UNIVERSITI SAINS MALAYSIA

First Semester Examination
2011/2012 Academic Session

January 2012

EMH 441/3 – Heat Transfer
[Pemindahan Haba]

Duration : 3 hours
Masa : 3 jam

INSTRUCTIONS TO CANDIDATE:
ARAHAN KEPADA CALON:

Please check that this paper contains **NINE (9)** printed pages, **SEVENTEEN (17)** pages appendix and **FIVE (5)** questions before you begin the examination.
Sila pastikan bahawa kertas soalan ini mengandungi ***SEMBILAN (9)*** *mukasurat bercetak,* ***TUJUH BELAS (17)*** *mukasurat lampiran dan* ***LIMA (5)*** *soalan sebelum anda memulakan peperiksaan.*

Answer **ALL** questions.
Jawab ***SEMUA*** *soalan.*

Appendix/*Lampiran :*

1. Appendix [17 pages/mukasurat]

You may answer all questions in **English** OR **Bahasa Malaysia** OR a combination of both.
Calon boleh menjawab semua soalan dalam ***Bahasa Malaysia*** *ATAU* ***Bahasa Inggeris*** *ATAU kombinasi kedua-duanya.*

Answer to each question must begin from a new page.
Jawapan untuk setiap soalan mestilah dimulakan pada mukasurat yang baru.

In the event of any discrepancies, the English version shall be used.
Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.

Q1. [a] Define the term 'one-dimensional'. For one dimensional case, steady-state conduction with the heat generation, derive the expression for the maximum temperature for heat conducted through a cylindrical shell of radius, r? Aid your answer with illustrations.

Definisikan terma satu dimensi. Untuk kes satu dimensi dalam keadaan mantap tanpa penjanaan haba, terbitkan persamaan suhu maksimum untuk haba konduksi melalui 'cylindrical shell' dengan jejari r. Terangkan jawapan beserta gambarajah.

(40 marks/*markah***)**

[b] To enhance the heat transfer from a silicon chip of width $W = 4\ mm$ on a side, a copper pin fin is brazed to the surface of the chip. The pin length and diameter are $L = 12\ mm$ and $D = 2\ mm$ respectively, and atmospheric air at V=10 m/s and $T_\infty = 300\ K$ is in crossflow over the pin. The surface of the chip and hence the base of the pin are maintained at a temperature of $T_b = 350\ K$, thermal conductivity $k = 399\ W/K$. Use the following Churchill and Bernstein correlation and the fin heat transfer rate equation to solve the problem.

Untuk meningkatkan pemindahan haba dari satu cip silicon yang berdimensi $W = 4\ mm$ pada satu sisi, satu sirip pin kuprum dilekatkan pada permukaan cip tersebut. Panjang dan diameter pin tersebut ialah $L = 12\ mm$ dan $D = 2\ mm$, masing-masing, dan halaju udara pada tekanan atmosfera ialah V=10m/s and $T_\infty = 300\ K$ *dalam aliran bertentangan dengan pin tersebut. Suhu permukaan cip dan dasar pin ditetapkan pada suhu $T_b = 350K$ dan konduktiviti $k = 399\ W/K$. Gunakan persamaan Churchill dan Bernstein dan kadar pemindahan haba sirip di bawah untuk menyelesaikan permasalahan berkaitan.*

$$Nu_d = 0.3 + \frac{0.62 Re_d^{1/2} Pr^{1/3}}{\left[1 + (0.4/Pr)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{Re_d}{282000}\right)^{5/8}\right]^{4/5}$$

$$q_f = \sqrt{\bar{h}PkA}\,(T_b - T_\infty)\frac{\sinh mL + (\bar{h}/mk)\cosh mL}{\cosh mL + (\bar{h}/mk)\sinh mL}$$

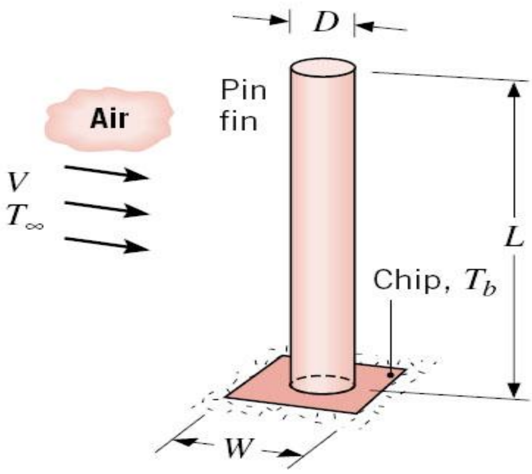

Figure Q1[a]
Rajah S1[a]

(i) **Assuming the chip to have a negligible effect on the flow over the pin, calculate the average convection coefficient for the surface of the pin?**

Anggapkan cip mempunyai kesan yang boleh diabaikan pada aliran melalui pin, kirakan pemalar perolakan purata pada permukaan pin tersebut.

(20 marks/*markah***)**

(ii) **Neglecting the radiation heat transfer and assuming the convection coefficient at the pin tip to equal that calculated in part (i), determine the pin heat transfer rate.**

Dengan mengabaikan pemindahan haba secara radiasi dan mengganggapkan pemalar perolakan pada hujung pin adalah sama dengan yang dikira di bahagian (i), dapatkan nilai kadar pemindahan haba pada pin.

(20 marks/*markah***)**

(iii) **Neglecting radiation, and assuming the convection coefficient at the exposed chip surface to equal that calculated in part (i), determine the total rate of heat transfer from the chip.**

Dengan mengabaikan pemindahan haba secara radiasi dan menganggapkan pemalar perolakan yang terdedah kepada permukaan cip adalah sama seperti yang dikira di bahagian (i), kira kadar pemindahan haba total daripada cip.

(20 marks/*markah***)**

Q2. [a] A system for heating water from an inlet temperature, $T_i = 20$℃ to an outlet temperature of $T_o = 60$℃ involves passing the water through a thick-walled tube having inner and outer diameters of 20 and 40mm. The outer surface of the tube is well insulated and electrical heating within the wall provides for a uniform heat generation rate at $\dot{q} = 10^6\ W/m^3$.

Satu sistem pemanasan air mempunyai suhu aliran masuk $T_i = 20$℃ dan aliran keluar pada suhu $T_o = 60$℃ melibatkan aliran air melalui tiub berdinding tebal yang mempunyai diameter dalam dan luar 20 dan 40 mm. permukaan luar tiub tersebut ditebat sepenuhnya dan pemanasan elektrikal di dalam dinding tersebut memberikan kadar penjanaan haba seragam pada $\dot{q} = 10^6\ W/m^3$.

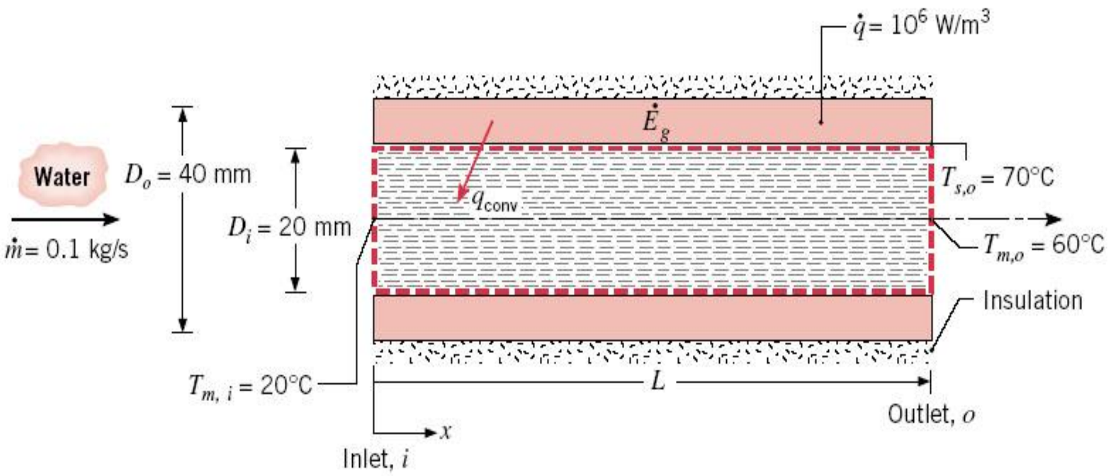

Figure Q2[a]
Rajah S2[a]

(i) Calculate the length of the tube to achieve the desired outlet temperature for the water mass flow rate of $\dot{m} = 0.1\ kg/s$, if the energy generated within the tube wall is equal to the rate of which is convected to the water.

Kirakan panjang diperlukan untuk tiub tersebut mencapai suhu keluaran untuk kadar aliran air $\dot{m} = 0.1\ kg/s$, sekiranya tenaga haba yang dijanakan di dalam dinding tiub adalah sama dengan kadar pemindahan haba secara konduksi kepada air.

(30 marks/*markah*)

(ii) If the inner surface temperature of the tube is $T_s = 70$℃ at the outlet, calculate local convection heat transfer coefficient at the outlet. Assume the uniform heat generation in the wall provides a constant surface heat flux.

Sekiranya suhu permukaan dalam ialah $T_s = 70$℃ pada keluaran, kirakan pemalar pemindahan haba setempat di keluaran. Anggapkan tenaga haba yang dijana di dalam dinding memberikan fluk haba yang malar.

(20 marks/*markah*)

[b] A horizontal high pressure steam pipe of 0.1m outside diameter passes through a large room whose wall and air temperature are $23^{\circ}C$. The pipe has an outside surface temperature of $165^{\circ}C$ and an emissivity of $\epsilon = 0.85$. Estimate the heat loss from the pipe per unit length (W/m). Given equation for the Nusselts number.

Satu paip stim mendatar bertekanan tinggi mempunyai diameter luar 0.1 mm diletakkan di dalam bilik besar yang bersuhu $23^{\circ}C$. Paip tersebut mempunyai suhu permukaan $165^{\circ}C$ dan emisiviti $\epsilon = 0.85$. Kirakan kehilangan haba daripada paip per unit panjang. Diberikan persamaan nombor Nusselts di bawah;

$$Nu_d = \left\{0.60 + \frac{0.387\, {Ra_d}^{1/6}}{[1 + (0.559/Pr)^{9/16}]^{8/27}}\right\}^2$$

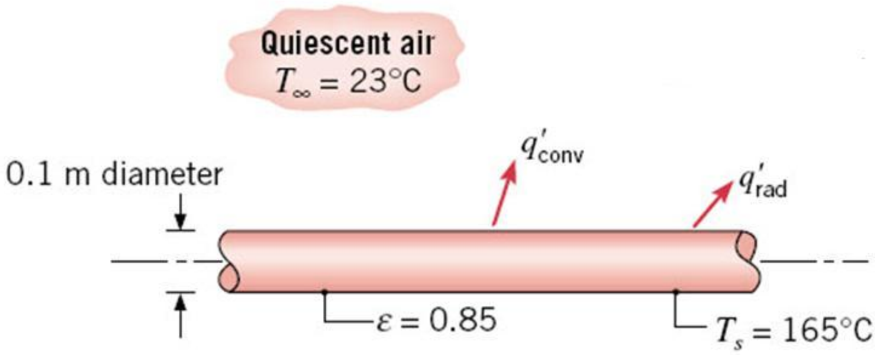

Figure Q2[b]
Rajah S2[b]

(50 marks/*markah*)

Q3. [a] Explain the physical mechanism of condensation with the aid of illustrations and discuss the four modes of condensation. In order to maintain high condensation and heat transfer rates, the droplet formation is superior to the film formation. Discuss how the droplet formation is common practice in the application of surface coatings.

Terangkan mekanisme fizikal kondensasi menggunakan gambarajah dan bincangkan empat mod kondensasi. Untuk mengekalkan tahap kondensasi yang tinggi dan kadar pemindahan haba, pembentukan titis adalah lebih baik daripada pembentukan filem. Bincangkan bagaimana pembentukan titis menjadi amalan biasa dalam aplikasi salutan permukaan.

(50 marks/*markah*)

[b] The outer surface of a vertical tube (as in Figure Q3[b]), which is 1m long and has an outer diameter of 0.08m, is exposed to saturated steam at atmospheric pressure and is maintained at 50˚C by the flow of cool water through the tube. Calculate is the rate of heat transfer (q) to the coolant and calculate is the rate at which steam is condensed at the surface ($\dot{m}$). Discuss how the condensation rate can be increased further and the effect on the heat transfer coefficient. Given the following relationships to solve the equation.

Pemukaan luar satu tiub menegak (seperti dalam Rajah S3[b]) adalah 1m panjang dan diameter luar ialah 80 mm, didedahkan pada stim tepu pada tekanan atmosfera dan ditetapkan pada suhu 50˚C pada aliran air sejuk melalui tiub. Kirakan kadar pemindahan haba (q) kepada bahan penyejuk melalui tiub tersebut dan kirakan kadar di mana stim tersebut dikondensasikan ($\dot{m}$) pada permukaan. Bincangkan bagaimana kadar kondensasi boleh ditingkatkan lagi dan kesan pada pemalar pemindahan haba. Diberikan persamaan di bawah untuk tujuan pengiraan.

$$h'_{fg} = h_{fg} + 0.68\, C_{p,l}(T_{sat} - T_s)$$

$$\bar{h}_{fg} = \frac{Re\, \mu_l h'_{fg}}{4L(T_{sat} - T_s)}$$

$$Re_\delta = \left(\frac{3.70 k_l L (T_{sat} - T_s)}{\mu_l h'_{fg} (\nu_l^2/g)^{1/3}} + 4.8 \right)^{0.82}$$

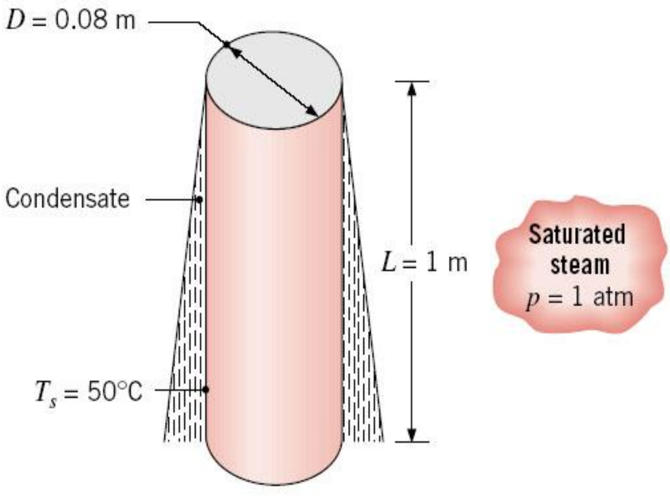

Figure Q3[b]
Rajah S3[b]

(50 marks/*markah*)

Q4. [a] Derive the following form of the effectiveness-NTU equation, ϵ for the effectiveness in a parallel flow double pipe heat exchanger from the equation.

Terbitkan persamaan kecekapan-NTU, ϵ untuk kecekapan sebuah pemindah haba dual-paip aliran selari daripada persamaan di bawah.

$$ln\frac{T_{h_2}-T_{c_2}}{T_{h_1}-T_{c_1}}=-UA\left(\frac{1}{\dot{m}_h c_h}+\frac{1}{\dot{m}_c c_c}\right)$$

$$\epsilon=\frac{1-exp[(-UA/\dot{m}_c\,C_c)(1+\dot{m}_c C_c/\dot{m}_h C_h)]}{1+\dot{m}_c C_c/\dot{m}_h C_h}$$

(50 marks/*markah*)

[b] Hot oil is to be cooled by water in a one-shell pass and 8-tube-passes heat exchanger as in the Figure Q4[b]. The tubes are thin-walled and are made of copper with an internal diameter of 1.4 cm. The length of each tube pass in the heat exchanger is 5 m and the overall heat transfer coefficient is 310 W/(m^2 ˚C). Water flows through the tubes at a rate of 0.2kg/s and the oil through the shell at a rate of 0.3kg/s. The water and the oil enter at temperatures of 20˚C and 150˚C respectively. Determine the rate of heat exchanger in the heat exchanger and the outlet temperatures of the water and the oil. Given $Cp_{oil}=2.13\,kJ/kg.℃$ and $Cp_{water}=4.18\,kJ/kg.℃$. Assume the heat exchanger is well insulated and use the $\epsilon-NTU$ method.

Minyak panas disejukkan menggunakan air di dalam penukar haba one-shell pass dan 8-tiub-passes seperti dalam Rajah S4[b]. Tiub-tiub tersebut adalah berdinding nipis dan dibuat dari kuprum dengan diameter dalam 1.4 cm. Panjang setiap tiub pass di dalam penukar haba ialah 5 m dan pemalar pemindahan haba keseluruhan ialah 310 W/(m^2 ˚C). Air mengalir melakui tiub-tiub tersebut pada kadar 0.2 kg/s dan kadar aliran minyak melalui shell ialah 0.3 kg/s. Air dan minyak memasuki pada suhu 20˚C dan 150˚C masing-masing. Kirakan kadar penukaran haba di dalam penukar haba dan suhu keluaran air dan minyak. Diberikan $Cp_{oil}=2.13\,kJ/kg.℃$ dan $Cp_{water}=4.18\,kJ/kg.℃$ Anggapkan pemindah haba ditebat sepenuhnya dan gunakan kaedah $\epsilon-NTU$.

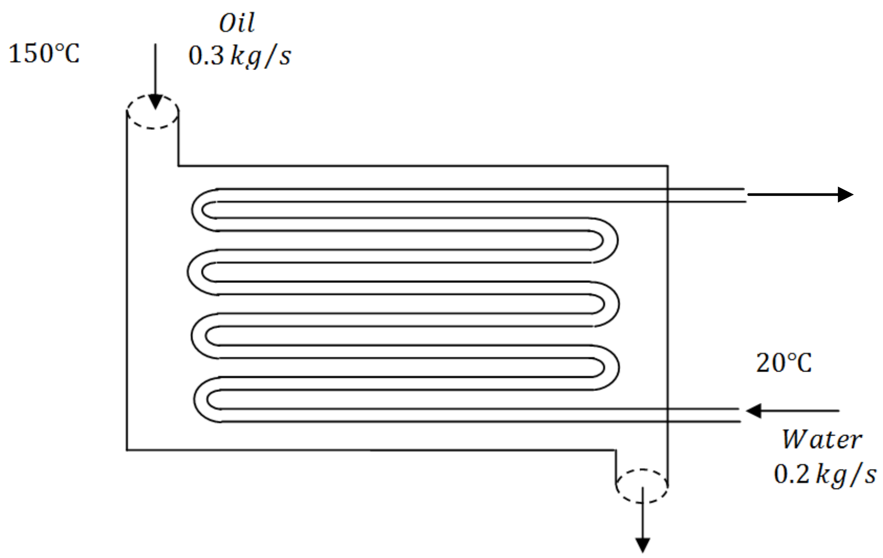

Figure Q4[b]
Rajah S4[b]

(50 marks/*markah*)

Q5. [a] Radiation heat transfer between surfaces depends on the orientation of the surfaces relative to each other as well as their radiation properties and temperatures. Discuss on the parameter use to account for the effects of orientation on radiation heat transfer between two surfaces.

Pemindahan haba secara radiasi antara dua permukaan bergantung kepada orientasi permukaan tersebut relatif sesama sendiri dan juga ciri-ciri radiasi dan suhu. Bincangkan parameter yang berkenaan untuk mengkaji kesan orientasi antara dua permukaan untuk pemindahan haba secara radiasi.

(30 marks/*markah*)

[b] Consider a cylindrical furnace with r=h=1m as shown in Figure Q5[b]. The top (surface 1) and the base (surface 2) of the furnace emissivity, $\epsilon_1 = 0.4$ and $\epsilon_2 = 0.8$ respectively, and are maintained at uniform temperature $T_1 = 700\,K$ and $T_2 = 500\,K$. The side surface closely approximates a blackbody and is maintained at a temperature of $T_3 = 400\,K$. Determine the net rate of radiation heat transfer at each surface during the steady-state operation and explain how these surfaces can be maintained at specified temperatures.

Pertimbangkan satu relau silinder dengan r=h=1m seperti dalam Rajah S5[b]. Permukaan atas (1) dan permukaan dasar (2) unutk emisiviti relau tersebut ialah $\epsilon_1 = 0.4$ dan $\epsilon_2 = 0.8$ masing-masing dan ditetapkan pada suhu $T_1 = 700\,K$ and $T_2 = 500\,K$. Permukaan sisi relau mempunyai nilai jasad hitam dan ditetapkan pada suhu $T_3 = 400\,K$. Kirakan kadar net pemindahan haba radiasi pada setiap permukaan relau semasa operasi keadaan mantap dan terangkan bagaimana permukaan-permukaan ini boleh ditetapkan pada suhu tertentu.

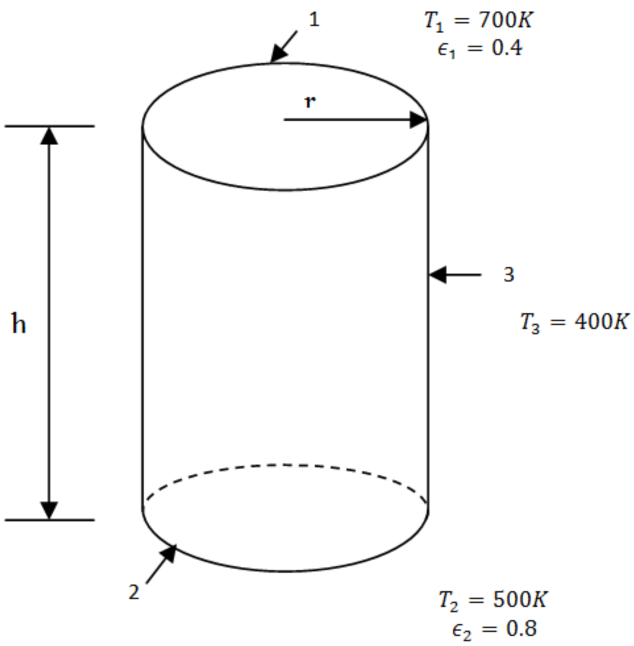

Figure Q5[b]
Rajah S5[b]

(70 marks/*markah*)

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APPENDIX 1/*LAMPIRAN 1*

Table A-5: Properties of air at atmospheric pressure.

Table A-5 | Properties of air at atmospheric pressure.†

The values of μ, k, c_p, and Pr are not strongly pressure-dependent and may be used over a fairly wide range of pressures

T, K	ρ kg/m^3	c_p kJ/kg · °C	$\mu \times 10^5$ kg/m · s	$\nu \times 10^6$ m^2/s	k W/m · °C	$\alpha \times 10^4$ m^2/s	Pr
100	3.6010	1.0266	0.6924	1.923	0.009246	0.02501	0.770
150	2.3675	1.0099	1.0283	4.343	0.013735	0.05745	0.753
200	1.7684	1.0061	1.3289	7.490	0.01809	0.10165	0.739
250	1.4128	1.0053	1.5990	11.31	0.02227	0.15675	0.722
300	1.1774	1.0057	1.8462	15.69	0.02624	0.22160	0.708
350	0.9980	1.0090	2.075	20.76	0.03003	0.2983	0.697
400	0.8826	1.0140	2.286	25.90	0.03365	0.3760	0.689
450	0.7833	1.0207	2.484	31.71	0.03707	0.4222	0.683
500	0.7048	1.0295	2.671	37.90	0.04038	0.5564	0.680
550	0.6423	1.0392	2.848	44.34	0.04360	0.6532	0.680
600	0.5879	1.0551	3.018	51.34	0.04659	0.7512	0.680
650	0.5430	1.0635	3.177	58.51	0.04953	0.8578	0.682
700	0.5030	1.0752	3.332	66.25	0.05230	0.9672	0.684
750	0.4709	1.0856	3.481	73.91	0.05509	1.0774	0.686
800	0.4405	1.0978	3.625	82.29	0.05779	1.1951	0.689
850	0.4149	1.1095	3.765	90.75	0.06028	1.3097	0.692
900	0.3925	1.1212	3.899	99.3	0.06279	1.4271	0.696
950	0.3716	1.1321	4.023	108.2	0.06525	1.5510	0.699
1000	0.3524	1.1417	4.152	117.8	0.06752	1.6779	0.702
1100	0.3204	1.160	4.44	138.6	0.0732	1.969	0.704
1200	0.2947	1.179	4.69	159.1	0.0782	2.251	0.707
1300	0.2707	1.197	4.93	182.1	0.0837	2.583	0.705
1400	0.2515	1.214	5.17	205.5	0.0891	2.920	0.705
1500	0.2355	1.230	5.40	229.1	0.0946	3.262	0.705
1600	0.2211	1.248	5.63	254.5	0.100	3.609	0.705
1700	0.2082	1.267	5.85	280.5	0.105	3.977	0.705
1800	0.1970	1.287	6.07	308.1	0.111	4.379	0.704
1900	0.1858	1.309	6.29	338.5	0.117	4.811	0.704
2000	0.1762	1.338	6.50	369.0	0.124	5.260	0.702
2100	0.1682	1.372	6.72	399.6	0.131	5.715	0.700
2200	0.1602	1.419	6.93	432.6	0.139	6.120	0.707
2300	0.1538	1.482	7.14	464.0	0.149	6.540	0.710
2400	0.1458	1.574	7.35	504.0	0.161	7.020	0.718
2500	0.1394	1.688	7.57	543.5	0.175	7.441	0.730

†From *Natl. Bur. Stand. (U.S.) Circ.* 564, 1955.

APPENDIX 2/*LAMPIRAN 2*

Table A-6: Thermophysical properties of saturated water.

TABLE A.6 Thermophysical Properties of Saturated Water[a]

Temperature, T (K)	Pressure, p (bars)[b]	Specific Volume (m³/kg) $v_f \cdot 10^3$	v_g	Heat of Vaporization, h_{fg} (kJ/kg)	Specific Heat (kJ/kg · K) $c_{p,f}$	$c_{p,g}$	Viscosity (N · s/m²) $\mu_f \cdot 10^6$	$\mu_g \cdot 10^6$	Thermal Conductivity (W/m · K) $k_f \cdot 10^3$	$k_g \cdot 10^3$	Prandtl Number Pr_f	Pr_g	Surface Tension, $\sigma_f \cdot 10^3$ (N/m)	Expansion Coefficient, $\beta_f \cdot 10^6$ (K⁻¹)	Temperature, T (K)
273.15	0.00611	1.000	206.3	2502	4.217	1.854	1750	8.02	569	18.2	12.99	0.815	75.5	−68.05	273.15
275	0.00697	1.000	181.7	2497	4.211	1.855	1652	8.09	574	18.3	12.22	0.817	75.3	−32.74	275
280	0.00990	1.000	130.4	2485	4.198	1.858	1422	8.29	582	18.6	10.26	0.825	74.8	46.04	280
285	0.01387	1.000	99.4	2473	4.189	1.861	1225	8.49	590	18.9	8.81	0.833	74.3	114.1	285
290	0.01917	1.001	69.7	2461	4.184	1.864	1080	8.69	598	19.3	7.56	0.841	73.7	174.0	290
295	0.02617	1.002	51.94	2449	4.181	1.868	959	8.89	606	19.5	6.62	0.849	72.7	227.5	295
300	0.03531	1.003	39.13	2438	4.179	1.872	855	9.09	613	19.6	5.83	0.857	71.7	276.1	300
305	0.04712	1.005	29.74	2426	4.178	1.877	769	9.29	620	20.1	5.20	0.865	70.9	320.6	305
310	0.06221	1.007	22.93	2414	4.178	1.882	695	9.49	628	20.4	4.62	0.873	70.0	361.9	310
315	0.08132	1.009	17.82	2402	4.179	1.888	631	9.69	634	20.7	4.16	0.883	69.2	400.4	315
320	0.1053	1.011	13.98	2390	4.180	1.895	577	9.89	640	21.0	3.77	0.894	68.3	436.7	320
325	0.1351	1.013	11.06	2378	4.182	1.903	528	10.09	645	21.3	3.42	0.901	67.5	471.2	325
330	0.1719	1.016	8.82	2366	4.184	1.911	489	10.29	650	21.7	3.15	0.908	66.6	504.0	330
335	0.2167	1.018	7.09	2354	4.186	1.920	453	10.49	656	22.0	2.88	0.916	65.8	535.5	335
340	0.2713	1.021	5.74	2342	4.188	1.930	420	10.69	660	22.3	2.66	0.925	64.9	566.0	340
345	0.3372	1.024	4.683	2329	4.191	1.941	389	10.89	668	22.6	2.45	0.933	64.1	595.4	345
350	0.4163	1.027	3.846	2317	4.195	1.954	365	11.09	668	23.0	2.29	0.942	63.2	624.2	350
355	0.5100	1.030	3.180	2304	4.199	1.968	343	11.29	671	23.3	2.14	0.951	62.3	652.3	355
360	0.6209	1.034	2.645	2291	4.203	1.983	324	11.49	674	23.7	2.02	0.960	61.4	697.9	360
365	0.7514	1.038	2.212	2278	4.209	1.999	306	11.69	677	24.1	1.91	0.969	60.5	707.1	365
370	0.9040	1.041	1.861	2265	4.214	2.017	289	11.89	679	24.5	1.80	0.978	59.5	728.7	370
373.15	1.0133	1.044	1.679	2257	4.217	2.029	279	12.02	680	24.8	1.76	0.984	58.9	750.1	373.15
375	1.0815	1.045	1.574	2252	4.220	2.036	274	12.09	681	24.9	1.70	0.987	58.6	761	375
380	1.2869	1.049	1.337	2239	4.226	2.057	260	12.29	683	25.4	1.61	0.999	57.6	788	380
385	1.5233	1.053	1.142	2225	4.232	2.080	248	12.49	685	25.8	1.53	1.004	56.6	814	385
390	1.794	1.058	0.980	2212	4.239	2.104	237	12.69	686	26.3	1.47	1.013	55.6	841	390
400	2.455	1.067	0.731	2183	4.256	2.158	217	13.05	688	27.2	1.34	1.033	53.6	896	400
410	3.302	1.077	0.553	2153	4.278	2.221	200	13.42	688	28.2	1.24	1.054	51.5	952	410
420	4.370	1.088	0.425	2123	4.302	2.291	185	13.79	688	29.8	1.16	1.075	49.4	1010	420
430	5.699	1.099	0.331	2091	4.331	2.369	173	14.14	685	30.4	1.09	1.10	47.2		430

APPENDIX 2/*LAMPIRAN 2*

CONTINUE...

440	7.333	1.110	0.261	2059	4.36	2.46	162	14.50	682	31.7	1.04	1.12	45.1		440
450	9.319	1.123	0.208	2024	4.40	2.56	152	14.85	678	33.1	0.99	1.14	42.9		450
460	11.71	1.137	0.167	1989	4.44	2.68	143	15.19	673	34.6	0.95	1.17	40.7		460
470	14.55	1.152	0.136	1951	4.48	2.79	136	15.54	667	36.3	0.92	1.20	38.5		470
480	17.90	1.167	0.111	1912	4.53	2.94	129	15.88	660	38.1	0.89	1.23	36.2		480
490	21.83	1.184	0.0922	1870	4.59	3.10	124	16.23	651	40.1	0.87	1.25	33.9	—	490
500	26.40	1.203	0.0766	1825	4.66	3.27	118	16.59	642	42.3	0.86	1.28	31.6	—	500
510	31.66	1.222	0.0631	1779	4.74	3.47	113	16.95	631	44.7	0.85	1.31	29.3	—	510
520	37.70	1.244	0.0525	1730	4.84	3.70	108	17.33	621	47.5	0.84	1.35	26.9	—	520
530	44.58	1.268	0.0445	1679	4.95	3.96	104	17.72	608	50.6	0.85	1.39	24.5	—	530
540	52.38	1.294	0.0375	1622	5.08	4.27	101	18.1	594	54.0	0.86	1.43	22.1	—	540
550	61.19	1.323	0.0317	1564	5.24	4.64	97	18.6	580	58.3	0.87	1.47	19.7	—	550
560	71.08	1.355	0.0269	1499	5.43	5.09	94	19.1	563	63.7	0.90	1.52	17.3	—	560
570	82.16	1.392	0.0228	1429	5.68	5.67	91	19.7	548	76.7	0.94	1.59	15.0	—	570
580	94.51	1.433	0.0193	1353	6.00	6.40	88	20.4	528	76.7	0.99	1.68	12.8	—	580
590	108.3	1.482	0.0163	1274	6.41	7.35	84	21.5	513	84.1	1.05	1.84	10.5	—	590
600	123.5	1.541	0.0137	1176	7.00	8.75	81	22.7	497	92.9	1.14	2.15	8.4	—	600
610	137.3	1.612	0.0115	1068	7.85	11.1	77	24.1	467	103	1.30	2.60	6.3	—	610
620	159.1	1.705	0.0094	941	9.35	15.4	72	25.9	444	114	1.52	3.46	4.5	—	620
625	169.1	1.778	0.0085	858	10.6	18.3	70	27.0	430	121	1.65	4.20	3.5	—	625
630	179.7	1.856	0.0075	781	12.6	22.1	67	28.0	412	130	2.0	4.8	2.6	—	630
635	190.9	1.935	0.0066	683	16.4	27.6	64	30.0	392	141	2.7	6.0	1.5	—	635
640	202.7	2.075	0.0057	560	26	42	59	32.0	367	155	4.2	9.6	0.8	—	640
645	215.2	2.351	0.0045	361	90	—	54	37.0	331	178	12	26	0.1	—	645
647.3[c]	221.2	3.170	0.0032	0	∞	∞	45	45.0	238	238	∞	∞	0.0	—	647.3[c]

[a]Adapted from Reference 22.
[b]1 bar = 10^5 N/m^2.
[c]Critical temperature.