UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2010/2011 Academic Session

April/May 2011

# EKC 222 – Chemical Engineering Thermodynamics
## *[Termodinamik Kejuruteraan Kimia]*

Duration : 3 hours
*[Masa : 3 jam]*

Please ensure that this examination paper contains SEVEN printed pages and FOUR printed page of Appendix before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi TUJUH muka surat yang bercetak dan EMPAT muka surat Lampiran sebelum anda memulakan peperiksaan ini.]*

**Instruction:** Answer **ALL** questions.

*[**Arahan:** Jawab **SEMUA** soalan.]*

In the event of any discrepancies, the English version shall be used.

*[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai].*

**Booklet of Thermodynamic Tables are provided.**
*Buku Jadual Termodinamik akan dibekalkan.*

1. [a] Answer the following questions in your own words:
*Jawab soalan-soalan berikut dengan perkataan anda sendiri:*

[i] As a consequence of thermal equilibrium, Zeroth Law of Thermodynamics can be defined and it serves as the working principle for thermometer. Explain why a piece of ice will melt in a glass of water under the context of Zeroth Law.

*Lanjutan dari keseimbangan terma, Hukum Termodinamik Sifar boleh ditakrifkan dan berfungsi sebagai prinsip kerja untuk termometer. Jelaskan mengapa seketul ais akan cair dalam segelas air di bawah Hukum Termodinamik Sifar.*

*[2 marks/markah]*

[ii] According to the 1st Law of Thermodynamics energy is always conserved. However, for exothermic reaction, energy is released to the surrounding. Explain why exothermic reaction is not violating the 1st Law.

*Menurut Hukum Termodinamik Pertama, tenaga selalunya diabadikan. Walau bagaimanapun, untuk tindak balas eksotermik, tenaga dilepaskan ke persekitaran. Jelaskan mengapa tindak balas eksotermik tidak melanggar Hukum Termodinamik Pertama.*

*[2 marks/markah]*

[iii] According to Clausius statement of 2nd Law of Thermodynamics, the entropy of the universe tends to a maximum. Explain why this statement leads to the impossibility of perpetual motion machine.

*Menurut kenyataan Clausius, bagi Hukum Termodinamik Kedua, entropi alam sekitar cenderung ke arah maksimum. Jelaskan mengapa kenyataan ini menjurus kepada ketidakmungkinan mesin gerak abadi.*

*[2 marks/markah]*

[b] For an ideal gas with constant heat capacities, show that
*Untuk gas unggul dengan muatan haba malar, tunjukkan:*

[i] For a temperature change from $T_1$ to $T_2$, $\Delta S$ of the gas is greater when the change occurs at constant pressure than when it occurs at constant volume.

*Bagi pertukaran suhu dari $T_1$ ke $T_2$, $\Delta S$ untuk gas ini m engalami perubahan lebih besar pada tekanan malar berbanding perubahan pada isipadu malar.*

[ii] For a pressure change from $P_1$ to $P_2$, the sign of $\Delta S$ for an isothermal changes is opposite that for a constant volume change.

*Bagi pertukaran tekanan dari $P_1$ ke $P_2$, tanda untuk $\Delta S$ bagi perubahan sesuhu adalah bertentangan dengan perubahan pada isipadu malar.*

Hint:
*Petunjuk:*

$$\Delta S = C_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right)$$

*[8 marks/markah]*

[c] Steam enters a nozzle at 4 MPa and 640 ºC with velocity of 20 m/s. This process may be considered reversible and adiabatic. The nozzle exit pressure is 0.1 MPa.

*Stim memasuki muncung pada 4 MPa dan 640 ºC dengan kelajuan 20 m/s. Proses ini adalah proses berbalik dan adiabatik. Tekanan keluaran muncung ini ialah 0.1 MPa.*

[i] Draw a sketch of this process. Include all known information.
*Lukiskan satu gambar rajah dengan semua informasi yang dibekalkan untuk mewakili proses ini.*

[ii] What is the entropy change of the stream?
*Apakah perubahan entropi untuk arus ini?*

[iii] What is the exit temperature?
*Apakah suhu keluaran?*

[iv] What is the exit velocity?
*Apakah kelajuan keluaran?*

*[11 marks/markah]*

2. [a] Briefly explain the phase change from point 1 to point 4 using Figure Q.2.[a].
*Terangkan dengan ringkas perubahan fasa dari titik 1 ke titik 4 menggunakan Rajah S.2.[a].*

*[3 marks/markah]*

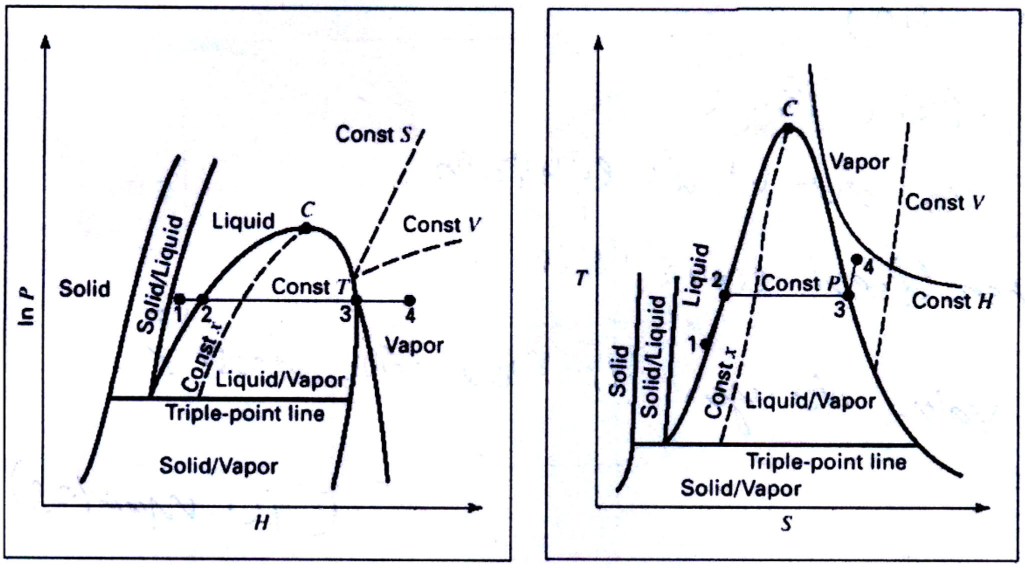


Figure Q.2.[a]
*Rajah S.2.[a]*

[b] What is the difference between
*Apakah perbezaan antara*

[i] a refrigerator and a heat pump
*peti sejuk dan pam haba*

[ii] a refrigerator and an air conditioner
*peti sejuk dan penyaman udara*

*[2 marks/markah]*

[c] Air enters the compressor of an ideal gas refrigeration cycle at 12°C and 50 kPa and the turbine at 47°C and 250 kPa. The mass flow rate of air through the cycle is 0.08 kg/s. Assuming variable specific heat for air, determine

*Udara memasuki pemampat suatu kitar penyejuk gas unggul pada 12°C dan 50 kPa dan sebuah turbin pada 47°C dan 250 kPa. Kadar aliran jisim udara melalui kitaran ialah 0.08 kg/s. Andaikan haba tentu bagi udara berubah, kirakan*

[i] the rate of refrigeration
*kadar penyejukkan*

[ii] the net power input, and
*masukan kuasa bersih, dan*

[iii] the coefficient of performance
*pekali prestasi*

*[10 marks/markah]*

[d] Calculate the fugacity of water at 647 K and 114 atm using
*Kirakan fugasiti air pada 647 K dan 114 atm menggunakan*

[i] the steam table
*jadual stim*

[ii] the van der Waals equation
*persamaan van der Waals*

[iii] generalized correlation
*sekaitan umum*

Which value do you believe the most? Justify.
*Nilai manakah yang anda paling percaya? Wajarkan jawapan anda.*

*[10 marks/markah]*

3. [a] In his book *The Trouble Waters*, Henry Morris an American young earth creationist proclaims:

*Dalam bukunya "The Trouble Waters", Henry Morris seorang pemuda Amerika yang mempercayai penciptaan bumi menyatakan:*

"The Law of increasing entropy is an impenetrable barrier which no evolutionary mechanism yet suggested has ever been able to overcome. Evolution and entropy are opposing and mutually exclusive concepts. If the entropy principle is really a universal law, then evolution must be impossible."

*"Hukum termodinamik tentang peningkatan entropi merupakan sekatan tak terbatas yang bertentangan dengan mekanisma evolusi. Evolusi dan entropi adalah dua konsep yang bertentangan dan tidak bersetujui di antara satu sama lain. Jika prinsip entropi adalah suatu hukum universal yang benar, maka evolusi mestilah mustahil."*

Is this argument scientifically sound? Explain.
*Adakah hujah ini saintifik? Jelaskan.* *[5 marks/markah]*

[b] Calculate the change in entropy when 1 mol of water is heated from 250 K to 290 K, given that the molar heat capacities at constant pressure $(C_p)_{\text{ice}}$ = 2.09 + 0.126$T$ [J/K] and $(C_p)_{\text{water}}$ = 75.3 J/K and the heat of melting $(\Delta H)_{\text{m}}$ = 6000 J/mol. (Hint: Melting point of water at 273 K, hence, the water is undergoing phase transition).

*Kirakan perubahan entropi apabila 1 mol air dipanaskan dari 250 K ke 290 K. Diberi muatan haba pada tekanan malar $(C_p)_{ais}$ = 2.09 + 0.126T [J/K] dan $(C_p)_{air}$ = 75.3 [J/K] dengan tenaga haba pencairan $(\Delta H)_m$ = 6000 J/mol. (Petunjuk: Suhu pencairan air ialah 273 K, justeru air mengalami perubahan fasa).*

Given: $\Delta H = nC_p dT$
*Diberi:*

*[6 marks/markah]*

[c] The equation of state of a van der Waals gas is given by
*Persamaan keadaan untuk gas van der Waals diberikan sebagai*

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT$$ Equation 3.1

*Persamaan 3.1*

Derive mathematical expressions for $W$, $\Delta U$, $Q$ and $\Delta H$ of this gas for an isothermal reversible expansion from an initial volume $V_1$ to final volume $V_2$. (Hint: $\left[\partial U / \partial V\right]_T = a / V^2$)

*Terbitkan perhubungan matematik untuk* $W$, $\Delta U$, $Q$ *dan* $\Delta H$ *untuk gas ini yang mengalami perkembangan berbalik sesuhu dari isipadu* $V_1$ *kepada* $V_2$. *(Petunjuk:* $\left[\partial U / \partial V\right]_T = a / V^2$*)*

*[14 marks/markah]*

4. [a] Briefly explain the use of the following equipments:
*Terangkan dengan ringkas kegunaan peralatan di bawah:*

[i] Turbine
*Turbin*

[ii] Compressor
*Pemampat*

[iii] Throttle valve
*Injap pendikit*

[iv] Expander
*Pengembang*

[v] Condenser
*Pemeluwap*

[vi] Evaporator
*Penyejat*

*[6 marks/markah]*

[b] Figure Q.4.[b] is a plot of the natural log of the activity coefficient (*In γi*) of a binary liquid mixture of species *a* and *b* vs. mole fraction of species a ($x_a$) at 300K.

*Rajah S.4.[b] ialah plot log asli pekali aktiviti* (In γi) *bagi satu campuran cecair binari* a *dan* b *melawan pecahan mol spesis* a ($x_a$) *pada 300K.*

[i] What is the reference state for each species?
*Apakah keadaan rujukan untuk setiap sepsis?*

[ii] Show that the Gibbs-Duham equation is satisfied at $x_a = 0.6$.
*Tunjukkan bahawa persamaan Gibbs-Duham dipatuhi pada* $x_a = 0.6$.

[iii] Come up with an appropriate model for $g^E$ for this system and find the value of the model parameters.

*Terbitkan model yang sesuai untuk $g^E$ bagi sistem ini, dan dapatkan nilai untuk parameter model.*

[iv] Is it possible for species *a* and *b* to separate into two liquid phase? Explain.
*Mungkinkah spesis* a *dan* b *dipisahkan kepada dua fasa cecair? Terangkan.*

*[19 marks/markah]*

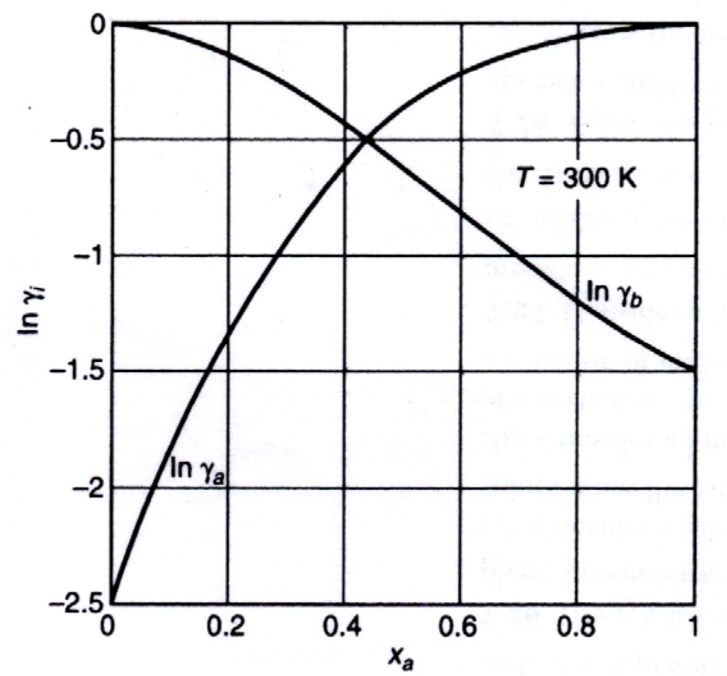


Figure Q.4.[b].
Rajah S.4.[b].

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<u>Appendix</u>

## Table A.2: Values of the Universal Gas Constant

$$R = 8.314\ \text{J mol}^{-1}\ \text{K}^{-1} = 8.314\ \text{m}^3\ \text{Pa mol}^{-1}\ \text{K}^{-1}$$
$$= 83.14\ \text{cm}^3\ \text{bar mol}^{-1}\ \text{K}^{-1} = 8{,}314\ \text{cm}^3\ \text{kPa mol}^{-1}\ \text{K}^{-1}$$
$$= 82.06\ \text{cm}^3\text{(atm) mol}^{-1}\ \text{K}^{-1} = 62{,}356\ \text{cm}^3\text{(torr) mol}^{-1}\ \text{K}^{-1}$$
$$= 1.987\text{(cal) mol}^{-1}\ \text{K}^{-1} = 1.986\text{(Btu)(lb mole)}^{-1}\text{(R)}^{-1}$$
$$= 0.7302\text{(ft)}^3\text{(atm)(lb mol)}^{-1}\text{(R)}^{-1} = 10.73\text{(ft)}^3\text{(psia)(lb mol)}^{-1}\text{(R)}^{-1}$$
$$= 1{,}545\text{(ft)(lb}_f\text{)(lb mol)}^{-1}\text{(R)}^{-1}$$

(H [=] kJ/kg, S [=] kJ/kgK)

**Table F.2. Superheated Steam, SI Units** (Continued)

| $P$/kPa ($t^{sat}$/°C) | | sat. liq. | sat. vap. | TEMPERATURE: $t$ °C (TEMPERATURE: $T$ kelvins) 425 (698.15) | 450 (723.15) | 475 (748.15) | 500 (773.15) | 525 (798.15) | 550 (823.15) | 600 (873.15) | 650 (923.15) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2400 (221.78) | $V$ | 1.193 | 83.199 | 130.44 | 135.61 | 140.73 | 145.82 | 150.88 | 155.91 | 165.92 | 175.86 |
| | $U$ | 949.066 | 2600.7 | 2984.5 | 3027.1 | 3069.9 | 3112.9 | 3156.1 | 3199.6 | 3287.7 | 3377.2 |
| | $H$ | 951.929 | 2800.4 | 3297.5 | 3352.6 | 3407.7 | 3462.9 | 3518.2 | 3573.8 | 3685.9 | 3799.3 |
| | $S$ | 2.5343 | 6.2690 | 7.1189 | 7.1964 | 7.2713 | 7.3439 | 7.4144 | 7.4830 | 7.6152 | 7.7414 |
| 2500 (223.94) | $V$ | 1.197 | 79.905 | 125.07 | 130.04 | 134.97 | 139.87 | 144.74 | 149.58 | 159.21 | 168.76 |
| | $U$ | 958.969 | 2601.2 | 2983.4 | 3026.2 | 3069.0 | 3112.1 | 3155.4 | 3198.9 | 3287.1 | 3376.7 |
| | $H$ | 961.962 | 2800.9 | 3296.1 | 3351.3 | 3406.5 | 3461.7 | 3517.2 | 3572.9 | 3685.1 | 3798.6 |
| | $S$ | 2.5543 | 6.2536 | 7.0986 | 7.1763 | 7.2513 | 7.3240 | 7.3946 | 7.4633 | 7.5956 | 7.7220 |
| 2600 (226.04) | $V$ | 1.201 | 76.856 | 120.11 | 124.91 | 129.66 | 134.38 | 139.07 | 143.74 | 153.01 | 162.21 |
| | $U$ | 968.597 | 2601.5 | 2982.3 | 3025.2 | 3068.1 | 3111.2 | 3154.6 | 3198.2 | 3286.5 | 3376.1 |
| | $H$ | 971.720 | 2801.4 | 3294.6 | 3349.9 | 3405.3 | 3460.6 | 3516.2 | 3571.9 | 3684.3 | 3797.9 |
| | $S$ | 2.5736 | 6.2387 | 7.0789 | 7.1568 | 7.2320 | 7.3048 | 7.3755 | 7.4443 | 7.5768 | 7.7033 |
| 2700 (228.07) | $V$ | 1.205 | 74.025 | 115.52 | 120.15 | 124.74 | 129.30 | 133.82 | 138.33 | 147.27 | 156.14 |
| | $U$ | 977.968 | 2601.8 | 2981.2 | 3024.2 | 3067.2 | 3110.4 | 3153.8 | 3197.5 | 3285.8 | 3375.6 |
| | $H$ | 981.222 | 2801.7 | 3293.1 | 3348.6 | 3404.0 | 3459.5 | 3515.2 | 3571.0 | 3683.5 | 3797.1 |
| | $S$ | 2.5924 | 6.2244 | 7.0600 | 7.1381 | 7.2134 | 7.2863 | 7.3571 | 7.4260 | 7.5587 | 7.6853 |
| 2800 (230.05) | $V$ | 1.209 | 71.389 | 111.25 | 115.74 | 120.17 | 124.58 | 128.95 | 133.30 | 141.94 | 150.50 |
| | $U$ | 987.100 | 2602.1 | 2980.2 | 3023.2 | 3066.3 | 3109.6 | 3153.1 | 3196.8 | 3285.2 | 3375.0 |
| | $H$ | 990.485 | 2802.0 | 3291.7 | 3347.3 | 3402.8 | 3458.4 | 3514.1 | 3570.0 | 3682.6 | 3796.4 |
| | $S$ | 2.6106 | 6.2104 | 7.0416 | 7.1199 | 7.1954 | 7.2685 | 7.3394 | 7.4084 | 7.5412 | 7.6679 |
| 2900 (231.97) | $V$ | 1.213 | 68.928 | 107.28 | 111.62 | 115.92 | 120.18 | 124.42 | 128.62 | 136.97 | 145.26 |
| | $U$ | 996.008 | 2602.3 | 2979.1 | 3022.3 | 3065.5 | 3108.8 | 3152.3 | 3196.1 | 3284.6 | 3374.5 |
| | $H$ | 999.524 | 2802.2 | 3290.2 | 3346.0 | 3401.6 | 3457.3 | 3513.1 | 3569.1 | 3681.8 | 3795.7 |
| | $S$ | 2.6283 | 6.1969 | 7.0239 | 7.1024 | 7.1780 | 7.2512 | 7.3222 | 7.3913 | 7.5243 | 7.6511 |
| 3000 (233.84) | $V$ | 1.216 | 66.626 | 103.58 | 107.79 | 111.95 | 116.08 | 120.18 | 124.26 | 132.34 | 140.36 |
| | $U$ | 1004.7 | 2602.4 | 2978.0 | 3021.3 | 3064.6 | 3107.9 | 3151.5 | 3195.4 | 3284.0 | 3373.9 |
| | $H$ | 1008.4 | 2802.3 | 3288.7 | 3344.6 | 3400.4 | 3456.2 | 3512.1 | 3568.1 | 3681.0 | 3795.0 |
| | $S$ | 2.6455 | 6.1837 | 7.0067 | 7.0854 | 7.1612 | 7.2345 | 7.3056 | 7.3748 | 7.5079 | 7.6349 |
| 3100 (235.67) | $V$ | 1.220 | 64.467 | 100.11 | 104.20 | 108.24 | 112.24 | 116.22 | 120.17 | 128.01 | 135.78 |
| | $U$ | 1013.2 | 2602.5 | 2976.9 | 3020.3 | 3063.7 | 3107.1 | 3150.8 | 3194.7 | 3283.3 | 3373.4 |
| | $H$ | 1017.0 | 2802.3 | 3287.3 | 3343.3 | 3399.2 | 3455.1 | 3511.0 | 3567.2 | 3680.2 | 3794.3 |
| | $S$ | 2.6623 | 6.1709 | 6.9900 | 7.0689 | 7.1448 | 7.2183 | 7.2895 | 7.3588 | 7.4920 | 7.6191 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *V* | 1.224 | 62.439 | 96.859 | 100.83 | 104.76 | 108.65 | 112.51 | 116.34 | 123.95 | 131.48 |
| 3200 | *U* | 1021.5 | 2602.5 | 2975.9 | 3019.3 | 3062.8 | 3106.3 | 3150.0 | 3193.9 | 3282.7 | 3372.8 |
| (237.45) | *H* | 1025.4 | 2802.3 | 3285.8 | 3342.0 | 3398.0 | 3454.0 | 3510.0 | 3566.2 | 3679.3 | 3793.6 |
| | *S* | 2.6786 | 6.1585 | 6.9738 | 7.0528 | 7.1290 | 7.2026 | 7.2739 | 7.3433 | 7.4767 | 7.6039 |
| | *V* | 1.227 | 60.529 | 93.805 | 97.668 | 101.49 | 105.27 | 109.02 | 112.74 | 120.13 | 127.45 |
| 3300 | *U* | 1029.7 | 2602.5 | 2974.8 | 3018.3 | 3061.9 | 3105.5 | 3149.2 | 3193.2 | 3282.1 | 3372.3 |
| (239.18) | *H* | 1033.7 | 2802.3 | 3284.3 | 3340.6 | 3396.8 | 3452.8 | 3509.0 | 3565.3 | 3678.5 | 3792.9 |
| | *S* | 2.6945 | 6.1463 | 6.9580 | 7.0373 | 7.1136 | 7.1873 | 7.2588 | 7.3282 | 7.4618 | 7.5891 |
| | *V* | 1.231 | 58.728 | 90.930 | 94.692 | 98.408 | 102.09 | 105.74 | 109.36 | 116.54 | 123.65 |
| 3400 | *U* | 1037.6 | 2602.5 | 2973.7 | 3017.4 | 3061.0 | 3104.6 | 3148.4 | 3192.5 | 3281.5 | 3371.7 |
| (240.88) | *H* | 1041.8 | 2802.1 | 3282.8 | 3339.3 | 3395.5 | 3451.7 | 3507.9 | 3564.3 | 3677.7 | 3792.1 |
| | *S* | 2.7101 | 6.1344 | 6.9426 | 7.0221 | 7.0986 | 7.1724 | 7.2440 | 7.3136 | 7.4473 | 7.5747 |
| | *V* | 1.235 | 57.025 | 88.220 | 91.886 | 95.505 | 99.088 | 102.64 | 106.17 | 113.15 | 120.07 |
| 3500 | *U* | 1045.4 | 2602.4 | 2972.6 | 3016.4 | 3060.1 | 3103.8 | 3147.7 | 3191.8 | 3280.8 | 3371.2 |
| (242.54) | *H* | 1049.8 | 2802.0 | 3281.3 | 3338.0 | 3394.3 | 3450.6 | 3506.9 | 3563.4 | 3676.9 | 3791.4 |
| | *S* | 2.7253 | 6.1228 | 6.9277 | 7.0074 | 7.0840 | 7.1580 | 7.2297 | 7.2993 | 7.4332 | 7.5607 |
| | *V* | 1.238 | 55.415 | 85.660 | 89.236 | 92.764 | 96.255 | 99.716 | 103.15 | 109.96 | 116.69 |
| 3600 | *U* | 1053.1 | 2602.2 | 2971.5 | 3015.4 | 3059.2 | 3103.0 | 3146.9 | 3191.1 | 3280.2 | 3370.6 |
| (244.16) | *H* | 1057.6 | 2801.7 | 3279.8 | 3336.6 | 3393.1 | 3449.5 | 3505.9 | 3562.4 | 3676.1 | 3790.7 |
| | *S* | 2.7401 | 6.1115 | 6.9131 | 6.9930 | 7.0698 | 7.1439 | 7.2157 | 7.2854 | 7.4195 | 7.5471 |
| | *V* | 1.242 | 53.888 | 83.238 | 86.728 | 90.171 | 93.576 | 96.950 | 100.30 | 106.93 | 113.49 |
| 3700 | *U* | 1060.6 | 2602.1 | 2970.4 | 3014.4 | 3058.2 | 3102.1 | 3146.1 | 3190.4 | 3279.6 | 3370.1 |
| (245.75) | *H* | 1065.2 | 2801.4 | 3278.4 | 3335.3 | 3391.9 | 3448.4 | 3504.9 | 3561.5 | 3675.2 | 3790.0 |
| | *S* | 2.7547 | 6.1004 | 6.8989 | 6.9790 | 7.0559 | 7.1302 | 7.2021 | 7.2719 | 7.4061 | 7.5339 |
| | *V* | 1.245 | 52.438 | 80.944 | 84.353 | 87.714 | 91.038 | 94.330 | 97.596 | 104.06 | 110.46 |
| 3800 | *U* | 1068.0 | 2601.9 | 2969.3 | 3013.4 | 3057.3 | 3101.3 | 3145.4 | 3189.6 | 3279.0 | 3369.5 |
| (247.31) | *H* | 1072.7 | 2801.1 | 3276.8 | 3333.9 | 3390.7 | 3447.2 | 3503.8 | 3560.5 | 3674.4 | 3789.3 |
| | *S* | 2.7689 | 6.0896 | 6.8849 | 6.9653 | 7.0424 | 7.1168 | 7.1888 | 7.2587 | 7.3931 | 7.5210 |
| | *V* | 1.249 | 51.061 | 78.767 | 82.099 | 85.383 | 88.629 | 91.844 | 95.033 | 101.35 | 107.59 |
| 3900 | *U* | 1075.3 | 2601.6 | 2968.2 | 3012.4 | 3056.4 | 3100.5 | 3144.6 | 3188.9 | 3278.3 | 3369.0 |
| (248.84) | *H* | 1080.1 | 2800.8 | 3275.3 | 3332.6 | 3389.4 | 3446.1 | 3502.8 | 3559.5 | 3673.6 | 3788.6 |
| | *S* | 2.7828 | 6.0789 | 6.8713 | 6.9519 | 7.0292 | 7.1037 | 7.1759 | 7.2459 | 7.3804 | 7.5084 |
| | *V* | 1.252 | 49.749 | 76.698 | 79.958 | 83.169 | 86.341 | 89.483 | 92.598 | 98.763 | 104.86 |
| 4000 | *U* | 1082.4 | 2601.3 | 2967.0 | 3011.4 | 3055.5 | 3099.6 | 3143.8 | 3188.2 | 3277.7 | 3368.4 |
| (250.33) | *H* | 1087.4 | 2800.3 | 3273.8 | 3331.2 | 3388.2 | 3445.0 | 3501.7 | 3558.6 | 3672.8 | 3787.9 |
| | *S* | 2.7965 | 6.0685 | 6.8581 | 6.9388 | 7.0163 | 7.0909 | 7.1632 | 7.2333 | 7.3680 | 7.4961 |

**Table F.2: Superheated Steam, SI Units**

| P/kPa ($t^{sat}$/°C) | | sat. liq. | sat. vap. | 75 (348.15) | 100 (373.15) | 125 (398.15) | 150 (423.15) | 175 (448.15) | 200 (473.15) | 225 (498.15) | 250 (523.15) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | TEMPERATURE: $t$ °C (TEMPERATURE: $T$ kelvins) | | | | | | | |
| 1 (6.98) | V | 1.000 | 129200. | 160640. | 172180. | 183720. | 195270. | 206810. | 218350. | 229890. | 241430. |
| | U | 29.334 | 2385.2 | 2480.8 | 2516.4 | 2552.3 | 2588.5 | 2624.9 | 2661.7 | 2698.8 | 2736.3 |
| | H | 29.335 | 2514.4 | 2641.5 | 2688.6 | 2736.0 | 2783.7 | 2831.7 | 2880.1 | 2928.7 | 2977.7 |
| | S | 0.1060 | 8.9767 | 9.3828 | 9.5136 | 9.6365 | 9.7527 | 9.8629 | 9.9679 | 10.0681 | 10.1641 |
| 10 (45.83) | V | 1.010 | 14670. | 16030. | 17190. | 18350. | 19510. | 20660. | 21820. | 22980. | 24130. |
| | U | 191.822 | 2438.0 | 2479.7 | 2515.6 | 2551.6 | 2588.0 | 2624.5 | 2661.4 | 2698.6 | 2736.1 |
| | H | 191.832 | 2584.8 | 2640.0 | 2687.5 | 2735.2 | 2783.1 | 2831.2 | 2879.6 | 2928.4 | 2977.4 |
| | S | 0.6493 | 8.1511 | 8.3168 | 8.4486 | 8.5722 | 8.6888 | 8.7994 | 8.9045 | 9.0049 | 9.1010 |
| 20 (60.09) | V | 1.017 | 7649.8 | 8000.0 | 8584.7 | 9167.1 | 9748.0 | 10320. | 10900. | 11480. | 12060. |
| | U | 251.432 | 2456.9 | 2478.4 | 2514.6 | 2550.9 | 2587.4 | 2624.1 | 2661.0 | 2698.3 | 2735.8 |
| | H | 251.453 | 2609.9 | 2638.4 | 2686.3 | 2734.2 | 2782.3 | 2830.6 | 2879.2 | 2928.0 | 2977.1 |
| | S | 0.8321 | 7.9094 | 7.9933 | 8.1261 | 8.2504 | 8.3676 | 8.4785 | 8.5839 | 8.6844 | 8.7806 |
| 30 (69.12) | V | 1.022 | 5229.3 | 5322.0 | 5714.4 | 6104.6 | 6493.2 | 6880.8 | 7267.5 | 7653.8 | 8039.7 |
| | U | 289.271 | 2468.6 | 2477.1 | 2513.6 | 2550.2 | 2586.8 | 2623.6 | 2660.7 | 2698.0 | 2735.6 |
| | H | 289.302 | 2625.4 | 2636.8 | 2685.1 | 2733.3 | 2781.6 | 2830.0 | 2878.7 | 2927.6 | 2976.8 |
| | S | 0.9441 | 7.7695 | 7.8024 | 7.9363 | 8.0614 | 8.1791 | 8.2903 | 8.3960 | 8.4967 | 8.5930 |
| 40 (75.89) | V | 1.027 | 3993.4 | ....... | 4279.2 | 4573.3 | 4865.8 | 5157.2 | 5447.8 | 5738.0 | 6027.7 |
| | U | 317.609 | 2477.1 | ....... | 2512.6 | 2549.4 | 2586.2 | 2623.2 | 2660.3 | 2697.7 | 2735.4 |
| | H | 317.650 | 2636.9 | ....... | 2683.8 | 2732.3 | 2780.9 | 2829.5 | 2878.2 | 2927.2 | 2976.5 |
| | S | 1.0261 | 7.6709 | ....... | 7.8009 | 7.9268 | 8.0450 | 8.1566 | 8.2624 | 8.3633 | 8.4598 |
| 50 (81.35) | V | 1.030 | 3240.2 | ....... | 3418.1 | 3654.5 | 3889.3 | 4123.0 | 4356.0 | 4588.5 | 4820.5 |
| | U | 340.513 | 2484.0 | ....... | 2511.7 | 2548.6 | 2585.6 | 2622.7 | 2659.9 | 2697.4 | 2735.1 |
| | H | 340.564 | 2646.0 | ....... | 2682.6 | 2731.4 | 2780.1 | 2828.9 | 2877.7 | 2926.8 | 2976.1 |
| | S | 1.0912 | 7.5947 | ....... | 7.6953 | 7.8219 | 7.9406 | 8.0526 | 8.1587 | 8.2598 | 8.3564 |
| 75 (91.79) | V | 1.037 | 2216.9 | ....... | 2269.8 | 2429.4 | 2587.3 | 2744.2 | 2900.2 | 3055.8 | 3210.9 |
| | U | 384.374 | 2496.7 | ....... | 2509.2 | 2546.7 | 2584.2 | 2621.6 | 2659.0 | 2696.7 | 2734.5 |
| | H | 384.451 | 2663.0 | ....... | 2679.4 | 2728.9 | 2778.2 | 2827.4 | 2876.6 | 2925.8 | 2975.3 |
| | S | 1.2131 | 7.4570 | ....... | 7.5014 | 7.6300 | 7.7500 | 7.8629 | 7.9697 | 8.0712 | 8.1681 |
| 100 (99.63) | V | 1.043 | 1693.7 | ....... | 1695.5 | 1816.7 | 1936.3 | 2054.7 | 2172.3 | 2289.4 | 2406.1 |
| | U | 417.406 | 2506.1 | ....... | 2506.6 | 2544.8 | 2582.7 | 2620.4 | 2658.1 | 2695.9 | 2733.9 |
| | H | 417.511 | 2675.4 | ....... | 2676.2 | 2726.5 | 2776.3 | 2825.9 | 2875.4 | 2924.9 | 2974.5 |
| | S | 1.3027 | 7.3598 | ....... | 7.3618 | 7.4923 | 7.6137 | 7.7275 | 7.8349 | 7.9369 | 8.0342 |

**Table F.2. Superheated Steam, SI Units** (Continued)

| | | | | TEMPERATURE: $t$ °C (TEMPERATURE: $T$ kelvins) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $P$/kPa | | sat. | sat. | 300 | 350 | 400 | 450 | 500 | 550 | 600 | 650 |
| ($t^{sat}$/°C) | | liq. | vap. | (573.15) | (623.15) | (673.15) | (723.15) | (773.15) | (823.15) | (873.15) | (923.15) |
| | $V$ | 1.000 | 129200. | 264500. | 287580. | 310660. | 333730. | 356810. | 379880. | 402960. | 426040. |
| 1 | $U$ | 29.334 | 2385.2 | 2812.3 | 2889.9 | 2969.1 | 3049.9 | 3132.4 | 3216.7 | 3302.6 | 3390.3 |
| (6.98) | $H$ | 29.335 | 2514.4 | 3076.8 | 3177.5 | 3279.7 | 3383.6 | 3489.2 | 3596.5 | 3705.6 | 3816.4 |
| | $S$ | 0.1060 | 8.9767 | 10.3450 | 10.5133 | 10.6711 | 10.8200 | 10.9612 | 11.0957 | 11.2243 | 11.3476 |
| | $V$ | 1.010 | 14670. | 26440. | 28750. | 31060. | 33370. | 35670. | 37980. | 40290. | 42600. |
| 10 | $U$ | 191.822 | 2438.0 | 2812.2 | 2889.8 | 2969.0 | 3049.8 | 3132.3 | 3216.6 | 3302.6 | 3390.3 |
| (45.83) | $H$ | 191.832 | 2584.8 | 3076.6 | 3177.3 | 3279.6 | 3383.5 | 3489.1 | 3596.5 | 3705.5 | 3816.3 |
| | $S$ | 0.6493 | 8.1511 | 9.2820 | 9.4504 | 9.6083 | 9.7572 | 9.8984 | 10.0329 | 10.1616 | 10.2849 |
| | $V$ | 1.017 | 7649.8 | 13210. | 14370. | 15520. | 16680. | 17830. | 18990. | 20140. | 21300. |
| 20 | $U$ | 251.432 | 2456.9 | 2812.0 | 2889.6 | 2968.9 | 3049.7 | 3132.3 | 3216.5 | 3302.5 | 3390.2 |
| (60.09) | $H$ | 251.453 | 2609.9 | 3076.4 | 3177.1 | 3279.4 | 3383.4 | 3489.0 | 3596.4 | 3705.4 | 3816.2 |
| | $S$ | 0.8321 | 7.9094 | 8.9618 | 9.1303 | 9.2882 | 9.4372 | 9.5784 | 9.7130 | 9.8416 | 9.9650 |
| | $V$ | 1.022 | 5229.3 | 8810.8 | 9581.2 | 10350. | 11120. | 11890. | 12660. | 13430. | 14190. |
| 30 | $U$ | 289.271 | 2468.6 | 2811.8 | 2889.5 | 2968.7 | 3049.6 | 3132.2 | 3216.5 | 3302.5 | 3390.2 |
| (69.12) | $H$ | 289.302 | 2625.4 | 3076.1 | 3176.9 | 3279.3 | 3383.3 | 3488.9 | 3596.3 | 3705.4 | 3816.2 |
| | $S$ | 0.9441 | 7.7695 | 8.7744 | 8.9430 | 9.1010 | 9.2499 | 9.3912 | 9.5257 | 9.6544 | 9.7778 |
| | $V$ | 1.027 | 3993.4 | 6606.5 | 7184.6 | 7762.5 | 8340.1 | 8917.6 | 9494.9 | 10070. | 10640. |
| 40 | $U$ | 317.609 | 2477.1 | 2811.6 | 2889.4 | 2968.6 | 3049.5 | 3132.1 | 3216.4 | 3302.4 | 3390.1 |
| (75.89) | $H$ | 317.650 | 2636.9 | 3075.9 | 3176.8 | 3279.1 | 3383.1 | 3488.8 | 3596.2 | 3705.3 | 3816.1 |
| | $S$ | 1.0261 | 7.6709 | 8.6413 | 8.8100 | 8.9680 | 9.1170 | 9.2583 | 9.3929 | 9.5216 | 9.6450 |
| | $V$ | 1.030 | 3240.2 | 5283.9 | 5746.7 | 6209.1 | 6671.4 | 7133.5 | 7595.5 | 8057.4 | 8519.2 |
| 50 | $U$ | 340.513 | 2484.0 | 2811.5 | 2889.2 | 2968.5 | 3049.4 | 3132.0 | 3216.3 | 3302.3 | 3390.1 |
| (81.35) | $H$ | 340.564 | 2646.0 | 3075.7 | 3176.6 | 3279.0 | 3383.0 | 3488.7 | 3596.1 | 3705.2 | 3816.0 |
| | $S$ | 1.0912 | 7.5947 | 8.5380 | 8.7068 | 8.8649 | 9.0139 | 9.1552 | 9.2898 | 9.4185 | 9.5419 |
| | $V$ | 1.037 | 2216.9 | 3520.5 | 3829.4 | 4138.0 | 4446.4 | 4754.7 | 5062.8 | 5370.9 | 5678.9 |
| 75 | $U$ | 384.374 | 2496.7 | 2811.0 | 2888.9 | 2968.2 | 3049.2 | 3131.8 | 3216.1 | 3302.2 | 3389.9 |
| (91.79) | $H$ | 384.451 | 2663.0 | 3075.1 | 3176.1 | 3278.6 | 3382.7 | 3488.4 | 3595.8 | 3705.0 | 3815.9 |
| | $S$ | 1.2131 | 7.4570 | 8.3502 | 8.5191 | 8.6773 | 8.8265 | 8.9678 | 9.1025 | 9.2312 | 9.3546 |
| | $V$ | 1.043 | 1693.7 | 2638.7 | 2870.8 | 3102.5 | 3334.0 | 3565.3 | 3796.5 | 4027.7 | 4258.8 |
| 100 | $U$ | 417.406 | 2506.1 | 2810.6 | 2888.6 | 2968.0 | 3049.0 | 3131.6 | 3216.0 | 3302.0 | 3389.8 |
| (99.63) | $H$ | 417.511 | 2675.4 | 3074.5 | 3175.6 | 3278.2 | 3382.4 | 3488.1 | 3595.6 | 3704.8 | 3815.7 |
| | $S$ | 1.3027 | 7.3598 | 8.2166 | 8.3858 | 8.5442 | 8.6934 | 8.8348 | 8.9695 | 9.0982 | 9.2217 |