
Question 2: (20 Marks)

A Consider a 5-m-high, 8-m-long, and 0.22-m-thick wall whose representative cross section is as given in the figure. The thermal conductivities of various materials used, in W/m°C, are $k_A = k_F = 2$, $k_B = 8$, $k_C = 20$, $k_D = 15$, and $k_E = 35$. The left and right surfaces of the wall are maintained at uniform temperatures of 300°C and 100°C, respectively. Assuming heat transfer through the wall to be one-dimensional, determine (*a*) the rate of heat transfer through the wall; (*b*) the temperature at the point where the sections *B*, *D*, and *E* meet; and (*c*) the temperature drop across the section *F*. Disregard any contact resistances at the interfaces.



Question 3: (15 Marks)

The forming section of a plastics plant puts out a continuous sheet of plastic that is 1.2 m wide and 2 mm thick at a rate of 15 m/min. The temperature of the plastic sheet is 90°C when it is exposed to the surrounding air, and the sheet is subjected to air flow at 30°C at a velocity of 3 m/s on both sides along its surfaces normal to the direction of motion of the sheet. The width of the air cooling section is such that a fixed point on the plastic sheet passes through that section in 2 s. Determine the rate of heat transfer from the plastic sheet to the air.



Question 4: (15 Marks)

A gray opaque surface at 600 K has an emittance of 0.45 and is exposed to a high-temperature heat source such that the irradiation on the surface is 50,000 W/m^2. Calculate the following heat fluxes:

(i) Absorbed flux
(ii) Reflected flux
(iii) Emitted flux
(iv) The radiosity

Table A.5 Thermophysical Properties of Saturated Fluids[a]

Saturated Liquids

T (K)	ρ (kg/m^3)	c_p (kJ/kg · K)	$\mu \cdot 10^2$ (N · s/m^2)	$\nu \cdot 10^6$ (m^2/s)	$k \cdot 10^3$ (W/m · K)	$\alpha \cdot 10^7$ (m^2/s)	Pr	$\beta \cdot 10^3$ (K^{-1})
Engine Oil (Unused)								
273	899.1	1.796	385	4280	147	0.910	47,000	0.70
280	895.3	1.827	217	2430	144	0.880	27,500	0.70
290	890.0	1.868	99.9	1120	145	0.872	12,900	0.70
300	884.1	1.909	48.6	550	145	0.859	6400	0.70
310	877.9	1.951	25.3	288	145	0.847	3400	0.70
320	871.8	1.993	14.1	161	143	0.823	1965	0.70
330	865.8	2.035	8.36	96.6	141	0.800	1205	0.70
340	859.9	2.076	5.31	61.7	139	0.779	793	0.70
350	853.9	2.118	3.56	41.7	138	0.763	546	0.70
360	847.8	2.161	2.52	29.7	138	0.753	395	0.70
370	841.8	2.206	1.86	22.0	137	0.738	300	0.70
380	836.0	2.250	1.41	16.9	136	0.723	233	0.70
390	830.6	2.294	1.10	13.3	135	0.709	187	0.70
400	825.1	2.337	0.874	10.6	134	0.695	152	0.70
410	818.9	2.381	0.698	8.52	133	0.682	125	0.70
420	812.1	2.427	0.564	6.94	133	0.675	103	0.70
430	806.5	2.471	0.470	5.83	132	0.662	88	0.70
Ethylene Glycol [$C_2H_4(OH)_2$]								
273	1130.8	2.294	6.51	57.6	242	0.933	617	0.65
280	1125.8	2.323	4.20	37.3	244	0.933	400	0.65
290	1118.8	2.368	2.47	22.1	248	0.936	236	0.65
300	1114.4	2.415	1.57	14.1	252	0.939	151	0.65
310	1103.7	2.460	1.07	9.65	255	0.939	103	0.65
320	1096.2	2.505	0.757	6.91	258	0.940	73.5	0.65
330	1089.5	2.549	0.561	5.15	260	0.936	55.0	0.65
340	1083.8	2.592	0.431	3.98	261	0.929	42.8	0.65
350	1079.0	2.637	0.342	3.17	261	0.917	34.6	0.65
360	1074.0	2.682	0.278	2.59	261	0.906	28.6	0.65
370	1066.7	2.728	0.228	2.14	262	0.900	23.7	0.65
373	1058.5	2.742	0.215	2.03	263	0.906	22.4	0.65
Glycerin [$C_3H_5(OH)_3$]								
273	1276.0	2.261	1060	8310	282	0.977	85,000	0.47
280	1271.9	2.298	534	4200	284	0.972	43,200	0.47
290	1265.8	2.367	185	1460	286	0.955	15,300	0.48
300	1259.9	2.427	79.9	634	286	0.935	6780	0.48
310	1253.9	2.490	35.2	281	286	0.916	3060	0.49
320	1247.2	2.564	21.0	168	287	0.897	1870	0.50

Table 4.10 The correlations contained in CONV. Evaluate all properties at the mean film temperature unless otherwise specified. All the heat transfer correlations are for isothermal walls. However, (1) item 1 can also be used for a uniform wall heat flux, and (2) values of $\overline{Nu}$ for external flows can also be used for a uniform wall heat flux, provided Eq. (4.82) is used to define the average heat transfer coefficient.

Item No	Configuration	Correlations		Comments
1	Turbulent flow in smooth ducts with fully developed hydrodynamics and heat transfer	$f = (0.790 \ln Re_{D_h} - 1.64)^{-2}; \quad 10^4 < Re_{D_h} < 5 \times 10^6$	(4.42)	$D_h = \frac{4A_c}{\mathscr{P}}$ (= D for a circular tube) Exponents for property and temperature ratio corrections for duct flows (subscripts s and b refer to wall and bulk values, respectively): see below
		$Nu_{D_h} = \frac{(f/8)(Re_{D_h} - 1000)Pr}{1 + 12.7(f/8)^{1/2}(Pr^{2/3} - 1)}; \quad 3000 < Re_{D_h} < 10^6$, $0.5 < Pr$	(4.45)	
2	Laminar flow in a pipe with fully developed hydrodynamics	$f = \frac{64}{Re_D}; \quad Re_D < 2300$	(4.39)	
		$\overline{Nu}_D = 3.66 + \frac{0.065(D/L)Re_D Pr}{1 + 0.04[(D/L)Re_D Pr]^{2/3}}; \quad Re_D < 2300$	(4.50)	
3	Laminar flow between parallel plates with fully developed hydrodynamics	$f = \frac{96}{Re_{D_h}}; \quad Re_{D_h} < 2800$	(Table 4.5)	$D_h = \frac{4A_c}{\mathscr{P}} = 2 \times$ Plate spacing
		$\overline{Nu}_{D_h} = 7.54 + \frac{0.03(D_h/L)Re_{D_h} Pr}{1 + 0.016[(D_h/L)Re_{D_h} Pr]^{2/3}}; \quad Re_{D_h} < 2800$	(4.51)	
4	Laminar boundary layer on a flat plate	$\overline{C}_f = 1.328 Re_L^{-1/2}; \quad 10^3 < Re_L \leq 5 \times 10^5$	(4.55)	
		$\overline{Nu} = 0.664 Re_L^{1/2} Pr^{1/3}; \quad 10^3 < Re_L \leq 5 \times 10^5, \quad Pr > 0.5$	(4.57)	
5	Turbulent boundary layer on a smooth flat plate	$\overline{C}_f = 1.328 Re_{tr}^{-1/2}\left(\frac{Re_{tr}}{Re_L}\right) + \frac{0.523}{\ln^2 0.06 Re_L} - \left(\frac{Re_{tr}}{Re_L}\right)\frac{0.523}{\ln^2 0.06 Re_{tr}}$ $Re_{tr} < Re_L < 10^9$	(4.62)	$Re_{tr} = 50{,}000 - 500{,}000$. Lower values are characteristic of practical situations where disturbing factors such as roughness and vibration are present
		$\overline{Nu} = 0.664 Re_{tr}^{1/2} Pr^{1/3} + 0.036 Re_L^{0.8} Pr^{0.43}\left[1 - (Re_{tr}/Re_L)^{0.8}\right]$ $Re_{tr} < Re_L < 3 \times 10^7$ $0.7 < Pr < 400$	(4.65)	

Type of Flow	Fluid	Wall Condition	f m	Nu n
Laminar	Liquids (μ_s/μ_b)	Heating	0.58	−0.11
		Cooling	0.50	−0.11
	Gases (T_s/T_b)	Heating	1	0
		Cooling	1	0
Turbulent	Liquids (μ_s/μ_b)	Heating	0.25	−0.25
		Cooling	0.25	−0.11
	Gases (T_s/T_b)	Heating	−0.2	−0.55
		Cooling	−0.1	0.0

(Continued)