UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2008/2009

April/May 2009

EKC 222 – Chemical Engineering Thermodynamics
[Termodinamik Kejuruteraan Kimia]

Duration : 3 hours
[Masa : 3 jam]

Please check that this examination paper consists of EIGHT pages of printed material and THREE pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi LAPAN muka surat yang bercetak dan TIGA muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instructions: Answer **FOUR** (4) questions. Answer **TWO** (2) questions from Section A. Answer **TWO** (2) questions from Section B.

*[**Arahan:** Jawab **EMPAT** (4) soalan. Jawab **DUA** (2) soalan dari Bahagian A. Jawab **DUA** (2) soalan dari Bahagian B.]*

Booklet of Thermodynamic Tables is provided.
Buku "Booklet of Thermodynamic Tables" diberikan.

You may answer the question either in Bahasa Malaysia or in English.

[Anda dibenarkan menjawab soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris.]

Section A : Answer any TWO questions.
Bahagian A : Jawab mana-mana DUA soalan.

1. [a] Water is being heated in a closed vessel while being stirred by stirrer. During the process, 40 kJ of heat is transferred to the water and 10 kJ of heat is lost to the surrounding air. The stirrer work amounts to 200 Nm. Determine the final energy of the system if its initial energy is 15 kJ.

1. [a] Air sedang dipanaskan dalam sebuah bekas tertutup sambil dianduk oleh pengaduk. Semasa proses tersebut, 40 kJ haba dipindahkan kepada air dan 10 kJ haba hilang ke udara persekitaran. Kerja pengaduk berjumlah 200 Nm. Tentukan tenaga akhir sistem tersebut jika tenaga awalnya ialah 15 kJ.

[5 marks/markah]

[b] A piston-cylinder device initially contains 50 L of water at 40°C and 200 kPa. Heat is transferred to the water at constant pressure until the entire water is vaporized.

[i] What is the mass of the water?
[ii] What is the final temperature?
[iii] Determine the total enthalpy change.
[iv] Show the process on a T-v diagram with respect to saturation lines.

[b] Suatu peranti omboh-silinder pada awalnya mengandungi 50 L air pada 40°C dan 200 kPa. Haba dipindahkan kepada air tersebut pada tekanan malar sehingga keseluruhan air terwap.

[i] Apakah jisim air tersebut?
[ii] Apakah suhu akhir?
[iii] Tentukan jumlah perubahan entalpi.
[iv] Tunjukkan proses tersebut pada satu gambarajah T-v dengan merujuk kepada garisan tepu.

[8 marks/markah]

[c] A frictionless piston-cylinder device contains 2 kg of nitrogen at 100 kPa and 300 K. The nitrogen is then compressed slowly according to the relation $PV^{1.4}$ = constant until it reaches a final temperature of 360 K. Calculate the work input during this process.

[c] Suatu peranti omboh-silinder tanpa geseran mengandungi 2 kg nitrogen pada 100 kPa dan 300 K. Nitrogen tersebut kemudiannya dimampatkan secara perlahan menurut hubungan $PV^{1.4}$ = malar sehingga ianya mencapai suhu akhir 360 K. Kirakan input kerja semasa proses ini berlaku.

[5 marks/markah]

[d] Complete the following table for water.

[d] Lengkapkan jadual berikut untuk air.

T,°C	P, kPa	v,m^3/kg	Phase description *Huraian fasa*
	12.352		Saturated mixture *Campuran tepu*
120.21		0.8858	
250	400		
110	600		

[4 marks/markah]

[e] Explain the difference between the macroscopic and microscopic forms of energy.

[e] Terangkan perbezaan antara tenaga makroskop dan mikroskop.

[3 marks/markah]

2. [a] Water is maintained at a constant pressure of 400 kPa while the temperature changes from 20°C to 400°C. Calculate the heat transfer and the entropy change.

2. [a] Air dikekalkan pada tekanan malar 400 kPa sementara suhu berubah dari 20°C ke 400°C. Kirakan pemindahan haba dan perubahan entropi.

[4 marks/markah]

[b] Calculate the pressure of steam at a temperature of 500°C and a density of 24 kg/m^3 using ideal gas law and steam table.

[b] Kirakan tekanan stim pada suhu 500°C dan ketumpatan 24 kg/m^3 dengan menggunakan hukum gas unggul dan jadual stim.

[4 marks/markah]

[c] A mass of 5 kg of saturated water vapor at 300 kPa is heated at constant pressure until the temperature reaches 200°C. Calculate the work done by the steam during this process.

[c] Wap air tepu dengan jisim 5 kg pada 300 kPa dipanaskan pada tekanan malar sehingga suhu mencecah 200°C. Kirakan kerja yang dilakukan oleh stim semasa proses ini berlaku.

[4 marks/markah]

[d] A 600 MW steam power generator, which is cooled by a nearby river, has a thermal efficiency of 40 percent. Determine the rate of heat transfer to the river water. Will the actual heat transfer rate be higher or lower than this value? Why?

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[d] *Sebuah penjana kuasa stim 600 MW yang disejukkan oleh sungai berdekatan mempunyai kecekapan haba 40 peratus. Tentukan kadar pemindahan haba ke air sungai. Adakah kadar pemindahan haba sebenar lebih tinggi atau rendah daripada nilai ini? Kenapa?*

[5 marks/markah]

[e] Determine the h_{fg} of refrigerant R134a at 10°C on the basis of the Clapeyron equation

[e] *Tentukan h_{fg} bagi bahan pendingin R134a pada 10°C berasaskan persamaan Clapeyron*

$$h_{fg} = T\, v_{fg} \left(\frac{\partial P}{\partial T}\right)_{v = v_0}$$

[4 marks/markah]

[f] What is the zeroth law of the thermodynamics?

[f] *Apakah hukum sifar termodinamik?*

[2 marks/markah]

[g] What is the difference between the critical point and the triple point?

[g] *Apakah perbezaan antara titik genting dengan titik tigaan?*

[2 marks/markah]

3. [a] Verify the validity of the Maxwell relation of the equation $\left(\frac{\partial S}{\partial P}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P$ for water at 250°C and 300 kPa.

3. *[a]* *Sahkan kesahihan hubungan Maxwell bagi persamaan* $\left(\frac{\partial S}{\partial P}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P$ *untuk air pada 250°C dan 300 kPa.*

[4 marks/markah]

[b] A Carnot heat engine receives 650 kJ of heat from a source of unknown temperature and rejects 250 kJ of it to a sink at 24°C. Determine the temperature of the source and the thermal efficiency of the heat engine.

[b] *Sebuah enjin haba Carnot menerima 650 kJ haba daripada suatu sumber yang tidak diketahui suhunya dan membuang 250 kJ daripada haba tersebut kepada suatu sink pada 24°C. Tentukan suhu sumber dan kecekapan haba enjin haba.*

[5 marks/markah]

[c] A frictionless piston provides a constant pressure of 400 kPa in a cylinder containing refrigerant R134a with an initial quality of 80 percent. Calculate the final temperature if 80 kJ/g of heat is transferred to the cylinder?

[c] *Suatu omboh tanpa geseran membekalkan tekanan malar 400 kPa di dalam suatu silinder yang mengandungi bahan pendingin R134a dengan mutu awal 80 peratus. Kirakan suhu akhir jika 80 kJ/g haba dipindahkan kepada silinder tersebut?*

[4 marks/markah]

[d] Complete the following table for refrigerant R134a.

[d] Lengkapkan jadual berikut bagi bahan pendingin R134a.

T,°C	P,kPa	h, m^3/kg	x	Phase description *Huraian fasa*
	600	180		
-10			0.6	
-14	500			

[4 marks/markah]

[e] A stone falls from rest with neglible interaction with its surroundings (no friction). Determine its velocity after it falls 5 m.

[e] Sebutir batu jatuh dari keadaan diam dengan saling tindakan yang boleh diabaikan dengan persekitarannya (tiada geseran). Tentukan halajunya setelah ia jatuh 5 m.

[4 marks/markah]

[f] What is the physical significance of the compressibility factor of gases?

[f] Apakah kepentingan fizikal faktor kebolehmampatan gas?

[2 marks/markah]

[g] In what forms can energy cross the boundaries of a closed system?

[g] Dalam bentuk apakah tenaga boleh merentasi sempadan suatu sistem tertutup?

[2 marks/markah]

Section B : Answer any TWO questions.
Bahagian B : Jawab mana-mana DUA soalan.

4. [a] Compute the standard heat of reaction for the hydrogenation of benzene to cyclohexane,

$$C_6H_6\,(\ell) + 3H_2\,(g) \rightarrow C_6H_{12}\,(\ell)$$

from the standard-heat-of-combustion data.

4. [a] Hitungkan haba tindak balas piawai penghidrogenan benzena ke sikloheksana,

$$C_6H_6\,(c) + 3H_2\,(g) \rightarrow C_6H_{12}\,(c)$$

dari data haba pembakaran piawai.

[7 marks/markah]

[b] A steam turbine in a small electric power plant is designed to acept 4500 kg/hr of steam at 60 bar and 500°C and exhaust the steam at 10 bar. Assuming that the turbine is adiabatic and has been well designed $\left(\dot{S}_{gen} = 0\right)$, compute the exit temperature of the steam and the power generated by the turbine.

[b] Satu turbin stim di dalam satu loji janakuasa elektrik kecil direkabentuk untuk menerima 4500 kg/jam stim pada 60 bar dan 500°C dan stim keluar pada 10 bar. Andaikan turbin ini adiabatik dan telah direka dengan baik $\left(\dot{S}_{gen} = 0\right)$, *hitungkan suhu keluaran stim dan kuasa yang dijana oleh stim.*

[8 marks/markah]

[c] Figure Q.4.[c] shows a simple liquefaction process without recycle. It is desired to produce liquefied natural gas (LNG), which is considered to be pure methane, from that gas at 1 bar and 280 K (condition at point 1). Leaving the cooler, methane is at 100 bar and 210 K (point 3). The flask drum is adiabatic and operates at 1 bar, and the compressor can be assumed to operate reversibly and adiabatically. However, because of the large pressure change, a three-stage compressor with intercooling is used. The first stage compresses the gas from 1 bar to 5 bar, the second stage from 5 bar to 25 bar, and the third stage from 25 bar to 100 bar. Between stages the gas is isobarically cooled to 280K.

Calculate the amount of work required for each kilogram of methane that passes through the compressor in the simple liquefaction process.

[c] Rajah S.4.[c] menunjukkan satu proses pencairan ringkas tanpa kitaran semula. Adalah dikehendaki untuk menghasilkan gas asli cecair (LNG), (metana tulen) dari gas tersebut pada 1 bar dan 280 K (keadaan pada titik 1). Meninggalkan penyejuk, metana berada pada 100 bar dan 210 K (titik 3). Tong kelalang adalah adiabatik dan beroperasi pada 1 bar, dan pemampat boleh diandaikan beroperasi secara boleh balik dan adiabatik. Walaubagaimanapun disebabkan oleh perubahan tekanan yang besar, satu pemampat tiga-peringkat dengan penyejuk saling hubung telah digunakan. Peringkat pertama memampat gas dari 1 bar ke 5 bar, peringkat kedua dari 5 bar ke 25 bar, dan peringkat ketiga dari 25 bar ke 100 bar. Antara peringkat gas disejukkan secara setekanan ke 280K.

Kirakan jumlah kerja diperlukan untuk setiap kilogram metana yang melalui pemampat dalam proses pencecairan mudah.

[10 marks/markah]

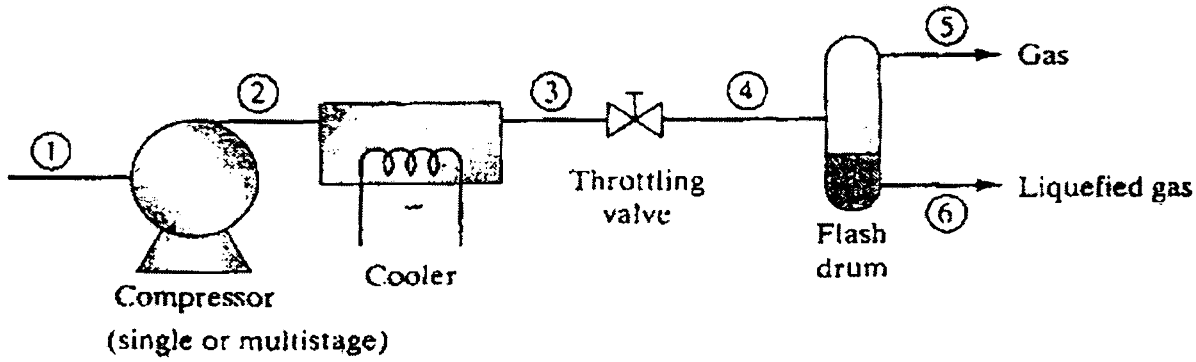

Figure Q.4.[c] : A simple liquefaction process without recycle.
Rajah S.4.[c] : Proses Pencecairan mudah tanpa kitaran semula.

5. [a] If the heat of combution of $(NH_2)_2$ CO (s), at 25°C is 631, 660 J/mol when the products are CO_2 (g), H_2O (ℓ) and N_2(g). What is $\Delta H_{f_{298}}$ for urea?

5. [a] Jika haba pembakaran $(NH_2)_2$ CO (p), pada 25°C ialah 631, 660 J/mol apabila produknya adalah CO_2 (g), H_2O (c) dan N_2(g). Apakah $\Delta H_{f_{298}}$ untuk urea?

[10 marks/markah]

[b] Define fugacity and fugacity coefficient.

[b] Difinasikan fugasiti dan pekali fugasiti.

[5 marks/markah]

[c] Compute the fugacity of liquid water at 300°C and 25 MPa.

[c] Hitungkan fugasiti cecair air pada 300°C dan 25 MPa.

[10 marks/markah]

6. [a] Define refrigeration and liquefaction.

6. [a] Definasikan penyejukan dan pencecairan.

[5 marks/markah]

[b] VLE data for methyl tert-butyl ether (1)/dichloromethane (2) at 308.15 K are given in Table Q.6.[b].

[b] Data VLE untuk metil tert-butil eter (1)/diklorometana (2) pada 308.15 K diberikan dalam Jadual S.6.[b].

Table Q.6.[b]
Jadual S.6.[b]

P/kPa	x_1	y_1	P/kPa	x_1	y_1
85.265	0.0000	0.0000	59.651	0.5036	0.3686
83.402	0.0330	0.0141	56.833	0.5749	0.4564
82.202	0.0579	0.0253	53.689	0.6736	0.5882
80.481	0.0924	0.0416	51.620	0.7676	0.7176
76.719	0.1665	0.0804	50.455	0.8476	0.8238
72.422	0.2482	0.1314	49.926	0.9093	0.9002
68.005	0.3322	0.1975	49.720	0.9529	0.9502
65.096	0.3880	0.2457	49.624	1.0000	1.0000

The data are well correlated by the three-parameter Margules equation
Data tersekait dengan baik oleh Persamaan Margules tiga-parameter

$$\frac{G^E}{RT} = (A_{21}x_1 + A_{12}x_2 - Cx_1x_2)x_1x_2$$

Implied by this equation are the expressions:
Persamaan terlibat adalah:

$$\ln \gamma_1 = x_2^2\left[A_{12} + 2(A_{21} - A_{12} - C)x_1 + 3Cx_1^2\right]$$

$$\ln \gamma_2 = x_1^2\left[A_{21} + 2(A_{12} - A_{21} - C)x_2 + 3Cx_2^2\right]$$

[i] Prepare a plot of $\ln\gamma_1$, γ_2 and G^E / x_1x_2RT vs. x_1 showing both the correlation and experimental values.

[i] Sediakan plot $\ln\gamma_1$, γ_2 dan G^E / x_1x_2RT melawan x_1 menunjukkan kedua-dua nilai sekaitan dan ujikaji.

[ii] Prepare a P – x – y diagram that compares the experimental data with the correlation determined in [ii].

[ii] Sediakan satu rajah P – x – y yang membandingkan data ujikaji dengan sekaitan yang dihitungkan dalam [ii].

[20 marks/markah]

The values of parameter that provide the best fit of G^E / RT to the data are as follow:

$$A_{12} = -0.336, \quad A_{21} = -0.535, \quad C = 0.195$$

Nilai-nilai parameter yang menyediakan padanan terbaik oleh G^E / RT kepada data adalah seperti di bawah:

$$A_{12} = -0.336, \quad A_{21} = -0.535, \quad C = 0.195$$

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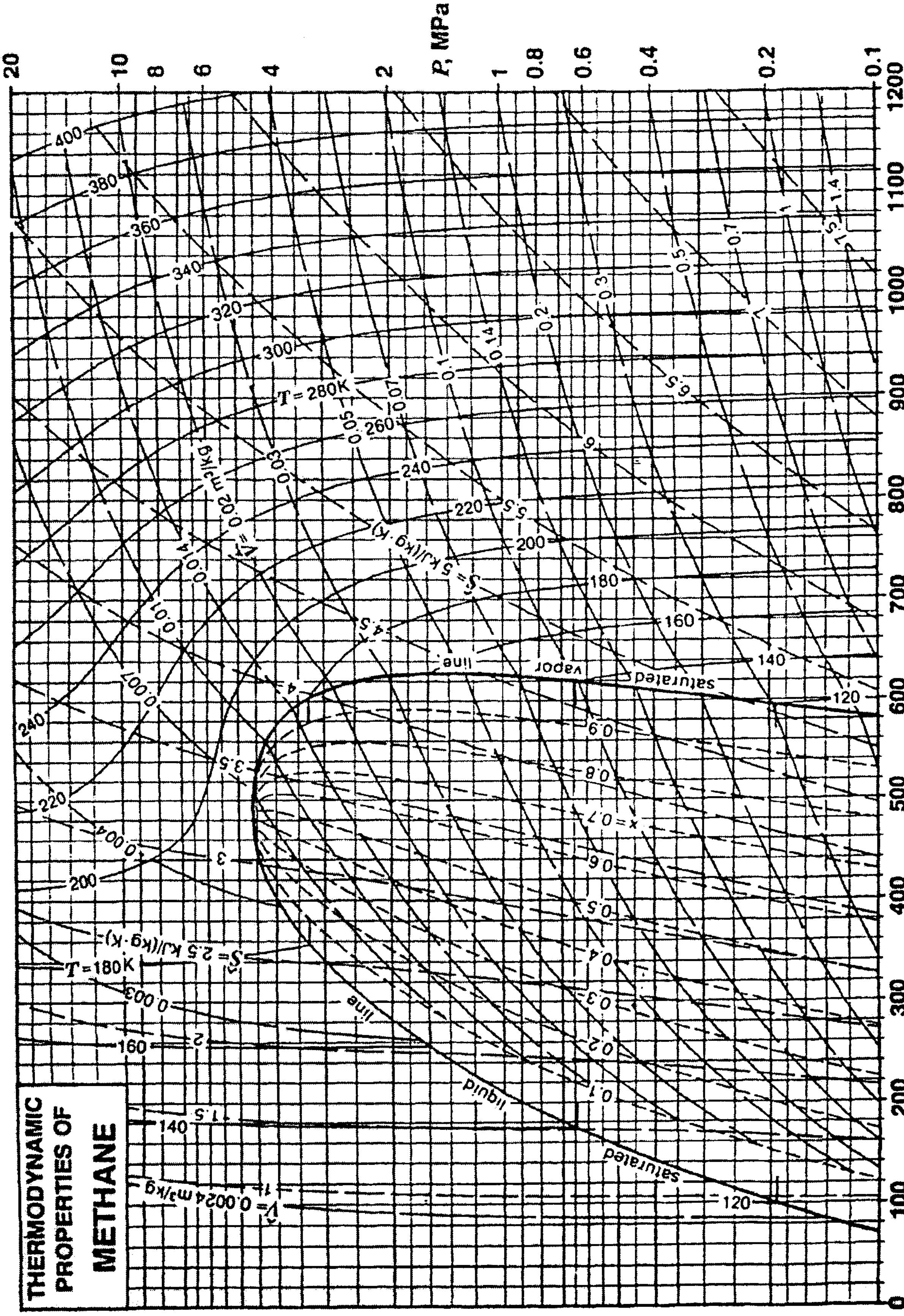
Appendix
Lampiran

Compound	Formula	State	Heat of Combustion in kJ/mol: H_2O (l) CO_2 (g)	Heat of Combustion in kJ/mol: H_2O (g) CO_2 (g)
Hydrogen	H_2	(g)	285.840	241.826
Carbon	C	(s, graphite)	393.513	—
Carbon monoxide	CO	(g)	282.989	—
Methane	CH_4	(g)	890.35	802.32
Ethane	C_2H_6	(g)	1559.88	1427.84
Propane	C_3H_8	(g)	2220.05	2044.00
Propane	C_3H_8	(l)	2204.06	2028.00
n-Butane	C_4H_{10}	(g)	2878.52	2658.45
n-Butane	C_4H_{10}	(l)	2857.02	2636.95
2-Methylpropane (isobutane)	C_4H_{10}	(g)	2871.65	2651.58
2-Methylpropane (isobutane)	C_4H_{10}	(l)	2851.92	2631.85
n-Pentane	C_5H_{12}	(g)	3536.15	3272.06
n-Pentane	C_5H_{12}	(l)	3509.54	3245.45
n-Hexane	C_6H_{14}	(g)	4194.75	3886.64
n-Hexane	C_6H_{14}	(l)	4163.12	3855.01
n-Heptane	C_7H_{16}	(g)	4853.48	4501.36
n-Heptane	C_7H_{16}	(l)	4816.91	4464.79
n-Octane	C_8H_{18}	(g)	5512.21	5116.07
n-Octane	C_8H_{18}	(l)	5470.71	5074.56
n-Nonane	C_9H_{20}	(g)	6170.98	5730.82
n-Nonane	C_9H_{20}	(l)	6124.54	5684.38
n-Decane	$C_{10}H_{22}$	(g)	6829.71	6345.58
n-Decane	$C_{10}H_{22}$	(l)	6778.33	6294.20
n-Dodecane	$C_{12}H_{26}$	(g)	8147.21	7575.05
n-Dodecane	$C_{12}H_{26}$	(l)	8085.96	7513.79
n-Hexadecane	$C_{16}H_{34}$	(g)	10782.17	10033.94
n-Hexadecane	$C_{16}H_{34}$	(l)	10701.17	9952.94
n-Eicosane	$C_{20}H_{42}$	(g)	13417.13	12492.84
n-Eicosane	$C_{20}H_{42}$	(l)	13316.37	12392.09
Benzene	C_6H_6	(g)	3301.51	3169.46
Benzene	C_6H_6	(l)	3267.62	3135.57
Methylbenzene (toluene)	C_7H_8	(g)	3947.94	3771.88
Methylbenzene (toluene)	C_7H_8	(l)	3909.95	3733.89

Appendix A.V (*Continued*)

Compound	Formula	State	Heat of Combustion in kJ/mol H_2O (l) CO_2 (g)	H_2O (g) CO_2 (g)
Ethylbenzene	C_8H_{10}	(g)	4607.13	4387.05
Ethylbenzene	C_8H_{10}	(l)	4564.87	4344.79
1,2-Dimethylbenzene (*o*-xylene)	C_8H_{10}	(g)	4596.29	4376.21
1,2-Dimethylbenzene (*o*-xylene)	C_8H_{10}	(l)	4552.86	4332.78
1,3-Dimethylbenzene (*m*-xylene)	C_8H_{10}	(g)	4594.53	4374.46
1,3-Dimethylbenzene (*m*-xylene)	C_8H_{10}	(l)	4551.86	4331.78
1,4-Dimethylbenzene (*p*-xylene)	C_8H_{10}	(g)	4595.25	4375.17
1,4-Dimethylbenzene (*p*-xylene)	C_8H_{10}	(l)	4552.86	4332.78
Cyclopentane	C_5H_{10}	(g)	3319.54	3099.47
Cyclopentane	C_5H_{10}	(l)	3290.88	3070.80
Methylcyclopentane	C_6H_{12}	(g)	3969.44	3705.35
Methylcyclopentane	C_6H_{12}	(l)	3937.73	3673.64
Cyclohexane	C_6H_{12}	(g)	3953.00	3688.91
Cyclohexane	C_6H_{12}	(l)	3919.91	3655.81
Methylcyclohexane	C_7H_{14}	(g)	4600.68	4292.57
Methylcyclohexane	C_7H_{14}	(l)	4565.29	4257.18
Ethene (ethylene)	C_2H_4	(g)	1410.99	1322.96
Propene (propylene)	C_3H_6	(g)	2058.47	1926.43
1-Butene	C_4H_8	(g)	2718.58	2542.53
Ethyne (acetylene)	C_2H_2	(g)	1299.61	1255.60
Propyne (methylacetylene)	C_3H_4	(g)	1937.65	1849.62
1-Butyne (ethylacetylene)	C_4H_6	(g)	2597.68	2465.64
2-Butyne (dimethylacetylene)	C_4H_6	(g)	2579.57	2447.53


THERMODYNAMIC
PROPERTIES OF
METHANE
P, MPa
Ĥ, kJ/kg
saturated liquid line
saturated vapor line