National Exams May 2015

04-CHEM-A2, Mechanical and Thermal Operations

3 hours duration

NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. The examination is an OPEN BOOK EXAM.
3. Candidates may use any **non-communicating** scientific calculator.
4. All problems are worth 25 points. **Two problems** from **each** of sections **A** and **B** must be attempted.
5. **Only the first two** questions as they appear in the answer book from each section will be marked.
6. State all assumptions clearly.

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Section A: Mechanical Operations

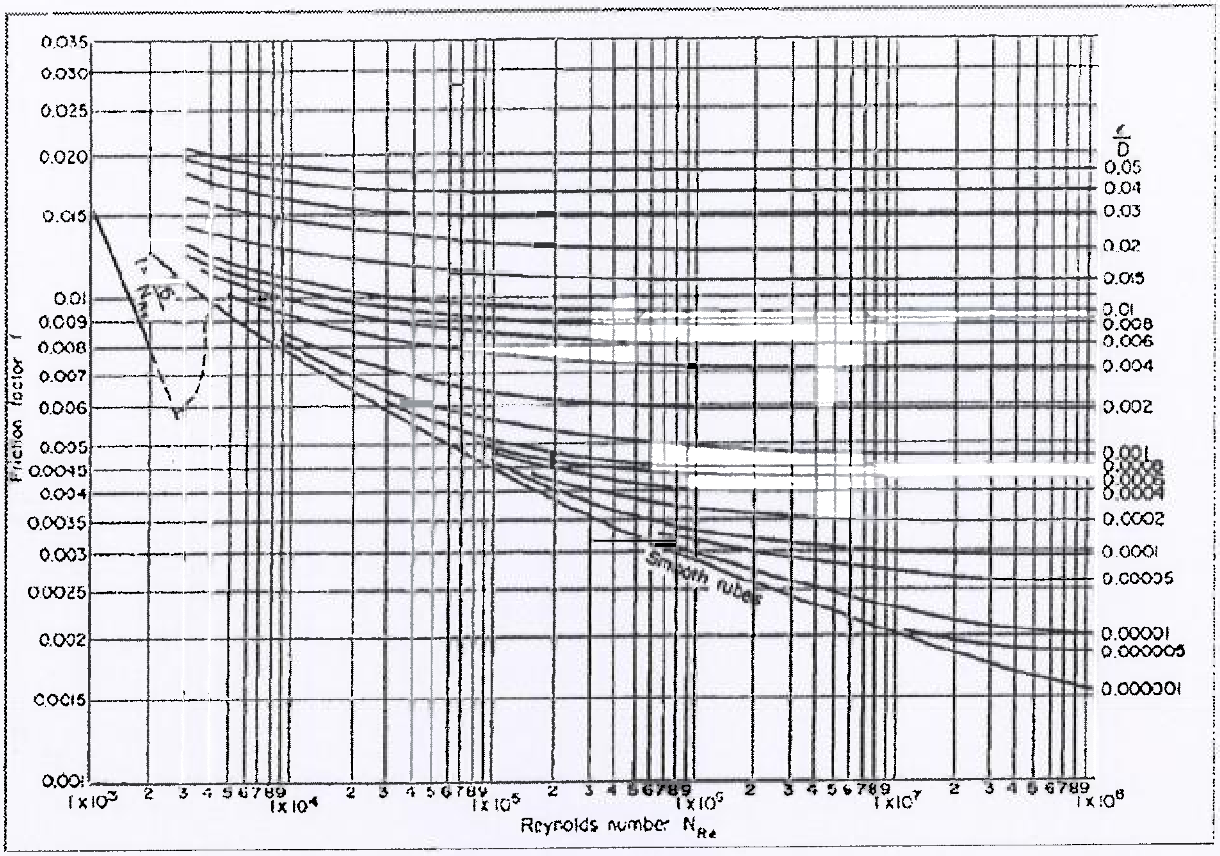
A1. Apple juice (density = 997.1 kg/m^3, viscosity = 2.1 x 10^{-3} Pa.s) is pumped at 27 °C from an open tank through a 1-inch nominal diameter smooth sanitary pipe (inside diameter = 2.291 cm) to a second tank at a higher level. The mass flow rate is 1 kg/s through 30 m of straight pipe with two 90° standard elbows and one angle valve (fully open). The supply tank maintains a liquid level of 3 m, and the apple juice leaves the system at elevation of 12 m above the floor. Compute the power requirements of the pump assuming an efficiency of 60%.

A2. A packed bed (void fraction = 0.48) containing uniform spherical particles (diameter = 3 mm, density = 4200 kg/m^3) is fluidized by means of a liquid (viscosity = 1 x 10^{-3} N.s/m^2, density = 1100 kg/m^3). Calculate the ratio of the settling velocity of particles to the minimum fluidization velocity for a bed of height "*l*". State clearly any assumptions made.

A3. Consider the following two systems: the first is a 1-inch diameter pipe with wall temperature at 21.11 °C and the other is a 0.5-inch diameter pipe with a wall temperature of 4.44 °C. Which system will give the least pressure drop for water flowing at 0.454 kg/s and cooled from 65.56 °C to 26.67 °C?

<u>DATA</u>:

Density of water = 988.6 kg/m^3
Specific heat capacity of water = 4.1868 kJ/kg °C
Viscosity of water = 5.829 x 10^{-4} kg/m.s
Thermal conductivity of water = 0.6542 W/m °C



Fanning friction factor (f) vs. Reynolds number (Re) for pipes
Transactions of the American Society of Mechanical Engineers, vol. 66, p.672 (1944)

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Section B: Thermal Operations

B1. A vertical plate (15 cm x 15 cm) at 40 °C is exposed to ambient still air at 20 °C. Compare the free convection heat transfer rate from the plate to the forced convection heat transfer rate that would result at a velocity equal to twice the maximum velocity under free convection conditions. The thermo-physical properties of dry air at atmospheric pressure are given below:

T $[K]$	ρ $\left[\frac{kg}{m^3}\right]$	μ $\left[10^{-6}\frac{N\cdot s}{m^2}\right]$	κ $\left[10^{-3}\frac{W}{m\cdot K}\right]$	C_p $\left[\frac{J}{kg\cdot K}\right]$	ρ/μ $\left[10^3\frac{s}{m^2}\right]$	$g\beta/(\nu\alpha)$ $\left[10^6\frac{1}{m^3\cdot K}\right]$	α $\left[10^{-6}\frac{m^2}{s}\right]$
200	1.7690	13.36	18.10	1006.4	132.4	638.6	10.17
210	1.6842	13.92	18.95	1006.1	121.0	505.2	11.18
220	1.6071	14.47	19.80	1005.7	111.1	404.2	12.25
230	1.5368	15.01	20.63	1005.6	102.4	327.0	13.35
240	1.4728	15.54	21.45	1005.5	94.8	267.3	14.49
250	1.4133	16.06	22.26	1005.4	88.0	220.4	15.67
260	1.3587	16.57	23.05	1005.5	82.0	183.3	16.87
270	1.3082	17.07	23.84	1005.5	76.6	153.6	18.12
280	1.2614	17.57	24.61	1005.7	71.8	129.6	19.40
290	1.2177	18.05	25.38	1006.0	67.5	110.1	20.72
300	1.1769	18.53	26.14	1006.3	63.5	94.1	22.07
310	1.1389	19.00	26.87	1006.8	59.9	80.9	23.43
320	1.1032	19.46	27.59	1007.3	56.7	70.0	24.83
330	1.0697	19.92	28.30	1007.9	53.7	60.8	26.25
340	1.0382	20.37	29.00	1008.5	51.0	53.1	27.70
350	1.0086	20.81	29.70	1009.2	48.5	46.5	29.18
360	0.9805	21.25	30.39	1010.0	46.1	41.0	30.69
370	0.9539	21.68	31.07	1010.9	44.0	36.2	32.22
380	0.9288	22.11	31.73	1012.0	42.0	32.1	33.76
390	0.9050	22.52	32.39	1013.0	40.2	28.6	35.33
400	0.8822	22.94	33.05	1014.2	38.5	25.5	36.94

B2. A double-effect forward-feed evaporator is required to give a product, which contains 50% by mass of solids. Each effect has 10 m^2 of heating surface, and the heat transfer coefficient in the first effect is 2.8 kW/m^2 K and 1.7 kW/m^2 K in the second effect. Dry and saturated steam is available at a pressure of 375 kPa and the condenser operates at a pressure of 13.5 kPa. The concentrated solution exhibits a boiling-point rise of 3 K. What is the maximum permissible feed rate if feed contains 10% solids and is at 310 K? The latent heat is 2330 kJ/kg and the specific heat capacity is 4.1868 kJ/kg under all the above conditions.

B3. A steam condenser employed in a power plant handles 35,000 kg of dry air per hour and saturated steam at 50 °C. The cooling water enters the condenser at 15 °C and leaves at 25 °C. The tubes (made of carbon steel with a thermal conductivity of 45 W/m K) have an inside diameter of 22.5 mm and an outside diameter of 25 mm. The water flows through the tubes at an average velocity of 2 m/s. The heat transfer coefficient on the steam side is 5000 W/m^2 K. Assume that the condensate coming out of the condenser is saturated water. Using the heat exchanger correction factor plot below, calculate

(a) Mass flow rate of water **[4 points]**

(b) Heat transfer surface area **[4 points]**

(c) Number of tubes required for the flow of water **[14 points]**

(d) Number of tube passes in the condenser if the length of each tube per pass should not exceed 2.5 m **[3 points]**

DATA:

Density of water = 998.8 kg/m^3

Specific heat capacity of water = 4180 J/kg K

Kinematic viscosity of water = 1.0006 x 10^{-6} m^2/s

Thermal conductivity of water = 0.59859 W/m K

Latent heat of steam = 2374 kJ/kg

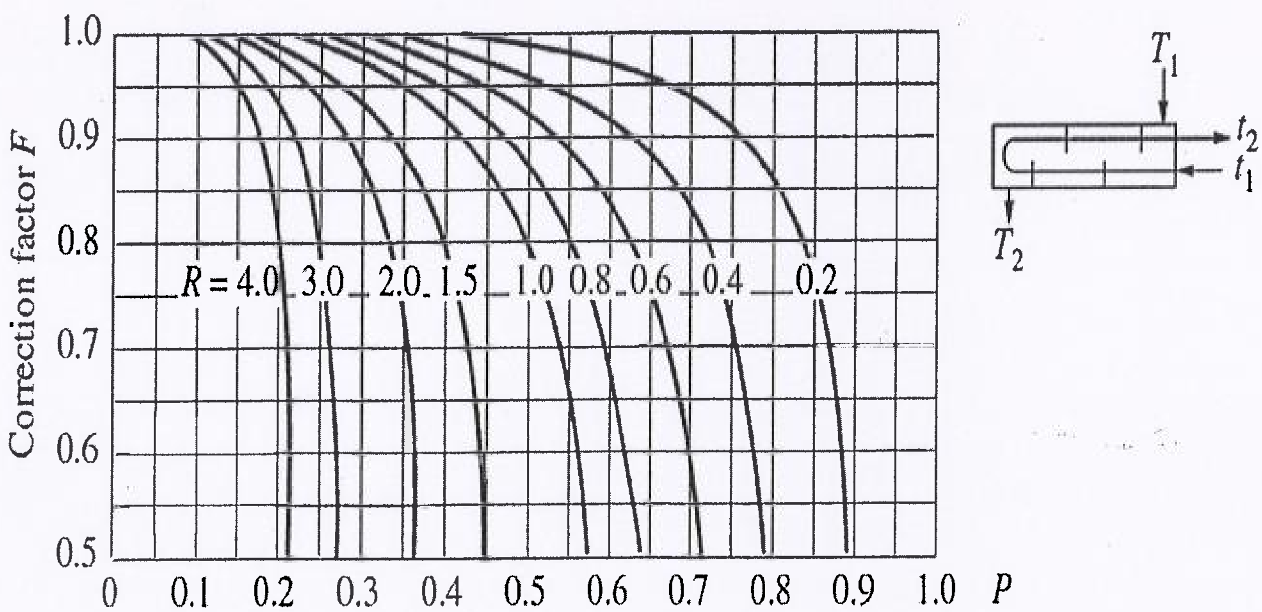

TABLE B.2 Saturated Water: Pressure Table

P kPa, MPa	T °C	$\hat{v}_l$ m³/kg	$\hat{v}_v$ m³/kg	$\hat{u}_l$ kJ/kg	$\Delta\hat{u}_{lv}$ kJ/kg	$\hat{u}_v$ kJ/kg	$\hat{h}_l$ kJ/kg	$\Delta\hat{h}_{lv}$ kJ/kg	$\hat{h}_v$ kJ/kg	$\hat{s}_l$ kJ/kg K	$\Delta\hat{s}_{lv}$ kJ/kg K	$\hat{s}_v$ kJ/kg K
0.6113	0.01	0.001000	206.132	0	2375.3	2375.3	0.00	2501.3	2501.3	0	9.1562	9.1562
1.0	6.98	0.001000	129.208	29.29	2355.7	2385.0	29.29	2484.9	2514.2	0.1059	8.8697	8.9756
1.5	13.03	0.001001	87.980	54.70	2338.6	2393.3	54.70	2470.6	2525.3	0.1956	8.6322	8.8278
2.0	17.50	0.001001	67.004	73.47	2326.0	2399.5	73.47	2460.0	2533.5	0.2607	8.4629	8.7236
2.5	21.08	0.001002	54.254	88.47	2315.9	2404.4	88.47	2451.6	2540.0	0.3120	8.3311	8.6431
3.0	24.08	0.001003	45.665	101.03	2307.5	2408.5	101.03	2444.5	2545.5	0.3545	8.2231	8.5775
4.0	28.96	0.001004	34.800	121.44	2293.7	2415.2	121.44	2432.9	2554.4	0.4226	8.0520	8.4746
5.0	32.88	0.001005	28.193	137.79	2282.7	2420.5	137.79	2423.7	2561.4	0.4763	7.9187	8.3950
7.5	40.29	0.001008	19.238	168.76	2261.7	2430.5	168.77	2406.0	2574.8	0.5763	7.6751	8.2514
10.0	45.81	0.001010	14.674	191.79	2246.1	2437.9	191.81	2392.8	2584.6	0.6492	7.5010	8.1501
15.0	53.97	0.001014	10.022	225.90	2222.8	2448.7	225.91	2373.1	2599.1	0.7548	7.2536	8.0084
20.0	60.06	0.001017	7.649	251.35	2205.4	2456.7	251.38	2358.3	2609.7	0.8319	7.0766	7.9085
25.0	64.97	0.001020	6.204	271.88	2191.2	2463.1	271.90	2346.3	2618.2	0.8930	6.9383	7.8313
30.0	69.10	0.001022	5.229	289.18	2179.2	2468.4	289.21	2336.1	2625.3	0.9439	6.8247	7.7686
40.0	75.87	0.001026	3.993	317.51	2159.5	2477.0	317.55	2319.2	2636.7	1.0258	6.6441	7.6700
50.0	81.33	0.001030	3.240	340.42	2143.4	2483.8	340.47	2305.4	2645.9	1.0910	6.5029	7.5939
75.0	91.77	0.001037	2.217	384.29	2112.4	2496.7	384.36	2278.6	2663.0	1.2129	6.2434	7.4563
0.100	99.62	0.001043	1.6940	417.33	2088.7	2506.1	417.44	2258.0	2675.5	1.3025	6.0568	7.3593
0.125	105.99	0.001048	1.3749	444.16	2069.3	2513.5	444.30	2241.1	2685.3	1.3739	5.9104	7.2843
0.150	111.37	0.001053	1.1593	466.92	2052.7	2519.6	467.08	2226.5	2693.5	1.4335	5.7897	7.2232
0.175	116.06	0.001057	1.0036	486.78	2038.1	2524.9	486.97	2213.6	2700.5	1.4848	5.6868	7.1717
0.200	120.23	0.001061	0.8857	504.47	2025.0	2529.5	504.68	2202.0	2706.6	1.5300	5.5970	7.1271
0.225	124.00	0.001064	0.7933	520.45	2013.1	2533.6	520.69	2191.3	2712.0	1.5705	5.5173	7.0878
0.250	127.43	0.001067	0.7187	535.08	2002.1	2537.2	535.34	2181.5	2716.9	1.6072	5.4455	7.0526
0.275	130.60	0.001070	0.6573	548.57	1992.0	2540.5	548.87	2172.4	2721.3	1.6407	5.3801	7.0208
0.300	133.55	0.001073	0.6058	561.13	1982.4	2543.6	561.45	2163.9	2725.3	1.6717	5.3201	6.9918
0.325	136.30	0.001076	0.5620	572.88	1973.5	2546.3	573.23	2155.8	2729.0	1.7005	5.2646	6.9651
0.350	138.88	0.001079	0.5243	583.93	1965.0	2548.9	584.31	2148.1	2732.4	1.7274	5.2130	6.9404
0.375	141.32	0.001081	0.4914	594.38	1956.9	2551.3	594.79	2140.8	2735.6	1.7527	5.1647	6.9174
0.40	143.63	0.001084	0.4625	604.29	1949.3	2553.6	604.73	2133.8	2738.5	1.7766	5.1193	6.8958
0.45	147.93	0.001088	0.4140	622.75	1934.9	2557.6	623.24	2120.7	2743.9	1.8206	5.0359	6.8565
0.50	151.86	0.001093	0.3749	639.66	1921.6	2561.2	640.21	2108.5	2748.7	1.8606	4.9606	6.8212
0.55	155.48	0.001097	0.3427	655.30	1909.2	2564.5	655.91	2097.0	2752.9	1.8972	4.8920	6.7892
0.60	158.85	0.001101	0.3157	669.88	1897.5	2567.4	670.54	2086.3	2756.8	1.9311	4.8289	6.7600
0.65	162.01	0.001104	0.2927	683.55	1886.5	2570.1	684.26	2076.0	2760.3	1.9627	4.7704	6.7330
0.70	164.97	0.001108	0.2729	696.43	1876.1	2572.5	697.20	2066.3	2763.5	1.9922	4.7158	6.7080