UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2010/2011

November 2010

EMH 441/3 – Heat Transfer
Pemindahan Haba

Duration : 3 hours
Masa : 3 jam

<u>INSTRUCTIONS TO CANDIDATE:</u>
<u>ARAHAN KEPADA CALON:</u>

Please check that this paper contains **<u>EIGHT (8)</u>** printed pages, **<u>TWO (2)</u>** pages appendix and **<u>SIX (6)</u>** questions before you begin the examination.
*Sila pastikan bahawa kertas soalan ini mengandungi **<u>LAPAN (8)</u>** mukasurat bercetak, **<u>DUA (2)</u>** mukasurat lampiran dan **<u>ENAM (6)</u>** soalan sebelum anda memulakan peperiksaan.*

Answer **<u>FIVE</u>** questions.
*Jawab **<u>LIMA</u>** soalan.*

Appendix/*Lampiran :*

1. Table A-5: Properties of air at atmospheric pressure. [1 page/mukasurat]
2. Table A-6: Thermophysical properties of saturated water. [1 page/mukasurat]

You may answer all questions in **<u>English</u>** OR **<u>Bahasa Malaysia</u>** OR a combination of both.
*Calon boleh menjawab semua soalan dalam **<u>Bahasa Malaysia</u>** ATAU **<u>Bahasa Inggeris</u>** 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] Uniform internal heat generation at $\dot{q} = 5 \times 10^7\ W/m^3$ is occurring in a cylindrical nuclear reactor fuel rod of 50 mm diameter (refer Figure Q1[b]) and under steady-state conditions. The temperature distribution is of the form of $T(r) = a + br^2$, where T is the in degrees Celcius and r is in meters. Given $a = 800°C$ and $b = -4.167 \times 10^5\ °C/m^2$. The rod properties are *k=30 W/m. K* and $\rho = 1100\ kg/m^2$ and $C_p = 800 J/kg.K$.

Di dalam sebuah reaktor nuklear, penjanaan haba dalam sebanyak $\dot{q} = 5 \times 10^7\ W/m^3$ berlaku pada rod bahan api silinder yang mempunyai diameter 50mm (rujuk Rajah S1[b]) dalam keadaan mantap. Taburan suhu pada rod tersebut diberikan dalam persamaan $T(r) = a + br^2$, di mana T adalah dalam Celcius dan r dalam unit meter. Diberikan $a = 800°C$ dan $b = -4.167 \times 10^5\ °C/m^2$. Rod tersebut mempunyai k = 30 W/m.K dan $\rho = 1100\ kg/m^2$ and $C_p = 800\ J/kg.K$.

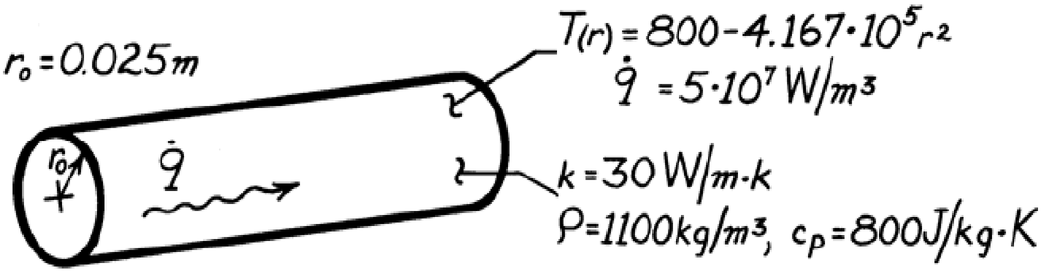

Figure Q1[a]
Rajah S1[a]

(i) Calculate the rate of heat transfer per unit length of the rod at *r = 0* (the centerline) and at *r = 25 mm* (at the surface)?

Apakah kadar pemindahan haba seunit panjang rod tersebut pada r = 0 (di tengah-tengah rod) dan r = 25 mm (pada permukaan rod)?

(50 marks/*markah*)

(ii) If the reactor power level is suddenly increased to $\dot{q} = 10^8\ W/m^3$, estimate the initial time rate of temperature change at *r = 0 and r = 25 mm*?

Sekiranya kuasa reaktor nuklear tersebut dinaikkan kepada $\dot{q} = 10^8\ W/m^3$, kirakan permulaan kadar perubahan suhu pada r = 0 and r = 25 mm?

(50 marks/*markah*)

Q2. **[a]** **Define the term 'one-dimensional'. For one dimensional case, steady-state conduction without heat generation, explain the temperature distribution in a plane wall? Aid your answer with illustrations.**

Takrifkan terma satu dimensi. Untuk kes satu dimensi dalam keadaan mantap tanpa penjanaan haba, terangkan taburan suhu untuk dinding rata. Sertakan gambarajah untuk jawapan anda.

(50 marks/*markah*)

[b] **A plane wall is a composite of two materials, A and B. The wall of the material A has uniform heat generation $\dot{q} = 1.5 \times 10^6\ W/m^3$, $k_A = 75\ W/m.K$ and thickness $L_A = 50\ mm$. The wall material B has no generation with $k_B = 150\ W/m.K$ and thickness, $L_B = 20mm$. The inner surface material A is well insulated, while the outer surface of material B is cooled by a water stream with $T_\infty = 30°C$ and $h = 1000\ W/m^2.K$.**

Satu dinding satah komposit terdiri daripada dua jenis bahan iaitu bahan A dan B. Dinding bahan A mempunyai penjanaan haba sebanyak $\dot{q} = 1.5 \times 10^6\ W/m^3$, $k_A = 75\ W/m.K$ dan tebal $L_A = 50\ mm$. Dinding bahan B tiada penjanaan haba dengan nilai $k_B = 150\ W/m.K$ dan tebal, $L_B = 20\ mm$. Permukaan dalam bahan A ditebat sepenuhnya, manakala permukaan luar bahan B disejukkan dengan menggunakan aliran air pada suhu $T_\infty = 30°C$ and $h = 1000\ W/m^2.K$.

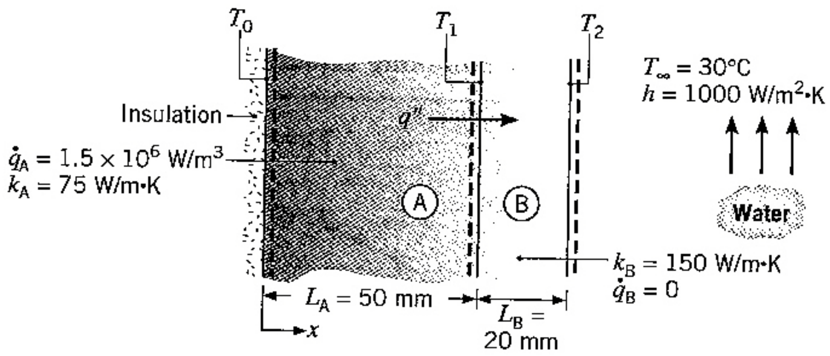

Figure Q2[b]
Rajah S2[b]

(i) **Sketch the temperature distribution that exists in the composite under steady-state conditions.**

Lakarkan taburan suhu yang wujud di dalam bahan komposit dalam keadaan mantap.

(20 marks/*markah*)

(ii) **Determine the temperature T_0 of the insulated surface and the temperature T_2 of the cooled surface.**

Kirakan suhu T_0 untuk permukaan yang ditebat dan suhu T_2 untuk permukaan yang disejukkan.

(30 marks/*markah*)

Q3. [a] What is the definition of the Prandtl number? How does the value of the Prandtl number affect the relative growth of the velocity and thermal boundary layers for laminar flow over a surface?

Definisikan nombor Prandtl. Bagaimana nilai sesuatu nombor Prandtl akan mempengaruhi peningkatan relatif halaju dan lapisan sempadan suhu untuk aliran laminar di atas sesuatu permukaan.

(50 marks/*markah*)

[b] A flat plate as in Figure Q3[b] of width 1m is maintained at a uniform surface temperature of $T_s = 150°C$ by using independently controlled, heat-generating rectangular module of thickness $a = 10\ mm$ and $b = 50\ mm$. Each module is insulated from its neighbours, as well as on its back side. Atmospheric air 25°C flows over the plate at a velocity of $30\ m/s$. The thermophysical properties of the module are $k = 5.2\ W/m.K$, $C_p = 320 J/kg.K$ and $\rho = 2300\ kg/m^3$.

Plat permukaan rata seperti dalam Rajah S3[b] yang mempunyai lebar 1m ditetapkan suhu permukaan pada $T_s = 150°C$ dengan menggunakan kawalan tak bersandar, modul penjana haba berbentuk segiempat yang mempunyai tebal $a = 10\ mm$ dan $b = 50\ mm$. Setiap modul tersebut ditebat dengan modul bersebelahan dan juga di sisi belakangnya. Suhu atmosfera 25°C mengalir pada plat tersebut pada halaju $30\ m/s$. Modul tersebut mempunyai $k = 5.2\ W/m.K$, $C_p = 320 J/kg.K$ dan $\rho = 2300\ kg/m^3$.

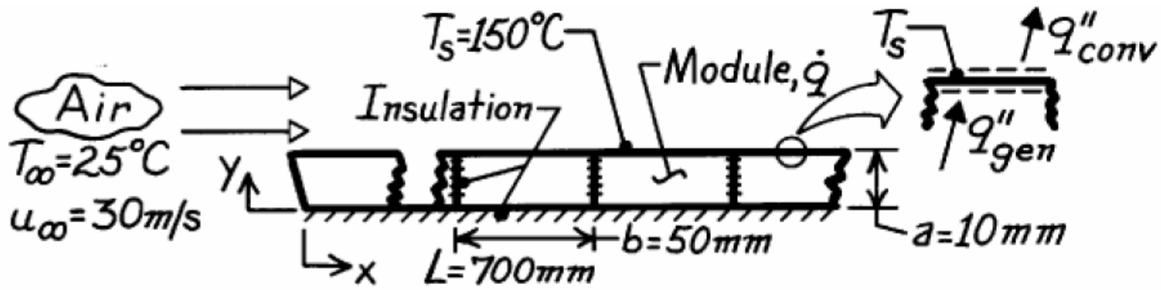

Figure Q2[c]
Rajah S2[c]

(i) Calculate the required power generation, $\dot{q}$ (W/m^3), in a module positioned at a distance 700 mm from the leading edge.

Kirakan kuasa janaan yang diperlukan $\dot{q}$ (W/m^3),dalam modul tersebut sekiranya diletakkan pada jarak 700 mm daripada sisi permulaan.

(20 marks/*markah*)

(ii) Calculate the maximum temperature T_{max} in the heating generating module.

Kirakan suhu maksimum T_{max} di dalam penjanaan haba modul tersebut.

(30 marks/*markah*)

Q4. [a] Explain with the aid of appropriate diagram illustrating the boiling curve, identify the key features of the boiling process at atmospheric pressure. Discuss the influence of the surface roughness for the nucleate boiling region.

Terangkan dengan bantuan gambarajah yang menunjukkan graf pendidihan, kenal pastikan sifat-sifat terlibat dalam proses pendidihan pada tekanan atmosfera. Bincangkan kesan kekasaran permukaan kepada sifat pendidihan nucleus.

(50 marks/*markah*)

[b] A nickel coated heater element (refer to Figure Q4[b]) with a thickness of 15mm and a thermal conductivity of $50\,W/m.K$ is exposed to saturated water at atmospheric pressure. A thermocouple is attached to the back surface, which is well insulated. Measurement at a particular operating condition yield an electrical power dissipation in the heater element of $6.950 \times 10^7\,W/m^3$ and a temperature of $T_0 = 266.4°C$.

Satu elemen pemanas yang dilapisi dengan nikel (rujuk Rajah S4[b]) mempunyai ketebalan 15 mm dan konduktiviti haba $50\,W/m.K$ terdedah kepada air pada tekanan atmosfera. Satu pengganding suhu di lekatkan pada permukaan belakang pemanas tersebut yang ditebat. Pengukuran pada keadaan operasi menghasilkan kehilangan kuasa elektrik melalui pelesapan sebanyak $6.950 \times 10^7\ W/m^3$ dan suhu $T_0 = 266.4°C$.

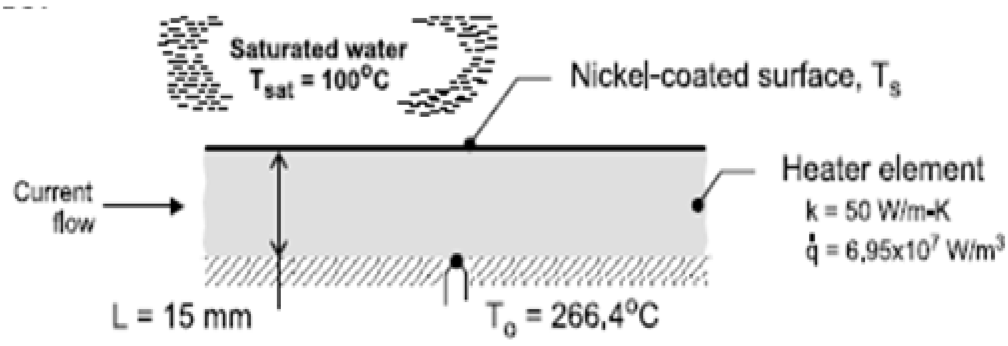

Figure Q2[c]
Rajah S2[c]

(i) **From the foregoing data, calculate the surface temperature, T_s, and the heat flux at the exposed surface.**

Berdasarkan data yang diberikan, kirakan suhu permukaan, T_s dan juga flux haba pada permukaan yang terdedah.

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

(ii) **Using the surface heat flux determined in part (i), estimate the surface temperature by applying an appropriate boiling correlation.**

Menggunakan jawapan flux haba permukaan pada bahagian (i), anggarkan suhu permukaan dengan menggunakan korelasi pendidihan yang bersesuaian.

(30 marks/*markah***)**

Q5. **[a]** **What is meant by the overall heat transfer coefficient? With an example, explain how the overall heat transfer coefficient is related to the total thermal resistance and the heat transfer between two fluids?**

Apakah yang dimaksudkan dengan pemalar pemindahan haba keseluruhan? Dengan mengemukakan satu contoh, terangkan bagaimana pemalar haba keseluruhan dikaitkan dengan rintangan haba keseluruhan dan pemindahan haba di antara dua bendalir?

(50 marks/*markah***)**

[b] **A steel tube $(k = 50\,W/m.K)$ of inner and outer diameters $D_i = 20mm$ and $D_o = 26\ mm$, respectively, is used to transfer heat from hot gases flowing over the tube $(h_h = 200\,W/m^2.K)$ to cold water flowing through tube $(h_c = 8000\,W/m^2.K)$. What is the cold-side overall heat transfer coefficient U_c? To enhance the heat transfer, 16 straight fins of rectangular profile are installed longitudinally along the outer surface of the tube. The fins are equally spaced around the circumference of the tube, each having a thickness of 2 mm and a length of 15 mm. What is the corresponding overall heat transfer coefficient U_c?**

Tiub keluli $(k = 50\,W/m.K)$ yang mempunyai diameter dalaman dan luaran $D_i = 20\ mm$ dan $D_o = 26\ mm$, digunakan untuk memindahkan haba daripada gas panas yang mengalir di dalam tiub $(h_h = 200\,W/m^2.K)$ ke air sejuk melalui tiub $(h_c = 8000\,W/m^2.K)$. Apakah pemalar pemindahan haba keseluruhan U_c? Untuk meningkatkan pemindahan haba, 16 sirip lurus yang mempunyai profil segiempat-tepat dipasangkan secara longitudinal di sepanjang permukaan luar tiub tersebut. Sirip-sirip tersebut direnggangkan pada jarak yang sama pada perimeter tiub, setiap satunya mempunyai ketebalan 2 mm dan panjang 15 mm. Kirakan pemalar pemindahan haba keseluruhan U_c?

(50 marks/*markah*)

Q6. [a] **What are the characteristics of a blackbody? The emissive power of a body *E* is defined as the energy emitted by the body per unit area and per unit time. Derive the Kirchhoff Law which relates the emissive power of a body and the material properties defined as in the Figure Q6[a]**

Apakah kriteria-kriteria suatu jasad hitam? Kuasa pancaran sesuatu jasad E didefinisikan sebagai tenaga yang dipancarkan oleh jasad tersebut per unit luas dan per unit masa. Terbitkan Hukum Kirchhoff yang menghubungkan kuasa pancaran sesuatu jasad dan ciri bahan seperti dalam Rajah S6[a].

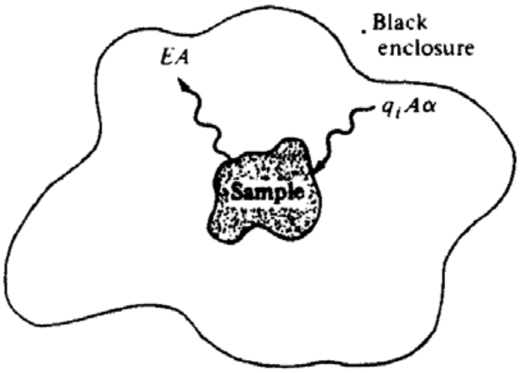

Figure Q6[a]
Rajah S6[a]

(50 marks/*markah*)

[b] **A partially transparent covering is placed over the square cavity as shown in the Figure Q6[b]. The inside temperature of the cavity can be varied from 350 to 500 K, and the assembly exchanges heat with a large room at 300 K. Suppose it is possible to fabricate the covering material such that a variable transmissivity can be tailored to produce a constant net radiant exchange between the assembly and room for the temperature range indicated. Perform an appropriate analysis to design a suitable set of radiation properties for the covering material. Be sure state clearly all assumptions.**

Satu pembalut lutsinar diletakkan di atas geronggang segi empat tepat seperti dalam Rajah S6[b]. Suhu pada bahagian dalam geronggang berada dalam julat 350 – 500 K dan berlaku pemindahan haba di antara objek dan bilik pada suhu 300 K. Sekiranya pembalut lutsinar tersebut boleh difabrikasikan, dengan syarat pembolehubah transmisiviti diambilkira untuk menghasilkan pertukaran sinar net antara objek dan bilik pada julat suhu yang dinyatakan. Hasilkan analisis yang bersesuaian untuk merekabentuk sejumlah set radiasi untuk sesuatu bahan pembalut. Nyatakan semua anggapan untuk analisis tersebut.

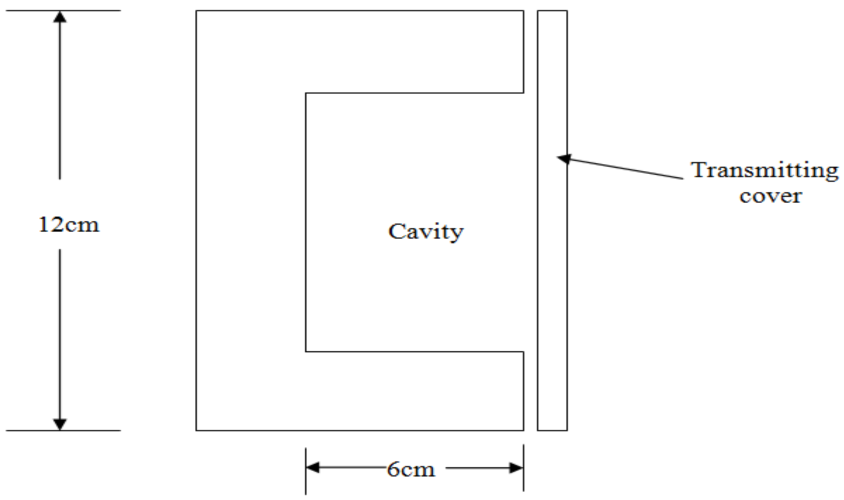

Figure Q6[b]
Rajah S6[b]

(50 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 (m^3/kg) $v_f \cdot 10^3$	Specific Volume (m^3/kg) v_g	Heat of Vaporization, h_{fg} (kJ/kg)	Specific Heat (kJ/kg · K) $c_{p,f}$	Specific Heat (kJ/kg · K) $c_{p,g}$	Viscosity (N · s/m^2) $\mu_f \cdot 10^6$	Viscosity (N · s/m^2) $\mu_g \cdot 10^6$	Thermal Conductivity (W/m · K) $k_f \cdot 10^3$	Thermal Conductivity (W/m · K) $k_g \cdot 10^3$	Prandtl Number Pr_f	Prandtl Number 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.