# 國立虎尾科技大學 110 學年度第 2 學期博士班資格考試題

系別：動力機械工程系機械與機電工程博士班 

科目：熱力學 Thermodynamics

注意事項：
（1）本試題共有 5 題，任選 5 題作答，每題 20 分，合計 100 分。
（2）請依序作答於答案卷上並註明題號，若未註明選答題號及超過規定題數時，謹採計作答順序較前之題目計分。
（3）可使用計算機 close book and can use calculator

一、Steam at 1.4 MPa, 300°C is flowing in a supply line with different insulated systems attached, as shown in Fig. 1. Valves on the empty systems are opened, they fill up to the supply pressure, and the valves are closed. We neglect kinetic and potential energies and want to determine the final temperature for all three cases.

20%

二、The following data are for a simple steam power plant as shown in Fig. 2. State 6 has $x_6 = 0.92$ and velocity of 200 m/s. The rate of steam flow is 25 kg/s, with 300 kW of power input to the pump. Piping diameters are 200 mm from the steam generator to the turbine and 75 mm from the condenser to the economizer and steam generator. Determine the velocity at state 5 and the power output of the turbine. Also find the rate of heat transfer in the economizer and steam generator. Note that the specific volume at state 5 is 0.06163 $m^3$/kg

20%

三、A steam turbine receives water at 15 MPa, 600°C at a rate of 100 kg/s, as shown in Fig. 3. In the middle section 20 kg/s is withdrawn at 2 MPa, 350°C and the rest exits the turbine at 75 kPa, with 95% quality. Assuming no heat transfer and no changes in kinetic energy, find the total turbine power output.

20%

四、A reversible steady state device, as shown in Fig. 4, receives a flow of 1 kg/s air at 400 K, 450 kPa and the air leaves at 600 K, 100 kPa. Heat transfer of 800 kW is added from a 1000 K reservoir, 100 kW rejected at 350 K and some heat transfer takes place at 500 K. Find the heat transferred at 500 K and the rate of work produced. The entropy change of air can be computed by the following equation with $c_p$ =1.004 kJ/kg-K and R =0.287 kJ/kg-K.

$$S_2 - S_1 = c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$$

20%

五、A two-stage air compressor has an intercooler between the two stages as shown in Fig.5. The inlet state is 100 kPa, 290 K, and the final exit pressure is 1.6 MPa. Assume that the constant pressure intercooler cools the air to the inlet temperature, $T_3 = T_1$. It can be shown that the optimal pressure, $P_2 = (P_1 P_4)^{1/2}$, for minimum total compressor work. Find the specific compressor works and the intercooler heat transfer for the optimal $P_2$. For air, $c_p$ =1.004 kJ/kg-K and $c_v$ =0.717 kJ/kg-K.

20%

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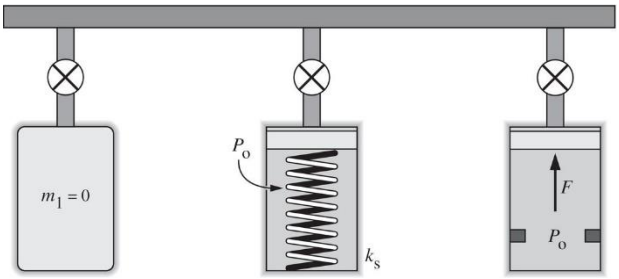
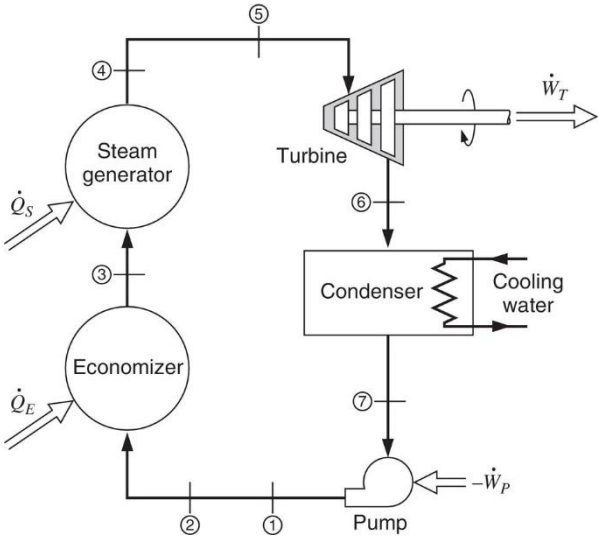



Fig. 1




| State | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $P$, kPa | 6200 | 6100 | 5900 | 5700 | 5500 | 10 | 9 |
| $T$, °C | | 45 | 175 | 500 | 490 | | 40 |
| $h$, kJ/kg | | 194 | 744 | 3426 | 3404 | | 168 |

Fig. 2

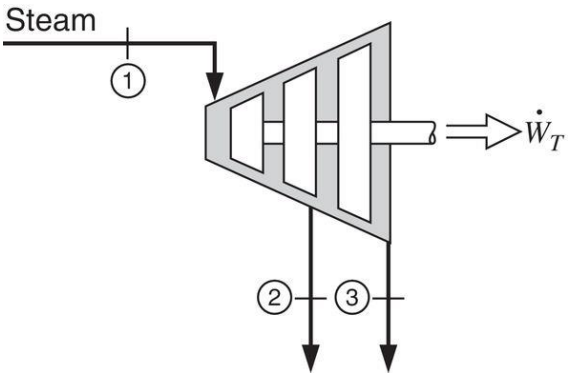



Fig. 3

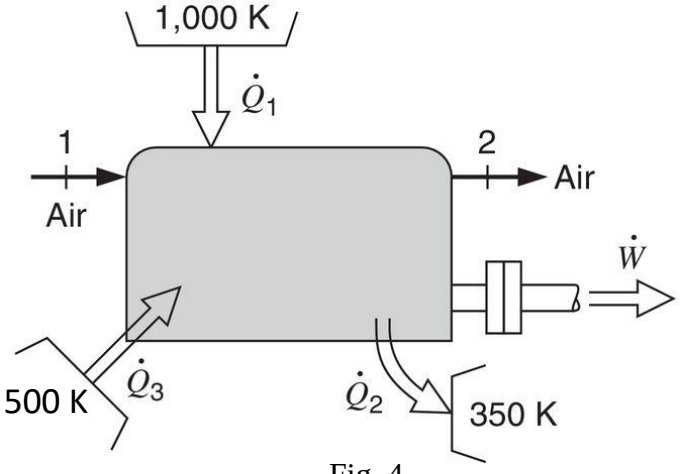



Fig. 4

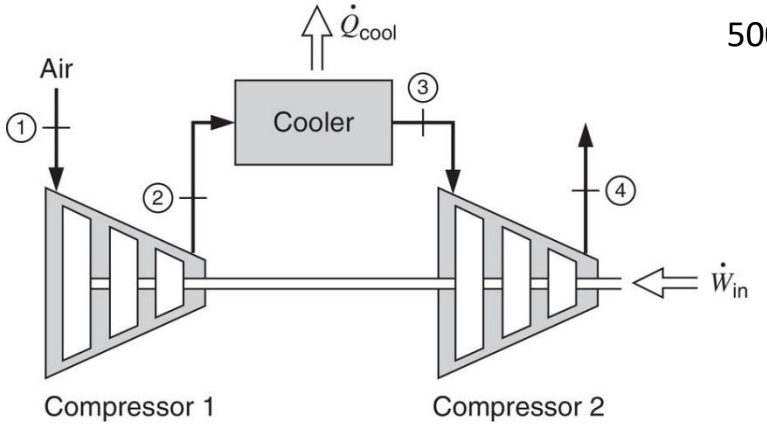



Fig. 5

TABLE B.1.2 Saturated Water Pressure Entry

| Press. (kPa) | Temp. (°C) | Specific Volume, m³/kg | | | Internal Energy, kJ/kg | | |
|---|---|---|---|---|---|---|---|
| | | Sat. Liquid $v_f$ | Evap. $v_{fg}$ | Sat. Vapor $v_g$ | Sat. Liquid $u_f$ | Evap. $u_{fg}$ | Sat. Vapor $u_g$ |
| 0.6113 | 0.01 | 0.001000 | 206.131 | 206.132 | 0 | 2375.3 | 2375.3 |
| 1 | 6.98 | 0.001000 | 129.20702 | 129.20802 | 29.29 | 2355.69 | 2384.98 |
| 1.5 | 13.03 | 0.001001 | 87.97913 | 87.98013 | 54.70 | 2338.63 | 2393.32 |
| 2 | 17.50 | 0.001001 | 67.00285 | 67.00385 | 73.47 | 2326.02 | 2399.48 |
| 2.5 | 21.08 | 0.001002 | 54.25285 | 54.25385 | 88.47 | 2315.93 | 2404.40 |
| 3 | 24.08 | 0.001003 | 45.66402 | 45.66502 | 101.03 | 2307.48 | 2408.51 |
| 4 | 28.96 | 0.001004 | 34.79915 | 34.80015 | 121.44 | 2293.73 | 2415.17 |
| 5 | 32.88 | 0.001005 | 28.19150 | 28.19251 | 137.79 | 2282.70 | 2420.49 |
| 7.5 | 40.29 | 0.001008 | 19.23674 | 19.23775 | 168.76 | 2261.74 | 2430.50 |
| 10 | 45.81 | 0.001010 | 14.67254 | 14.67355 | 191.79 | 2246.10 | 2437.89 |
| 15 | 53.97 | 0.001014 | 10.02117 | 10.02218 | 225.90 | 2222.83 | 2448.73 |
| 20 | 60.06 | 0.001017 | 7.64835 | 7.64937 | 251.35 | 2205.36 | 2456.71 |
| 25 | 64.97 | 0.001020 | 6.20322 | 6.20424 | 271.88 | 2191.21 | 2463.08 |
| 30 | 69.10 | 0.001022 | 5.22816 | 5.22918 | 289.18 | 2179.22 | 2468.40 |
| 40 | 75.87 | 0.001026 | 3.99243 | 3.99345 | 317.51 | 2159.49 | 2477.00 |
| 50 | 81.33 | 0.001030 | 3.23931 | 3.24034 | 340.42 | 2143.43 | 2483.85 |
| 75 | 91.77 | 0.001037 | 2.21607 | 2.21711 | 394.29 | 2112.39 | 2496.67 |
| 100 | 99.62 | 0.001043 | 1.69296 | 1.69400 | 417.33 | 2088.72 | 2506.06 |
| 125 | 105.99 | 0.001048 | 1.37385 | 1.37490 | 444.16 | 2069.32 | 2513.48 |
| 150 | 111.37 | 0.001053 | 1.15828 | 1.15933 | 466.92 | 2052.72 | 2519.64 |
| 175 | 116.06 | 0.001057 | 1.00257 | 1.00363 | 486.78 | 2038.12 | 2524.90 |
| 200 | 120.23 | 0.001061 | 0.88467 | 0.88573 | 504.47 | 2025.02 | 2529.49 |
| 225 | 124.00 | 0.001064 | 0.79219 | 0.79325 | 520.45 | 2013.10 | 2533.56 |
| 250 | 127.43 | 0.001067 | 0.71765 | 0.71871 | 535.08 | 2002.14 | 2537.21 |
| 275 | 130.60 | 0.001070 | 0.65624 | 0.65731 | 548.57 | 1991.95 | 2540.53 |
| 300 | 133.55 | 0.001073 | 0.60475 | 0.60582 | 561.13 | 1982.43 | 2543.55 |
| 325 | 136.30 | 0.001076 | 0.56093 | 0.56201 | 572.88 | 1973.46 | 2546.34 |
| 350 | 138.88 | 0.001079 | 0.52317 | 0.52425 | 583.93 | 1964.98 | 2548.92 |
| 375 | 141.32 | 0.001081 | 0.49029 | 0.49137 | 594.38 | 1956.93 | 2551.31 |
| 400 | 143.63 | 0.001084 | 0.46138 | 0.46246 | 604.29 | 1949.26 | 2553.55 |
| 450 | 147.93 | 0.001088 | 0.41289 | 0.41398 | 622.75 | 1934.87 | 2557.62 |
| 500 | 151.86 | 0.001093 | 0.37380 | 0.37489 | 639.66 | 1921.57 | 2561.23 |
| 550 | 155.48 | 0.001097 | 0.34159 | 0.34268 | 655.30 | 1909.17 | 2564.47 |
| 600 | 158.85 | 0.001101 | 0.31457 | 0.31567 | 669.88 | 1897.52 | 2567.40 |
| 650 | 162.01 | 0.001104 | 0.29158 | 0.29268 | 683.55 | 1886.51 | 2570.06 |
| 700 | 164.97 | 0.001108 | 0.27176 | 0.27286 | 696.43 | 1876.07 | 2572.49 |
| 750 | 167.77 | 0.001111 | 0.25449 | 0.25560 | 708.62 | 1866.11 | 2574.73 |
| 800 | 170.43 | 0.001115 | 0.23931 | 0.24043 | 720.20 | 1856.58 | 2576.79 |



TABLE B.1.2 Saturated Water Pressure Entry (*continued*)

| Press. (kPa) | Temp. (°C) | Enthalpy, kJ/kg | | | Entropy, kJ/kg-K | | |
|---|---|---|---|---|---|---|---|
| | | Sat. Liquid $h_f$ | Evap. $h_{fg}$ | Sat. Vapor $h_g$ | Sat. Liquid $s_f$ | Evap. $s_{fg}$ | Sat. Vapor $s_g$ |
| 0.6113 | 0.01 | 0.00 | 2501.3 | 2501.3 | 0 | 9.1562 | 9.1562 |
| 1.0 | 6.98 | 29.29 | 2484.89 | 2514.18 | 0.1059 | 8.8697 | 8.9756 |
| 1.5 | 13.03 | 54.70 | 2470.59 | 2525.30 | 0.1956 | 8.6322 | 8.8278 |
| 2.0 | 17.50 | 73.47 | 2460.02 | 2533.49 | 0.2607 | 8.4629 | 8.7236 |
| 2.5 | 21.08 | 88.47 | 2451.56 | 2540.03 | 0.3120 | 8.3311 | 8.6431 |
| 3.0 | 24.08 | 101.03 | 2444.47 | 2545.50 | 0.3545 | 8.2231 | 8.5775 |
| 4.0 | 28.96 | 121.44 | 2432.93 | 2554.37 | 0.4226 | 8.0520 | 8.4746 |
| 5.0 | 32.88 | 137.79 | 2423.66 | 2561.45 | 0.4763 | 7.9187 | 8.3950 |
| 7.5 | 40.29 | 168.77 | 2406.02 | 2574.79 | 0.5763 | 7.6751 | 8.2514 |
| 10 | 45.81 | 191.81 | 2392.82 | 2584.63 | 0.6492 | 7.5010 | 8.1501 |
| 15 | 53.97 | 225.91 | 2373.14 | 2599.06 | 0.7548 | 7.2536 | 8.0084 |
| 20 | 60.06 | 251.38 | 2358.33 | 2609.70 | 0.8319 | 7.0766 | 7.9085 |
| 25 | 64.97 | 271.90 | 2346.29 | 2618.19 | 0.8930 | 6.9383 | 7.8313 |
| 30 | 69.10 | 289.21 | 2336.07 | 2625.28 | 0.9439 | 6.8247 | 7.7686 |
| 40 | 75.87 | 317.55 | 2319.19 | 2636.74 | 1.0258 | 6.6441 | 7.6700 |
| 50 | 81.33 | 340.47 | 2305.40 | 2645.87 | 1.0910 | 6.5029 | 7.5939 |
| 75 | 91.77 | 384.36 | 2278.59 | 2662.96 | 1.2129 | 6.2434 | 7.4563 |
| 100 | 99.62 | 417.44 | 2258.02 | 2675.46 | 1.3025 | 6.0568 | 7.3593 |
| 125 | 105.99 | 444.30 | 2241.05 | 2685.35 | 1.3739 | 5.9104 | 7.2843 |
| 150 | 111.37 | 467.08 | 2226.46 | 2693.54 | 1.4335 | 5.7897 | 7.2232 |
| 175 | 116.06 | 486.97 | 2213.57 | 2700.53 | 1.4848 | 5.6868 | 7.1717 |
| 200 | 120.23 | 504.68 | 2201.96 | 2706.63 | 1.5300 | 5.5970 | 7.1271 |
| 225 | 124.00 | 520.69 | 2191.35 | 2712.04 | 1.5705 | 5.5173 | 7.0878 |
| 250 | 127.43 | 535.34 | 2181.55 | 2716.89 | 1.6072 | 5.4455 | 7.0526 |
| 275 | 130.60 | 548.87 | 2172.42 | 2721.29 | 1.6407 | 5.3801 | 7.0208 |
| 300 | 133.55 | 561.45 | 2163.85 | 2725.30 | 1.6717 | 5.3201 | 6.9918 |
| 325 | 136.30 | 573.23 | 2155.76 | 2728.99 | 1.7005 | 5.2646 | 6.9651 |
| 350 | 138.88 | 584.31 | 2148.10 | 2732.40 | 1.7274 | 5.2130 | 6.9404 |
| 375 | 141.32 | 594.79 | 2140.79 | 2735.58 | 1.7527 | 5.1647 | 6.9174 |
| 400 | 143.63 | 604.73 | 2133.81 | 2738.53 | 1.7766 | 5.1193 | 6.8958 |
| 450 | 147.93 | 623.24 | 2120.67 | 2743.91 | 1.8206 | 5.0359 | 6.8565 |
| 500 | 151.86 | 640.21 | 2108.47 | 2748.67 | 1.8606 | 4.9606 | 6.8212 |
| 550 | 155.48 | 655.91 | 2097.04 | 2752.94 | 1.8972 | 4.8920 | 6.7892 |
| 600 | 158.85 | 670.54 | 2086.26 | 2756.80 | 1.9311 | 4.8289 | 6.7600 |
| 650 | 162.01 | 684.26 | 2076.04 | 2760.30 | 1.9627 | 4.7704 | 6.7330 |
| 700 | 164.97 | 697.20 | 2066.30 | 2763.50 | 1.9922 | 4.7158 | 6.7080 |
| 750 | 167.77 | 709.45 | 2056.98 | 2766.43 | 2.0199 | 4.6647 | 6.6846 |
| 800 | 170.43 | 721.10 | 2048.04 | 2769.13 | 2.0461 | 4.6166 | 6.6627 |

TABLE B.1.3 Superheated Vapor Water (*continued*)

| Temp. (°C) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) |
|---|---|---|---|---|---|---|---|---|
| | 800 kPa (170.43°C) | | | | 1000 kPa (179.91°C) | | | |
| 700 | 0.56007 | 3476.22 | 3924.27 | 8.3770 | 0.44779 | 3475.35 | 3923.14 | 8.2731 |
| 800 | 0.61813 | 3661.14 | 4155.65 | 8.6033 | 0.49432 | 3660.46 | 4154.78 | 8.4996 |
| 900 | 0.67610 | 3852.77 | 4393.65 | 8.8153 | 0.54075 | 3852.19 | 4392.94 | 8.7118 |
| 1000 | 0.73401 | 4051.00 | 4638.20 | 9.0153 | 0.58712 | 4050.49 | 4637.60 | 8.9119 |
| 1100 | 0.79188 | 4255.57 | 4889.08 | 9.2049 | 0.63345 | 4255.09 | 4888.55 | 9.1016 |
| 1200 | 0.84974 | 4466.05 | 5145.85 | 9.3854 | 0.67977 | 4465.58 | 5145.36 | 9.2821 |
| 1300 | 0.90758 | 4681.81 | 5407.87 | 9.5575 | 0.72608 | 4681.33 | 5407.41 | 9.4542 |
| | 1200 kPa (187.99°C) | | | | 1400 kPa (195.07°C) | | | |
| Sat. | 0.16333 | 2588.82 | 2784.82 | 6.5233 | 0.14084 | 2592.83 | 2790.00 | 6.4692 |
| 200 | 0.16930 | 2612.74 | 2815.90 | 6.5898 | 0.14302 | 2603.09 | 2803.32 | 6.4975 |
| 250 | 0.19235 | 2704.20 | 2935.01 | 6.8293 | 0.16350 | 2698.32 | 2927.22 | 6.7467 |
| 300 | 0.21382 | 2789.22 | 3045.80 | 7.0316 | 0.18228 | 2785.16 | 3040.35 | 6.9533 |
| 350 | 0.23452 | 2872.16 | 3153.59 | 7.2120 | 0.20026 | 2869.12 | 3149.49 | 7.1359 |
| 400 | 0.25480 | 2954.90 | 3260.66 | 7.3773 | 0.21780 | 2952.50 | 3257.42 | 7.3025 |
| 500 | 0.29463 | 3122.72 | 3476.28 | 7.6758 | 0.25215 | 3121.10 | 3474.11 | 7.6026 |
| 600 | 0.33393 | 3295.60 | 3696.32 | 7.9434 | 0.28596 | 3294.44 | 3694.78 | 7.8710 |
| 700 | 0.37294 | 3474.48 | 3922.01 | 8.1881 | 0.31947 | 3473.61 | 3920.87 | 8.1160 |
| 800 | 0.41177 | 3659.77 | 4153.90 | 8.4149 | 0.35281 | 3659.09 | 4153.03 | 8.3431 |
| 900 | 0.45051 | 3851.62 | 4392.23 | 8.6272 | 0.38606 | 3851.05 | 4391.53 | 8.5555 |
| 1000 | 0.48919 | 4049.98 | 4637.00 | 8.8274 | 0.41924 | 4049.47 | 4636.41 | 8.7558 |
| 1100 | 0.52783 | 4254.61 | 4888.02 | 9.0171 | 0.45239 | 4254.14 | 4887.49 | 8.9456 |
| 1200 | 0.56646 | 4465.12 | 5144.87 | 9.1977 | 0.48552 | 4464.65 | 5144.38 | 9.1262 |
| 1300 | 0.60507 | 4680.86 | 5406.95 | 9.3698 | 0.51864 | 4680.39 | 5406.49 | 9.2983 |
| | 1600 kPa (201.40°C) | | | | 1800 kPa (207.15°C) | | | |
| Sat. | 0.12380 | 2595.95 | 2794.02 | 6.4217 | 0.11042 | 2598.38 | 2797.13 | 6.3793 |
| 250 | 0.14184 | 2692.26 | 2919.20 | 6.6732 | 0.12497 | 2686.02 | 2910.96 | 6.6066 |
| 300 | 0.15862 | 2781.03 | 3034.83 | 6.8844 | 0.14021 | 2776.83 | 3029.21 | 6.8226 |
| 350 | 0.17456 | 2866.05 | 3145.35 | 7.0693 | 0.15457 | 2862.95 | 3141.18 | 7.0099 |
| 400 | 0.19005 | 2950.09 | 3254.17 | 7.2373 | 0.16847 | 2947.66 | 3250.90 | 7.1793 |
| 500 | 0.22029 | 3119.47 | 3471.93 | 7.5389 | 0.19550 | 3117.84 | 3469.75 | 7.4824 |
| 600 | 0.24998 | 3293.27 | 3693.23 | 7.8080 | 0.22199 | 3292.10 | 3691.69 | 7.7523 |
| 700 | 0.27937 | 3472.74 | 3919.73 | 8.0535 | 0.24818 | 3471.87 | 3918.59 | 7.9983 |
| 800 | 0.30859 | 3658.40 | 4152.15 | 8.2808 | 0.27420 | 3657.71 | 4151.27 | 8.2258 |
| 900 | 0.33772 | 3850.47 | 4390.82 | 8.4934 | 0.30012 | 3849.90 | 4390.11 | 8.4386 |
| 1000 | 0.36678 | 4048.96 | 4635.81 | 8.6938 | 0.32598 | 4048.45 | 4635.21 | 8.6390 |
| 1100 | 0.39581 | 4253.66 | 4886.95 | 8.8837 | 0.35180 | 4253.18 | 4886.42 | 8.8290 |
| 1200 | 0.42482 | 4464.18 | 5143.89 | 9.0642 | 0.37761 | 4463.71 | 5143.40 | 9.0096 |
| 1300 | 0.45382 | 4679.92 | 5406.02 | 9.2364 | 0.40340 | 4679.44 | 5405.56 | 9.1817 |



TABLE B.1.3 Superheated Vapor Water (*continued*)

| Temp. (°C) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) |
|---|---|---|---|---|---|---|---|---|
| | 2000 kPa (212.42°C) | | | | 2500 kPa (223.99°C) | | | |
| Sat. | 0.09963 | 2600.26 | 2799.51 | 6.3408 | 0.07998 | 2603.13 | 2803.07 | 6.2574 |
| 250 | 0.11144 | 2679.58 | 2902.46 | 6.5452 | 0.08700 | 2662.55 | 2880.06 | 6.4084 |
| 300 | 0.12547 | 2772.56 | 3023.50 | 6.7663 | 0.09890 | 2761.56 | 3008.81 | 6.6437 |
| 350 | 0.13857 | 2859.81 | 3136.96 | 6.9562 | 0.10976 | 2851.84 | 3126.24 | 6.8402 |
| 400 | 0.15120 | 2945.21 | 3247.60 | 7.1270 | 0.12010 | 2939.03 | 3239.23 | 7.0147 |
| 450 | 0.16353 | 3030.41 | 3357.48 | 7.2844 | 0.13014 | 3025.43 | 3350.77 | 7.1745 |
| 500 | 0.17568 | 3116.20 | 3467.55 | 7.4316 | 0.13998 | 3112.08 | 3462.04 | 7.3233 |
| 600 | 0.19960 | 3290.93 | 3690.14 | 7.7023 | 0.15930 | 3287.99 | 3686.25 | 7.5960 |
| 700 | 0.22323 | 3470.99 | 3917.45 | 7.9487 | 0.17832 | 3468.80 | 3914.59 | 7.8435 |
| 800 | 0.24668 | 3657.03 | 4150.40 | 8.1766 | 0.19716 | 3655.30 | 4148.20 | 8.0720 |
| 900 | 0.27004 | 3849.33 | 4389.40 | 8.3895 | 0.21590 | 3847.89 | 4387.64 | 8.2853 |
| 1000 | 0.29333 | 4047.94 | 4634.61 | 8.5900 | 0.23458 | 4046.67 | 4633.12 | 8.4860 |
| 1100 | 0.31659 | 4252.71 | 4885.89 | 8.7800 | 0.25322 | 4251.52 | 4884.57 | 8.6761 |
| 1200 | 0.33984 | 4463.25 | 5142.92 | 8.9606 | 0.27185 | 4462.08 | 5141.70 | 8.8569 |
| 1300 | 0.36306 | 4678.97 | 5405.10 | 9.1328 | 0.29046 | 4677.80 | 5403.95 | 9.0291 |
| | 3000 kPa (233.90°C) | | | | 4000 kPa (250.40°C) | | | |
| Sat. | 0.06668 | 2604.10 | 2804.14 | 6.1869 | 0.04978 | 2602.27 | 2801.38 | 6.0700 |
| 250 | 0.07058 | 2644.00 | 2855.75 | 6.2871 | — | — | — | — |
| 300 | 0.08114 | 2750.05 | 2993.48 | 6.5389 | 0.05884 | 2725.33 | 2960.68 | 6.3614 |
| 350 | 0.09053 | 2843.66 | 3115.25 | 6.7427 | 0.06645 | 2826.65 | 3092.43 | 6.5820 |
| 400 | 0.09936 | 2932.75 | 3230.82 | 6.9211 | 0.07341 | 2919.88 | 3213.51 | 6.7689 |
| 450 | 0.10787 | 3020.38 | 3344.00 | 7.0833 | 0.08003 | 3010.13 | 3330.23 | 6.9362 |
| 500 | 0.11619 | 3107.92 | 3456.48 | 7.2337 | 0.08643 | 3099.49 | 3445.21 | 7.0900 |
| 600 | 0.13243 | 3285.03 | 3682.34 | 7.5084 | 0.09885 | 3279.06 | 3674.44 | 7.3688 |
| 700 | 0.14838 | 3466.59 | 3911.72 | 7.7571 | 0.11095 | 3462.15 | 3905.94 | 7.6198 |
| 800 | 0.16414 | 3653.58 | 4146.00 | 7.9862 | 0.12287 | 3650.11 | 4141.59 | 7.8502 |
| 900 | 0.17980 | 3846.46 | 4385.87 | 8.1999 | 0.13469 | 3843.59 | 4382.34 | 8.0647 |
| 1000 | 0.19541 | 4045.40 | 4631.63 | 8.4009 | 0.14645 | 4042.87 | 4628.65 | 8.2661 |
| 1100 | 0.21098 | 4250.33 | 4883.26 | 8.5911 | 0.15817 | 4247.96 | 4880.63 | 8.4566 |
| 1200 | 0.22652 | 4460.92 | 5140.49 | 8.7719 | 0.16987 | 4458.60 | 5138.07 | 8.6376 |
| 1300 | 0.24206 | 4676.63 | 5402.81 | 8.9442 | 0.18156 | 4674.29 | 5400.52 | 8.8099 |

TABLE B.1.3 Superheated Vapor Water (*continued*)

| Temp. (°C) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) |
|---|---|---|---|---|---|---|---|---|
| | 5000 kPa (263.99°C) | | | | 6000 kPa (275.64°C) | | | |
| Sat. | 0.03944 | 2597.12 | 2794.33 | 5.9733 | 0.03244 | 2589.69 | 2784.33 | 5.8891 |
| 300 | 0.04532 | 2697.94 | 2924.53 | 6.2083 | 0.03616 | 2667.22 | 2884.19 | 6.0673 |
| 350 | 0.05194 | 2808.67 | 3068.39 | 6.4492 | 0.04223 | 2789.61 | 3042.97 | 6.3334 |
| 400 | 0.05781 | 2906.58 | 3195.64 | 6.6458 | 0.04739 | 2892.81 | 3177.17 | 6.5407 |
| 450 | 0.06330 | 2999.64 | 3316.15 | 6.8185 | 0.05214 | 2988.90 | 3301.76 | 6.7192 |
| 500 | 0.06857 | 3090.92 | 3433.76 | 6.9758 | 0.05665 | 3082.20 | 3422.12 | 6.8802 |
| 550 | 0.07368 | 3181.82 | 3550.23 | 7.1217 | 0.06101 | 3174.57 | 3540.62 | 7.0287 |
| 600 | 0.07869 | 3273.01 | 3666.47 | 7.2588 | 0.06525 | 3266.89 | 3658.40 | 7.1676 |
| 700 | 0.08849 | 3457.67 | 3900.13 | 7.5122 | 0.07352 | 3453.15 | 3894.28 | 7.4234 |
| 800 | 0.09811 | 3646.62 | 4137.17 | 7.7440 | 0.08160 | 3643.12 | 4132.74 | 7.6566 |
| 900 | 0.10762 | 3840.71 | 4378.82 | 7.9593 | 0.08958 | 3837.84 | 4375.29 | 7.8727 |
| 1000 | 0.11707 | 4040.35 | 4625.69 | 8.1612 | 0.09749 | 4037.83 | 4622.74 | 8.0751 |
| 1100 | 0.12648 | 4245.61 | 4878.02 | 8.3519 | 0.10536 | 4243.26 | 4875.42 | 8.2661 |
| 1200 | 0.13587 | 4456.30 | 5135.67 | 8.5330 | 0.11321 | 4454.00 | 5133.28 | 8.4473 |
| 1300 | 0.14526 | 4671.96 | 5398.24 | 8.7055 | 0.12106 | 4669.64 | 5395.97 | 8.6199 |
| | 8000 kPa (295.06°C) | | | | 10000 kPa (311.06°C) | | | |
| Sat. | 0.02352 | 2569.79 | 2757.94 | 5.7431 | 0.01803 | 2544.41 | 2724.67 | 5.6140 |
| 300 | 0.02426 | 2590.93 | 2784.98 | 5.7905 | — | — | — | — |
| 350 | 0.02995 | 2747.67 | 2987.30 | 6.1300 | 0.02242 | 2699.16 | 2923.39 | 5.9442 |
| 400 | 0.03432 | 2863.75 | 3138.28 | 6.3633 | 0.02641 | 2832.38 | 3096.46 | 6.2119 |
| 450 | 0.03817 | 2966.66 | 3271.99 | 6.5550 | 0.02975 | 2943.32 | 3240.83 | 6.4189 |
| 500 | 0.04175 | 3064.30 | 3398.27 | 6.7239 | 0.03279 | 3045.77 | 3373.63 | 6.5965 |
| 550 | 0.04516 | 3159.76 | 3521.01 | 6.8778 | 0.03564 | 3144.54 | 3500.92 | 6.7561 |
| 600 | 0.04845 | 3254.43 | 3642.03 | 7.0205 | 0.03837 | 3241.68 | 3625.34 | 6.9028 |
| 700 | 0.05481 | 3444.00 | 3882.47 | 7.2812 | 0.04358 | 3434.72 | 3870.52 | 7.1687 |
| 800 | 0 06097 | 3636.08 | 4123.84 | 7.5173 | 0.04859 | 3628.97 | 4114.91 | 7.4077 |
| 900 | 0.06702 | 3832.08 | 4368.26 | 7.7350 | 0.05349 | 3826.32 | 4361.24 | 7.6272 |
| 1000 | 0.07301 | 4032.81 | 4616.87 | 7.9384 | 0.05832 | 4027.81 | 4611.04 | 7.8315 |
| 1100 | 0.07896 | 4238.60 | 4870.25 | 8.1299 | 0.06312 | 4233.97 | 4865.14 | 8.0236 |
| 1200 | 0.08489 | 4449.45 | 5128.54 | 8.3115 | 0.06789 | 4444.93 | 5123.84 | 8.2054 |
| 1300 | 0.09080 | 4665.02 | 5391.46 | 8.4842 | 0.07265 | 4660.44 | 5386.99 | 8.3783 |



TABLE B.1.3 Superheated Vapor Water (*continued*)

| Temp. (°C) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) |
|---|---|---|---|---|---|---|---|---|
| | 15000 kPa (342.24°C) | | | | 20000 kPa (365.81°C) | | | |
| Sat. | 0.01034 | 2455.43 | 2610.49 | 5.3097 | 0.00583 | 2293.05 | 2409.74 | 4.9269 |
| 350 | 0.01147 | 2520.36 | 2692.41 | 5.4420 | — | — | — | — |
| 400 | 0.01565 | 2740.70 | 2975.44 | 5.8810 | 0.00994 | 2619.22 | 2818.07 | 5.5539 |
| 450 | 0.01845 | 2879.47 | 3156.15 | 6.1403 | 0.01270 | 2806.16 | 3060.06 | 5.9016 |
| 500 | 0.02080 | 2996.52 | 3308.53 | 6.3442 | 0.01477 | 2942.82 | 3238.18 | 6.1400 |
| 550 | 0.02293 | 3104.71 | 3448.61 | 6.5198 | 0.01656 | 3062.34 | 3393.45 | 6.3347 |
| 600 | 0.02491 | 3208.64 | 3582.30 | 6.6775 | 0.01818 | 3174.00 | 3537.57 | 6.5048 |
| 650 | 0.02680 | 3310.37 | 3712.32 | 6.8223 | 0.01969 | 3281.46 | 3675.32 | 6.6582 |
| 700 | 0.02861 | 3410.94 | 3840.12 | 6.9572 | 0.02113 | 3386.46 | 3809.09 | 6.7993 |
| 800 | 0.03210 | 3610.99 | 4092.43 | 7.2040 | 0.02385 | 3592.73 | 4069.80 | 7.0544 |
| 900 | 0.03546 | 3811.89 | 4343.75 | 7.4279 | 0.02645 | 3797.44 | 4326.37 | 7.2830 |
| 1000 | 0.03875 | 4015.41 | 4596.63 | 7.6347 | 0.02897 | 4003.12 | 4582.45 | 7.4925 |
| 1100 | 0.04200 | 4222.55 | 4852.56 | 7.8282 | 0.03145 | 4211.30 | 4840.24 | 7.6874 |
| 1200 | 0.04523 | 4433.78 | 5112.27 | 8.0108 | 0.03391 | 4422.81 | 5100.96 | 7.8706 |
| 1300 | 0.04845 | 4649.12 | 5375.94 | 8.1839 | 0.03636 | 4637.95 | 5365.10 | 8.0441 |
| | 30000 kPa | | | | 40000 kPa | | | |
| 375 | 0.001789 | 1737.75 | 1791.43 | 3.9303 | 0.001641 | 1677.09 | 1742.71 | 3.8289 |
| 400 | 0.002790 | 2067.34 | 2151.04 | 4.4728 | 0.001908 | 1854.52 | 1930.83 | 4.1134 |
| 425 | 0.005304 | 2455.06 | 2614.17 | 5.1503 | 0.002532 | 2096.83 | 2198.11 | 4.5028 |
| 450 | 0.006735 | 2619.30 | 2821.35 | 5.4423 | 0.003693 | 2365.07 | 2512.79 | 4.9459 |
| 500 | 0.008679 | 2820.67 | 3081.03 | 5.7904 | 0.005623 | 2678.36 | 2903.26 | 5.4699 |
| 550 | 0.010168 | 2970.31 | 3275.36 | 6.0342 | 0.006984 | 2869.69 | 3149.05 | 5.7784 |
| 600 | 0.011446 | 3100.53 | 3443.91 | 6.2330 | 0.008094 | 3022.61 | 3346.38 | 6.0113 |
| 650 | 0.012596 | 3221.04 | 3598.93 | 6.4057 | 0.009064 | 3158.04 | 3520.58 | 6.2054 |
| 700 | 0.013661 | 3335.84 | 3745.67 | 6.5606 | 0.009942 | 3283.63 | 3681.29 | 6.3750 |
| 800 | 0.015623 | 3555.60 | 4024.31 | 6.8332 | 0.011523 | 3517.89 | 3978.80 | 6.6662 |
| 900 | 0.017448 | 3768.48 | 4291.93 | 7.0717 | 0.012963 | 3739.42 | 4257.93 | 6.9150 |
| 1000 | 0.019196 | 3978.79 | 4554.68 | 7.2867 | 0.014324 | 3954.64 | 4527.59 | 7.1356 |
| 1100 | 0.020903 | 4189.18 | 4816.28 | 7.4845 | 0.015643 | 4167.38 | 4793.08 | 7.3364 |
| 1200 | 0.022589 | 4401.29 | 5078.97 | 7.6691 | 0.016940 | 4380.11 | 5057.72 | 7.5224 |
| 1300 | 0.024266 | 4615.96 | 5343.95 | 7.8432 | 0.018229 | 4594.28 | 5323.45 | 7.6969 |

# 國立虎尾科技大學 111 學年度第 1 學期博士班資格考試題

系別：動力機械工程系機械與機電工程博士班 

科目：熱力學 Thermodynamics

注意事項：
（1）本試題共有 5 題，任選 5 題作答，每題 20 分，合計 100 分。
（2）請依序作答於答案卷上並註明題號，若未註明選答題號及超過規定題數時，謹採計作答順序較前之題目計分。
（3）可使用計算機 close book and can use calculator

一、Five kg of water in a piston/cylinder arrangement exists as saturated liquid/vapor mixture at 400 kPa, with a quality of 50%, as shown in Fig.1. It is now slowly heated so that the volume triples. The mass of the piston is such that a cylinder pressure of 800 kPa will float it. Find the (a) initial volume, (b) state when piston is just floating, (c) final temperature and volume of the water. Represent the process on P-v and T- v plot.

20%

二、The piston/cylinder setup shown in Fig. 2 contains 0.2 kg of water at 800 kPa, 700 °C. The water is now cooled with a constant force on the piston until it reaches one third (1/3) of the initial volume. After this, it cools to 150 kPa while the piston is against the stops. Find the final water pressure and the work and heat transfer in the overall process, and show the process in a P-v diagram.

20%

三、A steam turbine receives water at 20 MPa, 700°C at a rate of 100 kg/s, as shown in Fig. 3. In the middle section 30 kg/s is withdrawn at 3 MPa, 400°C and the rest exits the turbine at 75 kPa, with 95% quality. Assuming no heat transfer and no changes in kinetic energy, find the total turbine power output.

20%

四、A combination of a heat engine driving a heat pump, as shown in Fig.4, takes waste energy at 50°C as a source Qw1 to the heat engine, rejecting heat at 30°C. The remainder Qw2 goes into the heat pump that delivers a QH at 150°C. If the total waste energy is 5MW find the rate of energy delivered at the high temperature.

20%

五、A two-stage air compressor has an intercooler between the two stages as shown in Fig.5. The inlet state is 100 kPa, 290 K, and the final exit pressure is 1.6 MPa. Assume that the constant pressure intercooler cools the air to the inlet temperature, $T_3 = T_1$. It can be shown that the optimal pressure, $P_2 = (P_1 P_4)^{1/2}$, for minimum total compressor work. Find the specific compressor works and the intercooler heat transfer for the optimal $P_2$. For air, $c_p$ =1.004 kJ/kg-K and $c_v$ =0.717 kJ/kg-K.

20%

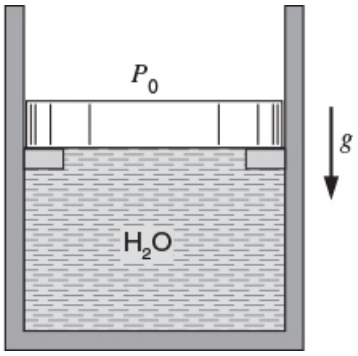



Fig. 1

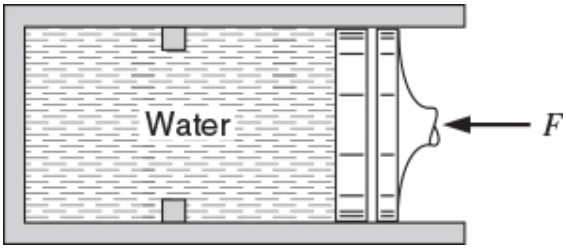



Fig. 2

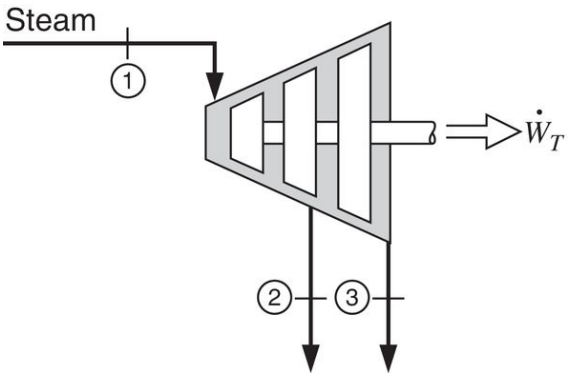



Fig. 3

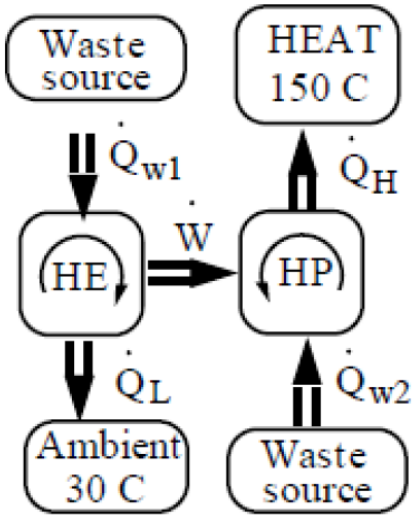



Fig. 4

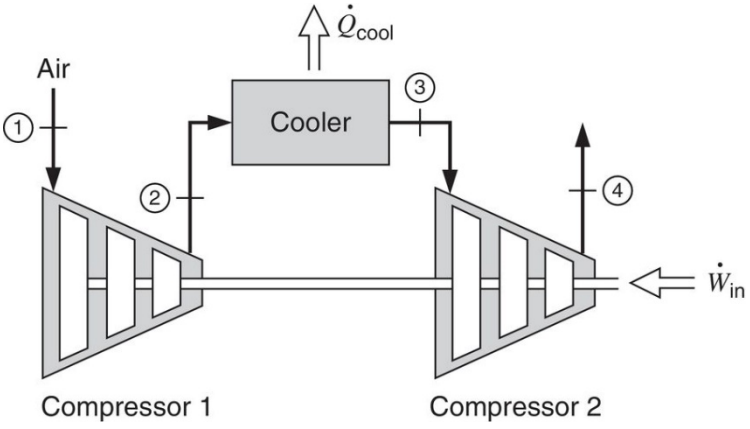



Fig. 5

TABLE B.1.2 Saturated Water Pressure Entry

| Press. (kPa) | Temp. (°C) | Specific Volume, m³/kg | | | Internal Energy, kJ/kg | | |
|---|---|---|---|---|---|---|---|
| | | Sat. Liquid $v_f$ | Evap. $v_{fg}$ | Sat. Vapor $v_g$ | Sat. Liquid $u_f$ | Evap. $u_{fg}$ | Sat. Vapor $u_g$ |
| 0.6113 | 0.01 | 0.001000 | 206.131 | 206.132 | 0 | 2375.3 | 2375.3 |
| 1 | 6.98 | 0.001000 | 129.20702 | 129.20802 | 29.29 | 2355.69 | 2384.98 |
| 1.5 | 13.03 | 0.001001 | 87.97913 | 87.98013 | 54.70 | 2338.63 | 2393.32 |
| 2 | 17.50 | 0.001001 | 67.00285 | 67.00385 | 73.47 | 2326.02 | 2399.48 |
| 2.5 | 21.08 | 0.001002 | 54.25285 | 54.25385 | 88.47 | 2315.93 | 2404.40 |
| 3 | 24.08 | 0.001003 | 45.66402 | 45.66502 | 101.03 | 2307.48 | 2408.51 |
| 4 | 28.96 | 0.001004 | 34.79915 | 34.80015 | 121.44 | 2293.73 | 2415.17 |
| 5 | 32.88 | 0.001005 | 28.19150 | 28.19251 | 137.79 | 2282.70 | 2420.49 |
| 7.5 | 40.29 | 0.001008 | 19.23674 | 19.23775 | 168.76 | 2261.74 | 2430.50 |
| 10 | 45.81 | 0.001010 | 14.67254 | 14.67355 | 191.79 | 2246.10 | 2437.89 |
| 15 | 53.97 | 0.001014 | 10.02117 | 10.02218 | 225.90 | 2222.83 | 2448.73 |
| 20 | 60.06 | 0.001017 | 7.64835 | 7.64937 | 251.35 | 2205.36 | 2456.71 |
| 25 | 64.97 | 0.001020 | 6.20322 | 6.20424 | 271.88 | 2191.21 | 2463.08 |
| 30 | 69.10 | 0.001022 | 5.22816 | 5.22918 | 289.18 | 2179.22 | 2468.40 |
| 40 | 75.87 | 0.001026 | 3.99243 | 3.99345 | 317.51 | 2159.49 | 2477.00 |
| 50 | 81.33 | 0.001030 | 3.23931 | 3.24034 | 340.42 | 2143.43 | 2483.85 |
| 75 | 91.77 | 0.001037 | 2.21607 | 2.21711 | 394.29 | 2112.39 | 2496.67 |
| 100 | 99.62 | 0.001043 | 1.69296 | 1.69400 | 417.33 | 2088.72 | 2506.06 |
| 125 | 105.99 | 0.001048 | 1.37385 | 1.37490 | 444.16 | 2069.32 | 2513.48 |
| 150 | 111.37 | 0.001053 | 1.15828 | 1.15933 | 466.92 | 2052.72 | 2519.64 |
| 175 | 116.06 | 0.001057 | 1.00257 | 1.00363 | 486.78 | 2038.12 | 2524.90 |
| 200 | 120.23 | 0.001061 | 0.88467 | 0.88573 | 504.47 | 2025.02 | 2529.49 |
| 225 | 124.00 | 0.001064 | 0.79219 | 0.79325 | 520.45 | 2013.10 | 2533.56 |
| 250 | 127.43 | 0.001067 | 0.71765 | 0.71871 | 535.08 | 2002.14 | 2537.21 |
| 275 | 130.60 | 0.001070 | 0.65624 | 0.65731 | 548.57 | 1991.95 | 2540.53 |
| 300 | 133.55 | 0.001073 | 0.60475 | 0.60582 | 561.13 | 1982.43 | 2543.55 |
| 325 | 136.30 | 0.001076 | 0.56093 | 0.56201 | 572.88 | 1973.46 | 2546.34 |
| 350 | 138.88 | 0.001079 | 0.52317 | 0.52425 | 583.93 | 1964.98 | 2548.92 |
| 375 | 141.32 | 0.001081 | 0.49029 | 0.49137 | 594.38 | 1956.93 | 2551.31 |
| 400 | 143.63 | 0.001084 | 0.46138 | 0.46246 | 604.29 | 1949.26 | 2553.55 |
| 450 | 147.93 | 0.001088 | 0.41289 | 0.41398 | 622.75 | 1934.87 | 2557.62 |
| 500 | 151.86 | 0.001093 | 0.37380 | 0.37489 | 639.66 | 1921.57 | 2561.23 |
| 550 | 155.48 | 0.001097 | 0.34159 | 0.34268 | 655.30 | 1909.17 | 2564.47 |
| 600 | 158.85 | 0.001101 | 0.31457 | 0.31567 | 669.88 | 1897.52 | 2567.40 |
| 650 | 162.01 | 0.001104 | 0.29158 | 0.29268 | 683.55 | 1886.51 | 2570.06 |
| 700 | 164.97 | 0.001108 | 0.27176 | 0.27286 | 696.43 | 1876.07 | 2572.49 |
| 750 | 167.77 | 0.001111 | 0.25449 | 0.25560 | 708.62 | 1866.11 | 2574.73 |
| 800 | 170.43 | 0.001115 | 0.23931 | 0.24043 | 720.20 | 1856.58 | 2576.79 |



TABLE B.1.2 Saturated Water Pressure Entry (*continued*)

| Press. (kPa) | Temp. (°C) | Enthalpy, kJ/kg | | | Entropy, kJ/kg-K | | |
|---|---|---|---|---|---|---|---|
| | | Sat. Liquid $h_f$ | Evap. $h_{fg}$ | Sat. Vapor $h_g$ | Sat. Liquid $s_f$ | Evap. $s_{fg}$ | Sat. Vapor $s_g$ |
| 0.6113 | 0.01 | 0.00 | 2501.3 | 2501.3 | 0 | 9.1562 | 9.1562 |
| 1.0 | 6.98 | 29.29 | 2484.89 | 2514.18 | 0.1059 | 8.8697 | 8.9756 |
| 1.5 | 13.03 | 54.70 | 2470.59 | 2525.30 | 0.1956 | 8.6322 | 8.8278 |
| 2.0 | 17.50 | 73.47 | 2460.02 | 2533.49 | 0.2607 | 8.4629 | 8.7236 |
| 2.5 | 21.08 | 88.47 | 2451.56 | 2540.03 | 0.3120 | 8.3311 | 8.6431 |
| 3.0 | 24.08 | 101.03 | 2444.47 | 2545.50 | 0.3545 | 8.2231 | 8.5775 |
| 4.0 | 28.96 | 121.44 | 2432.93 | 2554.37 | 0.4226 | 8.0520 | 8.4746 |
| 5.0 | 32.88 | 137.79 | 2423.66 | 2561.45 | 0.4763 | 7.9187 | 8.3950 |
| 7.5 | 40.29 | 168.77 | 2406.02 | 2574.79 | 0.5763 | 7.6751 | 8.2514 |
| 10 | 45.81 | 191.81 | 2392.82 | 2584.63 | 0.6492 | 7.5010 | 8.1501 |
| 15 | 53.97 | 225.91 | 2373.14 | 2599.06 | 0.7548 | 7.2536 | 8.0084 |
| 20 | 60.06 | 251.38 | 2358.33 | 2609.70 | 0.8319 | 7.0766 | 7.9085 |
| 25 | 64.97 | 271.90 | 2346.29 | 2618.19 | 0.8930 | 6.9383 | 7.8313 |
| 30 | 69.10 | 289.21 | 2336.07 | 2625.28 | 0.9439 | 6.8247 | 7.7686 |
| 40 | 75.87 | 317.55 | 2319.19 | 2636.74 | 1.0258 | 6.6441 | 7.6700 |
| 50 | 81.33 | 340.47 | 2305.40 | 2645.87 | 1.0910 | 6.5029 | 7.5939 |
| 75 | 91.77 | 384.36 | 2278.59 | 2662.96 | 1.2129 | 6.2434 | 7.4563 |
| 100 | 99.62 | 417.44 | 2258.02 | 2675.46 | 1.3025 | 6.0568 | 7.3593 |
| 125 | 105.99 | 444.30 | 2241.05 | 2685.35 | 1.3739 | 5.9104 | 7.2843 |
| 150 | 111.37 | 467.08 | 2226.46 | 2693.54 | 1.4335 | 5.7897 | 7.2232 |
| 175 | 116.06 | 486.97 | 2213.57 | 2700.53 | 1.4848 | 5.6868 | 7.1717 |
| 200 | 120.23 | 504.68 | 2201.96 | 2706.63 | 1.5300 | 5.5970 | 7.1271 |
| 225 | 124.00 | 520.69 | 2191.35 | 2712.04 | 1.5705 | 5.5173 | 7.0878 |
| 250 | 127.43 | 535.34 | 2181.55 | 2716.89 | 1.6072 | 5.4455 | 7.0526 |
| 275 | 130.60 | 548.87 | 2172.42 | 2721.29 | 1.6407 | 5.3801 | 7.0208 |
| 300 | 133.55 | 561.45 | 2163.85 | 2725.30 | 1.6717 | 5.3201 | 6.9918 |
| 325 | 136.30 | 573.23 | 2155.76 | 2728.99 | 1.7005 | 5.2646 | 6.9651 |
| 350 | 138.88 | 584.31 | 2148.10 | 2732.40 | 1.7274 | 5.2130 | 6.9404 |
| 375 | 141.32 | 594.79 | 2140.79 | 2735.58 | 1.7527 | 5.1647 | 6.9174 |
| 400 | 143.63 | 604.73 | 2133.81 | 2738.53 | 1.7766 | 5.1193 | 6.8958 |
| 450 | 147.93 | 623.24 | 2120.67 | 2743.91 | 1.8206 | 5.0359 | 6.8565 |
| 500 | 151.86 | 640.21 | 2108.47 | 2748.67 | 1.8606 | 4.9606 | 6.8212 |
| 550 | 155.48 | 655.91 | 2097.04 | 2752.94 | 1.8972 | 4.8920 | 6.7892 |
| 600 | 158.85 | 670.54 | 2086.26 | 2756.80 | 1.9311 | 4.8289 | 6.7600 |
| 650 | 162.01 | 684.26 | 2076.04 | 2760.30 | 1.9627 | 4.7704 | 6.7330 |
| 700 | 164.97 | 697.20 | 2066.30 | 2763.50 | 1.9922 | 4.7158 | 6.7080 |
| 750 | 167.77 | 709.45 | 2056.98 | 2766.43 | 2.0199 | 4.6647 | 6.6846 |
| 800 | 170.43 | 721.10 | 2048.04 | 2769.13 | 2.0461 | 4.6166 | 6.6627 |

TABLE B.1.3 Superheated Vapor Water (*continued*)

| Temp. (°C) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) |
|---|---|---|---|---|---|---|---|---|
| | 800 kPa (170.43°C) | | | | 1000 kPa (179.91°C) | | | |
| 700 | 0.56007 | 3476.22 | 3924.27 | 8.3770 | 0.44779 | 3475.35 | 3923.14 | 8.2731 |
| 800 | 0.61813 | 3661.14 | 4155.65 | 8.6033 | 0.49432 | 3660.46 | 4154.78 | 8.4996 |
| 900 | 0.67610 | 3852.77 | 4393.65 | 8.8153 | 0.54075 | 3852.19 | 4392.94 | 8.7118 |
| 1000 | 0.73401 | 4051.00 | 4638.20 | 9.0153 | 0.58712 | 4050.49 | 4637.60 | 8.9119 |
| 1100 | 0.79188 | 4255.57 | 4889.08 | 9.2049 | 0.63345 | 4255.09 | 4888.55 | 9.1016 |
| 1200 | 0.84974 | 4466.05 | 5145.85 | 9.3854 | 0.67977 | 4465.58 | 5145.36 | 9.2821 |
| 1300 | 0.90758 | 4681.81 | 5407.87 | 9.5575 | 0.72608 | 4681.33 | 5407.41 | 9.4542 |
| | 1200 kPa (187.99°C) | | | | 1400 kPa (195.07°C) | | | |
| Sat. | 0.16333 | 2588.82 | 2784.82 | 6.5233 | 0.14084 | 2592.83 | 2790.00 | 6.4692 |
| 200 | 0.16930 | 2612.74 | 2815.90 | 6.5898 | 0.14302 | 2603.09 | 2803.32 | 6.4975 |
| 250 | 0.19235 | 2704.20 | 2935.01 | 6.8293 | 0.16350 | 2698.32 | 2927.22 | 6.7467 |
| 300 | 0.21382 | 2789.22 | 3045.80 | 7.0316 | 0.18228 | 2785.16 | 3040.35 | 6.9533 |
| 350 | 0.23452 | 2872.16 | 3153.59 | 7.2120 | 0.20026 | 2869.12 | 3149.49 | 7.1359 |
| 400 | 0.25480 | 2954.90 | 3260.66 | 7.3773 | 0.21780 | 2952.50 | 3257.42 | 7.3025 |
| 500 | 0.29463 | 3122.72 | 3476.28 | 7.6758 | 0.25215 | 3121.10 | 3474.11 | 7.6026 |
| 600 | 0.33393 | 3295.60 | 3696.32 | 7.9434 | 0.28596 | 3294.44 | 3694.78 | 7.8710 |
| 700 | 0.37294 | 3474.48 | 3922.01 | 8.1881 | 0.31947 | 3473.61 | 3920.87 | 8.1160 |
| 800 | 0.41177 | 3659.77 | 4153.90 | 8.4149 | 0.35281 | 3659.09 | 4153.03 | 8.3431 |
| 900 | 0.45051 | 3851.62 | 4392.23 | 8.6272 | 0.38606 | 3851.05 | 4391.53 | 8.5555 |
| 1000 | 0.48919 | 4049.98 | 4637.00 | 8.8274 | 0.41924 | 4049.47 | 4636.41 | 8.7558 |
| 1100 | 0.52783 | 4254.61 | 4888.02 | 9.0171 | 0.45239 | 4254.14 | 4887.49 | 8.9456 |
| 1200 | 0.56646 | 4465.12 | 5144.87 | 9.1977 | 0.48552 | 4464.65 | 5144.38 | 9.1262 |
| 1300 | 0.60507 | 4680.86 | 5406.95 | 9.3698 | 0.51864 | 4680.39 | 5406.49 | 9.2983 |
| | 1600 kPa (201.40°C) | | | | 1800 kPa (207.15°C) | | | |
| Sat. | 0.12380 | 2595.95 | 2794.02 | 6.4217 | 0.11042 | 2598.38 | 2797.13 | 6.3793 |
| 250 | 0.14184 | 2692.26 | 2919.20 | 6.6732 | 0.12497 | 2686.02 | 2910.96 | 6.6066 |
| 300 | 0.15862 | 2781.03 | 3034.83 | 6.8844 | 0.14021 | 2776.83 | 3029.21 | 6.8226 |
| 350 | 0.17456 | 2866.05 | 3145.35 | 7.0693 | 0.15457 | 2862.95 | 3141.18 | 7.0099 |
| 400 | 0.19005 | 2950.09 | 3254.17 | 7.2373 | 0.16847 | 2947.66 | 3250.90 | 7.1793 |
| 500 | 0.22029 | 3119.47 | 3471.93 | 7.5389 | 0.19550 | 3117.84 | 3469.75 | 7.4824 |
| 600 | 0.24998 | 3293.27 | 3693.23 | 7.8080 | 0.22199 | 3292.10 | 3691.69 | 7.7523 |
| 700 | 0.27937 | 3472.74 | 3919.73 | 8.0535 | 0.24818 | 3471.87 | 3918.59 | 7.9983 |
| 800 | 0.30859 | 3658.40 | 4152.15 | 8.2808 | 0.27420 | 3657.71 | 4151.27 | 8.2258 |
| 900 | 0.33772 | 3850.47 | 4390.82 | 8.4934 | 0.30012 | 3849.90 | 4390.11 | 8.4386 |
| 1000 | 0.36678 | 4048.96 | 4635.81 | 8.6938 | 0.32598 | 4048.45 | 4635.21 | 8.6390 |
| 1100 | 0.39581 | 4253.66 | 4886.95 | 8.8837 | 0.35180 | 4253.18 | 4886.42 | 8.8290 |
| 1200 | 0.42482 | 4464.18 | 5143.89 | 9.0642 | 0.37761 | 4463.71 | 5143.40 | 9.0096 |
| 1300 | 0.45382 | 4679.92 | 5406.02 | 9.2364 | 0.40340 | 4679.44 | 5405.56 | 9.1817 |



TABLE B.1.3 Superheated Vapor Water (*continued*)

| Temp. (°C) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) |
|---|---|---|---|---|---|---|---|---|
| | 2000 kPa (212.42°C) | | | | 2500 kPa (223.99°C) | | | |
| Sat. | 0.09963 | 2600.26 | 2799.51 | 6.3408 | 0.07998 | 2603.13 | 2803.07 | 6.2574 |
| 250 | 0.11144 | 2679.58 | 2902.46 | 6.5452 | 0.08700 | 2662.55 | 2880.06 | 6.4084 |
| 300 | 0.12547 | 2772.56 | 3023.50 | 6.7663 | 0.09890 | 2761.56 | 3008.81 | 6.6437 |
| 350 | 0.13857 | 2859.81 | 3136.96 | 6.9562 | 0.10976 | 2851.84 | 3126.24 | 6.8402 |
| 400 | 0.15120 | 2945.21 | 3247.60 | 7.1270 | 0.12010 | 2939.03 | 3239.23 | 7.0147 |
| 450 | 0.16353 | 3030.41 | 3357.48 | 7.2844 | 0.13014 | 3025.43 | 3350.77 | 7.1745 |
| 500 | 0.17568 | 3116.20 | 3467.55 | 7.4316 | 0.13998 | 3112.08 | 3462.04 | 7.3233 |
| 600 | 0.19960 | 3290.93 | 3690.14 | 7.7023 | 0.15930 | 3287.99 | 3686.25 | 7.5960 |
| 700 | 0.22323 | 3470.99 | 3917.45 | 7.9487 | 0.17832 | 3468.80 | 3914.59 | 7.8435 |
| 800 | 0.24668 | 3657.03 | 4150.40 | 8.1766 | 0.19716 | 3655.30 | 4148.20 | 8.0720 |
| 900 | 0.27004 | 3849.33 | 4389.40 | 8.3895 | 0.21590 | 3847.89 | 4387.64 | 8.2853 |
| 1000 | 0.29333 | 4047.94 | 4634.61 | 8.5900 | 0.23458 | 4046.67 | 4633.12 | 8.4860 |
| 1100 | 0.31659 | 4252.71 | 4885.89 | 8.7800 | 0.25322 | 4251.52 | 4884.57 | 8.6761 |
| 1200 | 0.33984 | 4463.25 | 5142.92 | 8.9606 | 0.27185 | 4462.08 | 5141.70 | 8.8569 |
| 1300 | 0.36306 | 4678.97 | 5405.10 | 9.1328 | 0.29046 | 4677.80 | 5403.95 | 9.0291 |
| | 3000 kPa (233.90°C) | | | | 4000 kPa (250.40°C) | | | |
| Sat. | 0.06668 | 2604.10 | 2804.14 | 6.1869 | 0.04978 | 2602.27 | 2801.38 | 6.0700 |
| 250 | 0.07058 | 2644.00 | 2855.75 | 6.2871 | — | — | — | — |
| 300 | 0.08114 | 2750.05 | 2993.48 | 6.5389 | 0.05884 | 2725.33 | 2960.68 | 6.3614 |
| 350 | 0.09053 | 2843.66 | 3115.25 | 6.7427 | 0.06645 | 2826.65 | 3092.43 | 6.5820 |
| 400 | 0.09936 | 2932.75 | 3230.82 | 6.9211 | 0.07341 | 2919.88 | 3213.51 | 6.7689 |
| 450 | 0.10787 | 3020.38 | 3344.00 | 7.0833 | 0.08003 | 3010.13 | 3330.23 | 6.9362 |
| 500 | 0.11619 | 3107.92 | 3456.48 | 7.2337 | 0.08643 | 3099.49 | 3445.21 | 7.0900 |
| 600 | 0.13243 | 3285.03 | 3682.34 | 7.5084 | 0.09885 | 3279.06 | 3674.44 | 7.3688 |
| 700 | 0.14838 | 3466.59 | 3911.72 | 7.7571 | 0.11095 | 3462.15 | 3905.94 | 7.6198 |
| 800 | 0.16414 | 3653.58 | 4146.00 | 7.9862 | 0.12287 | 3650.11 | 4141.59 | 7.8502 |
| 900 | 0.17980 | 3846.46 | 4385.87 | 8.1999 | 0.13469 | 3843.59 | 4382.34 | 8.0647 |
| 1000 | 0.19541 | 4045.40 | 4631.63 | 8.4009 | 0.14645 | 4042.87 | 4628.65 | 8.2661 |
| 1100 | 0.21098 | 4250.33 | 4883.26 | 8.5911 | 0.15817 | 4247.96 | 4880.63 | 8.4566 |
| 1200 | 0.22652 | 4460.92 | 5140.49 | 8.7719 | 0.16987 | 4458.60 | 5138.07 | 8.6376 |
| 1300 | 0.24206 | 4676.63 | 5402.81 | 8.9442 | 0.18156 | 4674.29 | 5400.52 | 8.8099 |

TABLE B.1.3 Superheated Vapor Water (*continued*)

| Temp. (°C) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) |
|---|---|---|---|---|---|---|---|---|
| | 5000 kPa (263.99°C) | | | | 6000 kPa (275.64°C) | | | |
| Sat. | 0.03944 | 2597.12 | 2794.33 | 5.9733 | 0.03244 | 2589.69 | 2784.33 | 5.8891 |
| 300 | 0.04532 | 2697.94 | 2924.53 | 6.2083 | 0.03616 | 2667.22 | 2884.19 | 6.0673 |
| 350 | 0.05194 | 2808.67 | 3068.39 | 6.4492 | 0.04223 | 2789.61 | 3042.97 | 6.3334 |
| 400 | 0.05781 | 2906.58 | 3195.64 | 6.6458 | 0.04739 | 2892.81 | 3177.17 | 6.5407 |
| 450 | 0.06330 | 2999.64 | 3316.15 | 6.8185 | 0.05214 | 2988.90 | 3301.76 | 6.7192 |
| 500 | 0.06857 | 3090.92 | 3433.76 | 6.9758 | 0.05665 | 3082.20 | 3422.12 | 6.8802 |
| 550 | 0.07368 | 3181.82 | 3550.23 | 7.1217 | 0.06101 | 3174.57 | 3540.62 | 7.0287 |
| 600 | 0.07869 | 3273.01 | 3666.47 | 7.2588 | 0.06525 | 3266.89 | 3658.40 | 7.1676 |
| 700 | 0.08849 | 3457.67 | 3900.13 | 7.5122 | 0.07352 | 3453.15 | 3894.28 | 7.4234 |
| 800 | 0.09811 | 3646.62 | 4137.17 | 7.7440 | 0.08160 | 3643.12 | 4132.74 | 7.6566 |
| 900 | 0.10762 | 3840.71 | 4378.82 | 7.9593 | 0.08958 | 3837.84 | 4375.29 | 7.8727 |
| 1000 | 0.11707 | 4040.35 | 4625.69 | 8.1612 | 0.09749 | 4037.83 | 4622.74 | 8.0751 |
| 1100 | 0.12648 | 4245.61 | 4878.02 | 8.3519 | 0.10536 | 4243.26 | 4875.42 | 8.2661 |
| 1200 | 0.13587 | 4456.30 | 5135.67 | 8.5330 | 0.11321 | 4454.00 | 5133.28 | 8.4473 |
| 1300 | 0.14526 | 4671.96 | 5398.24 | 8.7055 | 0.12106 | 4669.64 | 5395.97 | 8.6199 |
| | 8000 kPa (295.06°C) | | | | 10000 kPa (311.06°C) | | | |
| Sat. | 0.02352 | 2569.79 | 2757.94 | 5.7431 | 0.01803 | 2544.41 | 2724.67 | 5.6140 |
| 300 | 0.02426 | 2590.93 | 2784.98 | 5.7905 | — | — | — | — |
| 350 | 0.02995 | 2747.67 | 2987.30 | 6.1300 | 0.02242 | 2699.16 | 2923.39 | 5.9442 |
| 400 | 0.03432 | 2863.75 | 3138.28 | 6.3633 | 0.02641 | 2832.38 | 3096.46 | 6.2119 |
| 450 | 0.03817 | 2966.66 | 3271.99 | 6.5550 | 0.02975 | 2943.32 | 3240.83 | 6.4189 |
| 500 | 0.04175 | 3064.30 | 3398.27 | 6.7239 | 0.03279 | 3045.77 | 3373.63 | 6.5965 |
| 550 | 0.04516 | 3159.76 | 3521.01 | 6.8778 | 0.03564 | 3144.54 | 3500.92 | 6.7561 |
| 600 | 0.04845 | 3254.43 | 3642.03 | 7.0205 | 0.03837 | 3241.68 | 3625.34 | 6.9028 |
| 700 | 0.05481 | 3444.00 | 3882.47 | 7.2812 | 0.04358 | 3434.72 | 3870.52 | 7.1687 |
| 800 | 0 06097 | 3636.08 | 4123.84 | 7.5173 | 0.04859 | 3628.97 | 4114.91 | 7.4077 |
| 900 | 0.06702 | 3832.08 | 4368.26 | 7.7350 | 0.05349 | 3826.32 | 4361.24 | 7.6272 |
| 1000 | 0.07301 | 4032.81 | 4616.87 | 7.9384 | 0.05832 | 4027.81 | 4611.04 | 7.8315 |
| 1100 | 0.07896 | 4238.60 | 4870.25 | 8.1299 | 0.06312 | 4233.97 | 4865.14 | 8.0236 |
| 1200 | 0.08489 | 4449.45 | 5128.54 | 8.3115 | 0.06789 | 4444.93 | 5123.84 | 8.2054 |
| 1300 | 0.09080 | 4665.02 | 5391.46 | 8.4842 | 0.07265 | 4660.44 | 5386.99 | 8.3783 |



TABLE B.1.3 Superheated Vapor Water (*continued*)

| Temp. (°C) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) | $v$ (m³/kg) | $u$ (kJ/kg) | $h$ (kJ/kg) | $s$ (kJ/kg-K) |
|---|---|---|---|---|---|---|---|---|
| | 15000 kPa (342.24°C) | | | | 20000 kPa (365.81°C) | | | |
| Sat. | 0.01034 | 2455.43 | 2610.49 | 5.3097 | 0.00583 | 2293.05 | 2409.74 | 4.9269 |
| 350 | 0.01147 | 2520.36 | 2692.41 | 5.4420 | — | — | — | — |
| 400 | 0.01565 | 2740.70 | 2975.44 | 5.8810 | 0.00994 | 2619.22 | 2818.07 | 5.5539 |
| 450 | 0.01845 | 2879.47 | 3156.15 | 6.1403 | 0.01270 | 2806.16 | 3060.06 | 5.9016 |
| 500 | 0.02080 | 2996.52 | 3308.53 | 6.3442 | 0.01477 | 2942.82 | 3238.18 | 6.1400 |
| 550 | 0.02293 | 3104.71 | 3448.61 | 6.5198 | 0.01656 | 3062.34 | 3393.45 | 6.3347 |
| 600 | 0.02491 | 3208.64 | 3582.30 | 6.6775 | 0.01818 | 3174.00 | 3537.57 | 6.5048 |
| 650 | 0.02680 | 3310.37 | 3712.32 | 6.8223 | 0.01969 | 3281.46 | 3675.32 | 6.6582 |
| 700 | 0.02861 | 3410.94 | 3840.12 | 6.9572 | 0.02113 | 3386.46 | 3809.09 | 6.7993 |
| 800 | 0.03210 | 3610.99 | 4092.43 | 7.2040 | 0.02385 | 3592.73 | 4069.80 | 7.0544 |
| 900 | 0.03546 | 3811.89 | 4343.75 | 7.4279 | 0.02645 | 3797.44 | 4326.37 | 7.2830 |
| 1000 | 0.03875 | 4015.41 | 4596.63 | 7.6347 | 0.02897 | 4003.12 | 4582.45 | 7.4925 |
| 1100 | 0.04200 | 4222.55 | 4852.56 | 7.8282 | 0.03145 | 4211.30 | 4840.24 | 7.6874 |
| 1200 | 0.04523 | 4433.78 | 5112.27 | 8.0108 | 0.03391 | 4422.81 | 5100.96 | 7.8706 |
| 1300 | 0.04845 | 4649.12 | 5375.94 | 8.1839 | 0.03636 | 4637.95 | 5365.10 | 8.0441 |
| | 30000 kPa | | | | 40000 kPa | | | |
| 375 | 0.001789 | 1737.75 | 1791.43 | 3.9303 | 0.001641 | 1677.09 | 1742.71 | 3.8289 |
| 400 | 0.002790 | 2067.34 | 2151.04 | 4.4728 | 0.001908 | 1854.52 | 1930.83 | 4.1134 |
| 425 | 0.005304 | 2455.06 | 2614.17 | 5.1503 | 0.002532 | 2096.83 | 2198.11 | 4.5028 |
| 450 | 0.006735 | 2619.30 | 2821.35 | 5.4423 | 0.003693 | 2365.07 | 2512.79 | 4.9459 |
| 500 | 0.008679 | 2820.67 | 3081.03 | 5.7904 | 0.005623 | 2678.36 | 2903.26 | 5.4699 |
| 550 | 0.010168 | 2970.31 | 3275.36 | 6.0342 | 0.006984 | 2869.69 | 3149.05 | 5.7784 |
| 600 | 0.011446 | 3100.53 | 3443.91 | 6.2330 | 0.008094 | 3022.61 | 3346.38 | 6.0113 |
| 650 | 0.012596 | 3221.04 | 3598.93 | 6.4057 | 0.009064 | 3158.04 | 3520.58 | 6.2054 |
| 700 | 0.013661 | 3335.84 | 3745.67 | 6.5606 | 0.009942 | 3283.63 | 3681.29 | 6.3750 |
| 800 | 0.015623 | 3555.60 | 4024.31 | 6.8332 | 0.011523 | 3517.89 | 3978.80 | 6.6662 |
| 900 | 0.017448 | 3768.48 | 4291.93 | 7.0717 | 0.012963 | 3739.42 | 4257.93 | 6.9150 |
| 1000 | 0.019196 | 3978.79 | 4554.68 | 7.2867 | 0.014324 | 3954.64 | 4527.59 | 7.1356 |
| 1100 | 0.020903 | 4189.18 | 4816.28 | 7.4845 | 0.015643 | 4167.38 | 4793.08 | 7.3364 |
| 1200 | 0.022589 | 4401.29 | 5078.97 | 7.6691 | 0.016940 | 4380.11 | 5057.72 | 7.5224 |
| 1300 | 0.024266 | 4615.96 | 5343.95 | 7.8432 | 0.018229 | 4594.28 | 5323.45 | 7.6969 |