NATIONAL EXAMINATIONS

DECEMBER 2019

# 16-MEC-B3 ENERGY CONVERSION AND POWER GENERATION

**Three hours duration**

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## Notes to Candidates

1. This is a **Closed Book** examination.

2. Examination paper consists of two Sections. **Section A is Calculative** with five (5) questions and **Section B is Descriptive** with three (3) questions.

3. **Do four (4) questions (including all parts of each question) from Section A (Calculative) and two (2) questions from Section B (Descriptive).**

4. **Six questions constitute a complete paper.** (Total 60 marks).

5. **All questions are of equal value.** (Each 10 marks).

6. If doubt exists as to the interpretation of any question or in the event of missing data, the candidate is urged to submit, with the answer paper, a clear statement of any assumptions made.

7. If any initial parts of a multi-part question cannot be solved the remaining parts may be worked by making appropriate assumptions for the first parts from the technical data given.

8. **Read the entire question before commencing the calculations** and take note of any hints or recommendations given.

9. Candidates may use one of the approved **Casio** or **Sharp** calculators.

10. **Reference data** for particular questions are given on pages 11 to 16. **All pages used are to be returned with the answer booklet showing where data has been obtained.**

11. **Reference formulae and constants** are given on pages 17 to 20.

12. **Steam Tables** from "Thermodynamics and Heat Power" are provided.

## SECTION A CALCULATIVE QUESTIONS

***Show all steps in the calculations and state the units for all intermediate and final answers.***

### QUESTION 1 ARC-100 REACTOR WITH STEAM CYCLE

Refer to the Examination Paper Attachments Page 11 **Steam Turbine for ARC-100 Nuclear Plant.**

The ARC-100 Small Modular Fast Breeder Reactor has been designed for small power applications using a modular construction and a long life of up to twenty years between refuelling. The attached page 11 shows diagrammatically the layout of the plant utilizing sodium as the reactor coolant and as the transfer fluid to the thermodynamic cycle. In this application a steam cycle is employed using water as the working fluid.

Technical parameters are as follows:

| | |
|---|---|
| Reactor core thermal power | 260 MW |
| Primary sodium inlet to reactor | 355°C |
| Primary sodium outlet from reactor | 510°C |
| Secondary sodium inlet to exchanger | 355°C (from steam generator) |
| Secondary sodium outlet from exchanger | 500°C (to steam generator) |
| Turbine inlet pressure | 5 MPa |
| Turbine exhaust pressure | 0.005 MPa |
| Turbine inlet temperature | 490°C |
| Feedwater pump outlet temperature | 33°C |
| Turbine internal efficiency | 85% |

Assume the following parameters:

| | |
|---|---|
| Sodium specific heat | 1.230 kJ/kg°C |
| Sodium density | 0.968 kg/m$^3$ |

Assume that the sodium parameters remain the same at elevated temperatures as at ambient conditions as given.

Assume also that there is no heat loss in the heat exchangers.

***Question continued on next page***

**QUESTION 1 Continued**

A preliminary estimate of the cycle efficiency is required in order to assess the efficiency of a simple steam cycle when this type of small reactor has been selected as a heat source.

Sketch the following:

(a) T-s diagram of the whole steam cycle showing all points to be calculated. Identify these points by number. (1)

Calculate the following:

(b) Mass flow rate of sodium in the secondary heat transfer loop (entering the steam generator) and of the steam (leaving the steam generator). (1)

(c) Enthalpies at all key points of the steam cycle as identified in (a) above. (5)

(d) Power output of the turbine. (1)

(e) Thermodynamic efficiency of the steam cycle. (1)

Answer the following:

(f) State with reasons how the overall cycle efficiency of this proposed plant could be improved. (1)

[ 10 marks ]

## QUESTION 2 ARC-100 REACTOR WITH GAS CYCLE

Refer to the Examination Paper Attachments Page 12 **Gas Turbine for ARC-100 Nuclear Plant.**

The ARC-100 Small Modular Fast Breeder Reactor has been designed for small power applications using a modular construction and a long life of up to twenty years between refuelling. The attached page 12 shows diagrammatically the layout of the plant utilizing sodium as the reactor coolant and as the transfer fluid to the thermodynamic cycle. In this application a gas cycle is employed using carbon dioxide as the working fluid.

It operates as a regenerative cycle with a recuperative heat exchanger (recuperator) to recover some turbine exhaust gas energy to preheat the compressor discharge gas.

Technical parameters are as follows:

| | |
|---|---|
| Carbon dioxide inlet to compressor | 32°C |
| Carbon dioxide inlet to turbine | 490°C |
| Carbon dioxide return temperature | 331°C |
| Carbon dioxide reject temperature | 136°C |
| Cooling water inlet temperature | 12°C |
| Recuperator terminal temperature differences | 10°C |
| Compressor inlet pressure | 7 MPa |
| Turbine inlet pressure | 21 MPa |
| Compressor efficiency | 90% |
| Turbine efficiency | 90% |
| Carbon dioxide mass flow rate | 1937 kg/s |

Assume the following parameters:

| | | |
|---|---|---|
| Carbon dioxide specific heat $c_p$ | 0.844 kJ/kg°C | (constant pressure) |
| Carbon dioxide specific heat $c_v$ | 0.655 kJ/kg°C | (constant volume) |

Assume that the parameters for carbon dioxide remain the same at elevated temperatures as at ambient conditions as given.

Assume also that there is no heat loss in the heat exchangers.

***Question continued on next page***

**QUESTION 2 Continued**

A verification of the cycle efficiency using a closed thermodynamic cycle with regeneration and carbon dioxide as the working fluid is required. Note that the recuperator temperature on the cold side outlet is 10°C lower than that on the hot side inlet and similarly the recuperator temperature on the hot side outlet is 10°C higher than on the cold side inlet.

Sketch the following:

(a) T-s diagram of the whole carbon dioxide cycle showing all points to be calculated. Identify these points by number. (1)

Calculate the following:

(b) Ideal and actual temperatures at the compressor outlet. (2)

(c) Ideal and actual temperatures at the turbine exhaust. (2)

(d) Boundary temperatures on both cold and hot sides of the recuperator. (1)

(e) Thermodynamic cycle efficiency. (2)

(f) Gas turbine net output. (1)

This cycle has a relatively low pressure ratio compared with most other gas turbine cycles.

(g) Explain why a low pressure ratio is advantageous in this application. *A sketch of a T-s diagram may be helpful to clarify the explanation.* (1)

[ 10 marks ]

## QUESTION 3 CONDENSER PERFORMANCE

Refer to the Examination Paper Attachments Page 13 **Koeberg Condenser** and Page 14 **Temperature Profiles.** Note that 1 bar = 0.1 MPa.

Consider the condenser to be operating under the given conditions. Sketch, in dotted lines on **each** of the given axes, the design temperature profile, with specified temperatures for both cooling water and steam, along the condenser tubes (from inlet to outlet). Show clearly the change in cooling water temperature $\Delta T$ and the difference between the average cooling water temperature and the condensing steam temperature $\theta$.

For the following no detailed calculations are required but use the basic equations for heat transfer in a heat exchanger and for temperature change in process fluids. Terminal temperatures should be rounded to the nearest 1°C before plotting as required below. The estimates should be based on average temperature differences (not log mean temperature differences) and in each case the new values for $\Delta T$ and $\theta$ should be stated.

If the conditions are changed as indicated below, sketch, in solid lines on the given axes, the anticipated temperature profiles, with numerical values for both cooling water and steam, across the condenser for each of the following conditions:

(a) Cooling water inlet temperature increased to 18°C. (2)

(b) Turbine load reduced to one quarter of its original value. (2)

(c) Cooling water flow reduced to one half of its original value which also results in the overall heat transfer coefficient being reduced to 70% of its original value. (3)

(d) Overall heat transfer coefficient reduced by 20% due to fouling of tubes. (3)

*Note: Return Page 14 with the examination answer booklet with your name on it.*

[ 10 marks ]

## QUESTION 4 PWR HEAT GENERATION

A typical Pressurised Water Reactor has the following core characteristics:

| | |
|---|---|
| Number of Fuel Assemblies in Reactor | 157 |
| Number of Fuel Rods per Assembly | 264 (17 x 17 array) |
| Fuel Rod Outside Diameter | 9.5 mm |
| Fuel Rod Cladding Thickness | 0.57 mm |
| Fuel Pellet Diameter | 8.19 mm |
| Fuel Rod Lattice Pitch | 12.6 mm |
| Fuel Rod Effective Length | 3.658 m |
| Equivalent Reactor Core Diameter | 3.040 m |
| Uranium Dioxide Density | 10 400 kg/m$^3$ |
| Reactor Coolant Inlet Temperature | 286°C |
| Reactor Coolant Outlet Temperature | 325°C |
| Coolant Flow Rate through Reactor Core | 12 600 kg/s |
| Coolant Pressure | 15.5 MPa |
| Average U-235 Enrichment | 2.8 % |
| Effective U-235 Fission Cross Section | 380 barns |
| Average Neutron Flux | 4.5 x $10^{17}$ neutron/m$^2$s |
| Energy per Fission | 32 pJ |

Determine the following assuming uniform conditions throughout the reactor core.

(a) Mass of fuel (uranium dioxide) in reactor (kg) (2)

(b) Total heat release rate in fuel based on fission parameters (MW) (5)

(c) Thermal power output based on coolant flow conditions (MW) (3)

The molecular mass of the fuel may be determined from the atomic mass numbers of the dominant isotopes of uranium dioxide.

Note: 1 barn = $10^{-28}$ m$^2$

[10 marks]

## QUESTION 5 STEAM CYCLE

Refer to the Examination Paper Attachments Page 15 **Heat Balance Diagram.**

Using the data given in the Heat Balance Diagram, calculate the following:

(a) Overall steam cycle efficiency based on heat input and electrical output. (3)

(b) Power output of the high pressure (HP) turbine. (3)

(c) Power output of the intermediate pressure (IP) turbine. (4)

*Note that the parameters on page 15 have been converted to SI units and temperatures and pressures in particular have been rounded to reduce the number of significant figures. Enthalpies therefore will not agree exactly with those in steam tables should these be referred to.*

[ 10 marks ]

## SECTION B DESCRIPTIVE QUESTIONS

***Note that a ten mark question requires an answer of approximately two full pages of complete explanations with sketches, if appropriate, to support the explanation.***

## QUESTION 6 ENERGY STORAGE

Electrical energy required by consumers must be produced instantaneously by power plants which must then operate with a constantly varying output. The demand for electricity is high during the day and low at night. It is therefore advantageous to store energy on a large scale in a different form.

Describe TWO different methods for storing energy on a large scale for later use. Clarify in what form is this energy. Explain limitations to these methods of storage. Indicate likely levels of efficiency in the recovery of this energy. Explain what would determine the economic viability of these energy storage methods.

[ 10 marks ]

## QUESTION 7 SYSTEM LOAD DEMAND

Refer to the Examination Paper Attachments Page 16 **System Load Demand**.

An isolated electrical power utility with no connections to other systems has the following sources of generating capacity:

- Nuclear
- Coal
- Gas
- Hydro (pumped storage only)

Each of these constitutes one quarter of the maximum capacity of the system. The water for the pumped storage hydro cannot be replenished since it is not on a river.

A typical daily load demand curve is given in the diagram. By marking or shading the squared areas on the diagram in an appropriate manner, show how you would operate the system to meet the demand on a daily basis. State the assumptions made and explain the reasoning for the scheduling and output of the power sources.

*Note: Return Page 16 with the examination answer booklet with your name on it.*

[ 10 marks ]

## QUESTION 8 ENVIRONMENTAL IMPACT

Compare the environmental impact of large scale electric power generation from each of the following (all three) sources of energy:

~ Coal (fossil fuel combustion)
~ Nuclear (nuclear fission)
~ Hydro (renewable energy)

(a) For each explain the physical impact or disruption of the environment to build the plant and to supply the energy required. Suggest ways of alleviating the problems. ( 3-5 marks )

(b) For each explain what detrimental effluents are produced during operation and by what mechanism and to what degree they can be minimised. ( 3-5 marks )

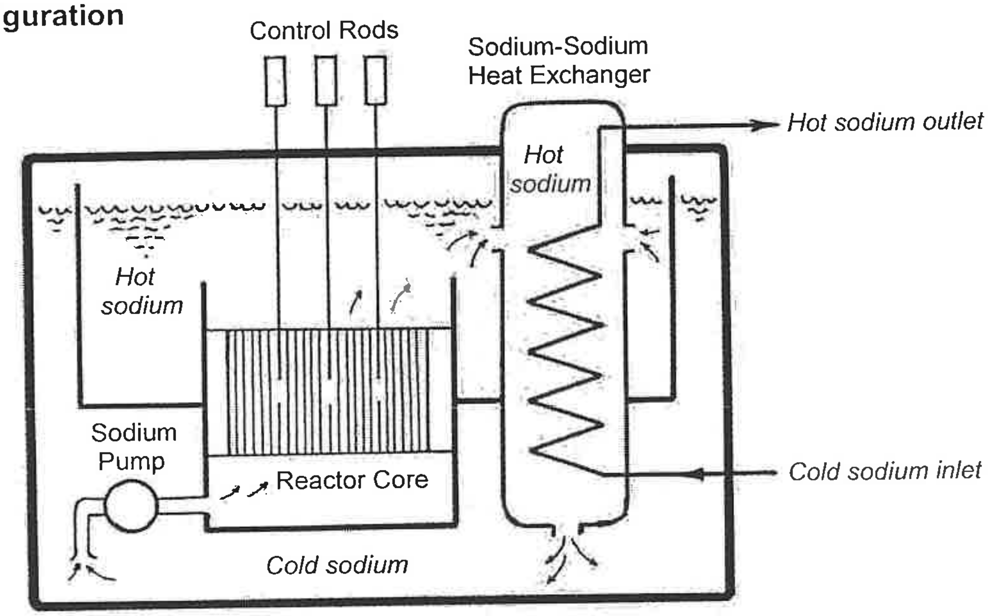
(c) For each explain what solid waste products are produced and how these products may be disposed of in a way that will not be detrimental to the environment. ( 3-5 marks )

[ 10 marks maximum ]

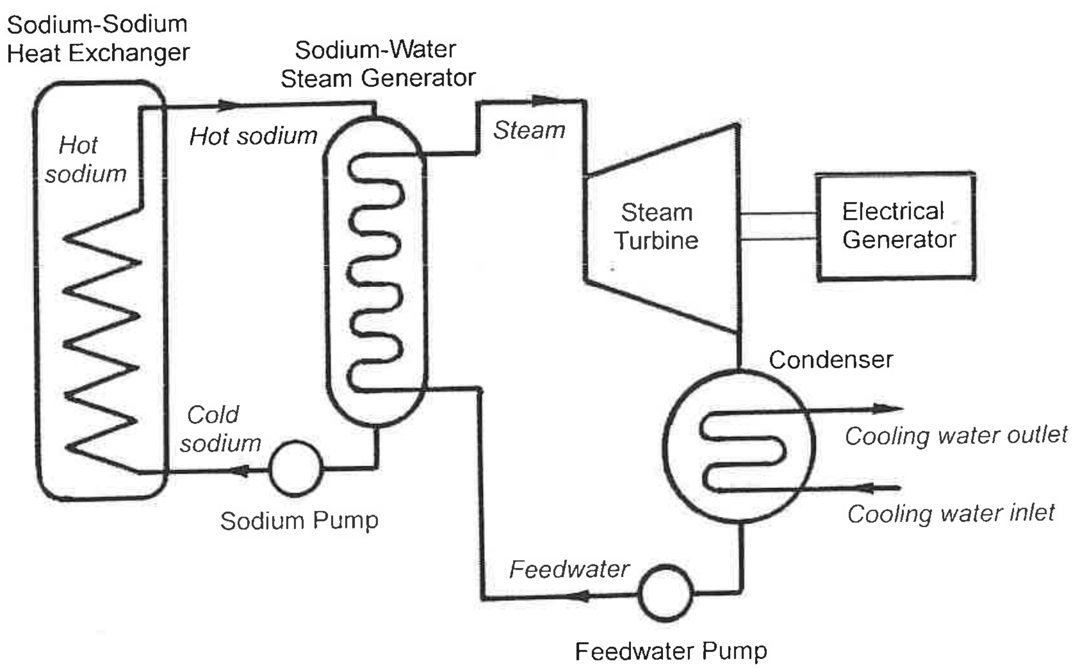
## EXAMINATION PAPER ATTACHMENTS

## QUESTION 1 STEAM TURBINE FOR ARC-100 NUCLEAR PLANT

### Reactor Configuration



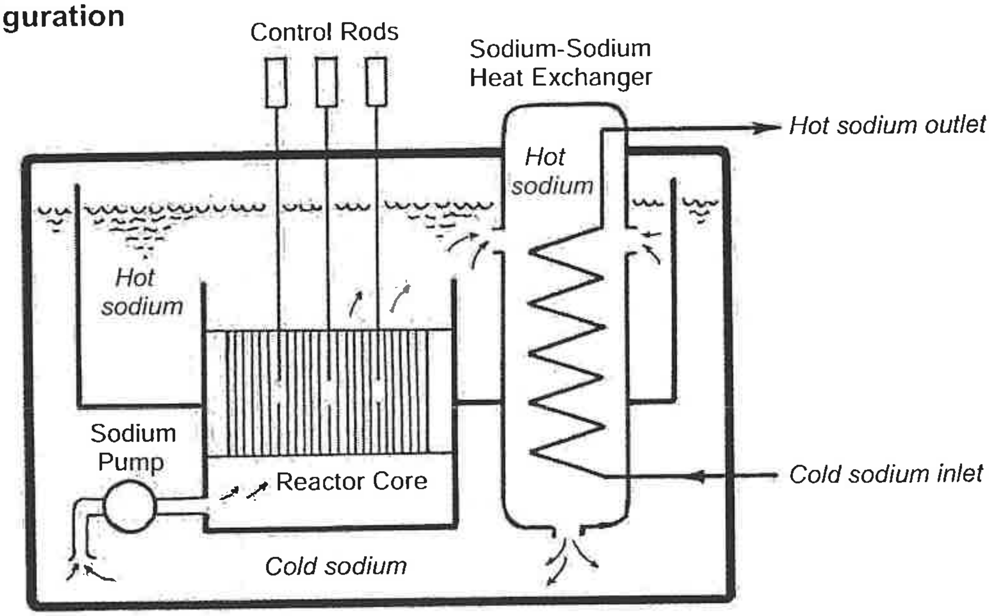

### Steam Turbine Circuit



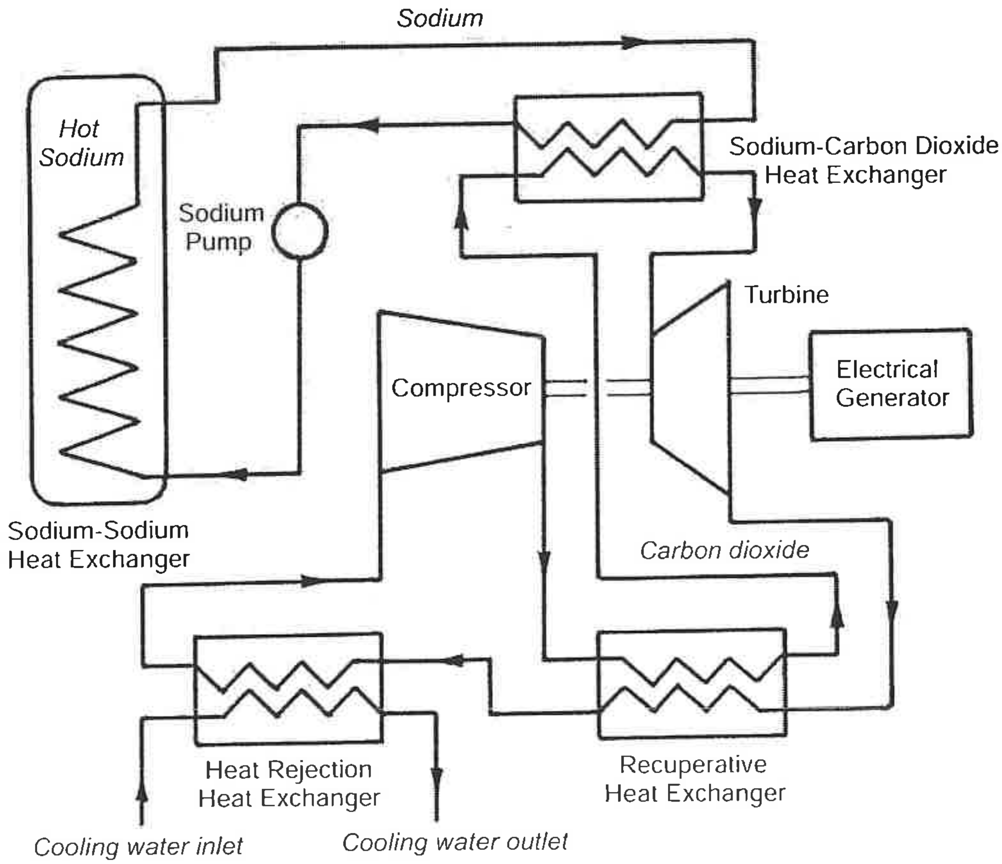
## EXAMINATION PAPER ATTACHMENTS

## QUESTION 2 GAS TURBINE FOR ARC-100 NUCLEAR PLANT

### Reactor Configuration




### Gas Turbine Circuit



## QUESTION 3 KOEBERG CONDENSER

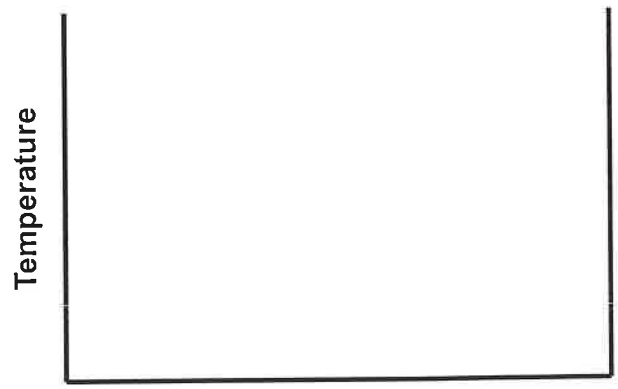
| | |
|---|---|
| Steam flow rate | 2996 t/h |
| Water make-up flow rate | 9 t/h |
| Cooling water flow rate | 141 000 t/h |
| Cooling water inlet temperature | 13°C |
| Cooling water outlet temperature | 24°C |
| Cooling water density | 1.025 |
| Cooling water friction head loss | 4.7 m |
| Mean steam velocity at tube bank | 92 m/s |
| Cooling water velocity inside tubes | 2 m/s |
| Number of tubes | 76968 |
| Number of support plates | 14 (per bundle) |
| Tube material | titanium |
| Cooling surface area | 57 426 $m^2$ |
| Tube overall length | 12.84 m |
| Tube effective length | 12.50 m |
| Tube diameter (OD) | 19 mm |
| Tube wall thickness (normal tubes) | 0.5 mm |
| Tube wall thickness (impact tubes) | 0.6 mm |
| Tube configuration | diagonal array |
| Tube pitch across array | 26 mm |
| Tube pitch along array | 45 mm |
| Tube fixing method | expanding |
| Tube mass | 132 t |
| Total volume under vacuum | 7500 $m^3$ |
| Steam inlet pressure | 0.043 bar abs |
| Steam inlet temperature | 30°C |
| Terminal temperature difference | 6°C |
| Condenser hotwell capacity | 700 $m^3$ (approx.) |
| Number of water boxes (inlet and outlet) | 12 |
| Water box internal lining | neoprene |
| Condenser shell thickness | 18 mm |
| Tube plate thickness | 25 mm |
| Support plate thickness | 12 mm |
| Condenser length | 43 m (approx.) |
| Condenser width | 25 m (approx.) |
| Condenser mass without LP Heaters | 1267 t |

**QUESTION 3 TEMPERATURE PROFILES** **NAME ..........................................**

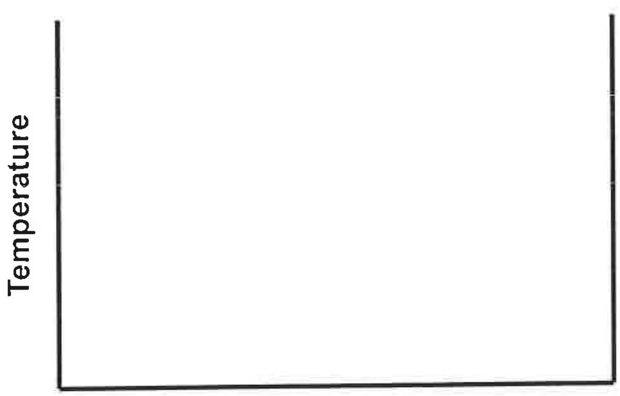
Show initial conditions as dotted lines on each diagram
Show new conditions for each case as solid lines
Give temperatures on axes
Show basic calculations and new values for $\Delta T$ and $\theta$ below each diagram

**(a) Increase in cooling water temperature**

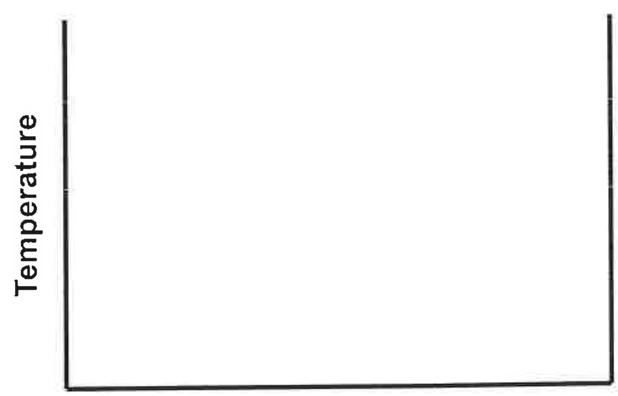

**(b) Reduction in turbine load**



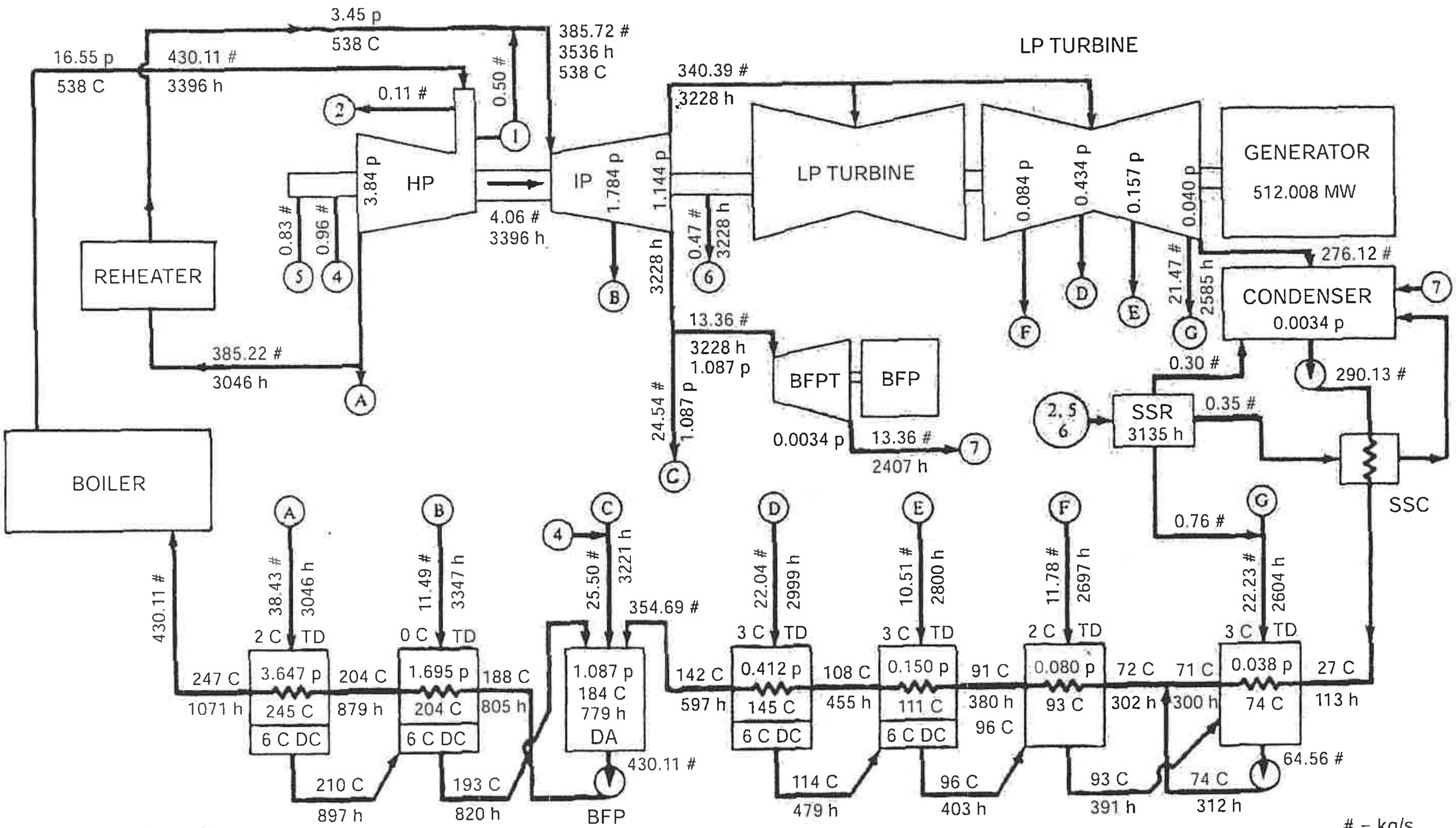

**(c) Reduction in cooling water flow**




**(d) Reduction in heat transfer coefficient**



## QUESTION 5 HEAT BALANCE DIAGRAM (512 MW REHEAT STEAM POWER PLANT)




# = kg/s
h = kJ/kg
p = Mpa
C = °C

HP FEEDWATER HEATERS

LP FEEDWATER HEATERS

# = kg/s
h = kJ/kg
p = Mpa
C = °C

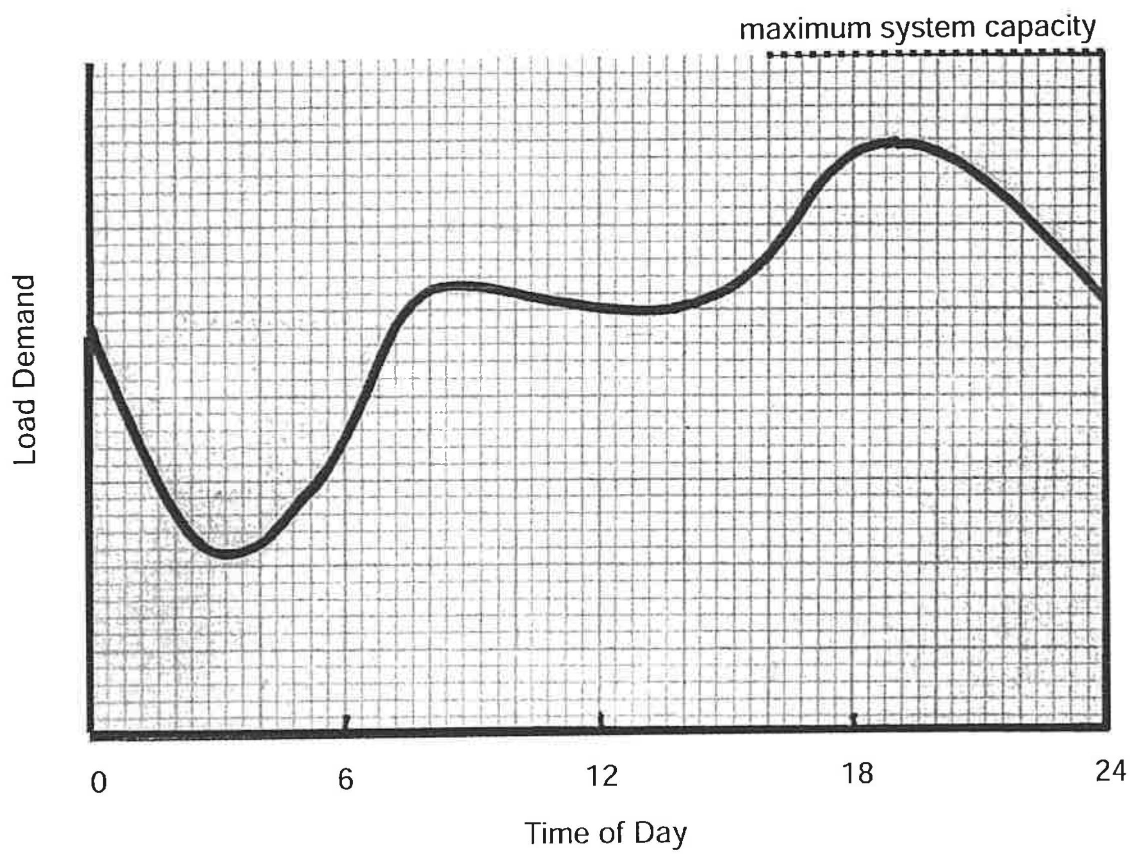
BFP = BOILER FEED PUMP
BFPT = BOILER FEED PUMP TURBINE

DA = DEAERATOR
DC = DRAIN COOLER

SSR = SEALING STEAM REGULATOR
SSC = SEALING STEAM CONDENSER

## EXAMINATION PAPER ATTACHMENTS

**QUESTION 7 SYSTEM LOAD DEMAND** **NAME** ..............................................



## EXAMINATION REFERENCE MATERIAL

## NOMENCLATURE FOR REFERENCE EQUATIONS (SI UNITS)

| | | |
|---|---|---|
| a | Acceleration | $m/s^2$ |
| A | Flow area, Surface area | $m^2$ |
| $c_p$ | Specific heat at constant pressure | J/kg°C |
| $c_v$ | Specific heat at constant volume | J/kg°C |
| D | Diameter | m |
| E | Energy | J |
| $E_f$ | Energy release per fission of one atom | |
| h | Specific enthalpy | J/kg |
| H | Enthalpy | J |
| F | Force | N |
| g | Gravitational acceleration | $m/s^2$ |
| k | Ratio of specific heats | |
| L | Length | m |
| m | Mass | kg |
| m | Fractional mass flow rate | |
| M | Mass flow rate | kg/s |
| M | Molecular weight | |
| N | Number of nuclei | number/g |
| $N_A$ | Avogadro's number | |
| $N_f$ | Number of fissile nuclei | $number/m^3$ |
| n | Gas expansion index | |
| p | Pressure | Pa |
| P | Power | W |
| q | Heat transferred | J/kg |
| q* | Heat release rate | $J/m^3$ |
| Q | Heat | J |
| Q | Volume flow rate | $m^3/s$ |
| R | Specific gas constant | J/kg°K |
| $R_0$ | Universal gas constant | J/kg-mole°K |
| s | Specific entropy | J/kg°K |
| S | Entropy | J/°K |
| t | Time | s |
| T | Temperature | °C |
| T | Absolute temperature | °K |
| u | Specific internal energy | J/kg |
| U | Internal energy | J |
| v | Specific volume | $m^3/kg$ |
| V | Volume | $m^3$ |
| V | Velocity | m/s |
| w | Specific work | J/kg |
| W | Work | J |

| | | |
|---|---|---|
| x | Length | m |
| z | Elevation | m |
| $\gamma$ | Fuel enrichment | |
| $\eta$ | Efficiency | |
| $\phi$ | Neutron flux | neutrons/m$^2$s |
| $\sigma_f$ | Cross section | barn |
| $\mu$ | Dynamic viscosity | Ns/m$^2$ |
| $<$ | Kinematic viscosity | m$^2$/s |
| $\rho$ | Density | kg/m$^3$ |
| T | Thrust | N |
| T | Torque | Nm |
| $\Omega$ | Heat transfer rate | J/s |

## CONSTANTS

For consistency in calculations the following constants should be used:

| | |
|---|---|
| Gravitational Acceleration | $g$ = 9.81 m/s |
| Atmospheric Pressure | $p$ = 100 kPa |
| Universal Gas Constant | $R_o$ = 8.314 kJ/kg mole°K |
| Density of Water | $\rho$ = 1000 kg/m$^3$ |
| Density of Air | $\rho$ = 1.21 kg/m$^3$ (at 15°C) |
| Specific Heat of Water | $c_p$ = 4.19 kJ/kg°C |
| Specific Heat of Air | $c_p$ = 1.005 kJ/kg°C |
| Specific Heat of Air | $c_v$ = 0.718 kJ/k°C |
| Specific Heat of Helium | $c_p$ = 5.193 kJ/kg°C |
| Specific Heat of Helium | $c_v$ = 3.116 kJ/kg°C |
| Specific Gas Constant for Air | $R$ = 0.287 kJ/kg°K |
| Avogadro's Number | $N_A$ = 0.602 x $10^{24}$ atoms/mole |
| Nuclear Cross Section | 1 barn = $10^{-28}$ m$^2$ |

## GENERAL REFERENCE EQUATIONS

### Ideal Gas Relationships

| | |
|---|---|
| Gas Law: | $pv = RT$ |
| Gas Law: | $pV = mRT$ |
| Specific Heat at Constant Pressure: | $c_p = \Delta h/\Delta T$ |
| Specific Heat at Constant Volume: | $c_v = \Delta u/\Delta T$ |
| Gas Constant: | $R = c_p - c_v$ |

| | |
|---|---|
| Specific Heat Ratio: | $k = c_p/c_v$ |
| Constant Volume: | $T_1/T_2 = p_1/p_2$ |
| Constant Pressure: | $T_1/T_2 = v_1/v_2$ |
| Constant Temperature: | $p_1v_1 = p_2v_2$ |
| Constant Entropy: | $p_1v_1^k = p_2v_2^k$ |
| Isentropic Relations: | $p_1/p_2 = (v_2/v_1)^k = (T_1/T_2)^{k/(k-1)}$ |
| | $T_1/T_2 = (v_2/v_1)^{k-1} = (p_1/p_2)^{(k-1)/k}$ |

**Work in Non-Flow Processes**

| | |
|---|---|
| Constant Pressure: | $w = p\,(v_2 - v_1)$ |
| Constant Temperature: | $w = p_1v_1 \ln(v_2/v_1)$ |
| Constant Entropy: | $w = (p_2v_2 - p_1v_1) / (1 - k)$ |
| | $w = (T_2 - T_1)\,R / (1 - k)$ |

**Work in Flow Processes**

| | |
|---|---|
| Constant Temperature: | $w = p_1v_1 \ln(v_2v_1)$ |
| Constant Volume: | $w = (p_2 - p_1)\,v$ |
| Constant Entropy: | $w = (p_1v_1 - p_2v_2)\,k / (k - 1)$ |

**Thermodynamics**

| | |
|---|---|
| First Law: | $dE = \delta Q - \delta W$ |
| Enthalpy: | $h = u + pv$ |
| Enthalpy Change | $\Delta h = \Delta u + \Delta(pv)$ |
| Continuity: | $\rho VA = \text{constant}$ |
| Flow Work: | $w = \Delta(pv)$ |
| Energy Equation: | $zg + V^2/2 + u + pv + \Delta w + \Delta q = \text{constant}$ |
| Entropy: | $\Delta s = q/T$ (reversible conditions) |

**Fluid Mechanics**

| | |
|---|---|
| Continuity Equation: | $\rho_1V_1A_1 = \rho_2V_2A_2 = M$ |
| Energy Equation: | $z_1g + V_1^2/2 + u_1 + p_1v_1 + w_{in} + q_{in}$ |
| | $= z_2g + V_2^2/2 + u_2 + p_2\,v_2 + w_{out} + q_{out}$ |
| Bernoulli's Equation: | $p_1/\rho g + z_1 + V_1^2/2g = p_2/\rho g + z_2 + V_2^2/2g$ |
| Momentum Equation: | $F = p_1A_1 - p_2A_2 - \rho VA(V_2 - V_1)$ |
| | (one dimensional) |

**Internal Combustion Engines**

| | |
|---|---|
| Power Output | $P = 2\pi N\tau / 60$ |
| Engine Capacity | $V_{total} = 1000\,(\pi D^2/4)\,LN_{cylinders}$ |
| Mean Effective Pressure | $MEP = Work / (V_1 - V_2)$ |

## Steam Turbines

Nozzle Equation: $h_1 - h_2 = (V_2^2 - V_1^2) / 2$

Work: $w = [(V_1^2{}_{absolute} - V_2^2{}_{absolute}) + (V_2^2{}_{relative} - V_1^2{}_{relative})] / 2$

## Gas Turbines

Isentropic Equation: $(T_2/T_1) = (p_2/p_1)^{(k-1)/k}$

Enthalpy Change: $h_1 - h_2 = c_p(T_1 - T_2)$ (ideal gas)

Nozzle Equation: $h_1 - h_2 = (V_2^2 - V_1^2) / 2$

## Jet Propulsion

Thrust: $\tau = M(V_{jet} - V_{aircraft})$

Thrust Power: $\tau V_{aircraft} = M(V_{jet} - V_{aircraft}) V_{aircraft}$

Jet Power: $P = M(V_{jet}^2 - V_{aircraft}^2) / 2$

Propulsion Efficiency: $\eta_p = 2V_{aircraft} / (V_{jet} + V_{aircraft})$

## Wind Turbines

Maximum Ideal Power: $P_{max} = 8\rho AV_1^3 / 27$

## Nuclear Energy

Number of nuclei per gram of material: $N = N_A / M$

Number of fissile nuclei per cm³ of material: $N_f = \gamma (N_A / M) \rho$

Heat release rate in nuclear fuel: $q^* = \phi N_f \sigma_f E_f$

## Cycle Efficiencies

$\eta_{cycle} = W_{out} / q_{in} = W_{out} / Q_{in} = P_{out} / \Omega_{in}$

$\eta_{Carnot} = (T_{hot} - T_{cold}) / T_{hot}$

$\eta_{Rankine} = (\Delta h_{turbine} - \Delta h_{pump}) / \Delta h_{boiler}$

$\eta_{Brayton} = (\Delta T_{turbine} - \Delta T_{Compressor}) / \Delta T_{combustion}$

## Component Efficiencies

$\eta_{boiler} = \Omega_{out} / \Omega_{in}$

$\eta_{boiler} = (\Omega_{in} / \Omega_{lost}) / \Omega_{in}$

$\eta_{turbine} = \Delta h_{actual} / \Delta h_{isentropic}$

$\eta_{nozzle} = \Delta h_{actual} / \Delta h_{isentropic}$

$\eta_{gas\ turbine} = \Delta T_{actual} / \Delta T_{isentropic}$

$\eta_{pump} = \Delta h_{isentropic} / \Delta h_{actual}$

$\eta_{compressor} = \Delta T_{isentropic} / \Delta T_{actual}$

# Thermodynamics and Heat Power

SIXTH EDITION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PRENTICE HALL

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**TABLE A.1 (SI)**

Saturation: Temperature (Steam)

| | | Specific Volume ($m^3/kg$) | | Internal Energy (kJ/kg) | | | Enthalpy (kJ/kg) | | | Entropy (kJ/kg · °k) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. °C $T$ | Press. kPa $P$ | Sat. Liquid $v_f$ | Sat. Vapor $v_g$ | Sat. Liquid $u_f$ | Evap. $u_{fg}$ | Sat. Vapor $u_g$ | Sat. Liquid $h_f$ | Evap. $h_{fg}$ | Sat. Vapor $h_g$ | Sat. Liquid $s_f$ | Evap. $s_{fg}$ | Sat. Vapor $s_g$ |
| 0.01 | 0.6113 | 0.001 000 | 206.14 | .00 | 2375.3 | 2375.3 | .01 | 2501.3 | 2501.4 | .0000 | 9.1562 | 9.1562 |
| 5 | 0.8721 | 0.001 000 | 147.12 | 20.97 | 2361.3 | 2382.3 | 20.98 | 2489.6 | 2510.6 | .0761 | 8.9496 | 9.0257 |
| 10 | 1.2276 | 0.001 000 | 106.38 | 42.00 | 2347.2 | 2389.2 | 42.01 | 2477.7 | 2519.8 | .1510 | 8.7498 | 8.9008 |
| 15 | 1.7051 | 0.001 001 | 77.93 | 62.99 | 2333.1 | 2396.1 | 62.99 | 2465.9 | 2528.9 | .2245 | 8.5569 | 8.7814 |
| 20 | 2.339 | 0.001 002 | 57.79 | 83.95 | 2319.0 | 2402.9 | 83.96 | 2454.1 | 2538.1 | .2966 | 8.3706 | 8.6672 |
| 25 | 3.169 | 0.001 003 | 43.36 | 104.88 | 2304.9 | 2409.8 | 104.89 | 2442.3 | 2547.2 | .3674 | 8.1905 | 8.5580 |
| 30 | 4.246 | 0.001 004 | 32.89 | 125.78 | 2290.8 | 2416.6 | 125.79 | 2430.5 | 2556.3 | .4369 | 8.0164 | 8.4533 |
| 35 | 5.628 | 0.001 006 | 25.22 | 146.67 | 2276.7 | 2423.4 | 146.68 | 2418.6 | 2565.3 | .5053 | 7.8478 | 8.3531 |
| 40 | 7.384 | 0.001 008 | 19.52 | 167.56 | 2262.6 | 2430.1 | 167.57 | 2406.7 | 2574.3 | .5725 | 7.6845 | 8.2570 |
| 45 | 9.593 | 0.001 010 | 15.26 | 188.44 | 2248.4 | 2436.8 | 188.45 | 2394.8 | 2583.2 | .6387 | 7.5261 | 8.1648 |
| 50 | 12.349 | 0.001 012 | 12.03 | 209.32 | 2234.2 | 2443.5 | 209.33 | 2382.7 | 2592.1 | .7038 | 7.3725 | 8.0763 |
| 55 | 15.758 | 0.001 015 | 9.568 | 230.21 | 2219.9 | 2450.1 | 230.23 | 2370.7 | 2600.9 | .7679 | 7.2234 | 7.9913 |
| 60 | 19.940 | 0.001 017 | 7.671 | 251.11 | 2205.5 | 2456.6 | 251.13 | 2358.5 | 2609.6 | .8312 | 7.0784 | 7.9096 |
| 65 | 25.03 | 0.001 020 | 6.197 | 272.02 | 2191.1 | 2463.1 | 272.06 | 2346.2 | 2618.3 | .8935 | 6.9375 | 7.8310 |
| 70 | 31.19 | 0.001 023 | 5.042 | 292.95 | 2176.6 | 2469.6 | 292.98 | 2333.8 | 2626.8 | .9549 | 6.8004 | 7.7553 |
| 75 | 38.58 | 0.001 026 | 4.131 | 313.90 | 2162.0 | 2475.9 | 313.93 | 2321.4 | 2635.3 | 1.0155 | 6.6669 | 7.6824 |
| 80 | 47.39 | 0.001 029 | 3.407 | 334.86 | 2147.4 | 2482.2 | 334.91 | 2308.8 | 2643.7 | 1.0753 | 6.5369 | 7.6122 |
| 85 | 57.83 | 0.001 033 | 2.828 | 355.84 | 2132.6 | 2488.4 | 355.90 | 2296.0 | 2651.9 | 1.1343 | 6.4102 | 7.5445 |
| 90 | 70.14 | 0.001 036 | 2.361 | 376.85 | 2117.7 | 2494.5 | 376.92 | 2283.2 | 2660.1 | 1.1925 | 6.2866 | 7.4791 |
| 95 | 84.55 | 0.001 040 | 1.982 | 397.88 | 2102.7 | 2500.6 | 397.96 | 2270.2 | 2668.1 | 1.2500 | 6.1659 | 7.4159 |

**TABLE A.1 (SI) (cont'd.)**

| Temp. °C $T$ | Press. kPa $P$ | Specific Volume (m³/kg) Sat. Liquid $v_f$ | Sat. Vapor $v_g$ | Internal Energy (kJ/kg) Sat. Liquid $u_f$ | Evap. $u_{fg}$ | Sat. Vapor $u_g$ | Enthalpy (kJ/kg) Sat. Liquid $h_f$ | Evap. $h_{fg}$ | Sat. Vapor $h_g$ | Entropy (kJ/kg · °k) Sat. Liquid $s_f$ | Evap. $s_{fg}$ | Sat. Vapor $s_g$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MPa | | | | | | | | | | | |
| 100 | 0.101 35 | 0.001 044 | 1.6729 | 418.94 | 2087.6 | 2506.5 | 419.04 | 2257.0 | 2676.1 | 1.3069 | 6.0480 | 7.3549 |
| 105 | 0.120 82 | 0.001 048 | 1.4194 | 440.02 | 2072.3 | 2512.4 | 440.15 | 2243.7 | 2683.8 | 1.3630 | 5.9328 | 7.2958 |
| 110 | 0.143 27 | 0.001 052 | 1.2102 | 461.14 | 2057.0 | 2518.1 | 461.30 | 2230.2 | 2691.5 | 1.4185 | 5.8202 | 7.2387 |
| 115 | 0.169 06 | 0.001 056 | 1.0366 | 482.30 | 2041.4 | 2523.7 | 482.48 | 2216.5 | 2699.0 | 1.4734 | 5.7100 | 7.1833 |
| 120 | 0.198 53 | 0.001 060 | 0.8919 | 503.50 | 2025.8 | 2529.3 | 503.71 | 2202.6 | 2706.3 | 1.5276 | 5.6020 | 7.1296 |
| 125 | 0.2321 | 0.001 065 | 0.7706 | 524.74 | 2009.9 | 2534.6 | 524.99 | 2188.5 | 2713.5 | 1.5813 | 5.4962 | 7.0775 |
| 130 | 0.2701 | 0.001 070 | 0.6685 | 546.02 | 1993.9 | 2539.9 | 546.31 | 2174.2 | 2720.5 | 1.6344 | 5.3925 | 7.0269 |
| 135 | 0.3130 | 0.001 075 | 0.5822 | 567.35 | 1977.7 | 2545.0 | 567.69 | 2159.6 | 2727.3 | 1.6870 | 5.2907 | 6.9777 |
| 140 | 0.3613 | 0.001 080 | 0.5089 | 588.74 | 1961.3 | 2550.0 | 589.13 | 2144.7 | 2733.9 | 1.7391 | 5.1908 | 6.9299 |
| 145 | 0.4154 | 0.001 085 | 0.4463 | 610.18 | 1944.7 | 2554.9 | 610.63 | 2129.6 | 2740.3 | 1.7907 | 5.0926 | 6.8833 |
| 150 | 0.4758 | 0.001 091 | 0.3928 | 631.68 | 1927.9 | 2559.5 | 632.20 | 2114.3 | 2746.5 | 1.8418 | 4.9960 | 6.8379 |
| 155 | 0.5431 | 0.001 096 | 0.3468 | 653.24 | 1910.8 | 2564.1 | 653.84 | 2098.6 | 2752.4 | 1.8925 | 4.9010 | 6.7935 |
| 160 | 0.6178 | 0.001 102 | 0.3071 | 674.87 | 1893.5 | 2568.4 | 675.55 | 2082.6 | 2758.1 | 1.9427 | 4.8075 | 6.7502 |
| 165 | 0.7005 | 0.001 108 | 0.2727 | 696.56 | 1876.0 | 2572.5 | 697.34 | 2066.2 | 2763.5 | 1.9925 | 4.7153 | 6.7078 |
| 170 | 0.7917 | 0.001 114 | 0.2428 | 718.33 | 1858.1 | 2576.5 | 719.21 | 2049.5 | 2768.7 | 2.0419 | 4.6244 | 6.6663 |
| 175 | 0.8920 | 0.001 121 | 0.2168 | 740.17 | 1840.0 | 2580.2 | 741.17 | 2032.4 | 2773.6 | 2.0909 | 4.5347 | 6.6256 |
| 180 | 1.0021 | 0.001 127 | 0.194 05 | 762.09 | 1821.6 | 2583.7 | 763.22 | 2015.0 | 2778.2 | 2.1396 | 4.4461 | 6.5857 |
| 185 | 1.1227 | 0.001 134 | 0.174 09 | 784.10 | 1802.9 | 2587.0 | 785.37 | 1997.1 | 2782.4 | 2.1879 | 4.3586 | 6.5465 |
| 190 | 1.2544 | 0.001 141 | 0.156 54 | 806.19 | 1783.8 | 2590.0 | 807.62 | 1978.8 | 2786.4 | 2.2359 | 4.2720 | 6.5079 |
| 195 | 1.3978 | 0.001 149 | 0.141 05 | 828.37 | 1764.4 | 2592.8 | 829.98 | 1960.0 | 2790.0 | 2.2835 | 4.1863 | 6.4698 |
| 200 | 1.5538 | 0.001 157 | 0.127 36 | 850.65 | 1744.7 | 2595.3 | 852.45 | 1940.7 | 2793.2 | 2.3309 | 4.1014 | 6.4323 |
| 205 | 1.7230 | 0.001 164 | 0.115 21 | 873.04 | 1724.5 | 2597.5 | 875.04 | 1921.0 | 2796.0 | 2.3780 | 4.0172 | 6.3952 |
| 210 | 1.9062 | 0.001 173 | 0.104 41 | 895.53 | 1703.9 | 2599.5 | 897.76 | 1900.7 | 2798.5 | 2.4248 | 3.9337 | 6.3585 |
| 215 | 2.104 | 0.001 181 | 0.094 79 | 918.14 | 1682.9 | 2601.1 | 920.62 | 1879.9 | 2800.5 | 2.4714 | 3.8507 | 6.3221 |
| 220 | 2.318 | 0.001 190 | 0.086 19 | 940.87 | 1661.5 | 2602.4 | 943.62 | 1858.5 | 2802.1 | 2.5178 | 3.7683 | 6.2861 |
| 225 | 2.548 | 0.001 199 | 0.078 49 | 963.73 | 1639.6 | 2603.3 | 966.78 | 1836.5 | 2803.3 | 2.5639 | 3.6863 | 6.2503 |
| 230 | 2.795 | 0.001 209 | 0.071 58 | 986.74 | 1617.2 | 2603.9 | 990.12 | 1813.8 | 2804.0 | 2.6099 | 3.6047 | 6.2146 |
| 235 | 3.060 | 0.001 219 | 0.065 37 | 1009.89 | 1594.2 | 2604.1 | 1013.62 | 1790.5 | 2804.2 | 2.6558 | 3.5233 | 6.1791 |
| 240 | 3.344 | 0.001 229 | 0.059 76 | 1033.21 | 1570.8 | 2604.0 | 1037.32 | 1766.5 | 2803.8 | 2.7015 | 3.4422 | 6.1437 |
| 245 | 3.648 | 0.001 240 | 0.054 71 | 1056.71 | 1546.7 | 2603.4 | 1061.23 | 1741.7 | 2803.0 | 2.7472 | 3.3612 | 6.1083 |

**TABLE A.1 (SI)** (cont'd.)

| Temp. °C $T$ | Press. MPa $P$ | Specific Volume (m³/kg) Sat. Liquid $v_f$ | Sat. Vapor $v_g$ | Internal Energy (kJ/kg) Sat. Liquid $u_f$ | Evap. $u_{fg}$ | Sat. Vapor $u_g$ | Enthalpy (kJ/kg) Sat. Liquid $h_f$ | Evap. $h_{fg}$ | Sat. Vapor $h_g$ | Entropy (kJ/kg · °k) Sat. Liquid $s_f$ | Evap. $s_{fg}$ | Sat. Vapor $s_g$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 250 | 3.973 | 0.001 251 | 0.050 13 | 1080.39 | 1522.0 | 2602.4 | 1085.36 | 1716.2 | 2801.5 | 2.7927 | 3.2802 | 6.0730 |
| 255 | 4.319 | 0.001 263 | 0.045 98 | 1104.28 | 1496.7 | 2600.9 | 1109.73 | 1689.8 | 2799.5 | 2.8383 | 3.1992 | 6.0375 |
| 260 | 4.688 | 0.001 276 | 0.042 21 | 1128.39 | 1470.6 | 2599.0 | 1134.37 | 1662.5 | 2796.9 | 2.8838 | 3.1181 | 6.0019 |
| 265 | 5.081 | 0.001 289 | 0.038 77 | 1152.74 | 1443.9 | 2596.6 | 1159.28 | 1634.4 | 2793.6 | 2.9294 | 3.0368 | 5.9662 |
| 270 | 5.499 | 0.001 302 | 0.035 64 | 1177.36 | 1416.3 | 2593.7 | 1184.51 | 1605.2 | 2789.7 | 2.9751 | 2.9551 | 5.9301 |
| 275 | 5.942 | 0.001 317 | 0.032 79 | 1202.25 | 1387.9 | 2590.2 | 1210.07 | 1574.9 | 2785.0 | 3.0208 | 2.8730 | 5.8938 |
| 280 | 6.412 | 0.001 332 | 0.030 17 | 1227.46 | 1358.7 | 2586.1 | 1235.99 | 1543.6 | 2779.6 | 3.0668 | 2.7903 | 5.8571 |
| 285 | 6.909 | 0.001 348 | 0.027 77 | 1253.00 | 1328.4 | 2581.4 | 1262.31 | 1511.0 | 2773.3 | 3.1130 | 2.7070 | 5.8199 |
| 290 | 7.436 | 0.001 366 | 0.025 57 | 1278.92 | 1297.1 | 2576.0 | 1289.07 | 1477.1 | 2766.2 | 3.1594 | 2.6227 | 5.7821 |
| 295 | 7.993 | 0.001 384 | 0.023 54 | 1305.2 | 1264.7 | 2569.9 | 1316.3 | 1441.8 | 2758.1 | 3.2062 | 2.5375 | 5.7437 |
| 300 | 8.581 | 0.001 404 | 0.021 67 | 1332.0 | 1231.0 | 2563.0 | 1344.0 | 1404.9 | 2749.0 | 3.2534 | 2.4511 | 5.7045 |
| 305 | 9.202 | 0.001 425 | 0.019 948 | 1359.3 | 1195.9 | 2555.2 | 1372.4 | 1366.4 | 2738.7 | 3.3010 | 2.3633 | 5.6643 |
| 310 | 9.856 | 0.001 447 | 0.018 350 | 1387.1 | 1159.4 | 2546.4 | 1401.3 | 1326.0 | 2727.3 | 3.3493 | 2.2737 | 5.6230 |
| 315 | 10.547 | 0.001 472 | 0.016 867 | 1415.5 | 1121.1 | 2536.6 | 1431.0 | 1283.5 | 2714.5 | 3.3982 | 2.1821 | 5.5804 |
| 320 | 11.274 | 0.001 499 | 0.015 488 | 1444.6 | 1080.9 | 2525.5 | 1461.5 | 1238.6 | 2700.1 | 3.4480 | 2.0882 | 5.5362 |
| 330 | 12.845 | 0.001 561 | 0.012 996 | 1505.3 | 993.7 | 2498.9 | 1525.3 | 1140.6 | 2665.9 | 3.5507 | 1.8909 | 5.4417 |
| 340 | 14.586 | 0.001 638 | 0.010 797 | 1570.3 | 894.3 | 2464.6 | 1594.2 | 1027.9 | 2622.0 | 3.6594 | 1.6763 | 5.3357 |
| 350 | 16.513 | 0.001 740 | 0.008 813 | 1641.9 | 776.6 | 2418.4 | 1670.6 | 893.4 | 2563.9 | 3.7777 | 1.4335 | 5.2112 |
| 360 | 18.651 | 0.001 893 | 0.006 945 | 1725.2 | 626.3 | 2351.5 | 1760.5 | 720.5 | 2481.0 | 3.9147 | 1.1379 | 5.0526 |
| 370 | 21.03 | 0.002 213 | 0.004 925 | 1844.0 | 384.5 | 2228.5 | 1890.5 | 441.6 | 2332.1 | 4.1106 | .6865 | 4.7971 |
| 374.14 | 22.09 | 0.003 155 | 0.003 155 | 2029.6 | 0 | 2029.6 | 2099.3 | 0 | 2099.3 | 4.4298 | 0 | 4.4298 |

**TABLE A.2 (SI)**
Saturation Pressures (Steam)

| Press. kPa $P$ | Temp. °C $T$ | Specific Volume (m³/kg) Sat. Liquid $v_f$ | Specific Volume (m³/kg) Sat. Vapor $v_g$ | Internal Energy (kJ/kg) Sat. Liquid $u_f$ | Internal Energy (kJ/kg) Evap. $u_{fg}$ | Internal Energy (kJ/kg) Sat. Vapor $u_g$ | Enthalpy (kJ/kg) Sat. Liquid $h_f$ | Enthalpy (kJ/kg) Evap. $h_{fg}$ | Enthalpy (kJ/kg) Sat. Vapor $h_g$ | Entropy (kJ/kg · °k) Sat. Liquid $s_f$ | Entropy (kJ/kg · °k) Evap. $s_{fg}$ | Entropy (kJ/kg · °k) Sat. Vapor $s_g$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.6113 | 0.01 | 0.001 000 | 206.14 | .00 | 2375.3 | 2375.3 | .01 | 2501.3 | 2501.4 | .0000 | 9.1562 | 9.1562 |
| 1.0 | 6.98 | 0.001 000 | 129.21 | 29.30 | 2355.7 | 2385.0 | 29.30 | 2484.9 | 2514.2 | .1059 | 8.8697 | 8.9756 |
| 1.5 | 13.03 | 0.001 001 | 87.98 | 54.71 | 2338.6 | 2393.3 | 54.71 | 2470.6 | 2525.3 | .1957 | 8.6322 | 8.8279 |
| 2.0 | 17.50 | 0.001 001 | 67.00 | 73.48 | 2326.0 | 2399.5 | 73.48 | 2460.0 | 2533.5 | .2607 | 8.4629 | 8.7237 |
| 2.5 | 21.08 | 0.001 002 | 54.25 | 88.48 | 2315.9 | 2404.4 | 88.49 | 2451.6 | 2540.0 | .3120 | 8.3311 | 8.6432 |
| 3.0 | 24.08 | 0.001 003 | 45.67 | 101.04 | 2307.5 | 2408.5 | 101.05 | 2444.5 | 2545.5 | .3545 | 8.2231 | 8.5776 |
| 4.0 | 28.96 | 0.001 004 | 34.80 | 121.45 | 2293.7 | 2415.2 | 121.46 | 2432.9 | 2554.4 | .4226 | 8.0520 | 8.4746 |
| 5.0 | 32.88 | 0.001 005 | 28.19 | 137.81 | 2282.7 | 2420.5 | 137.82 | 2423.7 | 2561.5 | .4764 | 7.9187 | 8.3951 |
| 7.5 | 40.29 | 0.001 008 | 19.24 | 168.78 | 2261.7 | 2430.5 | 168.79 | 2406.0 | 2574.8 | .5764 | 7.6750 | 8.2515 |
| 10 | 45.81 | 0.001 010 | 14.67 | 191.82 | 2246.1 | 2437.9 | 191.83 | 2392.8 | 2584.7 | .6493 | 7.5009 | 8.1502 |
| 15 | 53.97 | 0.001 014 | 10.02 | 225.92 | 2222.8 | 2448.7 | 225.94 | 2373.1 | 2599.1 | .7549 | 7.2536 | 8.0085 |
| 20 | 60.06 | 0.001 017 | 7.649 | 251.38 | 2205.4 | 2456.7 | 251.40 | 2358.3 | 2609.7 | .8320 | 7.0766 | 7.9085 |
| 25 | 64.97 | 0.001 020 | 6.204 | 271.90 | 2191.2 | 2463.1 | 271.93 | 2346.3 | 2618.2 | .8931 | 6.9383 | 7.8314 |
| 30 | 69.10 | 0.001 022 | 5.229 | 289.20 | 2179.2 | 2468.4 | 289.23 | 2336.1 | 2625.3 | .9439 | 6.8247 | 7.7686 |
| 40 | 75.87 | 0.001 027 | 3.993 | 317.53 | 2159.5 | 2477.0 | 317.58 | 2319.2 | 2636.8 | 1.0259 | 6.6441 | 7.6700 |
| 50 | 81.33 | 0.001 030 | 3.240 | 340.44 | 2143.4 | 2483.9 | 340.49 | 2305.4 | 2645.9 | 1.0910 | 6.5029 | 7.5939 |
| 75 | 91.78 | 0.001 037 | 2.217 | 384.31 | 2112.4 | 2496.7 | 384.39 | 2278.6 | 2663.0 | 1.2130 | 6.2434 | 7.4564 |
| MPa | | | | | | | | | | | | |
| 0.100 | 99.63 | 0.001 043 | 1.6940 | 417.36 | 2088.7 | 2506.1 | 417.46 | 2258.0 | 2675.5 | 1.3026 | 6.0568 | 7.3594 |
| 0.125 | 105.99 | 0.001 048 | 1.3749 | 444.19 | 2069.3 | 2513.5 | 444.32 | 2241.0 | 2685.4 | 1.3740 | 5.9104 | 7.2844 |
| 0.150 | 111.37 | 0.001 053 | 1.1593 | 466.94 | 2052.7 | 2519.7 | 467.11 | 2226.5 | 2693.6 | 1.4336 | 5.7897 | 7.2233 |
| 0.175 | 116.06 | 0.001 057 | 1.0036 | 486.80 | 2038.1 | 2524.9 | 486.99 | 2213.6 | 2700.6 | 1.4849 | 5.6868 | 7.1717 |
| 0.200 | 120.23 | 0.001 061 | 0.8857 | 504.49 | 2025.0 | 2529.5 | 504.70 | 2201.9 | 2706.7 | 1.5301 | 5.5970 | 7.1271 |
| 0.225 | 124.00 | 0.001 064 | 0.7933 | 520.47 | 2013.1 | 2533.6 | 520.72 | 2191.3 | 2712.1 | 1.5706 | 5.5173 | 7.0878 |

TABLE A.2 (SI) (cont'd.)

| Press. MPa $P$ | Temp. °C $T$ | Specific Volume Sat. Liquid $v_f$ | Sat. Vapor $v_g$ | Internal Energy Sat. Liquid $u_f$ | Evap. $u_{fg}$ | Sat. Vapor $u_g$ | Enthalpy Sat. Liquid $h_f$ | Evap. $h_{fg}$ | Sat. Vapor $h_g$ | Entropy Sat. Liquid $s_f$ | Evap. $s_{fg}$ | Sat. Vapor $s_g$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.250 | 127.44 | 0.001 067 | 0.7187 | 535.10 | 2002.1 | 2537.2 | 535.37 | 2181.5 | 2716.9 | 1.6072 | 5.4455 | 7.0527 |
| 0.275 | 130.60 | 0.001 070 | 0.6573 | 548.59 | 1991.9 | 2540.5 | 548.89 | 2172.4 | 2721.3 | 1.6408 | 5.3801 | 7.0209 |
| 0.300 | 133.55 | 0.001 073 | 0.6058 | 561.15 | 1982.4 | 2543.6 | 561.47 | 2163.8 | 2725.3 | 1.6718 | 5.3201 | 6.9919 |
| 0.325 | 136.30 | 0.001 076 | 0.5620 | 572.90 | 1973.5 | 2546.4 | 573.25 | 2155.8 | 2729.0 | 1.7006 | 5.2646 | 6.9652 |
| 0.350 | 138.88 | 0.001 079 | 0.5243 | 583.95 | 1965.0 | 2548.9 | 584.33 | 2148.1 | 2732.4 | 1.7275 | 5.2130 | 6.9405 |
| 0.375 | 141.32 | 0.001 081 | 0.4914 | 594.40 | 1956.9 | 2551.3 | 594.81 | 2140.8 | 2735.6 | 1.7528 | 5.1647 | 6.9175 |
| 0.40 | 143.63 | 0.001 084 | 0.4625 | 604.31 | 1949.3 | 2553.6 | 604.74 | 2133.8 | 2738.6 | 1.7766 | 5.1193 | 6.8959 |
| 0.45 | 147.93 | 0.001 088 | 0.4140 | 622.77 | 1934.9 | 2557.6 | 623.25 | 2120.7 | 2743.9 | 1.8207 | 5.0359 | 6.8565 |
| 0.50 | 151.86 | 0.001 093 | 0.3749 | 639.68 | 1921.6 | 2561.2 | 640.23 | 2108.5 | 2748.7 | 1.8607 | 4.9606 | 6.8213 |
| 0.55 | 155.48 | 0.001 097 | 0.3427 | 655.32 | 1909.2 | 2564.5 | 655.93 | 2097.0 | 2753.0 | 1.8973 | 4.8920 | 6.7893 |
| 0.60 | 158.85 | 0.001 101 | 0.3157 | 669.90 | 1897.5 | 2567.4 | 670.56 | 2086.3 | 2756.8 | 1.9312 | 4.8288 | 6.7600 |
| 0.65 | 162.01 | 0.001 104 | 0.2927 | 683.56 | 1886.5 | 2570.1 | 684.28 | 2076.0 | 2760.3 | 1.9627 | 4.7703 | 6.7331 |
| 0.70 | 164.97 | 0.001 108 | 0.2729 | 696.44 | 1876.1 | 2572.5 | 697.22 | 2066.3 | 2763.5 | 1.9922 | 4.7158 | 6.7080 |
| 0.75 | 167.78 | 0.001 112 | 0.2556 | 708.64 | 1866.1 | 2574.7 | 709.47 | 2057.0 | 2766.4 | 2.0200 | 4.6647 | 6.6847 |
| 0.80 | 170.43 | 0.001 115 | 0.2404 | 720.22 | 1856.6 | 2576.8 | 721.11 | 2048.0 | 2769.1 | 2.0462 | 4.6166 | 6.6628 |
| 0.85 | 172.96 | 0.001 118 | 0.2270 | 731.27 | 1847.4 | 2578.7 | 732.22 | 2039.4 | 2771.6 | 2.0710 | 4.5711 | 6.6421 |
| 0.90 | 175.38 | 0.001 121 | 0.2150 | 741.83 | 1838.6 | 2580.5 | 742.83 | 2031.1 | 2773.9 | 2.0946 | 4.5280 | 6.6226 |
| 0.95 | 177.69 | 0.001 124 | 0.2042 | 751.95 | 1830.2 | 2582.1 | 753.02 | 2023.1 | 2776.1 | 2.1172 | 4.4869 | 6.6041 |
| 1.00 | 179.91 | 0.001 127 | 0.194 44 | 761.68 | 1822.0 | 2583.6 | 762.81 | 2015.3 | 2778.1 | 2.1387 | 4.4478 | 6.5865 |
| 1.10 | 184.09 | 0.001 133 | 0.177 53 | 780.09 | 1806.3 | 2586.4 | 781.34 | 2000.4 | 2781.7 | 2.1792 | 4.3744 | 6.5536 |
| 1.20 | 187.99 | 0.001 139 | 0.163 33 | 797.29 | 1791.5 | 2588.8 | 798.65 | 1986.2 | 2784.8 | 2.2166 | 4.3067 | 6.5233 |
| 1.30 | 191.64 | 0.001 144 | 0.151 25 | 813.44 | 1777.5 | 2591.0 | 814.93 | 1972.7 | 2787.6 | 2.2515 | 4.2438 | 6.4953 |
| 1.40 | 195.07 | 0.001 149 | 0.140 84 | 828.70 | 1764.1 | 2592.8 | 830.30 | 1959.7 | 2790.0 | 2.2842 | 4.1850 | 6.4693 |

TABLE A.2 (SI) (cont'd.)

| Press. MPa $P$ | Temp. °C $T$ | Specific Volume (m³/kg) Sat. Liquid $v_f$ | Sat. Vapor $v_g$ | Internal Energy (kJ/kg) Sat. Liquid $u_f$ | Evap. $u_{fg}$ | Sat. Vapor $u_g$ | Enthalpy (kJ/kg) Sat. Liquid $h_f$ | Evap. $h_{fg}$ | Sat. Vapor $h_g$ | Entropy (kJ/kg · °k) Sat. Liquid $s_f$ | Evap. $s_{fg}$ | Sat. Vapor $s_g$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.50 | 198.32 | 0.001 154 | 0.131 77 | 843.16 | 1751.3 | 2594.5 | 844.89 | 1947.3 | 2792.2 | 2.3150 | 4.1298 | 6.4448 |
| 1.75 | 205.76 | 0.001 166 | 0.113 49 | 876.46 | 1721.4 | 2597.8 | 878.50 | 1917.9 | 2796.4 | 2.3851 | 4.0044 | 6.3896 |
| 2.00 | 212.42 | 0.001 177 | 0.099 63 | 906.44 | 1693.8 | 2600.3 | 908.79 | 1890.7 | 2799.5 | 2.4474 | 3.8935 | 6.3409 |
| 2.25 | 218.45 | 0.001 187 | 0.088 75 | 933.83 | 1668.2 | 2602.0 | 936.49 | 1865.2 | 2801.7 | 2.5035 | 3.7937 | 6.2972 |
| 2.5 | 223.99 | 0.001 197 | 0.079 98 | 959.11 | 1644.0 | 2603.1 | 962.11 | 1841.0 | 2803.1 | 2.5547 | 3.7028 | 6.2575 |
| 3.0 | 233.90 | 0.001 217 | 0.066 68 | 1004.78 | 1599.3 | 2604.1 | 1008.42 | 1795.7 | 2804.2 | 2.6457 | 3.5412 | 6.1869 |
| 3.5 | 242.60 | 0.001 235 | 0.057 07 | 1045.43 | 1558.3 | 2603.7 | 1049.75 | 1753.7 | 2803.4 | 2.7253 | 3.4000 | 6.1253 |
| 4 | 250.40 | 0.001 252 | 0.049 78 | 1082.31 | 1520.0 | 2602.3 | 1087.31 | 1714.1 | 2801.4 | 2.7964 | 3.2737 | 6.0701 |
| 5 | 263.99 | 0.001 286 | 0.039 44 | 1147.81 | 1449.3 | 2597.1 | 1154.23 | 1640.1 | 2794.3 | 2.9202 | 3.0532 | 5.9734 |
| 6 | 275.64 | 0.001 319 | 0.032 44 | 1205.44 | 1384.3 | 2589.7 | 1213.35 | 1571.0 | 2784.3 | 3.0267 | 2.8625 | 5.8892 |
| 7 | 285.88 | 0.001 351 | 0.027 37 | 1257.55 | 1323.0 | 2580.5 | 1267.00 | 1505.1 | 2772.1 | 3.1211 | 2.6922 | 5.8133 |
| 8 | 295.06 | 0.001 384 | 0.023 52 | 1305.57 | 1264.2 | 2569.8 | 1316.64 | 1441.3 | 2758.0 | 3.2068 | 2.5364 | 5.7432 |
| 9 | 303.40 | 0.001 418 | 0.020 48 | 1350.51 | 1207.3 | 2557.8 | 1363.26 | 1378.9 | 2742.1 | 3.2858 | 2.3915 | 5.6772 |
| 10 | 311.06 | 0.001 452 | 0.018 026 | 1393.04 | 1151.4 | 2544.4 | 1407.56 | 1317.1 | 2724.7 | 3.3596 | 2.2544 | 5.6141 |
| 11 | 318.15 | 0.001 489 | 0.015 987 | 1433.7 | 1096.0 | 2529.8 | 1450.1 | 1255.5 | 2705.6 | 3.4295 | 2.1233 | 5.5527 |
| 12 | 324.75 | 0.001 527 | 0.014 263 | 1473.0 | 1040.7 | 2513.7 | 1491.3 | 1193.6 | 2684.9 | 3.4962 | 1.9962 | 5.4924 |
| 13 | 330.93 | 0.001 567 | 0.012 780 | 1511.1 | 985.0 | 2496.1 | 1531.5 | 1130.7 | 2662.2 | 3.5606 | 1.8718 | 5.4323 |
| 14 | 336.75 | 0.001 611 | 0.011 485 | 1548.6 | 928.2 | 2476.8 | 1571.1 | 1066.5 | 2637.6 | 3.6232 | 1.7485 | 5.3717 |
| 15 | 342.24 | 0.001 658 | 0.010 337 | 1585.6 | 869.8 | 2455.5 | 1610.5 | 1000.0 | 2610.5 | 3.6848 | 1.6249 | 5.3098 |
| 16 | 347.44 | 0.001 711 | 0.009 306 | 1622.7 | 809.0 | 2431.7 | 1650.1 | 930.6 | 2580.6 | 3,7461 | 1.4994 | 5.2455 |
| 17 | 352.37 | 0.001 770 | 0.008 364 | 1660.2 | 744.8 | 2405.0 | 1690.3 | 856.9 | 2547.2 | 3.8079 | 1.3698 | 5.1777 |
| 18 | 357.06 | 0.001 840 | 0.007 489 | 1698.9 | 675.4 | 2374.3 | 1732.0 | 777.1 | 2509.1 | 3.8715 | 1.2329 | 5.1044 |
| 19 | 361.54 | 0.001 924 | 0.006 657 | 1739.9 | 598.1 | 2338.1 | 1776.5 | 688.0 | 2464.5 | 3.9388 | 1.0839 | 5.0228 |
| 20 | 365.81 | 0.002 036 | 0.005 834 | 1785.6 | 507.5 | 2293.0 | 1826.3 | 583.4 | 2409.7 | 4.0139 | .9130 | 4.9269 |
| 21 | 369.89 | 0.002 207 | 0.004 952 | 1842.1 | 388.5 | 2230.6 | 1888.4 | 446.2 | 2334.6 | 4.1075 | .6938 | 4.8013 |
| 22 | 373.80 | 0.002 742 | 0.003 568 | 1961.9 | 125.2 | 2087.1 | 2022.2 | 143.4 | 2165.6 | 4.3110 | .2216 | 4.5327 |
| 22.09 | 374.14 | 0.003 155 | 0.003 155 | 2029.6 | 0 | 2029.6 | 2099.3 | 0 | 2099.3 | 4.4298 | 0 | 4.4298 |

**TABLE A.3 (SI)**

Properties of Superheated Steam

| $T$ | $P$ = .010 MPa (45.81) | | | | $P$ = .050 MPa (81.33) | | | | $P$ = .10 MPa (99.63) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $v$ | $u$ | $h$ | $s$ | $v$ | $u$ | $h$ | $s$ | $v$ | $u$ | $h$ | $s$ |
| Sat. | 14.674 | 2437.9 | 2584.7 | 8.1502 | 3.240 | 2483.9 | 2645.9 | 7.5939 | 1.6940 | 2506.1 | 2675.5 | 7.3594 |
| 50 | 14.869 | 2443.9 | 2592.6 | 8.1749 | | | | | | | | |
| 100 | 17.196 | 2515.5 | 2687.5 | 8.4479 | 3.418 | 2511.6 | 2682.5 | 7.6947 | 1.6958 | 2506.7 | 2676.2 | 7.3614 |
| 150 | 19.512 | 2587.9 | 2783.0 | 8.6882 | 3.889 | 2585.6 | 2780.1 | 7.9401 | 1.9364 | 2582.8 | 2776.4 | 7.6134 |
| 200 | 21.825 | 2661.3 | 2879.5 | 8.9038 | 4.356 | 2659.9 | 2877.7 | 8.1580 | 2.172 | 2658.1 | 2875.3 | 7.8343 |
| 250 | 24.136 | 2736.0 | 2977.3 | 9.1002 | 4.820 | 2735.0 | 2976.0 | 8.3556 | 2.406 | 2733.7 | 2974.3 | 8.0333 |
| 300 | 26.445 | 2812.1 | 3076.5 | 9.2813 | 5.284 | 2811.3 | 3075.5 | 8.5373 | 2.639 | 2810.4 | 3074.3 | 8.2158 |
| 400 | 31.063 | 2968.9 | 3279.6 | 9.6077 | 6.209 | 2968.5 | 3278.9 | 8.8642 | 3.103 | 2967.9 | 3278.2 | 8.5435 |
| 500 | 35.679 | 3132.3 | 3489.1 | 9.8978 | 7.134 | 3132.0 | 3488.7 | 9.1546 | 3.565 | 3131.6 | 3488.1 | 8.8342 |
| 600 | 40.295 | 3302.5 | 3705.4 | 10.1608 | 8.057 | 3302.2 | 3705.1 | 9.4178 | 4.028 | 3301.9 | 3704.7 | 9.0976 |
| 700 | 44.911 | 3479.6 | 3928.7 | 10.4028 | 8.981 | 3479.4 | 3928.5 | 9.6599 | 4.490 | 3479.2 | 3928.2 | 9.3398 |
| 800 | 49.526 | 3663.8 | 4159.0 | 10.6281 | 9.904 | 3663.6 | 4158.9 | 9.8852 | 4.952 | 3663.5 | 4158.6 | 9.5652 |
| 900 | 54.141 | 3855.0 | 4396.4 | 10.8396 | 10.828 | 3854.9 | 4396.3 | 10.0967 | 5.414 | 3854.8 | 4396.1 | 9.7767 |
| 1000 | 58.757 | 4053.0 | 4640.6 | 11.0393 | 11.751 | 4052.9 | 4640.5 | 10.2964 | 5.875 | 4052.8 | 4640.3 | 9.9764 |
| 1100 | 63.372 | 4257.5 | 4891.2 | 11.2287 | 12.674 | 4257.4 | 4891.1 | 10.4859 | 6.337 | 4257.3 | 4891.0 | 10.1659 |
| 1200 | 67.987 | 4467.9 | 5147.8 | 11.4091 | 13.597 | 4467.8 | 5147.7 | 10.6662 | 6.799 | 4467.7 | 5147.6 | 10.3463 |
| 1300 | 72.602 | 4683.7 | 5409.7 | 11.5811 | 14.521 | 4683.6 | 5409.6 | 10.8382 | 7.260 | 4683.5 | 5409.5 | 10.5183 |
| | $P$ = .20 MPa (120.23) | | | | $P$ = .30 MPa (133.55) | | | | $P$ = .40 MPa (143.63) | | | |
| Sat. | .8857 | 2529.5 | 2706.7 | 7.1272 | .6058 | 2543.6 | 2725.3 | 6.9919 | .4625 | 2553.6 | 2738.6 | 6.8959 |
| 150 | .9596 | 2576.9 | 2768.8 | 7.2795 | .6339 | 2570.8 | 2761.0 | 7.0778 | .4708 | 2564.5 | 2752.8 | 6.9299 |
| 200 | 1.0803 | 2654.4 | 2870.5 | 7.5066 | .7163 | 2650.7 | 2865.6 | 7.3115 | .5342 | 2646.8 | 2860.5 | 7.1706 |
| 250 | 1.1988 | 2731.2 | 2971.0 | 7.7086 | .7964 | 2728.7 | 2967.6 | 7.5166 | .5951 | 2726.1 | 2964.2 | 7.3789 |
| 300 | 1.3162 | 2808.6 | 3071.8 | 7.8926 | .8753 | 2806.7 | 3069.3 | 7.7022 | .6548 | 2804.8 | 3066.8 | 7.5662 |
| 400 | 1.5493 | 2966.7 | 3276.6 | 8.2218 | 1.0315 | 2965.6 | 3275.0 | 8.0330 | .7726 | 2964.4 | 3273.4 | 7.8985 |

## TABLE A.3 (SI) (cont'd.)

| $T$ | $v$ | $u$ | $h$ | $s$ | $v$ | $u$ | $h$ | $s$ | $v$ | $u$ | $h$ | $s$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ = .20 MPa (120.23) | | | | $P$ = .30 MPa (133.55) | | | | $P$ = .40 MPa (143.63) | | | |
| 500 | 1.7814 | 3130.8 | 3487.1 | 8.5133 | 1.1867 | 3130.0 | 3486.0 | 8.3251 | .8893 | 3129.2 | 3484.9 | 8.1913 |
| 600 | 2.013 | 3301.4 | 3704.0 | 8.7770 | 1.3414 | 3300.8 | 3703.2 | 8.5892 | 1.0055 | 3300.2 | 3702.4 | 8.4558 |
| 700 | 2.244 | 3478.8 | 3927.6 | 9.0194 | 1.4957 | 3478.4 | 3927.1 | 8.8319 | 1.1215 | 3477.9 | 3926.5 | 8.6987 |
| 800 | 2.475 | 3663.1 | 4158.2 | 9.2449 | 1.6499 | 3662.9 | 4157.8 | 9.0576 | 1.2372 | 3662.4 | 4157.3 | 8.9244 |
| 900 | 2.706 | 3854.5 | 4395.8 | 9.4566 | 1.8041 | 3854.2 | 4395.4 | 9.2692 | 1.3529 | 3853.9 | 4395.1 | 9.1362 |
| 1000 | 2.937 | 4052.5 | 4640.0 | 9.6563 | 1.9581 | 4052.3 | 4639.7 | 9.4690 | 1.4685 | 4052.0 | 4639.4 | 9.3360 |
| 1100 | 3.168 | 4257.0 | 4890.7 | 9.8458 | 2.1121 | 4256.8 | 4890.4 | 9.6585 | 1.5840 | 4256.5 | 4890.2 | 9.5256 |
| 1200 | 3.399 | 4467.5 | 5147.3 | 10.0262 | 2.2661 | 4467.2 | 5147.1 | 9.8389 | 1.6996 | 4467.0 | 5146.8 | 9.7060 |
| 1300 | 3.630 | 4683.2 | 5409.3 | 10.1982 | 2.4201 | 4683.0 | 5409.0 | 10.0110 | 1.8151 | 4682.8 | 5408.8 | 9.8780 |
| | $P$ = .50 MPa (151.86) | | | | $P$ = .60 MPa (158.85) | | | | $P$ = .80 MPa (170.43) | | | |
| Sat. | .3749 | 2561.2 | 2748.7 | 6.8213 | .3157 | 2567.4 | 2756.8 | 6.7600 | .2404 | 2576.8 | 2769.1 | 6.6628 |
| 200 | .4249 | 2642.9 | 2855.4 | 7.0592 | .3520 | 2638.9 | 2850.1 | 6.9665 | .2608 | 2630.6 | 2839.3 | 6.8158 |
| 250 | .4744 | 2723.5 | 2960.7 | 7.2709 | .3938 | 2720.9 | 2957.2 | 7.1816 | .2931 | 2715.5 | 2950.0 | 7.0384 |
| 300 | .5226 | 2802.9 | 3064.2 | 7.4599 | .4344 | 2801.0 | 3061.6 | 7.3724 | .3241 | 2797.2 | 3056.5 | 7.2328 |
| 350 | .5701 | 2882.6 | 3167.7 | 7.6329 | .4742 | 2881.2 | 3165.7 | 7.5464 | .3544 | 2878.2 | 3161.7 | 7.4089 |
| 400 | .6173 | 2963.2 | 3271.9 | 7.7938 | .5137 | 2962.1 | 3270.3 | 7.7079 | .3843 | 2959.7 | 3267.1 | 7.5716 |
| 500 | .7109 | 3128.4 | 3483.9 | 8.0873 | .5920 | 3127.6 | 3482.8 | 8.0021 | .4433 | 3126.0 | 3480.6 | 7.8673 |
| 600 | .8041 | 3299.6 | 3701.7 | 7.3522 | .6697 | 3299.1 | 3700.9 | 8.2674 | .5018 | 3297.9 | 3699.4 | 8.1333 |
| 700 | .8969 | 3477.5 | 3925.9 | 8.5952 | .7472 | 3477.0 | 3925.3 | 8.5107 | .5601 | 3476.2 | 3924.2 | 8.3770 |
| 800 | .9896 | 3662.1 | 4156.9 | 8.8211 | .8245 | 3661.8 | 4156.5 | 8.7367 | .6181 | 3661.1 | 4155.6 | 8.6033 |
| 900 | 1.0822 | 3853.6 | 4394.7 | 9.0329 | .9017 | 3853.4 | 4394.4 | 8.9486 | .6761 | 3852.8 | 4393.7 | 8.8153 |
| 1000 | 1.1747 | 4051.8 | 4639.1 | 9.2328 | .9788 | 4051.5 | 4638.8 | 9.1485 | .7340 | 4051.0 | 4638.2 | 9.0153 |
| 1100 | 1.2672 | 4256.3 | 4889.9 | 9.4224 | 1.0559 | 4256.1 | 4889.6 | 9.3381 | .7919 | 4255.6 | 4889.1 | 9.2050 |
| 1200 | 1.3596 | 4466.8 | 5146.6 | 9.6029 | 1.1330 | 4466.5 | 5146.3 | 9.5185 | .8497 | 4466.1 | 5145.9 | 9.3855 |
| 1300 | 1.4521 | 4682.5 | 5408.6 | 9.7749 | 1.2101 | 4682.3 | 5408.3 | 9.6906 | .9076 | 4681.8 | 5407.9 | 9.5575 |

## TABLE A.3 (SI) (cont'd.)

| $T$ | $v$ | $u$ | $h$ | $s$ | $v$ | $u$ | $h$ | $s$ | $v$ | $u$ | $h$ | $s$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ = 1.00 MPa (179.91) | | | | $P$ = 1.20 MPa (187.99) | | | | $P$ = 1.40 MPa (195.07) | | | |
| Sat. | .194 44 | 2583.6 | 2778.1 | 6.5865 | .163 33 | 2588.8 | 2784.8 | 6.5233 | .140 84 | 2592.8 | 2790.0 | 6.4693 |
| 200 | .2060 | 2621.9 | 2827.9 | 6.6940 | .169 30 | 2612.8 | 2815.9 | 6.5898 | .143 02 | 2603.1 | 2803.3 | 6.4975 |
| 250 | .2327 | 2709.9 | 2942.6 | 6.9247 | .192 34 | 2704.2 | 2935.0 | 6.8294 | .163 50 | 2698.3 | 2927.2 | 6.7467 |
| 300 | .2579 | 2793.2 | 3051.2 | 7.1229 | .2138 | 2789.2 | 3045.8 | 7.0317 | .182 28 | 2785.2 | 3040.4 | 6.9534 |
| 350 | .2825 | 2875.2 | 3157.7 | 7.3011 | .2345 | 2872.2 | 3153.6 | 7.2121 | .2003 | 2869.2 | 3149.5 | 7.1360 |
| 400 | .3066 | 2957.3 | 3263.9 | 7.4651 | .2548 | 2954.9 | 3260.7 | 7.3774 | .2178 | 2952.5 | 3257.5 | 7.3026 |
| 500 | .3541 | 3124.4 | 3478.5 | 7.7622 | .2946 | 3122.8 | 3476.3 | 7.6759 | .2521 | 3121.1 | 3474.1 | 7.6027 |
| 600 | .4011 | 3296.8 | 3697.9 | 8.0290 | .3339 | 3295.6 | 3696.3 | 7.9435 | .2860 | 3294.4 | 3694.8 | 7.8710 |
| 700 | .4478 | 3475.3 | 3923.1 | 8.2731 | .3729 | 3474.4 | 3922.0 | 8.1881 | .3195 | 3473.6 | 3920.8 | 8.1160 |
| 800 | .4943 | 3660.4 | 4154.7 | 8.4996 | .4118 | 3659.7 | 4153.8 | 8.4148 | .3528 | 3659.0 | 4153.0 | 8.3431 |
| 900 | .5407 | 3852.2 | 4392.9 | 8.7118 | .4505 | 3851.6 | 4392.2 | 8.6272 | .3861 | 3851.1 | 4391.5 | 8.5556 |
| 1000 | .5871 | 4050.5 | 4637.6 | 8.9119 | .4892 | 4050.0 | 4637.0 | 8.8274 | .4192 | 4049.5 | 4636.4 | 8.7559 |
| 1100 | .6335 | 4255.1 | 4888.6 | 9.1017 | .5278 | 4254.6 | 4888.0 | 9.0172 | .4524 | 4254.1 | 4887.5 | 8.9457 |
| 1200 | .6798 | 4465.6 | 5145.4 | 9.2822 | .5665 | 4465.1 | 5144.9 | 9.1977 | .4855 | 4464.7 | 5144.4 | 9.1262 |
| 1300 | .7261 | 4681.3 | 5407.4 | 9.4543 | .6051 | 4680.9 | 5407.0 | 9.3698 | .5186 | 4680.4 | 5406.5 | 9.2984 |
| | $P$ = 1.60 MPa (201.41) | | | | $P$ = 1.80 MPa (207.15) | | | | $P$ = 2.00 MPa (212.42) | | | |
| Sat. | .123 80 | 2596.0 | 2794.0 | 6.4218 | .110 42 | 2598.4 | 2797.1 | 6.3794 | .099 63 | 2600.3 | 2799.5 | 6.3409 |
| 225 | .132 87 | 2644.7 | 2857.3 | 6.5518 | .116 73 | 2636.6 | 2846.7 | 6.4808 | .103 77 | 2628.3 | 2835.8 | 6.4147 |
| 250 | .141 84 | 2692.3 | 2919.2 | 6.6732 | .124 97 | 2686.0 | 2911.0 | 6.6066 | .111 44 | 2679.6 | 2902.5 | 6.5453 |
| 300 | .158 62 | 2781.1 | 3034.8 | 6.8844 | .140 21 | 2776.9 | 3029.2 | 6.8226 | .125 47 | 2772.6 | 3023.5 | 6.7664 |
| 350 | .174 56 | 2866.1 | 3145.4 | 7.0694 | .154 57 | 2863.0 | 3141.2 | 7.0100 | .138 57 | 2859.8 | 3137.0 | 6.9563 |
| 400 | .190 05 | 2950.1 | 3254.2 | 7.2374 | .168 47 | 2947.7 | 3250.9 | 7.1794 | .151 20 | 2945.2 | 3247.6 | 7.1271 |
| 500 | .2203 | 3119.5 | 3472.0 | 7.5390 | .195 50 | 3117.9 | 3469.8 | 7.4825 | .175 68 | 3116 2 | 3467.6 | 7.4317 |
| 600 | .2500 | 3293.3 | 3693.2 | 7.8080 | .2220 | 3292.1 | 3691.7 | 7.7523 | .199 60 | 3290.9 | 3690.1 | 7.7024 |
| 700 | .2794 | 3472.7 | 3919.7 | 8.0535 | .2482 | 3471.8 | 3918.5 | 7.9983 | .2232 | 3470.9 | 3917.4 | 7.9487 |

## TABLE A.3 (SI) (cont'd.)

| T | v | u | h | s | v | u | h | s | v | u | h | s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P = 1.60$ MPa (201.41) | | | | $P = 1.80$ MPa (207.15) | | | | $P = 2.00$ MPa (212.42) | | | |
| 800 | .3086 | 3658.3 | 4152.1 | 8.2808 | .2742 | 3657.6 | 4151.2 | 8.2258 | .2467 | 3657.0 | 4150.3 | 8.1765 |
| 900 | .3377 | 3850.5 | 4390.8 | 8.4935 | .3001 | 3849.9 | 4390.1 | 8.4386 | .2700 | 3849.3 | 4389.4 | 8.3895 |
| 1000 | .3668 | 4049.0 | 4635.8 | 8.6938 | .3260 | 4048.5 | 4635.2 | 8.6391 | .2933 | 4048.0 | 4634.6 | 8.5901 |
| 1100 | .3958 | 4253.7 | 4887.0 | 8.8837 | .3518 | 4253.2 | 4886.4 | 8.8290 | .3166 | 4252.7 | 4885.9 | 8.7800 |
| 1200 | .4248 | 4464.2 | 5143.9 | 9.0643 | .3776 | 4463.7 | 5143.4 | 9.0096 | .3398 | 4463.3 | 5142.9 | 8.9607 |
| 1300 | .4538 | 4679.9 | 5406.0 | 9.2364 | .4034 | 4679.5 | 5405.6 | 9.1818 | .3631 | 4679.0 | 5405.1 | 9.1329 |
| | $P = 2.50$ MPa (223.99) | | | | $P = 3.00$ MPa (233.90) | | | | $P = 3.50$ MPa (242.60) | | | |
| Sat. | .079 98 | 2603.1 | 2803.1 | 6.2575 | .066 68 | 2604.1 | 2804.2 | 6.1869 | .057 07 | 2603.7 | 2803.4 | 6.1253 |
| 225 | .080 27 | 2605.6 | 2806.3 | 6.2639 | | | | | | | | |
| 250 | .087 00 | 2662.6 | 2880.1 | 6.4085 | .070 58 | 2644.0 | 2855.8 | 6.2872 | .058 72 | 2623.7 | 2829.2 | 6.1749 |
| 300 | .098 90 | 2761.6 | 3008.8 | 6.6438 | .081 14 | 2750.1 | 2993.5 | 6.5390 | .068 42 | 2738.0 | 2977.5 | 6.4461 |
| 350 | .109 76 | 2851.9 | 3126.3 | 6.8403 | .090 53 | 2843.7 | 3115.3 | 6.7428 | .076 78 | 2835.3 | 3104.0 | 6.6579 |
| 400 | .120 10 | 2939.1 | 3239.3 | 7.0148 | .099 36 | 2932.8 | 3230.9 | 6.9212 | .084 53 | 2926.4 | 3222.3 | 6.8405 |
| 450 | .130 14 | 3025.5 | 3350.8 | 7.1746 | .107 87 | 3020.4 | 3344.0 | 7.0834 | .091 96 | 3015.3 | 3337.2 | 7.0052 |
| 500 | .139 98 | 3112.1 | 3462.1 | 7.3234 | .116 19 | 3108.0 | 3456.5 | 7.2338 | .099 18 | 3103.0 | 3450.9 | 7.1572 |
| 600 | .159 30 | 3288.0 | 3686.3 | 7.5960 | .132 43 | 3285.0 | 3682.3 | 7.5085 | .113 24 | 3282.1 | 3678.4 | 7.4339 |
| 700 | .178 32 | 3468.7 | 3914.5 | 7.8435 | .148 38 | 3466.5 | 3911.7 | 7.7571 | .126 99 | 3464.3 | 3908.8 | 7.6837 |
| 800 | .197 16 | 3655.3 | 4148.2 | 8.0720 | .164 14 | 3653.5 | 4145.9 | 7.9862 | .140 56 | 3651.8 | 4143.7 | 7.9134 |
| 900 | .215 90 | 3847.9 | 4387.6 | 8.2853 | .179 80 | 3846.5 | 4385.9 | 8.1999 | .154 02 | 3845.0 | 4384.1 | 8.1276 |
| 1000 | .2346 | 4046.7 | 4633.1 | 8.4861 | .195 41 | 4045.4 | 4631.6 | 8.4009 | .167 43 | 4044.1 | 4630.1 | 8.3288 |
| 1100 | .2532 | 4251.5 | 4884.6 | 8.6762 | .210 98 | 4250.3 | 4883.3 | 8.5912 | .180 80 | 4249.2 | 4881.9 | 8.5192 |
| 1200 | .2718 | 4462.1 | 5141.7 | 8.8569 | .226 52 | 4460.9 | 5140.5 | 8.7720 | .194 15 | 4459.8 | 5139.3 | 8.7000 |
| 1300 | .2905 | 4677.8 | 5404.0 | 9.0291 | .242 06 | 4676.6 | 5402.8 | 8.9442 | .207 49 | 4675.5 | 5401.7 | 8.8723 |

**TABLE A.3 (SI) (cont'd.)**

| T | v | u | h | s | v | u | h | s | v | u | h | s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P = 4.0 MPa (250.40) | | | | P = 4.5 MPa (257.49) | | | | P = 5.0 MPa (263.99) | | | |
| Sat. | .049 78 | 2602.3 | 2801.4 | 6.0701 | .044 06 | 2600.1 | 2798.3 | 6.0198 | .039 44 | 2597.1 | 2794.3 | 5.9734 |
| 275 | .054 57 | 2667.9 | 2886.2 | 6.2285 | .047 30 | 2650.3 | 2863.2 | 6.1401 | .041 41 | 2631.3 | 2838.3 | 6.0544 |
| 300 | .058 84 | 2725.3 | 2960.7 | 6.3615 | .051 35 | 2712.0 | 2943.1 | 6.2828 | .045 32 | 2698.0 | 2924.5 | 6.2084 |
| 350 | .066 45 | 2826.7 | 3092.5 | 6.5821 | .058 40 | 2817.8 | 3080.6 | 6.5131 | .051 94 | 2808.7 | 3068.4 | 6.4493 |
| 400 | .073 41 | 2919.9 | 3213.6 | 6.7690 | .064 75 | 2913.3 | 3204.7 | 6.7047 | .057 81 | 2906.6 | 3195.7 | 6.6459 |
| 450 | .080 02 | 3010.2 | 3330.3 | 6.9363 | .070 74 | 3005.0 | 3323.3 | 6.8746 | .063 30 | 2999.7 | 3316.2 | 6.8186 |
| 500 | .086 43 | 3099.5 | 3445.3 | 7.0901 | .076 51 | 3095.3 | 3439.6 | 7.0301 | .068 57 | 3091.0 | 3433.8 | 6.9759 |
| 600 | .098 85 | 3279.1 | 3674.4 | 7.3688 | .087 65 | 3276.0 | 3670.5 | 7.3110 | .078 69 | 3273.0 | 3666.5 | 7.2589 |
| 700 | .110 95 | 3462.1 | 3905.9 | 7.6198 | .098 47 | 3459.9 | 3903.0 | 7.5631 | .088 49 | 3457.6 | 3900.1 | 7.5122 |
| 800 | .122 87 | 3650.0 | 4141.5 | 7.8502 | .109 11 | 3648.3 | 4139.3 | 7.7942 | .098 11 | 3646.6 | 4137.1 | 7.7440 |
| 900 | .134 69 | 3843.6 | 4382.3 | 8.0647 | .119 65 | 3842.2 | 4380.6 | 8.0091 | .107 62 | 3840.7 | 4378.8 | 7.9593 |
| 1000 | .146 45 | 4042.9 | 4628.7 | 8.2662 | .130 13 | 4041.6 | 4627.2 | 8.2108 | .117 07 | 4040.4 | 4625.7 | 8.1612 |
| 1100 | .158 17 | 4248.0 | 4880.6 | 8.4567 | .140 56 | 4246.8 | 4879.3 | 8.4015 | .126 48 | 4245.6 | 4878.0 | 8.3520 |
| 1200 | .169 87 | 4458.6 | 5138.1 | 8.6376 | .150 98 | 4457.5 | 5136.9 | 8.5825 | .135 87 | 4456.3 | 5135.7 | 8.5331 |
| 1300 | .181 56 | 4674.3 | 5400.5 | 8.8100 | .161 39 | 4673.1 | 5399.4 | 8.7549 | .145 26 | 4672.0 | 5398.2 | 8.7055 |
| | P = 6.0 MPa (275.64) | | | | P = 7.0 MPa (285.88) | | | | P = 8.0 MPa (295.06) | | | |
| Sat. | .032 44 | 2589.7 | 2784.3 | 5.8892 | .027 37 | 2580.5 | 2772.1 | 5.8133 | .023 52 | 2569.8 | 2758.0 | 5.7432 |
| 300 | .036 16 | 2667.2 | 2884.2 | 6.0674 | .029 47 | 2632.2 | 2838.4 | 5.9305 | .024 26 | 2590.9 | 2785.0 | 5.7906 |
| 350 | .042 23 | 2789.6 | 3043.0 | 6.3335 | .035 24 | 2769.4 | 3016.0 | 6.2283 | .029 95 | 2747.7 | 2987.3 | 6.1301 |
| 400 | .047 39 | 2892.9 | 3177.2 | 6.5408 | .039 93 | 2878.6 | 3158.1 | 6.4478 | .034 32 | 2863.8 | 3138.3 | 6.3634 |
| 450 | .052 14 | 2988.9 | 3301.8 | 6.7193 | .044 16 | 2978.0 | 3287.1 | 6.6327 | .038 17 | 2966.7 | 3272.0 | 6.5551 |
| 500 | .056 65 | 3082.2 | 3422.2 | 6.8803 | .048 14 | 3073.4 | 3410.3 | 6.7975 | .041 75 | 3064.3 | 3398.3 | 6.7240 |
| 550 | .061 01 | 3174.6 | 3540.6 | 7.0288 | .051 95 | 3167.2 | 3530.9 | 6.9486 | .045 16 | 3159.8 | 3521.0 | 6.8778 |
| 600 | .065 25 | 3266.9 | 3658.4 | 7.1677 | .055 65 | 3260.7 | 3650.3 | 7.0894 | .048 45 | 3254.4 | 3642.0 | 7.0206 |

TABLE A.3 (SI) (cont'd.)

| T | v | u | h | s | v | u | h | s | v | u | h | s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P = 6.0$ MPa (275.64) | | | | $P = 7.0$ MPa (285.88) | | | | $P = 8.0$ MPa (295.06) | | | |
| 700 | .073 52 | 3453.1 | 3894.2 | 7.4234 | .062 83 | 3448.5 | 3888.3 | 7.3476 | .054 81 | 3443.9 | 3882.4 | 7.2812 |
| 800 | .081 60 | 3643.1 | 4132.7 | 7.6566 | .069 81 | 3639.5 | 4128.2 | 7.5822 | .060 97 | 3636.0 | 4123.8 | 7.5173 |
| 900 | .089 58 | 3837.8 | 4375.3 | 7.8727 | .076 69 | 3835.0 | 4371.8 | 7.7991 | .067 02 | 3832.1 | 4368.3 | 7.7351 |
| 1000 | .097 49 | 4037.8 | 4622.7 | 8.0751 | .083 50 | 4035.3 | 4619.8 | 8.0020 | .073 01 | 4032.8 | 4616.9 | 7.9384 |
| 1100 | .105 36 | 4243.3 | 4875.4 | 8.2661 | .090 27 | 4240.9 | 4872.8 | 8.1933 | .078 96 | 4238.6 | 4870.3 | 8.1300 |
| 1200 | .113 21 | 4454.0 | 5133.3 | 8.4474 | .097 03 | 4451.7 | 5130.9 | 8.3747 | .084 89 | 4449.5 | 5128.5 | 8.3115 |
| 1300 | .121 06 | 4669.6 | 5396.0 | 8.6199 | .103 77 | 4667.3 | 5393.7 | 8.5473 | .090 80 | 4665.0 | 5391.5 | 8.4842 |
| | $P = 9.0$ MPa (303.40) | | | | $P = 10.0$ MPa (311.06) | | | | $P = 12.5$ MPa (327.89) | | | |
| Sat. | .020 48 | 2557.8 | 2742.1 | 5.6772 | .018 026 | 2544.4 | 2724.7 | 5.6141 | .013 495 | 2505.1 | 2673.8 | 5.4624 |
| 325 | .023 27 | 2646.6 | 2856.0 | 5.8712 | .019 861 | 2610.4 | 2809.1 | 5.7568 | | | | |
| 350 | .025 80 | 2724.4 | 2956.6 | 6.0361 | .022 42 | 2699.2 | 2923.4 | 5.9443 | .016 126 | 2624.6 | 2826.2 | 5.7118 |
| 400 | .029 93 | 2848.4 | 3117.8 | 6.2854 | .026 41 | 2832.4 | 3096.5 | 6.2120 | .020 00 | 2789.3 | 3039.3 | 6.0417 |
| 450 | .033 50 | 2955.2 | 3256.6 | 6.4844 | .029 75 | 2943.4 | 3240.9 | 6.4190 | .022 99 | 2912.5 | 3199.8 | 6.2719 |
| 500 | .036 77 | 3055.2 | 3386.1 | 6.6576 | .032 79 | 3045.8 | 3373.7 | 6.5966 | .025 60 | 3021.7 | 3341.8 | 6.4618 |
| 550 | .039 87 | 3152.2 | 3511.0 | 6.8142 | .035 64 | 3144.6 | 3500.9 | 6.7561 | .028 01 | 3125.0 | 3475.2 | 6.6290 |
| 600 | .042 85 | 3248.1 | 3633.7 | 6.9589 | .038 37 | 3241.7 | 3625.3 | 6.9029 | .030 29 | 3225.4 | 3604.0 | 6.7810 |
| 650 | .045 74 | 3343.6 | 3755.3 | 7.0943 | .041 01 | 3338.2 | 3748.2 | 7.0398 | .032 48 | 3324.4 | 3730.4 | 6.9218 |
| 700 | .048 57 | 3439.3 | 3876.5 | 7.2221 | .043 58 | 3434.7 | 3870.5 | 7.1687 | .034 60 | 3422.9 | 3855.3 | 7.0536 |
| 800 | .054 09 | 3632.5 | 4119.3 | 7.4596 | .048 59 | 3628.9 | 4114.8 | 7.4077 | .038 69 | 3620.0 | 4103.6 | 7.2965 |
| 900 | .059 50 | 3829.2 | 4364.8 | 7.6783 | .053 49 | 3826.3 | 4361.2 | 7.6272 | .042 67 | 3819.1 | 4352.5 | 7.5182 |
| 1000 | .064 85 | 4030.3 | 4614.0 | 7.8821 | .058 32 | 4027.8 | 4611.0 | 7.8315 | .046 58 | 4021.6 | 4603.8 | 7.7237 |
| 1100 | .070 16 | 4236.3 | 4867.7 | 8.0740 | .063 12 | 4234.0 | 4865.1 | 8.0237 | .050 45 | 4228.2 | 4858.8 | 7.9165 |
| 1200 | .075 44 | 4447.2 | 5126.2 | 8.2556 | .067 89 | 4444.9 | 5123.8 | 8.2055 | .054 30 | 4439.3 | 5118.0 | 8.0987 |
| 1300 | .080 72 | 4662.7 | 5389.2 | 8.4284 | .072 65 | 4460.5 | 5387.0 | 8.3783 | .058 13 | 4654.8 | 5381.4 | 8.2717 |

TABLE A.3 (SI) (cont'd.)

| $T$ | $v$ | $u$ | $h$ | $s$ | $v$ | $u$ | $h$ | $s$ | $v$ | $u$ | $h$ | $s$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ = 15.0 MPa (342.24) | | | | $P$ = 17.5 MPa (354.75) | | | | $P$ = 20.0 MPa (365.81) | | | |
| Sat. | .010 337 | 2455.5 | 2610.5 | 5.3098 | .007 920 | 2390.2 | 2528.8 | 5.1419 | .005 834 | 2293.0 | 2409.7 | 4.9269 |
| 350 | .011 470 | 2520.4 | 2692.4 | 5.4421 | | | | | | | | |
| 400 | .015 649 | 2740.7 | 2975.5 | 5.8811 | .012 447 | 2685.0 | 2902.9 | 5.7213 | .009 942 | 2619.3 | 2818.1 | 5.5540 |
| 450 | .018 445 | 2879.5 | 3156.2 | 6.1404 | .015 174 | 2844.2 | 3109.7 | 6.0184 | .012 695 | 2806.2 | 3060.1 | 5.9017 |
| 500 | .020 80 | 2996.6 | 3308.6 | 6.3443 | .017 358 | 2970.3 | 3274.1 | 6.2383 | .014 768 | 2942.9 | 3238.2 | 6.1401 |
| 550 | .022 93 | 3104.7 | 3448.6 | 6.5199 | .019 288 | 3083.9 | 3421.4 | 6.4230 | .016 555 | 3062.4 | 3393.5 | 6.3348 |
| 600 | .024 91 | 3208.6 | 3582.3 | 6.6776 | .021 06 | 3191.5 | 3560.1 | 6.5866 | .018 178 | 3174.0 | 3537.6 | 6.5048 |
| 650 | .026 80 | 3310.3 | 3712.3 | 6.8224 | .022 74 | 3296.0 | 3693.9 | 6.7357 | .019 693 | 3281.4 | 3675.3 | 6.6582 |
| 700 | .028 61 | 3410.9 | 3840.1 | 6.9572 | .024 34 | 3398.7 | 3824.6 | 6.8736 | .021 13 | 3386.4 | 3809.0 | 6.7993 |
| 800 | .032 10 | 3610.9 | 4092.4 | 7.2040 | .027 38 | 3601.8 | 4081.1 | 7.1244 | .023 85 | 3592.7 | 4069.7 | 7.0544 |
| 900 | .035 46 | 3811.9 | 4343.8 | 7.4279 | .030 31 | 3804.7 | 4335.1 | 7.3507 | .026 45 | 3797.5 | 4326.4 | 7.2830 |
| 1000 | .038 75 | 4015.4 | 4596.6 | 7.6348 | .033 16 | 4009.3 | 4589.5 | 7.5589 | .028 97 | 4003.1 | 4582.5 | 7.4925 |
| 1100 | .042 00 | 4222.6 | 4852.6 | 7.8283 | .035 97 | 4216.9 | 4846.4 | 7.7531 | .031 45 | 4211.3 | 4840.2 | 7.6874 |
| 1200 | .045 23 | 4433.8 | 5112.3 | 8.0108 | .038 76 | 4428.3 | 5106.6 | 7.9360 | .033 91 | 4422.8 | 5101.0 | 7.8707 |
| 1300 | .048 45 | 4649.1 | 5376.0 | 8.1840 | .041 54 | 4643.5 | 5370.5 | 8.1093 | .036 36 | 4638.0 | 5365.1 | 8.0442 |
| | $P$ = 25.0 MPa | | | | $P$ = 30.0 MPa | | | | $P$ = 35.0 MPa | | | |
| 375 | .001 973 1 | 1798.7 | 1848.0 | 4.0320 | .001 789 2 | 1737.8 | 1791.5 | 3.9305 | .001 700 3 | 1702.9 | 1762.4 | 3.8722 |
| 400 | .006 004 | 2430.1 | 2580.2 | 5.1418 | .002 790 | 2067.4 | 2151.1 | 4.4728 | .002 100 | 1914.1 | 1987.6 | 4.2126 |
| 425 | .007 881 | 2609.2 | 2806.3 | 5.4723 | .005 303 | 2455.1 | 2614.2 | 5.1504 | .003 428 | 2253.4 | 2373.4 | 4.7747 |
| 450 | .009 162 | 2720.7 | 2949.7 | 5.6744 | .006 735 | 2619.3 | 2821.4 | 5.4424 | .004 961 | 2498.7 | 2672.4 | 5.1962 |
| 500 | .011 123 | 2884.3 | 3162.4 | 5.9592 | .008 678 | 2820.7 | 3081.1 | 5.7905 | .006 927 | 2751.9 | 2994.4 | 5.6282 |
| 550 | .012 724 | 3017.5 | 3335.6 | 6.1765 | .010 168 | 2970.3 | 3275.4 | 6.0342 | .008 345 | 2921.0 | 3213.0 | 5.9026 |
| 600 | .014 137 | 3137.9 | 3491.4 | 6.3602 | .011 446 | 3100.5 | 3443.9 | 6.2331 | .009 527 | 3062.0 | 3395.5 | 6.1179 |
| 650 | .015 433 | 3251.6 | 3637.4 | 6.5229 | .012 596 | 3221.0 | 3598.9 | 6.4058 | .010 575 | 3189.8 | 3559.9 | 6.3010 |

TABLE A.3 (SI) (cont'd.)

| $T$ | $v$ | $u$ | $h$ | $s$ | $v$ | $u$ | $h$ | $s$ | $v$ | $u$ | $h$ | $s$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P = 25.0$ MPa | | | | $P = 30.0$ MPa | | | | $P = 35.0$ MPa | | | |
| 700 | .016 646 | 3361.3 | 3777.5 | 6.6707 | .013 661 | 3335.8 | 3745.6 | 6.5606 | .011 533 | 3309.8 | 3713.5 | 6.4631 |
| 800 | .018 912 | 3574.3 | 4047.1 | 6.9345 | .015 623 | 3555.5 | 4024.2 | 6.8332 | .013 278 | 3536.7 | 4001.5 | 6.7450 |
| 900 | .021 045 | 3783.0 | 4309.1 | 7.1680 | .017 448 | 3768.5 | 4291.9 | 7.0718 | .014 883 | 3754.0 | 4274.9 | 6.9886 |
| 1000 | .023 10 | 3990.9 | 4568.5 | 7.3802 | .019 196 | 3978.8 | 4554.7 | 7.2867 | .016 410 | 3966.7 | 4541.1 | 7.2064 |
| 1100 | .025 12 | 4200.2 | 4828.2 | 7.5765 | .020 903 | 4189.2 | 4816.3 | 7.4845 | .017 895 | 4178.3 | 4804.6 | 7.4057 |
| 1200 | .027 11 | 4412.0 | 5089.9 | 7.7605 | .022 589 | 4401.3 | 5079.0 | 7.6692 | .019 360 | 4390.7 | 5068.3 | 7.5910 |
| 1300 | .029 10 | 4626.9 | 5354.4 | 7.9342 | .024 266 | 4616.0 | 5344.0 | 7.8432 | .020 815 | 4605.1 | 5333.6 | 7.7653 |
| | $P = 40.0$ MPa | | | | $P = 50.0$ MPa | | | | $P = 60.0$ MPa | | | |
| 375 | .001 640 7 | 1677.1 | 1742.8 | 3.8290 | .001 559 4 | 1638.6 | 1716.6 | 3.7639 | .001 502 8 | 1609.4 | 1699.5 | 3.7141 |
| 400 | .001 907 7 | 1854.6 | 1930.9 | 4.1135 | .001 730 9 | 1788.1 | 1874.6 | 4.0031 | .001 633 5 | 1745.4 | 1843.4 | 3.9318 |
| 425 | .002 532 | 2096.9 | 2198.1 | 4.5029 | .002 007 | 1959.7 | 2060.0 | 4.2734 | .001 816 5 | 1892.7 | 2001.7 | 4.1626 |
| 450 | .003 693 | 2365.1 | 2512.8 | 4.9459 | .002 486 | 2159.6 | 2284.0 | 4.5884 | .002 085 | 2053.9 | 2179.0 | 4.4121 |
| 500 | .005 622 | 2678.4 | 2903.3 | 5.4700 | .003 892 | 2525.5 | 2720.1 | 5.1726 | .002 956 | 2390.6 | 2567.9 | 4.9321 |
| 550 | .006 984 | 2869.7 | 3149.1 | 5.7785 | .005 118 | 2763.6 | 3019.5 | 5.5485 | .003 956 | 2658.8 | 2896.2 | 5.3441 |
| 600 | .008 094 | 3022.6 | 3346.4 | 6.0114 | .006 112 | 2942.0 | 3247.6 | 5.8178 | .004 834 | 2861.1 | 3151.2 | 5.6452 |
| 650 | .009 063 | 3158.0 | 3520.6 | 6.2054 | .006 966 | 3093.5 | 3441.8 | 6.0342 | .005 595 | 3028.8 | 3364.5 | 5.8829 |
| 700 | .009 941 | 3283.6 | 3681.2 | 6.3750 | .007 727 | 3230.5 | 3616.8 | 6.2189 | .006 272 | 3177.2 | 3553.5 | 6.0824 |
| 800 | .011 523 | 3517.8 | 3978.7 | 6.6662 | .009 076 | 3479.8 | 3933.6 | 6.5290 | .007 459 | 3441.5 | 3889.1 | 6.4109 |
| 900 | .012 962 | 3739.4 | 4257.9 | 6.9150 | .010 283 | 3710.3 | 4224.4 | 6.7882 | .008 508 | 3681.0 | 4191.5 | 6.6805 |
| 1000 | .014 324 | 3954.6 | 4527.6 | 7.1356 | .011 411 | 3930.5 | 4501.1 | 7.0146 | .009 480 | 3906.4 | 4475.2 | 6.9127 |
| 1100 | .015 642 | 4167.4 | 4793.1 | 7.3364 | .012 496 | 4145.7 | 4770.5 | 7.2184 | .010 409 | 4124.1 | 4748.6 | 7.1195 |
| 1200 | .016 940 | 4380.1 | 5057.7 | 7.5224 | .013 561 | 4359.1 | 5037.2 | 7.4058 | .011 317 | 4338.2 | 5017.2 | 7.3083 |
| 1300 | .018 229 | 4594.3 | 5323.5 | 7.6969 | .014 616 | 4572.8 | 5303.6 | 7.5808 | .012 215 | 4551.4 | 5284.3 | 7.4837 |

**TABLE 4**

| Liquid | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| p (t Sat.) MPa | 0 | | | | 2.5 (223.99) | | | | 5.0 (263.99) | | | |
| t | $10^3v$ | u | h | s | $10^3v$ | u | h | s | $10^3v$ | u | h | s |
| Sat. | | | | | 1.1973 | 959.1 | 962.1 | 2.5546 | 1.2859 | 1147.8 | 1154.2 | 2.9202 |
| 0 | 1.0002 | −0.03 | −0.03 | −0.0001 | 0.9990 | −0.00 | 2.50 | −0.0000 | 0.9977 | 0.04 | 5.04 | 0.0001 |
| 20 | 1.0018 | 83.95 | 83.95 | 0.2966 | 1.0006 | 83.80 | 86.30 | 0.2961 | 0.9995 | 83.65 | 88.65 | 0.2956 |
| 40 | 1.0078 | 167.56 | 167.56 | 0.5725 | 1.0067 | 167.25 | 169.77 | 0.5715 | 1.0056 | 166.95 | 171.97 | 0.5705 |
| 60 | 1.0172 | 251.12 | 251.12 | 0.8312 | 1.0160 | 250.67 | 253.21 | 0.8298 | 1.0149 | 250.23 | 255.30 | 0.8285 |
| 80 | 1.1291 | 334.87 | 334.87 | 1.0753 | 1.0280 | 334.29 | 336.86 | 1.0737 | 1.0268 | 333.72 | 338.85 | 1.0720 |
| 100 | 1.0436 | 418.96 | 418.96 | 1.3069 | 1.0423 | 418.24 | 420.85 | 1.3050 | 1.0410 | 417.52 | 422.72 | 1.3030 |
| 120 | 1.0604 | 503.57 | 503.57 | 1.5278 | 1.0590 | 502.68 | 505.33 | 1.5255 | 1.0576 | 501.80 | 507.09 | 1.5233 |
| 140 | 1.0800 | 588.89 | 588.89 | 1.7395 | 1.0784 | 587.82 | 590.52 | 1.7369 | 1.0768 | 586.76 | 592.15 | 1.7343 |
| 160 | 1.1024 | 675.19 | 675.19 | 1.9434 | 1.1006 | 673.90 | 676.65 | 1.9404 | 1.0988 | 672.62 | 678.12 | 1.9375 |
| 180 | 1.1283 | 762.72 | 762.72 | 2.1410 | 1.1261 | 761.16 | 763.97 | 2.1375 | 1.1240 | 759.63 | 765.25 | 2.1341 |
| 200 | 1.1581 | 851.8 | 851.8 | 2.3334 | 1.1555 | 849.9 | 852.8 | 2.3294 | 1.1530 | 848.1 | 853.9 | 2.3255 |
| 210 | 1.1749 | 897.1 | 897.1 | 2.4281 | 1.1720 | 895.0 | 898.0 | 2.4238 | 1.1691 | 893.0 | 898.8 | 2.4195 |
| 220 | 1.1930 | 943.0 | 943.0 | 2.5221 | 1.1898 | 940.7 | 943.7 | 2.5174 | 1.1866 | 938.4 | 944.4 | 2.5128 |
| 230 | 1.2129 | 989.6 | 989.6 | 2.6157 | 1.2092 | 987.0 | 990.1 | 2.6105 | 1.2056 | 984.5 | 990.6 | 2.6055 |
| 240 | 1.2347 | 1037.1 | 1037.1 | 2.7091 | 1.2305 | 1034.2 | 1037.2 | 2.7034 | 1.2264 | 1031.4 | 1037.5 | 2.6979 |
| 250 | 1.2590 | 1085.6 | 1085.6 | 2.8027 | 1.2540 | 1082.3 | 1085.4 | 2.7964 | 1.2493 | 1079.1 | 1085.3 | 2.7902 |
| 260 | 1.2862 | 1135.4 | 1135.4 | 2.8970 | 1.2804 | 1131.6 | 1134.8 | 2.8898 | 1.2749 | 1127.9 | 1134.3 | 2.8830 |
| 270 | 1.3173 | 1186.8 | 1186.8 | 2.9926 | 1.3102 | 1182.4 | 1185.7 | 2.9844 | 1.3036 | 1178.2 | 1184.3 | 2.9766 |
| 280 | 1.3535 | 1240.4 | 1240.4 | 3.0904 | 1.3447 | 1235.1 | 1238.5 | 3.0808 | 1.3365 | 1230.2 | 1236.8 | 3.0717 |
| 290 | 1.3971 | 1297.0 | 1297.0 | 3.1918 | 1.3855 | 1290.5 | 1294.0 | 3.1801 | 1.3750 | 1284.4 | 1291.3 | 3.1693 |
| 300 | 1.4520 | 1358.1 | 1358.1 | 3.2992 | 1.4357 | 1349.6 | 1353.2 | 3.2843 | 1.4214 | 1341.9 | 1349.0 | 3.2708 |
| 310 | | | | | | | | | 1.4803 | 1404.1 | 1411.5 | 3.3789 |

**FIGURE 5.11a** Extract from subcooled table (SI units).

**TABLE A.4 (SI)**
Properties of Compressed Liquid (Steam)

| | P = 5 MPa (263.99) | | | | P = 10 MPa (311.06) | | | | P = 15 MPa (342.24) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *T* | *v* | *u* | *h* | *s* | *v* | *u* | *h* | *s* | *v* | *u* | *h* | *s* |
| Sat. | .001 285 9 | 1147.8 | 1154.2 | 2.9202 | .001 452 4 | 1393.0 | 1407.6 | 3.3596 | .001 658 1 | 1585.6 | 1610.5 | 3.6848 |
| 0 | .000 997 7 | .04 | 5.04 | .0001 | .000 995 2 | .09 | 10.04 | .0002 | .000 992 8 | .15 | 15.05 | .0004 |
| 20 | .000 999 5 | 83.65 | 88.65 | .2956 | .000 997 2 | 83.36 | 93.33 | .2945 | .000 995 0 | 83.06 | 97.99 | .2934 |
| 40 | .001 005 6 | 166.95 | 171.97 | .5705 | .001 003 4 | 166.35 | 176.38 | .5686 | .001 001 3 | 165.76 | 180.78 | .5666 |
| 60 | .001 014 9 | 250.23 | 255.30 | .8285 | .001 012 7 | 249.36 | 259.49 | .8258 | .001 010 5 | 248.51 | 263.67 | .8232 |
| 80 | .001 026 8 | 333.72 | 338.85 | 1.0720 | .001 024 5 | 332.59 | 342.83 | 1.0688 | .001 022 2 | 331.48 | 346.81 | 1.0656 |
| 100 | .001 041 0 | 417.52 | 422.72 | 1.3030 | .001 038 5 | 416.12 | 426.50 | 1.2992 | .001 036 1 | 414.74 | 430.28 | 1.2955 |
| 120 | .001 057 6 | 501.80 | 507.09 | 1.5233 | .001 054 9 | 500.08 | 510.64 | 1.5189 | .001 052 2 | 498.40 | 514.19 | 1.5145 |
| 140 | .001 076 8 | 586.76 | 592.15 | 1.7343 | .001 073 7 | 584.68 | 595.42 | 1.7292 | .001 070 7 | 582.66 | 598.72 | 1.7242 |
| 160 | .001 098 8 | 672.62 | 678.12 | 1.9375 | .001 095 3 | 670.13 | 681.08 | 1.9317 | .001 091 8 | 667.71 | 684.09 | 1.9260 |
| 180 | .001 124 0 | 759.63 | 765.25 | 2.1341 | .001 119 9 | 756.65 | 767.84 | 2.1275 | .001 115 9 | 753.76 | 770.50 | 2.1210 |
| 200 | .001 153 0 | 848.1 | 853.9 | 2.3255 | .001 148 0 | 844.5 | 856.0 | 2.3178 | .001 143 3 | 841.0 | 858.2 | 2.3104 |
| 220 | .001 186 6 | 938.4 | 944.4 | 2.5128 | .001 180 5 | 934.1 | 945.9 | 2.5039 | .001 174 8 | 929.9 | 947.5 | 2.4953 |
| 240 | .001 226 4 | 1031.4 | 1037.5 | 2.6979 | .001 218 7 | 1026.0 | 1038.1 | 2.6872 | .001 211 4 | 1020.8 | 1039.0 | 2.6771 |
| 260 | .001 274 9 | 1127.9 | 1134.3 | 2.8830 | .001 264 5 | 1121.1 | 1133.7 | 2.8699 | .001 255 0 | 1114.6 | 1133.4 | 2.8576 |
| 280 | | | | | .001 321 6 | 1220.9 | 1234.1 | 3.0548 | .001 308 4 | 1212.5 | 1232.1 | 3.0393 |
| 300 | | | | | .001 397 2 | 1328.4 | 1342.3 | 3.2469 | .001 377 0 | 1316.6 | 1337.3 | 3.2260 |
| 320 | | | | | | | | | .001 472 4 | 1431.1 | 1453.2 | 3.4247 |
| 340 | | | | | | | | | .001 631 1 | 1567.5 | 1591.9 | 3.6546 |

TABLE A.4 (SI) (cont'd.)

| | P = 20 MPa (365.81) | | | | P = 30 MPa | | | | P = 50 MPa | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | v | u | h | s | v | u | h | s | v | u | h | s |
| Sat. | .002 036 | 1785.6 | 1826.3 | 4.0139 | | | | | | | | |
| 0 | .000 990 4 | .19 | 20.01 | .0004 | .000 985 6 | .25 | 29.82 | .0001 | .000 976 6 | .20 | 49.03 | .0014 |
| 20 | .000 992 8 | 82.77 | 102.62 | .2923 | .000 988 6 | 82.17 | 111.84 | .2899 | .000 980 4 | 81.00 | 130.02 | .2848 |
| 40 | .000 999 2 | 165.17 | 185.16 | .5646 | .000 995 1 | 164.04 | 193.89 | .5607 | .000 987 2 | 161.86 | 211.21 | .5527 |
| 60 | .001 008 4 | 247.68 | 267.85 | .8206 | .001 004 2 | 246.06 | 276.19 | .8154 | .000 996 2 | 242.98 | 292.79 | .8052 |
| 80 | .001 019 9 | 330.40 | 350.80 | 1.0624 | .001 015 6 | 328.30 | 358.77 | 1.0561 | .001 007 3 | 324.34 | 374.70 | 1.0440 |
| 100 | .001 033 7 | 413.39 | 434.06 | 1.2917 | .001 029 0 | 410.78 | 441.66 | 1.2844 | .001 020 1 | 405.88 | 456.89 | 1.2703 |
| 120 | .001 049 6 | 496.76 | 517.76 | 1.5102 | .001 044 5 | 493.59 | 524.93 | 1.5018 | .001 034 8 | 487.65 | 539.39 | 1.4857 |
| 140 | .001 067 8 | 580.69 | 602.04 | 1.7193 | .001 062 1 | 576.88 | 608.75 | 1.7098 | .001 051 5 | 569.77 | 622.35 | 1.6915 |
| 160 | .001 088 5 | 665.35 | 687.12 | 1.9204 | .001 082 1 | 660.82 | 693.28 | 1.9096 | .001 070 3 | 652.41 | 705.92 | 1.8891 |
| 180 | .001 112 0 | 750.95 | 773.20 | 2.1147 | .001 104 7 | 745.59 | 778.73 | 2.1024 | .001 091 2 | 735.69 | 790.25 | 2.0794 |
| 200 | .001 138 8 | 837.7 | 860.5 | 2.3031 | .001 130 2 | 831.4 | 865.3 | 2.2893 | .001 114 6 | 819.7 | 875.5 | 2.2634 |
| 220 | .001 169 3 | 925.9 | 949.3 | 2.4870 | .001 159 0 | 918.3 | 953.1 | 2.4711 | .001 140 8 | 904.7 | 961.7 | 2.4419 |
| 240 | .001 204 6 | 1016.0 | 1040.0 | 2.6674 | .001 192 0 | 1006.9 | 1042.6 | 2.6490 | .001 170 2 | 990.7 | 1049.2 | 2.6158 |
| 260 | .001 246 2 | 1108.6 | 1133.5 | 2.8459 | .001 230 3 | 1097.4 | 1134.3 | 2.8243 | .001 203 4 | 1078.1 | 1138.2 | 2.7860 |
| 280 | .001 296 5 | 1204.7 | 1230.6 | 3.0248 | .001 275 5 | 1190.7 | 1229.0 | 2.9986 | .001 241 5 | 1167.2 | 1229.3 | 2.9537 |
| 300 | .001 359 6 | 1306.1 | 1333.3 | 3.2071 | .001 330 4 | 1287.9 | 1327.8 | 3.1741 | .001 286 0 | 1258.7 | 1323.0 | 3.1200 |
| 320 | .001 443 7 | 1415.7 | 1444.6 | 3.3979 | .001 399 7 | 1390.7 | 1432.7 | 3.3539 | .001 338 8 | 1353.3 | 1420.2 | 3.2868 |
| 340 | .001 568 4 | 1539.7 | 1571.0 | 3.6075 | .001 492 0 | 1501.7 | 1546.5 | 3.5426 | .001 403 2 | 1452.0 | 1522.1 | 3.4557 |
| 360 | .001 822 6 | 1702.8 | 1739.3 | 3.8772 | .001 626 5 | 1626.6 | 1675.4 | 3.7494 | .001 483 8 | 1556.0 | 1630.2 | 3.6291 |
| 380 | | | | | .001 869 1 | 1781.4 | 1837.5 | 4.0012 | .001 588 4 | 1667.2 | 1746.6 | 3.8101 |