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# NANYANG TECHNOLOGICAL UNIVERSITY

## SEMESTER 2 EXAMINATION 2016-2017

## MA2003 – INTRODUCTION TO THERMO-FLUIDS

April/May 2017 Time allowed: 2½ hour

**INSTRUCTIONS**

1. This paper contains **FOUR** (4) questions and comprises **ELEVEN** (11) pages.
2. Answer **ALL** questions.
3. All questions carry equal marks.
4. This is a **CLOSED-BOOK** examination
5. Relevant Thermodynamics tables are provided in the Appendix (pages 5 to 11).

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1. The tank as shown in Figure 1 comprises two cylindrical shaped closed subsystems A and B. The tank is completely insulated. A frictionless piston separates the two subsystems. The Subsystem A contains $9 \times 10^{-3}$ $m^3$ of liquid water – vapour mixture with a quality of 85 percent at the pressure of 125 kPa. The piston has a cross-sectional area of 60 $cm^2$. The subsystem B contains 0.1 kg of air with the pressure and temperature of 100 kPa and 30 °C, respectively. A 15 W heating coil is placed inside the subsystem A causing the piston to move up and push the stopper. The final pressure of subsystem A is 300 kPa. No heat is transferred from subsystem A to subsystem B through the piston. You may assume air as ideal gas. For air, the ideal gas constant (R) is given as 0.287 kJ/kg. K. The specific heat capacity at constant pressure ($c_p$) is 1.008 kJ/kg. K and the specific heat at constant volume ($c_v$) is 0.721 kJ/kg. K.

(a) Calculate the initial temperature and the mass of water vapour at subsystem A. (3 marks)

(b) Define the state at which the piston just touches the stopper. (3 marks)

(c) Calculate the work done by subsystem A up to the final state. Show the process in P-v diagram (6 marks)

(d) Calculate the required time to power the heating coil for the final pressure of 300 kPa (for subsystem A) (7 marks)

Note: Question 1 continues on page 2.
Figure 1 appears on page 2.



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(e) What is the final temperature of subsystem B? Draw the P-v diagram for subsystem B and show how the states change from initial to final. (6 marks)

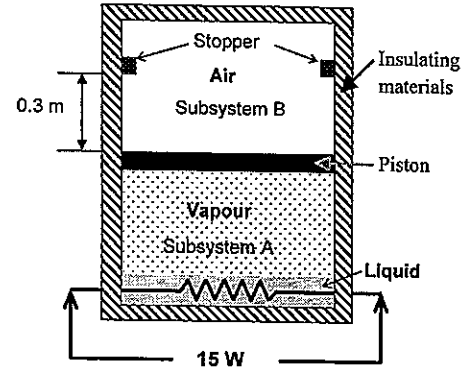


Figure 1

2. In a geothermal power plant, steam with a volumetric flow rate of 30 $m^3$/min enters a well-insulated steam turbine at 10 MPa and 400 °C (state 1) as shown schematically in Figure 2. The steam is extracted from the turbine at the pressure and temperature of 1 MPa and 200 °C with the mass flow rate of 10 kg/s (first exit, state 2), and the rest of the steam expands to a pressure of 100 kPa with the quality of 85 % (second exit, state 3).

(a) Write the overall mass and energy balances of the system with necessary assumptions. (7 marks)

(b) Calculate the power developed by the turbine. (8 marks)

(c) Calculate the mass flow rate of liquid water at the second exit of the steam turbine. (5 marks)

(d) Draw P- v diagram and show states 1, 2 and 3 with their corresponding constant temperature lines. (5 marks)

Note: Figure 2 appears on page 3.



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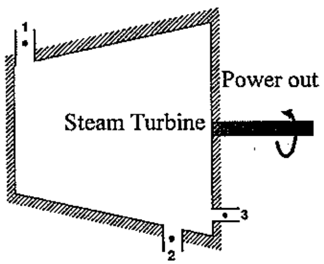


Figure 2

3 (a) A tunnel is to be built under a 50m-deep, 300m-long lake. The engineer produced two designs shown in Figure 3 below: one is a semicircular 10-m-diameter tunnel, and the other is a symmetrically triangular tunnel. Determine the total hydrostatic force acting on the roof of each design of the tunnel. Then compare which design subjects to less force.

(15 marks)

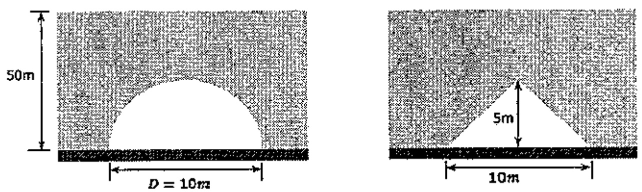


Figure 3

(b) A can is completely filled with Pepsi drink whose density is 1100 kg/m$^3$. The can is 5cm in diameter and is 20cm high. The can is now rotated about its vertical axis at a rate of 30 rpm (round per minute) and is free falling. Determine the pressure difference between the center of the top surface and the edge of the bottom surface. The equation for fluid in solid rotation is $dp = \rho r\omega^2 dr - \rho(g + a_z)dz$.

(10 marks)

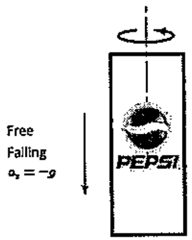


Figure 4



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4 (a) Rain water flows horizontally onto a porous playground bed through a duct which has a width of 50cm and a height of 5 cm. The velocity distribution of the rain water out of the duct can be approximated by a triangular shape along the duct's height, with a maximum of 1 m/s at the duct's center and 0.1 m/s at both bottom and top of the duct, as shown in the figure. The velocity distribution of rain water across the duct's width is the same. The playground bed absorbs the water at a uniform vertical velocity of 0.5 mm/s. How big is the surface area of the playground bed in order to completely absorb the rain water steadily?

(10 marks)

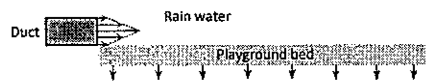



Figure 5

(b) A contractor is to empty the liquid natural gas (LNG) from a cylindrical tank via a venting hose at the bottom of the tank, as shown in the following figure. The length of the hose can be neglected. The initial gage pressure of the air inside the tank is $p_{ini} = 2\,p_{atm}$. The air can be considered an ideal gas and its temperature is maintained constant during the whole process. Initial heights of air and LNG inside the tank are $H_1$ and $H_2$, respectively. The diameter of the tank is D, and the diameter of the hose is d. The velocity distribution out of the hose can be assumed uniform, and the velocity at the top surface of LNG can be assumed negligible. Specific weight of LNG is $\gamma$. In terms of the given variables, find the formula to compute the time needed to empty the tank.

(15 marks)

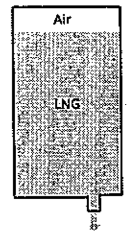



Figure 6

MA2003 April 2017

(1) a) $P_{A1} = 125\ kPa$

Continues after point 1c

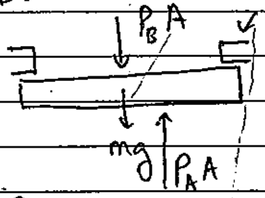
Saturated mixture → $T_{A1} = 105.97\ °C$

$v_{A1} = v_f + x(v_g - v_f)$

$= 0.001048 + 0.85(1.3750 - 0.001048)$

$= 1.169\ m^3/kg$

b) Assume quasi-equilibrium process → the piston is at equilibrium at all times. Since subsystem A gets electrical work, it will expand and pushes the piston upwards. The result is subsystem B gets compressed and its pressure increases. To maintain piston's equilibrium, the pressure of subsystem A also increases. The increase in pressure of subsystem A must equal to the increase in pressure of subsystem B.




c) Subsystem B

Initial state: $P_{B1} = 100\ kPa$, $T_{B1} = 30°C = 303.15\ K$

$m_B = 0.1\ kg$, $R = 0.287\ kJ/kg\,K$

$$V_{B1} = \frac{m_B R T_{B1}}{P_{B1}} = \frac{0.1 \times 0.287 \times 303.15}{100}$$

$= 0.087\ m^3$

Final state: $V_{B2} = V_{B1} - A\Delta h$

$= 0.087 - 60 \times 10^{-4} \times 0.3$

$= 0.0852\ m^3$

Adiabatic process → $PV^{\gamma} = \text{constant} = K$

$$\gamma = \frac{C_p}{C_v} = \frac{1.008}{0.721}$$ ~~$= 1.398 \approx 1.4$~~

$P_{B1} V_{B1}^{\gamma} = P_{B2} V_{B2}^{\gamma}$

$$P_{B2} = P_{B1}\left(\frac{V_{B1}}{V_{B2}}\right)^{\gamma}$$ ~~$= 100\left(\frac{0.087}{0.0852}\right)^{1.4} = 102.97\ kPa$~~



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Work for adiabatic process

$$W = \int_1^2 P\, d\forall = \int_1^2 \frac{K}{\forall^{\gamma}}\, d\forall$$

$$= \frac{1}{1-\gamma}\left(K\forall_1^{1-\gamma} - K\forall_2^{1-\gamma}\right)$$

$$= \frac{1}{1-\gamma}\left(P_1\forall_1 - P_2\forall_2\right)$$

$$W_B = \frac{1}{1-\gamma}\left(P_{B1}\forall_{B1} - P_{B2}\forall_{B2}\right)$$

$$= \frac{1}{1-1.4}\left(100 \times 0.087 - 102.37 \times 0.0852\right)$$

$$= 0.18261 \text{ kJ}$$

Subsystem A

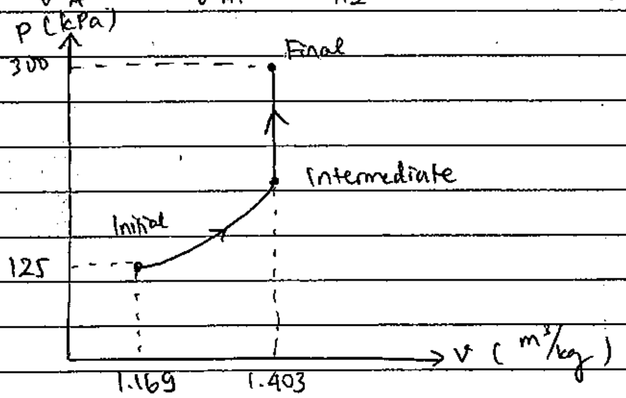
Intermediate state → when the piston just touches the stopper

Initial to intermediate → $W_{A1} = -W_B$

$= -0.18261$ kJ

Intermediate to final → $W_{A2} = 0$ because isochoric process

$W_A = W_{A1} + W_{A2} = -0.18261$ kJ (work is done by subsystem A)




(Point 1a continues)

$$m_A = \frac{V_{A1}}{v_{A1}}$$

$$= \frac{9\times10^{-3}}{1.169} = 7.7\times10^{-3} \text{ kg}$$

$$m_{Ag} = x\, m_A$$

$$= 0.85 \times 7.7\times10^{-3}$$

$$= 6.545 \times 10^{-3} \text{ kg}$$



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d) $\forall_{A2} = \forall_{A1} + A\Delta h$

$= 9\times10^{-3} + 60\times10^{-4}\times0.3$

$= 10.8\times10^{-3}\ m^3$

$= 0.0108\ m^3$

$v_{A2} = \frac{\forall_{A2}}{m_A}$

$= \frac{0.0108}{7.7\times10^{-3}} = 1.403\ m^3/kg$

$P_{A2} = 300\ kPa$

$v_{A2} > v_g @300kPa \rightarrow$ superheated vapor

$v@600°C < v_{A2} < v@700°C$

$\frac{1.403 - 1.34139}{1.49580 - 1.34139} = \frac{u_{A2} - 3301.6}{3479.5 - 3301.6}$

$u_{A2} = 3372.58\ kJ/kg$

$u_{A1} = u_{f1} + x\,u_{fg1}$

$= 444.23 + 0.85\times2068.8$

$= 2202.71\ kJ/kg$

$Q - W_e = m_A(u_{A2} - u_{A1})$

$0 - W_e = 7.7\times10^{-3}(3372.58 - 2202.71)$

$W_e = -9.008\ kJ$

$P\times t = |W_e|$

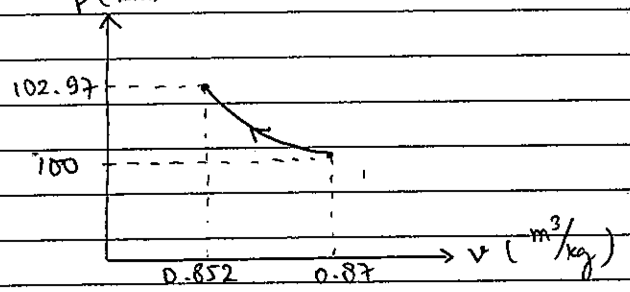
$t = \frac{9.008\times10^3}{15} = 600.53\ s \approx 10\ mins$

e) $T_{B2} = \frac{P_{B2}\forall_{B2}}{m_B R} = \frac{102.97\times0.0852}{0.1\times0.287} = 305.68\ K$

$= 32.53\ °C$

$v_{B1} = \frac{\forall_{B1}}{m_B} = \frac{0.087}{0.1} = 0.87\ m^3/kg$

$v_{B2} = \frac{\forall_{B2}}{m_B} = \frac{0.0852}{0.1} = 0.852\ m^3/kg$




u. Pg. 3

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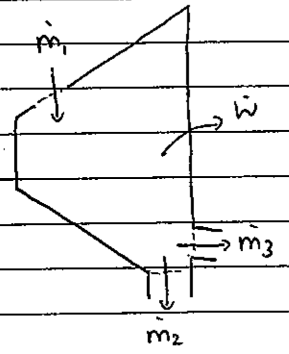
(2)




a) Conservation of mass

$\dot{m}_1 = \dot{m}_2 + \dot{m}_3$ ---- (1)

Assume kinetic energy change and potential energy change negligible

Energy balance

$\dot{Q} - \dot{W} = \dot{m}_2 h_2 + \dot{m}_3 h_3 - \dot{m}_1 h_1$

"Well-insulated turbine" → $\dot{Q} = 0$

$-\dot{W} = \dot{m}_2 h_2 + \dot{m}_3 h_3 - \dot{m}_1 h_1$ --- (2)

b) State 1 : $P_1 = 10\ MPa$, $T_1 = 400°C$, $\dot{V}_1 = 30\ m^3/min$

$= 0.5\ m^3/s$

superheated vapor

$v_1 = 0.026436\ m^3/kg$, $h_1 = 3097.5\ kJ/kg$

$\dot{m}_1 = \frac{\dot{V}_1}{v_1} = \frac{0.5}{0.026436} = 18.914\ kg/s$

State 2 : $P_2 = 1\ MPa$, $T_2 = 200°C$, $\dot{m}_2 = 10\ kg/s$

superheated vapor

$h_2 = 2828.3\ kJ/kg$

State 3 : $P_3 = 100\ kPa$, $x_3 = 0.85$, $T_3 = 99.61°C$

$h_3 = h_f + x_3 h_{fg}$

$= 417.51 + 0.85 \times 2257.5$

$= 2336.385\ kJ/kg$

(1) ... $\dot{m}_1 = \dot{m}_2 + \dot{m}_3$

$18.914 = 10 + \dot{m}_3$

$\dot{m}_3 = 8.914\ kg/s$

(2) ... $\dot{W} = \dot{m}_1 h_1 - \dot{m}_2 h_2 - \dot{m}_3 h_3$

$= 18.914 \times 3097.5 - 10 \times 2828.3 - 8.914 \times 2336.385$

$= 9476.58\ W$

$= 9.477\ kW$

c) $\dot{m}_3 = 8.914\ kg/s$ (refer to point 2b)

d) State 2 → $v_2 = 0.20602\ m^3/kg$

State 3 → $v_3 = 0.001043 + 0.85 \times (1.6941 - 0.001043)$

$= 1.4401\ m^3/kg$



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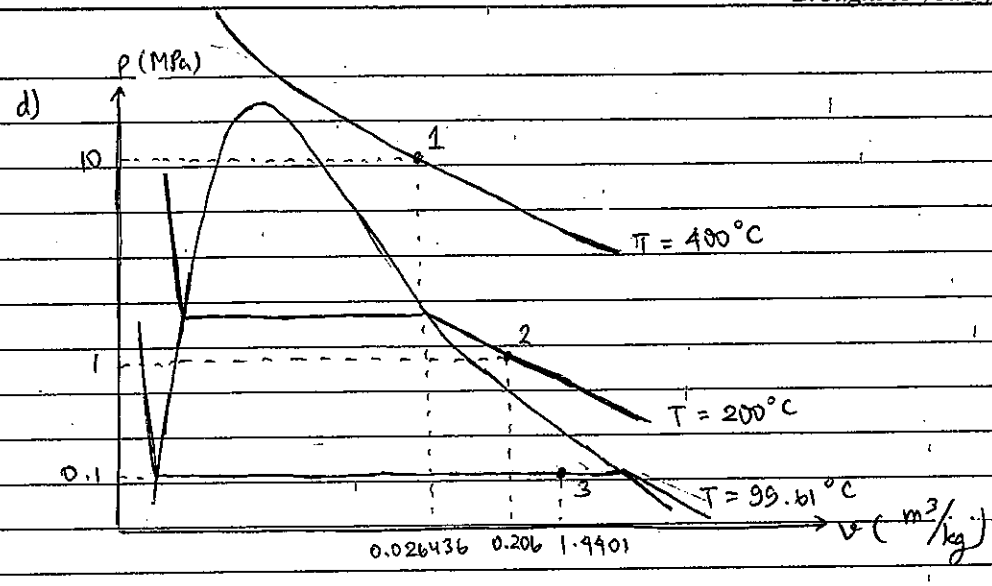
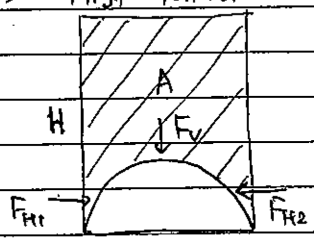
d)




③ a) First tunnel




$A = HD - \frac{1}{4}\pi D^2$

$= 50 \times 10 - \frac{1}{4}\pi \times 10^2$

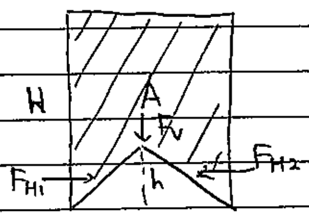
$= 421.46 \ m^2$

$F_v = \rho g \forall = \rho g A w$

$= 1000 \times 9.81 \times 421.46 \times 300$

$= 1.24 \ GN$

Second tunnel




$A = HD - \frac{1}{2}Dh$

$= 50 \times 10 - \frac{1}{2} \times 10 \times 5$

$= 475 \ m^2$

$F_v = \rho g \forall = \rho g A w$

$= 1000 \times 9.81 \times 475 \times 300$

$= 1.398 \ GN$

* First tunnel is subjected to less force.
$F_{H1}$ and $F_{H2}$ will negate each other due to tunnel's symmetry for both tunnel



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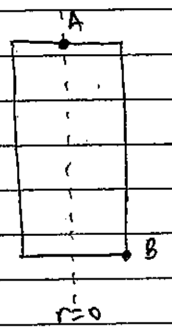
b) $\omega = 30$ rpm

$= \dfrac{30 \times 2\pi}{60} = \pi$ rad/s



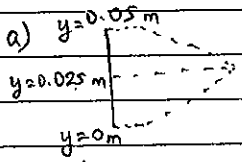

$$\int_A^B dp = \int_A^B \rho r \omega^2 dr - \int_A^B \rho (g-g)\, dz$$

$$P_B - P_A = \frac{1}{2}\rho\omega^2 (r_B^2 - r_A^2)$$

$$\Delta P = \left|\frac{1}{2} \times 1100 \times \pi^2 \times ((2.5\times10^{-2})^2 - 0^2)\right|$$

$$= 3.393 \text{ Pa}$$

(4) a)




width $w = 0.5$ m

$0 \le y \le 0.025$

$V(0) = 0.1$ ; $V(0.025) = 1$

$$\frac{y-0}{0.025-0} = \frac{V-0.1}{1-0.1}$$

$$V = 36y + 0.1$$

$0.025 \le y \le 0.05$

$V(0.025) = 1$ ; $V(0.05) = 0.1$

$$\frac{y-0.025}{0.05-0.025} = \frac{V-1}{0.1-1}$$

$$V = -36y + 1.9$$

$$\cancel{\frac{\partial}{\partial t}\int \rho\, dV} + \int_{duct} \rho \vec{V}\cdot\vec{n}\, dA + \int_{bed} \rho \vec{V}\cdot\vec{n}\, dA = 0$$

steady flow

$$\int_0^{0.025} \cancel{\rho}(-36y - 0.1)\, w\, dy + \int_{0.025}^{0.05} \cancel{\rho}(36y - 1.9)\, w\, dy + \cancel{\rho} V A = 0$$

$$0.5 \times \left[-18y^2 - 0.1y\right]_0^{0.025} + 0.5 \times \left[18y^2 - 1.9y\right]_{0.025}^{0.05} + 0.5\times10^{-3} A = 0$$

$$-0.006875 - 0.006875 + 0.0005 A = 0$$

$$A = 27.5 \text{ m}^2$$



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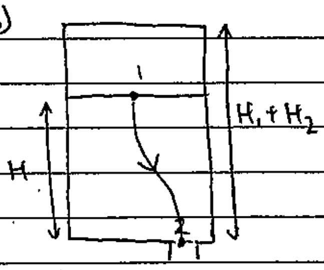
b)




For air

$$(p_{ini} + p_{atm})\,\forall_{ini} = p\,\forall$$

$$3p_{atm} \times \tfrac{1}{4}\pi D^2 \times H_1 = p \times \tfrac{1}{4}\pi D^2 \times (H_1 + H_2 - H)$$

$$p = \frac{3\,p_{atm}\,H_1}{H_1 + H_2 - H}$$

Bernoulli equation for point 1 and point 2

$$\frac{p}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{p_{atm}}{\rho g} + \frac{V_2^2}{2g} + z_2$$

$$\frac{p}{\rho g} + H = \frac{p_{atm}}{\rho g} + \frac{V_2^2}{2g}$$

$$V_2 = \sqrt{2g\left(\frac{p - p_{atm}}{\gamma}\right) + 2gH}$$

Continuity equation for LNG

$$\frac{\partial}{\partial t}\int \rho\, d\forall + \int \rho \vec{V}\cdot\vec{n}\, dA = 0$$

$$\rho \frac{d\forall}{dt} + \rho V_2 A_2 = 0$$

$$\tfrac{1}{4}\pi D^2 \frac{dH}{dt} + \tfrac{1}{4}\pi d^2 V_2 = 0$$

$$\frac{dH}{dt} = -\frac{d^2}{D^2} V_2$$

$$\int_0^T dt = \int_{H_2}^{0} -\frac{D^2}{d^2}\frac{dH}{V_2}$$

$$T = \int_{H_2}^{0} -\frac{D^2}{d^2} \times \frac{dH}{\sqrt{\frac{2g}{\gamma}(p - p_{atm}) + 2gH}}$$

$$T = \frac{D^2}{d^2}\int_0^{H_2} \frac{dH}{\sqrt{\frac{2g}{\gamma}\left(\frac{3p_{atm}H_1}{H_1+H_2-H} - p_{atm}\right) + 2gH}}$$

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# NANYANG TECHNOLOGICAL UNIVERSITY

## SEMESTER 1 EXAMINATION 2017-2018

## MA2003 – INTRODUCTION TO THERMO-FLUIDS

November/December 2017 | Time allowed: 2½ hours

## INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **NINE (9)** pages.
2. Answer **ALL FOUR** questions.
3. This is a **CLOSED-BOOK** examination.
4. All questions carry equal marks.
5. Relevant Thermodynamics tables and formulas for second moment of inertia are provided in the Appendix (pages 7 to 9).

---

1. The tank as shown in Figure 1 comprises two cylindrical shaped closed Subsystems A and B. The tank is completely insulated. A frictionless piston separates the two subsystems. The Subsystem A contains $3 \times 10^{-3}$ $m^3$ of R134a liquid – vapour mixture with a quality of 80 percent at the pressure of 320 kPa. The piston is free to move and has a cross-sectional area of 40 $cm^2$. The Subsystem B contains 0.05 kg of air with the pressure and temperature of 100 kPa (gauge) and 33 °C, respectively. The Subsystem B also contains a spring with the spring constant of 7.5 kN/m. The Subsystem A is now brought in thermal contact with a heat source of $\boldsymbol{Q}$. Heat transfer causes the piston to move up and push the spring. The final pressure of Subsystem A is found to be 500 kPa. No heat is transferred from Subsystem A to Subsystem B through the piston. You may assume air as ideal gas. For air, the ideal gas constant (R) is given as 0.287 kJ/kg. K, the specific heat capacity at constant pressure ($c_p$) is 1.008 kJ/kg.K, the specific heat capacity at constant volume ($c_v$) is 0.721 kJ/kg.K and the compression coefficient under adiabatic condition can be considered 1.4. The effects of spring volume are neglected. The atmospheric pressure of air is considered 101.325 kPa.

(a) Calculate the initial temperature and the mass of R134a at Subsystem A. (3 marks)

(b) Calculate the distance travelled by the piston from initial to final state. (3 marks)

(c) Calculate the work done by Subsystem A up to its final state. Show the process in P-v diagram.

(6 marks)

Note: Question 1 continues on page 2.
Figure 1 appears on page 2.

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(d) Calculate the amount of heat $Q$ to the system. What is the final temperature of Subsystem A? (7 marks)

(e) What are the final temperature and pressure of Subsystem B? (6 marks)

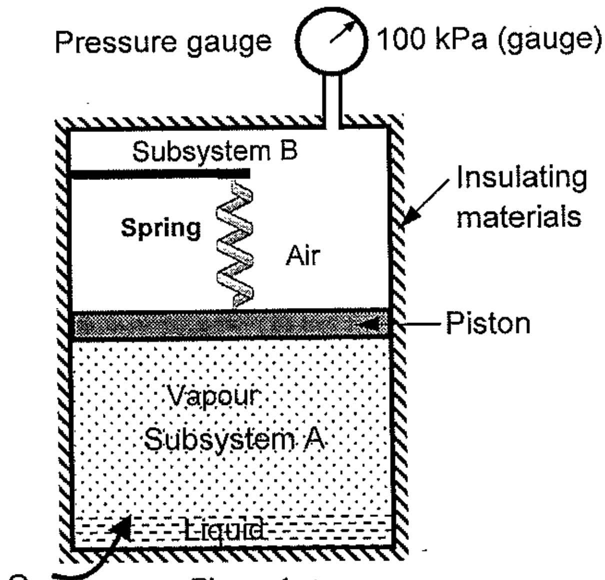


Figure 1

2. Three main components namely compressor, heat exchanger and throttling device are shown in Figure 2. At first, saturated R134a vapour with a mass flow rate of 0.3 kg/s and 240 kPa enters the compressor at point 1 and leaves at point 2 at 60 °C and 1600 kPa. The heat loss to the surroundings from the compressor is 3 kW. Next, the working R134a fluid directly goes to the heat exchanger, where R134a is cooled by water flow. The water is not mixed with R134a in the heat exchanger. The refrigerant R134a leaves from the heat exchanger (point 3) at the pressure of 1600 kPa under the saturated liquid condition. Finally R134a is throttled to 240 kPa (point 4). The cooling water enters the heat exchanger (point 5) at 25 °C and leaves at 35 °C (point 6). The specific heat capacity of liquid water is considered 4.18 kJ/kg.K. The change in the kinetic and potential energy in the process can be neglected. The pressure drop and heat loss at the connection between main components are negligible. All state points are shown in Figure 2.

(a) Calculate the power input to the compressor. (6 marks)

(b) Calculate the heat loss from the heat exchanger. (5 marks)

(c) Calculate the quality of R134a fluid at the outlet of the throttling device. (5 marks)

(d) Calculate the mass flow rates of both liquid and vapour phases at state point 4. (5 marks)

(e) Calculate the mass flow rate of cooling water at point 5. (4 marks)

Note: Figure 2 appears on page 3.

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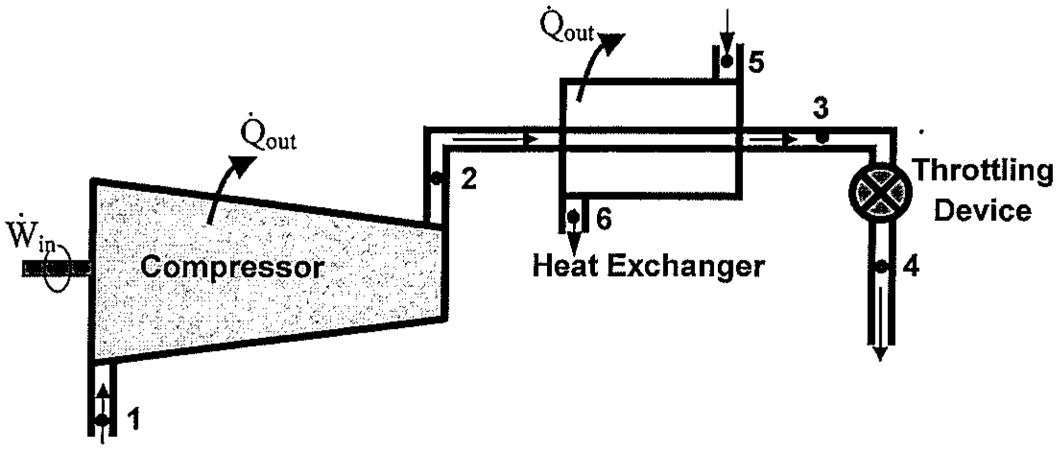


Figure 2

3 (a) A tank of width $W$ (dimension into paper), shown in Figure 3, has a gate connected to the tank through the hinge at the top. The gate comprises of a half cylinder and a rectangular plate, which separates the tank into two compartments. The left compartment is open to the air at atmospheric pressure $P_{atm}$ and filled with water. The density of water is $\rho$, and the initial water level is $H$. The right compartment is initially filled with compressed air of gauge pressure $P_0$ ($P_0 > 0$). A torque $T$ is applied at the hinge to keep the gate shut at all times. Due to a small leak at the bottom of the gate, the water leaks to the right compartment.

When the water level drops by height $h$, determine:

(i) The air gauge pressure $P_{air}$. (3 marks)

In terms of $P_{air}$ and $h$, determine:

(ii) The total horizontal force on the gate $F_H$, (3 marks)

(iii) The distance $y$ (location of the force $F_H$), (3 marks)

(iv) The total vertical force on the gate $F_V$, (3 marks)

(v) Eventually the water level will reach the equilibrium such that there is no leak and torque, $T = 0$. Assuming at this equilibrium state, the water level at the left compartment is $H - h_{eq}$, set up the equation for $h_{eq}$. You are not required to solve it.

(3 marks)

Note: Question 3 continues on page 4
Figure 3 appears on page 4.



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You may assume:
1. The mass of the gate and the dimension of the leak can be neglected.
2. The flow rate through the leak is extremely small, so the process at any instant is quasi-steady.
3. The air remains trapped within the right compartment and behaves ideal gas with constant temperature.

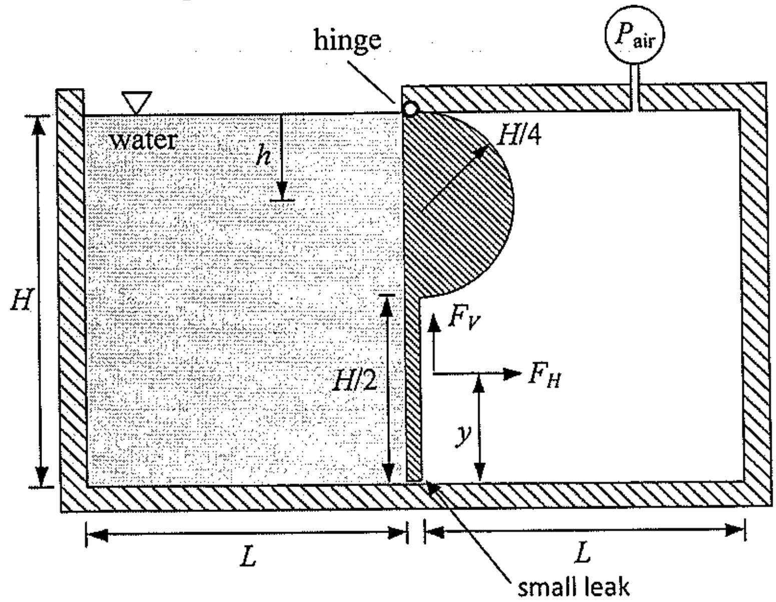


Figure 3

(b) A 2-m long (dimension into paper) barge with the cross-sectional dimension as shown in Figure 4 is floating on water of density 1000 kg/m$^3$. The density of this homogeneous barge is 300 kg/m$^3$.

(i) Determine the height $y$ measured from the water surface to the bottom surface of the barge.

(2 marks)

(ii) Is this configuration stable? Please provide necessary calculations to justify your answer.

(3 marks)

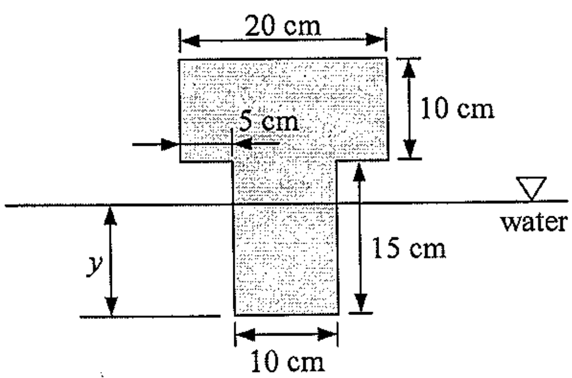


Figure 4

Note: Question 3 continues on page 5.

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(c) A rectangular tank with negligible width (dimension in the $y$ direction) is fully filled with water of density $\rho$ is shown in Figure 5. The tank is fully sealed (except at point $O$, which is exposed to the atmosphere) and rotates at a constant angular speed $\omega$ about the axis parallel to the $z$ axis passing through point $O$. Determine the gauge pressure at the point $A$ (left bottom corner as shown in Figure 5) in terms of the given variables.

(5 marks)

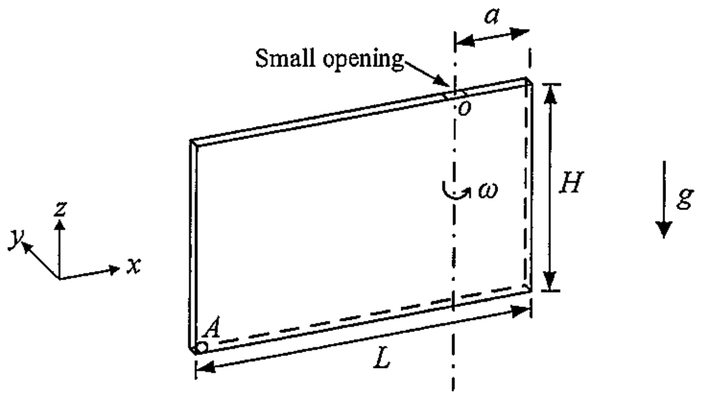


Figure 5

4 (a) Water of density $\rho$ flows in a pipe of varying diameter and exits to the atmosphere as shown in Figure 6. The flow is assumed to be steady and ideal. The velocity across the cross section area is uniform. The gauge pressure at point $A$ is $P_A$.

(i) Determine the velocities $V_2$ and $V_3$ in terms of $V_1$. (4 marks)

(ii) Draw the relevant streamlines and determine the volumetric flowrate in terms of only the following variables: $P_A$, $D_1$, $\rho$, and the pitot static tube reading $h_2$.

(8 marks)

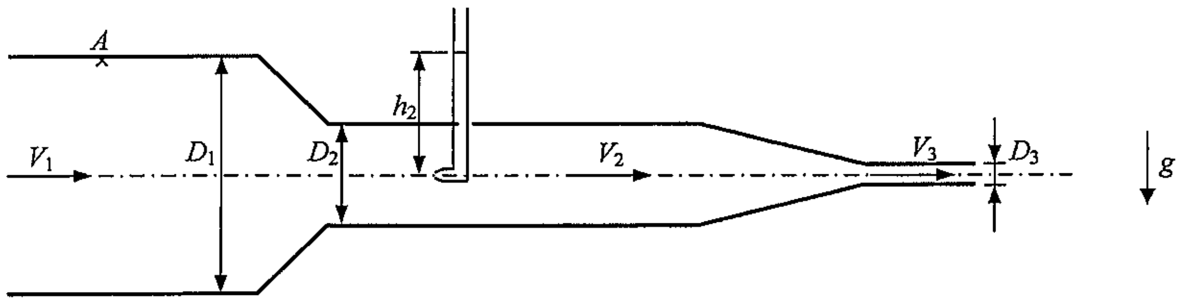


Figure 6

Note: Question 4 continues on page 6.

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(b) An experiment setup shown in Figure 7 is performed in the zero-gravity space station to inflate a balloon. The experiment is conducted by first pumping the air of density $\rho_{air}$ into a tank of diameter $D$ which is initially filled with water of height $H_1$, while keeping the valve closed. The absolute pressure of the compressed air ($P_{air}$) at this stage is $P_0$. An empty balloon is then connected to the pipe and the valve is opened. The water flows through the pipe and fills the balloon. The water density is $\rho_w$. The pressure in the balloon $P_b$ depends on the volume of the balloon $\forall$ given by $P_b = C\forall$. At the steady state, the astronaut finds that the water level in the tank drops by the height of $h$ and the volume of the balloon is $\forall_f$.

If $\forall = \forall_f\left[1-e^{(-t/\tau)}\right]$, where $\tau$ is a constant,

(i) determine the time taken to inflate the balloon to a volume of 0.5 $\forall_f$.

(2 marks)

(ii) determine the mass influx to the balloon.

(4 marks)

(iii) determine the final volume of the balloon is $\forall_f$ in terms of $h$ and solve for $h$ in terms of $P_0$, $H_2$, $D$ and $C$.

(7 marks)

You may assume the air is an ideal gas.

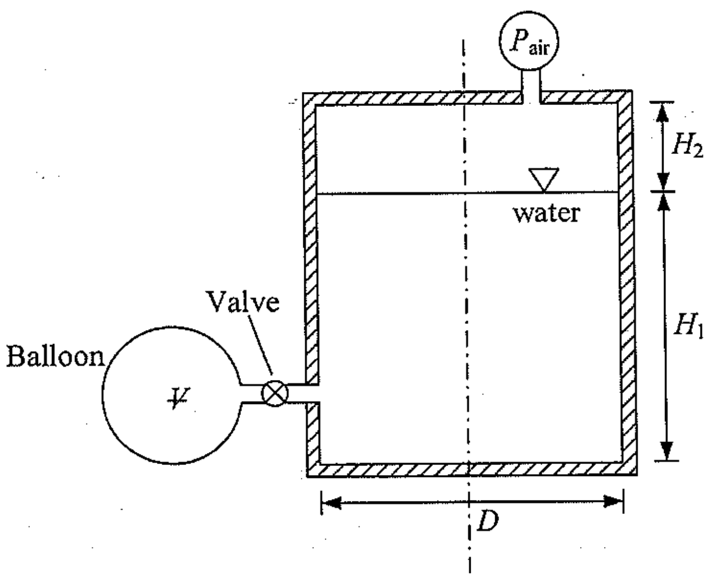


Figure 7

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# APPENDIX

## Table 1- Pressure Table for R134a

Saturated refrigerant-134a—Pressure table

| | | Specific volume, $m^3/kg$ | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg · K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Press., $P$ kPa | Sat. temp., $T_{sat}$ °C | 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, $s_g$ |
| 60 | −36.95 | 0.0007098 | 0.31121 | 3.798 | 205.32 | 209.12 | 3.841 | 223.95 | 227.79 | 0.01634 | 0.94807 | 0.96441 |
| 70 | −33.87 | 0.0007144 | 0.26929 | 7.680 | 203.20 | 210.88 | 7.730 | 222.00 | 229.73 | 0.03267 | 0.92775 | 0.96042 |
| 80 | −31.13 | 0.0007185 | 0.23753 | 11.15 | 201.30 | 212.46 | 11.21 | 220.25 | 231.46 | 0.04711 | 0.90999 | 0.95710 |
| 90 | −28.65 | 0.0007223 | 0.21263 | 14.31 | 199.57 | 213.88 | 14.37 | 218.65 | 233.02 | 0.06008 | 0.89419 | 0.95427 |
| 100 | −26.37 | 0.0007259 | 0.19254 | 17.21 | 197.98 | 215.19 | 17.28 | 217.16 | 234.44 | 0.07188 | 0.87995 | 0.95183 |
| 120 | −22.32 | 0.0007324 | 0.16212 | 22.40 | 195.11 | 217.51 | 22.49 | 214.48 | 236.97 | 0.09275 | 0.85503 | 0.94779 |
| 140 | −18.77 | 0.0007383 | 0.14014 | 26.98 | 192.57 | 219.54 | 27.08 | 212.08 | 239.16 | 0.11087 | 0.83368 | 0.94456 |
| 160 | −15.60 | 0.0007437 | 0.12348 | 31.09 | 190.27 | 221.35 | 31.21 | 209.90 | 241.11 | 0.12693 | 0.81496 | 0.94190 |
| 180 | −12.73 | 0.0007487 | 0.11041 | 34.83 | 188.16 | 222.99 | 34.97 | 207.90 | 242.86 | 0.14139 | 0.79826 | 0.93965 |
| 200 | −10.09 | 0.0007533 | 0.099867 | 38.28 | 186.21 | 224.48 | 38.43 | 206.03 | 244.46 | 0.15457 | 0.78316 | 0.93773 |
| 240 | −5.38 | 0.0007620 | 0.083897 | 44.48 | 182.67 | 227.14 | 44.66 | 202.62 | 247.28 | 0.17794 | 0.75664 | 0.93458 |
| 280 | −1.25 | 0.0007699 | 0.072352 | 49.97 | 179.50 | 229.46 | 50.18 | 199.54 | 249.72 | 0.19829 | 0.73381 | 0.93210 |
| 320 | 2.46 | 0.0007772 | 0.063604 | 54.92 | 176.61 | 231.52 | 55.16 | 196.71 | 251.88 | 0.21637 | 0.71369 | 0.93006 |
| 360 | 5.82 | 0.0007841 | 0.056738 | 59.44 | 173.94 | 233.38 | 59.72 | 194.08 | 253.81 | 0.23270 | 0.69566 | 0.92836 |
| 400 | 8.91 | 0.0007907 | 0.051201 | 63.62 | 171.45 | 235.07 | 63.94 | 191.62 | 255.55 | 0.24761 | 0.67929 | 0.92691 |
| 450 | 12.46 | 0.0007985 | 0.045619 | 68.45 | 168.54 | 237.00 | 68.81 | 188.71 | 257.53 | 0.26465 | 0.66069 | 0.92535 |
| 500 | 15.71 | 0.0008059 | 0.041118 | 72.93 | 165.82 | 238.75 | 73.33 | 185.98 | 259.30 | 0.28023 | 0.64377 | 0.92400 |
| 550 | 18.73 | 0.0008130 | 0.037408 | 77.10 | 163.25 | 240.35 | 77.54 | 183.38 | 260.92 | 0.29461 | 0.62821 | 0.92282 |
| 600 | 21.55 | 0.0008199 | 0.034295 | 81.02 | 160.81 | 241.83 | 81.51 | 180.90 | 262.40 | 0.30799 | 0.61378 | 0.92177 |
| 650 | 24.20 | 0.0008266 | 0.031646 | 84.72 | 158.48 | 243.20 | 85.26 | 178.51 | 263.77 | 0.32051 | 0.60030 | 0.92081 |
| 700 | 26.69 | 0.0008331 | 0.029361 | 88.24 | 156.24 | 244.48 | 88.82 | 176.21 | 265.03 | 0.33230 | 0.58763 | 0.91994 |
| 750 | 29.06 | 0.0008395 | 0.027371 | 91.59 | 154.08 | 245.67 | 92.22 | 173.98 | 266.20 | 0.34345 | 0.57567 | 0.91912 |
| 800 | 31.31 | 0.0008458 | 0.025621 | 94.79 | 152.00 | 246.79 | 95.47 | 171.82 | 267.29 | 0.35404 | 0.56431 | 0.91835 |
| 850 | 33.45 | 0.0008520 | 0.024069 | 97.87 | 149.98 | 247.85 | 98.60 | 169.71 | 268.31 | 0.36413 | 0.55349 | 0.91762 |
| 900 | 35.51 | 0.0008580 | 0.022683 | 100.83 | 148.01 | 248.85 | 101.61 | 167.66 | 269.26 | 0.37377 | 0.54315 | 0.91692 |
| 950 | 37.48 | 0.0008641 | 0.021438 | 103.69 | 146.10 | 249.79 | 104.51 | 165.64 | 270.15 | 0.38301 | 0.53323 | 0.91624 |
| 1000 | 39.37 | 0.0008700 | 0.020313 | 106.45 | 144.23 | 250.68 | 107.32 | 163.67 | 270.99 | 0.39189 | 0.52368 | 0.91558 |
| 1200 | 46.29 | 0.0008934 | 0.016715 | 116.70 | 137.11 | 253.81 | 117.77 | 156.10 | 273.87 | 0.42441 | 0.48863 | 0.91303 |
| 1400 | 52.40 | 0.0009166 | 0.014107 | 125.94 | 130.43 | 256.37 | 127.22 | 148.90 | 276.12 | 0.45315 | 0.45734 | 0.91050 |
| 1600 | 57.88 | 0.0009400 | 0.012123 | 134.43 | 124.04 | 258.47 | 135.93 | 141.93 | 277.86 | 0.47911 | 0.42873 | 0.90784 |
| 1800 | 62.87 | 0.0009639 | 0.010559 | 142.33 | 117.83 | 260.17 | 144.07 | 135.11 | 279.17 | 0.50294 | 0.40204 | 0.90498 |
| 2000 | 67.45 | 0.0009886 | 0.009288 | 149.78 | 111.73 | 261.51 | 151.76 | 128.33 | 280.09 | 0.52509 | 0.37675 | 0.90184 |
| 2500 | 77.54 | 0.0010566 | 0.006936 | 166.99 | 96.47 | 263.45 | 169.63 | 111.16 | 280.79 | 0.57531 | 0.31695 | 0.89226 |
| 3000 | 86.16 | 0.0011406 | 0.005275 | 183.04 | 80.22 | 263.26 | 186.46 | 92.63 | 279.09 | 0.62118 | 0.25776 | 0.87894 |

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## Table 2- Superheated vapour Table for R134a

Superheated refrigerant-134a (*Continued*)

| T °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 | v m³/kg | u kJ/kg | h kJ/kg | s kJ/kg · K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P = 0.50 MPa ($T_{sat}$ = 15.71°C) | | | | P = 0.60 MPa ($T_{sat}$ = 21.55°C) | | | | P = 0.70 MPa ($T_{sat}$ = 26.69°C) | | | |
| Sat. | 0.041118 | 238.75 | 259.30 | 0.9240 | 0.034295 | 241.83 | 262.40 | 0.9218 | 0.029361 | 244.48 | 265.03 | 0.9199 |
| 20 | 0.042115 | 242.40 | 263.46 | 0.9383 | | | | | | | | |
| 30 | 0.044338 | 250.84 | 273.01 | 0.9703 | 0.035984 | 249.22 | 270.81 | 0.9499 | 0.029966 | 247.48 | 268.45 | 0.9313 |
| 40 | 0.046456 | 259.26 | 282.48 | 1.0011 | 0.037865 | 257.86 | 280.58 | 0.9816 | 0.031696 | 256.39 | 278.57 | 0.9641 |
| 50 | 0.048499 | 267.72 | 291.96 | 1.0309 | 0.039659 | 266.48 | 290.28 | 1.0121 | 0.033322 | 265.20 | 288.53 | 0.9954 |
| 60 | 0.050485 | 276.25 | 301.50 | 1.0599 | 0.041389 | 275.15 | 299.98 | 1.0417 | 0.034875 | 274.01 | 298.42 | 1.0256 |
| 70 | 0.052427 | 284.89 | 311.10 | 1.0883 | 0.043069 | 283.89 | 309.73 | 1.0705 | 0.036373 | 282.87 | 308.33 | 1.0549 |
| 80 | 0.054331 | 293.64 | 320.80 | 1.1162 | 0.044710 | 292.73 | 319.55 | 1.0987 | 0.037829 | 291.80 | 318.28 | 1.0835 |
| 90 | 0.056205 | 302.51 | 330.61 | 1.1436 | 0.046318 | 301.67 | 329.46 | 1.1264 | 0.039250 | 300.82 | 328.29 | 1.1114 |
| 100 | 0.058053 | 311.50 | 340.53 | 1.1705 | 0.047900 | 310.73 | 339.47 | 1.1536 | 0.040642 | 309.95 | 338.40 | 1.1389 |
| 110 | 0.059880 | 320.63 | 350.57 | 1.1971 | 0.049458 | 319.91 | 349.59 | 1.1803 | 0.042010 | 319.19 | 348.60 | 1.1658 |
| 120 | 0.061687 | 329.89 | 360.73 | 1.2233 | 0.050997 | 329.23 | 359.82 | 1.2067 | 0.043358 | 328.55 | 358.90 | 1.1924 |
| 130 | 0.063479 | 339.29 | 371.03 | 1.2491 | 0.052519 | 338.67 | 370.18 | 1.2327 | 0.044688 | 338.04 | 369.32 | 1.2186 |
| 140 | 0.065256 | 348.83 | 381.46 | 1.2747 | 0.054027 | 348.25 | 380.66 | 1.2584 | 0.046004 | 347.66 | 379.86 | 1.2444 |
| 150 | 0.067021 | 358.51 | 392.02 | 1.2999 | 0.055522 | 357.96 | 391.27 | 1.2838 | 0.047306 | 357.41 | 390.52 | 1.2699 |
| 160 | 0.068775 | 368.33 | 402.72 | 1.3249 | 0.057006 | 367.81 | 402.01 | 1.3088 | 0.048597 | 367.29 | 401.31 | 1.2951 |
| | P = 0.80 MPa ($T_{sat}$ = 31.31°C) | | | | P = 0.90 MPa ($T_{sat}$ = 35.51°C) | | | | P = 1.00 MPa ($T_{sat}$ = 39.37°C) | | | |
| Sat. | 0.025621 | 246.79 | 267.29 | 0.9183 | 0.022683 | 248.85 | 269.26 | 0.9169 | 0.020313 | 250.68 | 270.99 | 0.9156 |
| 40 | 0.027035 | 254.82 | 276.45 | 0.9480 | 0.023375 | 253.13 | 274.17 | 0.9327 | 0.020406 | 251.30 | 271.71 | 0.9179 |
| 50 | 0.028547 | 263.86 | 286.69 | 0.9802 | 0.024809 | 262.44 | 284.77 | 0.9660 | 0.021796 | 260.94 | 282.74 | 0.9525 |
| 60 | 0.029973 | 272.83 | 296.81 | 1.0110 | 0.026146 | 271.60 | 295.13 | 0.9976 | 0.023068 | 270.32 | 293.38 | 0.9850 |
| 70 | 0.031340 | 281.81 | 306.88 | 1.0408 | 0.027413 | 280.72 | 305.39 | 1.0280 | 0.024261 | 279.59 | 303.85 | 1.0160 |
| 80 | 0.032659 | 290.84 | 316.97 | 1.0698 | 0.028630 | 289.86 | 315.63 | 1.0574 | 0.025398 | 288.86 | 314.25 | 1.0458 |
| 90 | 0.033941 | 299.95 | 327.10 | 1.0981 | 0.029806 | 299.06 | 325.89 | 1.0860 | 0.026492 | 298.15 | 324.64 | 1.0748 |
| 100 | 0.035193 | 309.15 | 337.30 | 1.1258 | 0.030951 | 308.34 | 336.19 | 1.1140 | 0.027552 | 307.51 | 335.06 | 1.1031 |
| 110 | 0.036420 | 318.45 | 347.59 | 1.1530 | 0.032068 | 317.70 | 346.56 | 1.1414 | 0.028584 | 316.94 | 345.53 | 1.1308 |
| 120 | 0.037625 | 327.87 | 357.97 | 1.1798 | 0.033164 | 327.18 | 357.02 | 1.1684 | 0.029592 | 326.47 | 356.06 | 1.1580 |
| 130 | 0.038813 | 337.40 | 368.45 | 1.2061 | 0.034241 | 336.76 | 367.58 | 1.1949 | 0.030581 | 336.11 | 366.69 | 1.1846 |
| 140 | 0.039985 | 347.06 | 379.05 | 1.2321 | 0.035302 | 346.46 | 378.23 | 1.2210 | 0.031554 | 345.85 | 377.40 | 1.2109 |
| 150 | 0.041143 | 356.85 | 389.76 | 1.2577 | 0.036349 | 356.28 | 389.00 | 1.2467 | 0.032512 | 355.71 | 388.22 | 1.2368 |
| 160 | 0.042290 | 366.76 | 400.59 | 1.2830 | 0.037384 | 366.23 | 399.88 | 1.2721 | 0.033457 | 365.70 | 399.15 | 1.2623 |
| 170 | 0.043427 | 376.81 | 411.55 | 1.3080 | 0.038408 | 376.31 | 410.88 | 1.2972 | 0.034392 | 375.81 | 410.20 | 1.2875 |
| 180 | 0.044554 | 386.99 | 422.64 | 1.3327 | 0.039423 | 386.52 | 422.00 | 1.3221 | 0.035317 | 386.04 | 421.36 | 1.3124 |
| | P = 1.20 MPa ($T_{sat}$ = 46.29°C) | | | | P = 1.40 MPa ($T_{sat}$ = 52.40°C) | | | | P = 1.60 MPa ($T_{sat}$ = 57.88°C) | | | |
| Sat. | 0.016715 | 253.81 | 273.87 | 0.9130 | 0.014107 | 256.37 | 276.12 | 0.9105 | 0.012123 | 258.47 | 277.86 | 0.9078 |
| 50 | 0.017201 | 257.63 | 278.27 | 0.9267 | | | | | | | | |
| 60 | 0.018404 | 267.56 | 289.64 | 0.9614 | 0.015005 | 264.46 | 285.47 | 0.9389 | 0.012372 | 260.89 | 280.69 | 0.9163 |
| 70 | 0.019502 | 277.21 | 300.61 | 0.9938 | 0.016060 | 274.62 | 297.10 | 0.9733 | 0.013430 | 271.76 | 293.25 | 0.9535 |
| 80 | 0.020529 | 286.75 | 311.39 | 1.0248 | 0.017023 | 284.51 | 308.34 | 1.0056 | 0.014362 | 282.09 | 305.07 | 0.9875 |
| 90 | 0.021506 | 296.26 | 322.07 | 1.0546 | 0.017923 | 294.28 | 319.37 | 1.0364 | 0.015215 | 292.17 | 316.52 | 1.0194 |
| 100 | 0.022442 | 305.80 | 332.73 | 1.0836 | 0.018778 | 304.01 | 330.30 | 1.0661 | 0.016014 | 302.14 | 327.76 | 1.0500 |
| 110 | 0.023348 | 315.38 | 343.40 | 1.1118 | 0.019597 | 313.76 | 341.19 | 1.0949 | 0.016773 | 312.07 | 338.91 | 1.0795 |
| 120 | 0.024228 | 325.03 | 354.11 | 1.1394 | 0.020388 | 323.55 | 352.09 | 1.1230 | 0.017500 | 322.02 | 350.02 | 1.1081 |
| 130 | 0.025086 | 334.77 | 364.88 | 1.1664 | 0.021155 | 333.41 | 363.02 | 1.1504 | 0.018201 | 332.00 | 361.12 | 1.1360 |
| 140 | 0.025927 | 344.61 | 375.72 | 1.1930 | 0.021904 | 343.34 | 374.01 | 1.1773 | 0.018882 | 342.05 | 372.26 | 1.1632 |
| 150 | 0.026753 | 354.56 | 386.66 | 1.2192 | 0.022636 | 353.37 | 385.07 | 1.2038 | 0.019545 | 352.17 | 383.44 | 1.1900 |
| 160 | 0.027566 | 364.61 | 397.69 | 1.2449 | 0.023355 | 363.51 | 396.20 | 1.2298 | 0.020194 | 362.38 | 394.69 | 1.2163 |
| 170 | 0.028367 | 374.78 | 408.82 | 1.2703 | 0.024061 | 373.75 | 407.43 | 1.2554 | 0.020830 | 372.69 | 406.02 | 1.2421 |
| 180 | 0.029158 | 385.08 | 420.07 | 1.2954 | 0.024757 | 384.10 | 418.76 | 1.2807 | 0.021456 | 383.11 | 417.44 | 1.2676 |

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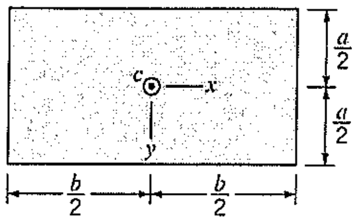
## Table 3: Formulas for second moment of area and centroid



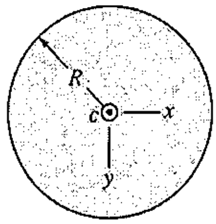

$A = ba$

$I_{xc} = \frac{1}{12} ba^3$

$I_{yc} = \frac{1}{12} ab^3$

$I_{xyc} = 0$

(*a*) Rectangle

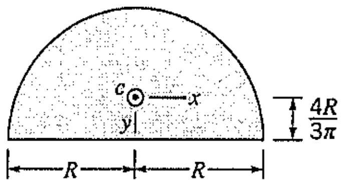



$A = \pi R^2$

$I_{xc} = I_{yc} = \frac{\pi R^4}{4}$

$I_{xyc} = 0$

(*b*) Circle



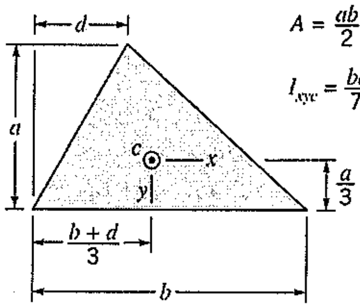

$A = \frac{\pi R^2}{2}$

$I_{xc} = 0.1098R^4$

$I_{yc} = 0.3927R^4$

$I_{xyc} = 0$

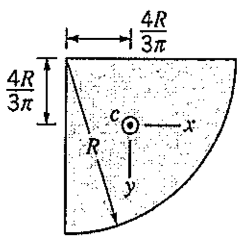
(*c*) Semicircle




$A = \frac{ab}{2}$  $I_{xc} = \frac{ba^3}{36}$

$I_{xyc} = \frac{ba^2}{72}(b - 2d)$

(*d*) Triangle




$A = \frac{\pi R^2}{4}$

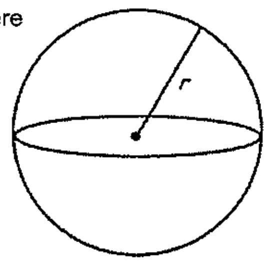
$I_{xc} = I_{yc} = 0.05488R^4$

$I_{xyc} = -0.01647R^4$

(*e*) Quarter circle

## Table 4: Formula for volume

sphere




Volume $V = \frac{4}{3}\pi r^3$

**END OF PAPER**

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MA2003 17/18 sem 1

1. a) At $P = 320kPa$, $x = 0.80$

$T = T_{sat@320kPa} = 2.46°C$

$v = v_{f@320kPa} + 0.80\, v_{fg@320kPa}$

$= 0.0007772 + 0.80\,(0.063604 - 0.0007772)$

$= 0.051039\ m^3/kg$

$m = \frac{V}{v} = \frac{3\times10^{-3}}{0.051039} = 0.0588kg$

b) At Final State, $P = 500kPa$

At 320kPa, $v_g = 0.063604\ m^3/kg$

$\Delta x$ when subsystem A is saturated vapour

$= \frac{0.063604 \times 0.058779 - 3\times10^{-3}}{40\times10^{-2}\times10^{-2}}$

$= 0.18464\ m$

$\Delta F = k\Delta x = \Delta P A$

$\Delta x = \frac{A}{k}\Delta P$

$\Delta x$ when subsystem A changes from saturated vapour to final state

$= \frac{40\times10^{-2}\times10^{-2}}{7.5}(500-320)$

$= 0.096m$

Total distance travelled by piston from initial to final state

$= 0.18464 + 0.096$

$= 0.281\ m$

c) $v_{final} = 0.063604 + \frac{0.096\times40\times10^{-2}\times10^{-2}}{0.058779} = 0.070137\ m^3/kg$

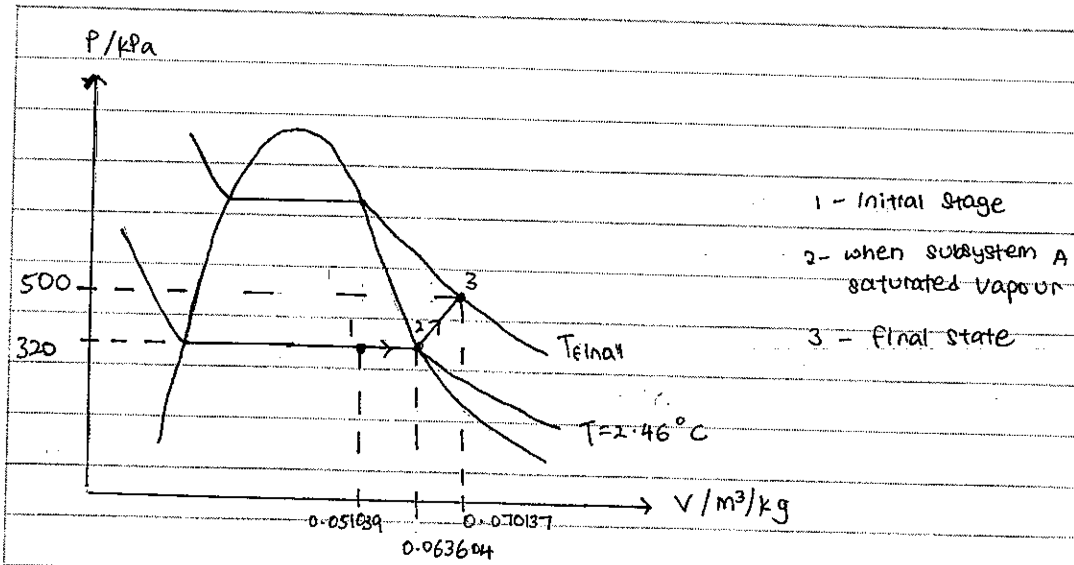
At 500kPa, $v_{final} > v_{g@500kPa}$ => Superheated vapour

Work done by subsystem A

$= 320 \times 0.058779\,(0.063604 - 0.051039) + \frac{320+500}{2} \times 0.058779\,(0.070137 - 0.063604)$

$= 0.394kJ$

(P-V diagram next page)




d) $Q - W = m(u_{final} - u_{initial})$

$u_{initial} = u_{f@320kPa} + 0.80\,u_{fg@320kPa}$

$= 54.92 + 0.80 \times 176.61$

$= 196.208\ kJ/kg$

At 500kPa, $V_{final} = 0.070137\ m^3/kg > V_{g@500kPa}$ => superheated vapour

$T = \frac{0.070137 - 0.068775}{0.068775 - 0.067021}(160-150) + 160 = 167.77°C$

$u_{final} = \frac{0.070137 - 0.068775}{0.068775 - 0.067021}(368.33 - 358.51) + 368.33 = 375.955\ kJ/kg$

$Q - 0.394 = 0.058779(375.955 - 196.208)$

$Q = 10.96\ kJ$

e) $PV = mRT$

$(100 + 101.325) \times V = 0.05 \times 0.287 \times (33 + 273)$

$V = 0.021811\ m^3$

$P_1V_1^{1.4} = P_2V_2^{1.4}$ under adiabatic conditions

$(100+101.325)(0.021811)^{1.4} = P_2(0.021811 - 0.281 \times 40 \times 10^{-4})^{1.4}$

$P_2 = 216.78kPa$ absolute => Gauge $P_2 = 115.46kPa$

$T = \frac{PV}{Rm} = \frac{216.78 \times (0.021811 - 0.281 \times 40 \times 10^{-4})}{0.287 \times 0.05}$

$= 312.54K = 39.54°C$

2. a) $\sum \dot{m}_{in} = \sum \dot{m}_{out} \Rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m} = 0.3 kg/s$

At 240 kPa, R134a is in saturated vapour state

$h_1 = h_{g@240kPa} = 247.28 kJ/kg$

At P=1600kPa, T=50°C > $T_{sat@1600kPa}$ ⇒ Superheated vapour

$h_2 = 280.69 kJ/kg$

$\dot{Q}_{in} - \dot{Q}_{out} + \dot{W}_{in} - \dot{W}_{out} = \dot{m}(h_2 - h_1 + \frac{V_2^2}{2} - \frac{V_1^2}{2} + g(z_2 - z_1))$

$-\dot{Q}_{out} + \dot{W}_{in} = \dot{m}(h_2 - h_1)$

$-3 + \dot{W}_{in} = 0.3(280.69 - 247.28)$

$\dot{W}_{in} = 13.023 kW$

b) At P=1600kPa, $h_3 = h_{f@1600kPa} = 135.93 kJ/kg$

$\dot{m}_2 = \dot{m}_3 = \dot{m} = 0.3 kg/s$

$\dot{W} = 0$

$\dot{Q} = \dot{m}(h_3 - h_2)$ assuming KE and PE changes are neglected

$= 0.3(135.93 - 280.69)$

$= -43.428 kW$

Heat loss from heat exchanger is 43.428kW

c) $\dot{W} = 0$, $\dot{Q} = 0$

$\Delta KE = 0$, $\Delta PE = 0$

$\therefore h_3 = h_4 = 135.93 kJ/kg$

At 240kPa, $h_4 = h_{f@240kPa} + x\, h_{fg@240kPa}$

$135.93 = 44.66 + x(202.62)$

$x = 0.450$

d) $\dot{m} = 0.3 kg/s$

Mass flow rate of vapour $= x\dot{m} = 0.450 \times 0.3 = 0.135 kg/s$

Mass flow rate of liquid $= 0.3 - 0.135 = 0.165 kg/s$

e) Heat loss from heat exchanger = heat gained by water = 43.428kW

$\dot{Q} = \dot{m}c(T_6 - T_5)$

$43.428 = \dot{m} \times 4.18 \times (35 - 25)$

$\dot{m} = 1.04 kg/s$

3. a) (i) Initial absolute pressure = $P_0 + P_{atm}$

Initial volume $V_i = \left[LH - \frac{1}{2}\pi\left(\frac{H}{4}\right)^2\right]\omega$

Final volume $V_f = \left[LH - \frac{1}{2}\pi\left(\frac{H}{4}\right)^2 - Lh\right]\omega$

At constant temperature, $P_i V_i = P_f V_f$

$$(P_0 + P_{atm})\left(LH - \frac{\pi H^2}{32}\right)\omega = P_f\left(LH - \frac{\pi H^2}{32} - Lh\right)\omega$$

$$P_f = (P_0 + P_{atm})\frac{LH - \frac{\pi H^2}{32}}{LH - Lh - \frac{\pi H^2}{32}}$$

$$P_{air} = (P_0 + P_{atm})\frac{LH - \frac{\pi H^2}{32}}{LH - Lh - \frac{\pi H^2}{32}} - P_{atm}$$

(ii) $F_{H,\omega,left} = \rho g h_c A = \rho g\left(\frac{H-h}{2}\right)\left(\frac{H-h}{2}\right)\omega$

$= \rho g\left(\frac{H-h}{2}\right)^2\omega$

$F_{H,air,right} = P_{air} H\omega$

$F_{H,\omega,right} = \rho g h_c A = \rho g\left(\frac{h}{2}\right)\left(\frac{h}{2}\right)\omega$

$= \frac{\rho g h^2\omega}{4}$

$$\overset{+}{\rightarrow}\ F_H = \frac{\rho g(H-h)^2\omega}{4} - P_{air}H\omega - \frac{\rho g h^2\omega}{4}$$

(iii) $y_{\omega,left}F_{\omega,left} + y_{air}F_{air} + y_{\omega,right}F_{\omega,right} = y_H F_H$

$$\frac{\rho g(H-h)^2\omega}{4}\left(\frac{H-h}{3}\right) - P_{air}H\omega\left(\frac{H}{2}\right) - \frac{\rho g h^2\omega}{4}\left(\frac{h}{3}\right) = y_H F_H$$

$$\frac{\rho g(H-h)^3\omega}{12} - \frac{P_{air}H^2\omega}{2} - \frac{\rho g h^3\omega}{12} = y_H F_H$$

$$y_H = \frac{\frac{1}{12}\left[\rho g(H-h)^3\omega - 6P_{air}H^2\omega - \rho g h^3\omega\right]}{\frac{1}{4}\left[\rho g(H-h)^2\omega - 4P_{air}H\omega - \rho g h^2\omega\right]}$$

$$= \frac{\rho g(H-h)^3 - 6P_{air}H^2 - \rho g h^3}{3\rho g(H-h)^2 - 12P_{air}H - 3\rho g h^2}$$

(iv) $F_{V,air} = 0$

$F_{V,\omega,left} = 0$

$F_{V,\omega,right} = 0$ assuming $h \le \frac{H}{2}$

$F_V = 0$

(v) $T = 0$

$$\rho g\left(\frac{H-h_{eq}}{2}\right)^2\omega\left(H - \frac{H-h}{3}\right) = P_{air}H\omega\left(\frac{H}{2}\right) + \frac{\rho g h_{eq}^2\omega}{4}\left(H - \frac{h_{eq}}{3}\right)$$

$$\rho g\left(\frac{H-h_{eq}}{2}\right)^2\left(\frac{2H+h}{3}\right) = \frac{P_{air}H^2}{2} + \frac{\rho g h_{eq}^2}{4}\left(H - \frac{h_{eq}}{3}\right)$$

b) (i) $F_w = F_B$

$\rho_B g \forall_B = \rho_w g \forall_{displaced}$

$300(0.2\times0.1+0.1\times0.15)(2) = 1000(0.1y)(2)$

$y = 0.105\,m$

(ii) $\overline{GM} = \frac{I_o}{\forall} - \overline{CG}$

Taking reference from bottom surface,

$OC = \frac{0.105}{2} = 0.0525\,m$


$y_1A_1 + y_2A_2 = OG\,A_{total}$

$\frac{0.15}{2}\times0.10\times0.15 + 0.2\times0.1\times0.2 = OG\,(0.10\times0.15+0.1\times0.2)$

$OG = 0.14643\,m$

$CG = OG - OC = 0.09393\,m$

$\overline{GM} = \frac{I_o}{\forall_{displaced}} - \overline{CG}$

$= \frac{\frac{1}{12}\times2\times0.1^3}{0.1\times0.105\times2}$ ~~$-0.09393$~~

$= -0.086 < 0$

The configuration is not stable

c) $dp = \frac{\partial p}{\partial r}dr + \frac{\partial p}{\partial z}dz$

$\frac{\partial p}{\partial r} = \rho r\omega^2$, $\frac{\partial p}{\partial z} = -\rho(g+a_z)$

$a_z = 0 \Rightarrow \frac{\partial p}{\partial z} = -\rho g$

$dp = \rho r\omega^2 dr - \rho g\,dz$

$\int dp = \int \rho r\omega^2 dr - \int \rho g\,dz$

$P_A - P_0 = \frac{\rho r\omega^2 r_A^2}{2} - \frac{\rho r\omega^2 r_0^2}{2} - \rho g(z_A - z_0)$

Taking O as reference point,

(gauge) $P_0 = 0$, $r_0 = 0$, $z_0 = 0$

$P_A = \frac{\rho\omega^2 r_A^2}{2} - \rho g z_A$

$r_A = L-a$, $z_A = -H$

$\therefore P_A = \frac{\rho\omega^2(L-a)^2}{2} + \rho g H$

4\. a)(i) Steady flow $\Rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}_3$

Since density is constant, $Q_1 = Q_2 = Q_3$

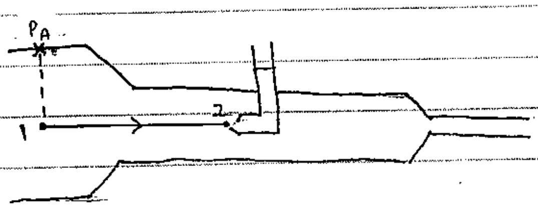
$V_1 \pi \left(\frac{D_1^2}{4}\right) = V_2 \pi \left(\frac{D_2^2}{4}\right)$

$V_2 = \left(\frac{D_1}{D_2}\right)^2 V_1$

$V_1 \pi \left(\frac{D_1^2}{4}\right) = V_3 \pi \left(\frac{D_3^2}{4}\right)$

$V_3 = \left(\frac{D_1}{D_3}\right)^2 V_1$

(ii)




$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$

$z_1 = z_2$ , $V_2 = 0$

$P_1 = P_A + \rho g\left(\frac{D_1}{2}\right)$ , $P_2 = \rho g h_2$

$\frac{P_A}{\rho g} + \frac{D_1}{2} + \frac{V_1^2}{2g} = h_2$

$\frac{V_1^2}{2g} = h_2 - \frac{P_A}{\rho g} - \frac{D_1}{2}$

~~$V_1 = \sqrt{2gh_2 - \frac{2P_A}{\rho} - gD_1}$~~

$Q = V_1 \pi \left(\frac{D_1^2}{4}\right) = \frac{\pi D_1^2}{4}\sqrt{2gh_2 - \frac{2P_A}{\rho} - gD_1}$

b) (i) $\forall = \forall_f \left[1 - e^{(-t/\tau)}\right]$

When $\forall = 0.5\forall_f$,

$0.5\forall_f = \forall_f \left[1 - e^{(-t/\tau)}\right]$

$1 - e^{(-t/\tau)} = 0.5$

$e^{-t/\tau} = 0.5$

$-\frac{t}{\tau} = \ln 0.5$

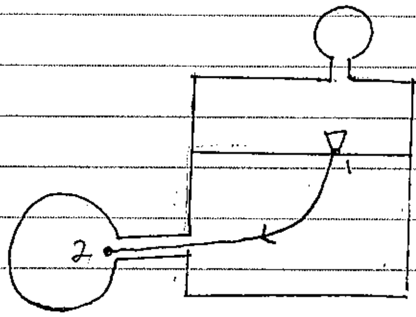
$t = -\tau \ln 0.5$

(ii) $\forall = \forall_f \left[1 - e^{(-t/\tau)}\right] = \forall_f - \forall_f e^{(-t/\tau)}$

$\frac{d\forall}{dt} = -\forall_f e^{(-t/\tau)}\left(-\frac{1}{\tau}\right) = \frac{\forall_f}{\tau} e^{(-t/\tau)}$

$\frac{dM}{dt} = \frac{\rho_w \forall_f}{\tau} e^{-t/\tau}$

(iii) $\forall_f = \frac{\pi D^2}{4} h$




$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

$$\frac{P_1}{\rho} + \frac{V_1^2}{2} + gz = \frac{P_2}{\rho} + \frac{V_2^2}{2} + gz_2$$

Since $g = 0$,

$$\frac{P_1}{\rho} + \frac{V_1^2}{2} = \frac{P_2}{\rho} + \frac{V_2^2}{2}$$

$V_1 = 0,\ V_2 = 0 \Rightarrow P_1 = P_2 = P_b = C\forall_f$

Initial $P_{air} = P_o$

Initial $\forall_{air} = \frac{\pi D^2 H_2}{4}$

Final $P_{air} = P_b = C\forall_f$

Final $\forall_{air} = \frac{\pi D^2}{4}(H_2 + h)$

Assuming temperature is constant,

$$P_o \forall_o = P_f \forall_f$$

$$\frac{\pi D^2 H_2 P_o}{4} = \frac{C\forall_f \pi D^2}{4}(H_2 + h)$$

$$\forall_f = \frac{H_2 P_o}{C(H_2 + h)}$$

$$\frac{\pi D^2}{4} h = \frac{H_2 P_o}{C(H_2 + h)}$$

$$h(H_2 + h) = \frac{4 H_2 P_o}{\pi D^2 C}$$

$$h^2 + H_2 h - \frac{4 H_2 P_o}{\pi D^2 C} = 0$$

$$h = \frac{-H_2 \pm \sqrt{H_2^2 + \frac{16 H_2 P_o}{\pi D^2 C}}}{2}$$

**DISCLAIMER:** *The solutions are done by students who scored A or above in this subject. MAE Club and Campus supplies are not liable or responsible for any errors in the contents of these solutions. Students are advised to take the solutions as a guide rather than absolute answers to exam paper.*

***Should there be any mistake identified, please proceed to the Facebook link encoded in the QR code to feedback or submit correct answers. The link is: http://bit.ly/2lW2C32***

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# NANYANG TECHNOLOGICAL UNIVERSITY

## SEMESTER 2 EXAMINATION 2017-2018

## MA2003 – INTRODUCTION TO THERMO-FLUIDS

April/May 2018 Time allowed: 2½ hours

**INSTRUCTIONS**

1. This paper contains **FOUR (4)** questions and comprises **TWELVE (12)** pages.
2. Answer **ALL FOUR** questions.
3. All questions carry equal marks.
4. This is a **CLOSED-BOOK** examination.
5. Relevant Thermodynamics tables and formulas for second moment of inertia are provided in the Appendix (pages 6 to 12).

---

1. 2 kg of air (assumed to be an ideal gas with R = 0.287 kJ/kg·K and constant $c_v$ of 0.718 kJ/kg·K) is contained in a piston-cylinder-spring-stopper configuration as shown in Figure 1. The air is initially at a pressure of 100 kPa and temperature of 300 K. Heat is slowly added to the air and, under the compressive force of the spring, its pressure increases to 200 kPa when the piston just touches the stopper, where its volume will be 1.5 times the initial volume. Heat addition is continued until the final pressure of the air is 300 kPa.

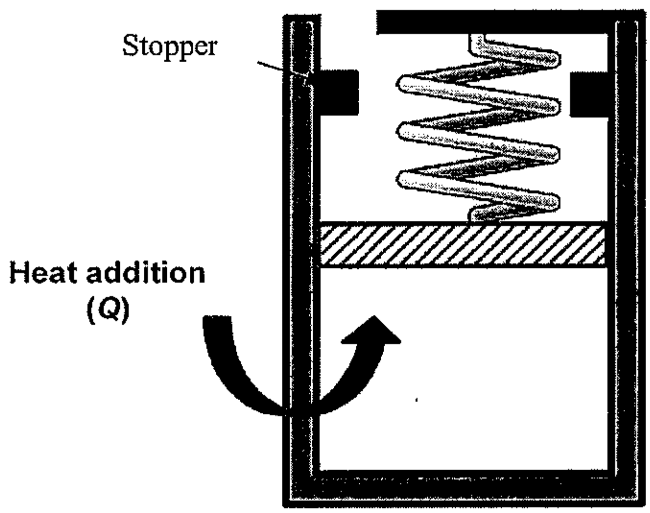


Figure 1

Note: Question 1 continues on page 2.



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(a) Draw a P-V diagram to show clearly the processes that the air undergoes from initial state, to intermediate state (when the piston first touches the stopper), and then to the final state.

(5 marks)

(b) What is the intermediate and final temperature of the air?

(4 marks)

(c) What is the total heat added to reach the final state of the air?

(6 marks)

(d) If the same amount of heat is added to 2 kg of water in a separate, simple piston-cylinder device (i.e. no spring, no stopper) at 100 kPa and 30°C, what will be the final pressure, temperature and phase of the water? What will be the work done?

(7 marks)

(e) Without performing any calculations, describe what would happen if the same amount of heat is added to 2 kg of R-134a in a separate, simple piston-cylinder device at 100 kPa and 30°C. Include description of the expected initial and final phase of the R-134a.

(3 marks)

2. The steam turbine shown in Figure 2 is used for co-generation of power and heat. Steam enters the turbine at 20 bar and 500°C, with a flow rate of 20 kg/s. Power is generated as the steam flows through the blades of the turbine. In the original design, half of the steam flow is extracted for heating purposes at 10 bar and 300°C. The rest exits the turbine at 50°C and quality of 80%. Change in potential and kinetic energy may be neglected.

(a) Draw a P-v diagram indicating clearly the three known states of the steam as it enters and exits the turbine.

(5 marks)

(b) Assuming no heat losses within the turbine, what is the power output of the turbine?

(10 marks)

(c) If the extracted steam is used in a heat exchanger to provide heating after which it becomes saturated liquid water at 10 bar, how much heat does the extracted steam provide? What is the ratio of power to heat output of the cogeneration plant?

(5 marks)

(d) If the same amount of steam is extracted at a higher pressure and temperature of 16 bar and 400°C, and turbine exit condition remains unchanged, what will be the new power to heat output ratio of the cogeneration turbine?

(5 marks)

Note: Figure 2 appears on page 3.

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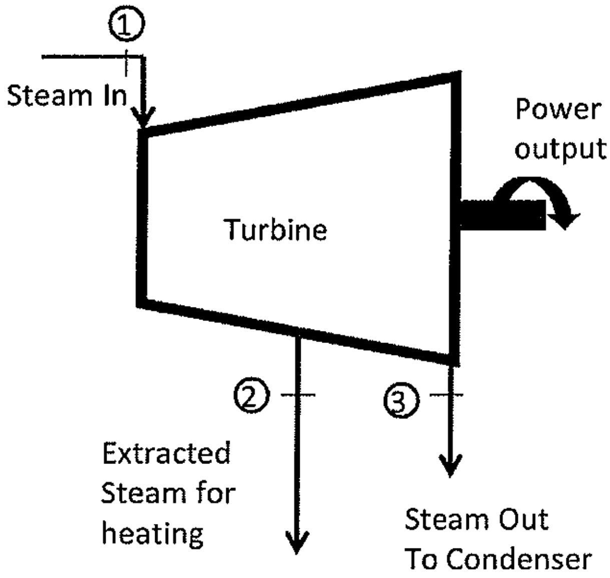


Figure 2

3 (a) Water flows steadily with negligible viscous effects through the pipe shown in Figure 3. It is known that the 5-cm diameter section of thin-walled tubing will collapse if the pressure within it becomes 50 kPa below atmospheric pressure. Determine the maximum value that $h$ can have without causing collapse of the tubing.

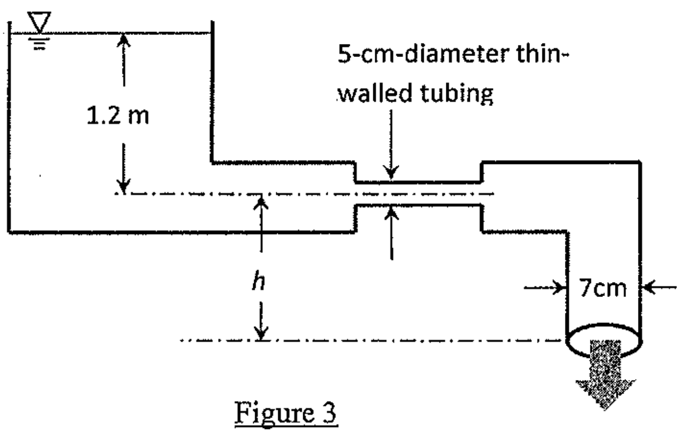


Figure 3

(10 marks)

(b) A 40-ton, 5-m-diameter hemispherical dome on a level surface is filled with water, as shown in Figure 4. Engineer Joe claims that he can lift this dome by attaching a long tube to the top and filling it with water. Determine the required height of water in the tube to lift the dome, if his claim works. Assume the total weight of the tube and the water in the tube is negligibly small compared with the weight of the dome. Hints: 1 ton = 1000 kg. The volume of a sphere is $\frac{4}{3}\pi r^3$

Note: Figure 4 appears on page 4.



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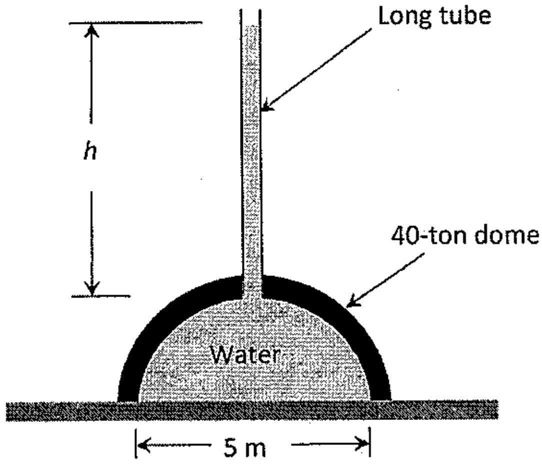


Figure 4

(15 marks)

4 (a) Consider a water tank as shown in Figure 5. The width (the direction into the paper) of the tank is 5 m. Initially the tank is half full. Then the circular pipe on the top starts to feed in the water with a volume flow rate of 15 $m^3/s$. At the same time, the tank starts to discharge the water from the bottom with a trapezoid-shaped velocity distribution shown in the figure. The maximum velocity around the central region of the tank is $v_{max} = 0.3\ m/s$. The leaking is estimated to be 0.5 kg/s. Is the water inside the tank increasing or decreasing? If it is increasing, how long will the tank get filled; and if it is decreasing, how long will the tank become empty?

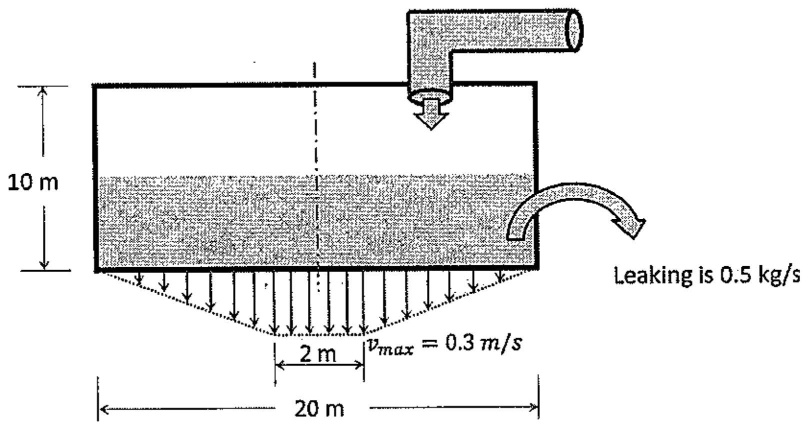


Figure 5

(15 marks)

Note: Question 4 continues on page 5.

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(b) A container full of a special liquid is to be transported by a cargo ship. There is a small vent at the upper-left corner of the container to expose the liquid to the atmosphere but the liquid remains trapped in the container. The vapor pressure of the liquid is 30 kPa. What is the horizontal acceleration (both direction and magnitude) that will cause the liquid to vaporize inside the container? The density of the fluid is $1.43\times10^3$ kg/m$^3$. The atmospheric pressure is 101.3 kPa.

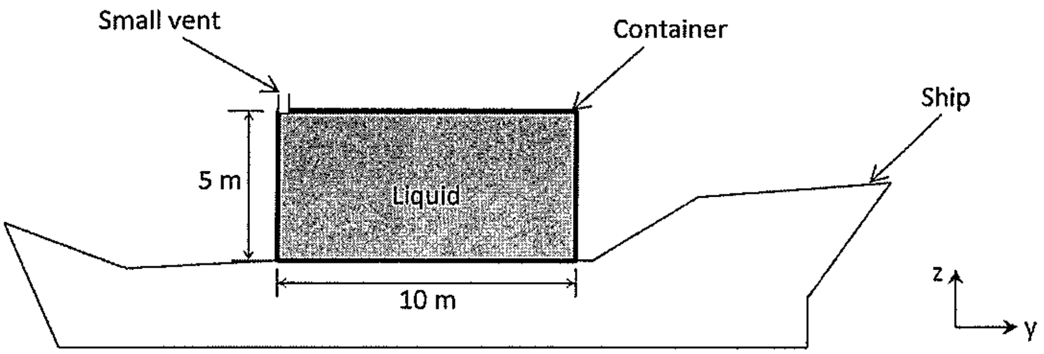


Figure 6

(10 marks)



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# APPENDIX

## Table 1: Saturated Water – Temperature Table

Saturated water—Temperature table

| | | Specific volume, m³/kg | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg · K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp., $T$ °C | Sat. press., $P_{sat}$ kPa | 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 | 0.6117 | 0.001000 | 206.00 | 0.000 | 2374.9 | 2374.9 | 0.001 | 2500.9 | 2500.9 | 0.0000 | 9.1556 | 9.1556 |
| 5 | 0.8725 | 0.001000 | 147.03 | 21.019 | 2360.8 | 2381.8 | 21.020 | 2489.1 | 2510.1 | 0.0763 | 8.9487 | 9.0249 |
| 10 | 1.2281 | 0.001000 | 106.32 | 42.020 | 2346.6 | 2388.7 | 42.022 | 2477.2 | 2519.2 | 0.1511 | 8.7488 | 8.8999 |
| 15 | 1.7057 | 0.001001 | 77.885 | 62.980 | 2332.5 | 2395.5 | 62.982 | 2465.4 | 2528.3 | 0.2245 | 8.5559 | 8.7803 |
| 20 | 2.3392 | 0.001002 | 57.762 | 83.913 | 2318.4 | 2402.3 | 83.915 | 2453.5 | 2537.4 | 0.2965 | 8.3696 | 8.6661 |
| 25 | 3.1698 | 0.001003 | 43.340 | 104.83 | 2304.3 | 2409.1 | 104.83 | 2441.7 | 2546.5 | 0.3672 | 8.1895 | 8.5567 |
| 30 | 4.2469 | 0.001004 | 32.879 | 125.73 | 2290.2 | 2415.9 | 125.74 | 2429.8 | 2555.6 | 0.4368 | 8.0152 | 8.4520 |
| 35 | 5.6291 | 0.001006 | 25.205 | 146.63 | 2276.0 | 2422.7 | 146.64 | 2417.9 | 2564.6 | 0.5051 | 7.8466 | 8.3517 |
| 40 | 7.3851 | 0.001008 | 19.515 | 167.53 | 2261.9 | 2429.4 | 167.53 | 2406.0 | 2573.5 | 0.5724 | 7.6832 | 8.2556 |
| 45 | 9.5953 | 0.001010 | 15.251 | 188.43 | 2247.7 | 2436.1 | 188.44 | 2394.0 | 2582.4 | 0.6386 | 7.5247 | 8.1633 |
| 50 | 12.352 | 0.001012 | 12.026 | 209.33 | 2233.4 | 2442.7 | 209.34 | 2382.0 | 2591.3 | 0.7038 | 7.3710 | 8.0748 |
| 55 | 15.763 | 0.001015 | 9.5639 | 230.24 | 2219.1 | 2449.3 | 230.26 | 2369.8 | 2600.1 | 0.7680 | 7.2218 | 7.9898 |
| 60 | 19.947 | 0.001017 | 7.6670 | 251.16 | 2204.7 | 2455.9 | 251.18 | 2357.7 | 2608.8 | 0.8313 | 7.0769 | 7.9082 |
| 65 | 25.043 | 0.001020 | 6.1935 | 272.09 | 2190.3 | 2462.4 | 272.12 | 2345.4 | 2617.5 | 0.8937 | 6.9360 | 7.8296 |
| 70 | 31.202 | 0.001023 | 5.0396 | 293.04 | 2175.8 | 2468.9 | 293.07 | 2333.0 | 2626.1 | 0.9551 | 6.7989 | 7.7540 |
| 75 | 38.597 | 0.001026 | 4.1291 | 313.99 | 2161.3 | 2475.3 | 314.03 | 2320.6 | 2634.6 | 1.0158 | 6.6655 | 7.6812 |
| 80 | 47.416 | 0.001029 | 3.4053 | 334.97 | 2146.6 | 2481.6 | 335.02 | 2308.0 | 2643.0 | 1.0756 | 6.5355 | 7.6111 |
| 85 | 57.868 | 0.001032 | 2.8261 | 355.96 | 2131.9 | 2487.8 | 356.02 | 2295.3 | 2651.4 | 1.1346 | 6.4089 | 7.5435 |
| 90 | 70.183 | 0.001036 | 2.3593 | 376.97 | 2117.0 | 2494.0 | 377.04 | 2282.5 | 2659.6 | 1.1929 | 6.2853 | 7.4782 |
| 95 | 84.609 | 0.001040 | 1.9808 | 398.00 | 2102.0 | 2500.1 | 398.09 | 2269.6 | 2667.6 | 1.2504 | 6.1647 | 7.4151 |
| 100 | 101.42 | 0.001043 | 1.6720 | 419.06 | 2087.0 | 2506.0 | 419.17 | 2256.4 | 2675.6 | 1.3072 | 6.0470 | 7.3542 |
| 105 | 120.90 | 0.001047 | 1.4186 | 440.15 | 2071.8 | 2511.9 | 440.28 | 2243.1 | 2683.4 | 1.3634 | 5.9319 | 7.2952 |
| 110 | 143.38 | 0.001052 | 1.2094 | 461.27 | 2056.4 | 2517.7 | 461.42 | 2229.7 | 2691.1 | 1.4188 | 5.8193 | 7.2382 |
| 115 | 169.18 | 0.001056 | 1.0360 | 482.42 | 2040.9 | 2523.3 | 482.59 | 2216.0 | 2698.6 | 1.4737 | 5.7092 | 7.1829 |
| 120 | 198.67 | 0.001060 | 0.89133 | 503.60 | 2025.3 | 2528.9 | 503.81 | 2202.1 | 2706.0 | 1.5279 | 5.6013 | 7.1292 |
| 125 | 232.23 | 0.001065 | 0.77012 | 524.83 | 2009.5 | 2534.3 | 525.07 | 2188.1 | 2713.1 | 1.5816 | 5.4956 | 7.0771 |
| 130 | 270.28 | 0.001070 | 0.66808 | 546.10 | 1993.4 | 2539.5 | 546.38 | 2173.7 | 2720.1 | 1.6346 | 5.3919 | 7.0265 |
| 135 | 313.22 | 0.001075 | 0.58179 | 567.41 | 1977.3 | 2544.7 | 567.75 | 2159.1 | 2726.9 | 1.6872 | 5.2901 | 6.9773 |
| 140 | 361.53 | 0.001080 | 0.50850 | 588.77 | 1960.9 | 2549.6 | 589.16 | 2144.3 | 2733.5 | 1.7392 | 5.1901 | 6.9294 |
| 145 | 415.68 | 0.001085 | 0.44600 | 610.19 | 1944.2 | 2554.4 | 610.64 | 2129.2 | 2739.8 | 1.7908 | 5.0919 | 6.8827 |
| 150 | 476.16 | 0.001091 | 0.39248 | 631.66 | 1927.4 | 2559.1 | 632.18 | 2113.8 | 2745.9 | 1.8418 | 4.9953 | 6.8371 |
| 155 | 543.49 | 0.001096 | 0.34648 | 653.19 | 1910.3 | 2563.5 | 653.79 | 2098.0 | 2751.8 | 1.8924 | 4.9002 | 6.7927 |
| 160 | 618.23 | 0.001102 | 0.30680 | 674.79 | 1893.0 | 2567.8 | 675.47 | 2082.0 | 2757.5 | 1.9426 | 4.8066 | 6.7492 |
| 165 | 700.93 | 0.001108 | 0.27244 | 696.46 | 1875.4 | 2571.9 | 697.24 | 2065.6 | 2762.8 | 1.9923 | 4.7143 | 6.7067 |
| 170 | 792.18 | 0.001114 | 0.24260 | 718.20 | 1857.5 | 2575.7 | 719.08 | 2048.8 | 2767.9 | 2.0417 | 4.6233 | 6.6650 |
| 175 | 892.60 | 0.001121 | 0.21659 | 740.02 | 1839.4 | 2579.4 | 741.02 | 2031.7 | 2772.7 | 2.0906 | 4.5335 | 6.6242 |
| 180 | 1002.8 | 0.001127 | 0.19384 | 761.92 | 1820.9 | 2582.8 | 763.05 | 2014.2 | 2777.2 | 2.1392 | 4.4448 | 6.5841 |
| 185 | 1123.5 | 0.001134 | 0.17390 | 783.91 | 1802.1 | 2586.0 | 785.19 | 1996.2 | 2781.4 | 2.1875 | 4.3572 | 6.5447 |
| 190 | 1255.2 | 0.001141 | 0.15636 | 806.00 | 1783.0 | 2589.0 | 807.43 | 1977.9 | 2785.3 | 2.2355 | 4.2705 | 6.5059 |
| 195 | 1398.8 | 0.001149 | 0.14089 | 828.18 | 1763.6 | 2591.7 | 829.78 | 1959.0 | 2788.8 | 2.2831 | 4.1847 | 6.4678 |
| 200 | 1554.9 | 0.001157 | 0.12721 | 850.46 | 1743.7 | 2594.2 | 852.26 | 1939.8 | 2792.0 | 2.3305 | 4.0997 | 6.4302 |

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Saturated water—Temperature table (*Continued*)

| | | *Specific volume,* $m^3/kg$ | | *Internal energy,* kJ/kg | | | *Enthalpy,* kJ/kg | | | *Entropy,* kJ/kg · K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp., $T$ °C | Sat. press., $P_{sat}$ kPa | 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, $s_g$ |
| 205 | 1724.3 | 0.001164 | 0.11508 | 872.86 | 1723.5 | 2596.4 | 874.87 | 1920.0 | 2794.8 | 2.3776 | 4.0154 | 6.3930 |
| 210 | 1907.7 | 0.001173 | 0.10429 | 895.38 | 1702.9 | 2598.3 | 897.61 | 1899.7 | 2797.3 | 2.4245 | 3.9318 | 6.3563 |
| 215 | 2105.9 | 0.001181 | 0.094680 | 918.02 | 1681.9 | 2599.9 | 920.50 | 1878.8 | 2799.3 | 2.4712 | 3.8489 | 6.3200 |
| 220 | 2319.6 | 0.001190 | 0.086094 | 940.79 | 1660.5 | 2601.3 | 943.55 | 1857.4 | 2801.0 | 2.5176 | 3.7664 | 6.2840 |
| 225 | 2549.7 | 0.001199 | 0.078405 | 963.70 | 1638.6 | 2602.3 | 966.76 | 1835.4 | 2802.2 | 2.5639 | 3.6844 | 6.2483 |
| 230 | 2797.1 | 0.001209 | 0.071505 | 986.76 | 1616.1 | 2602.9 | 990.14 | 1812.8 | 2802.9 | 2.6100 | 3.6028 | 6.2128 |
| 235 | 3062.6 | 0.001219 | 0.065300 | 1010.0 | 1593.2 | 2603.2 | 1013.7 | 1789.5 | 2803.2 | 2.6560 | 3.5216 | 6.1775 |
| 240 | 3347.0 | 0.001229 | 0.059707 | 1033.4 | 1569.8 | 2603.1 | 1037.5 | 1765.5 | 2803.0 | 2.7018 | 3.4405 | 6.1424 |
| 245 | 3651.2 | 0.001240 | 0.054656 | 1056.9 | 1545.7 | 2602.7 | 1061.5 | 1740.8 | 2802.2 | 2.7476 | 3.3596 | 6.1072 |
| 250 | 3976.2 | 0.001252 | 0.050085 | 1080.7 | 1521.1 | 2601.8 | 1085.7 | 1715.3 | 2801.0 | 2.7933 | 3.2788 | 6.0721 |
| 255 | 4322.9 | 0.001263 | 0.045941 | 1104.7 | 1495.8 | 2600.5 | 1110.1 | 1689.0 | 2799.1 | 2.8390 | 3.1979 | 6.0369 |
| 260 | 4692.3 | 0.001276 | 0.042175 | 1128.8 | 1469.9 | 2598.7 | 1134.8 | 1661.8 | 2796.6 | 2.8847 | 3.1169 | 6.0017 |
| 265 | 5085.3 | 0.001289 | 0.038748 | 1153.3 | 1443.2 | 2596.5 | 1159.8 | 1633.7 | 2793.5 | 2.9304 | 3.0358 | 5.9662 |
| 270 | 5503.0 | 0.001303 | 0.035622 | 1177.9 | 1415.7 | 2593.7 | 1185.1 | 1604.6 | 2789.7 | 2.9762 | 2.9542 | 5.9305 |
| 275 | 5946.4 | 0.001317 | 0.032767 | 1202.9 | 1387.4 | 2590.3 | 1210.7 | 1574.5 | 2785.2 | 3.0221 | 2.8723 | 5.8944 |
| 280 | 6416.6 | 0.001333 | 0.030153 | 1228.2 | 1358.2 | 2586.4 | 1236.7 | 1543.2 | 2779.9 | 3.0681 | 2.7898 | 5.8579 |
| 285 | 6914.6 | 0.001349 | 0.027756 | 1253.7 | 1328.1 | 2581.8 | 1263.1 | 1510.7 | 2773.7 | 3.1144 | 2.7066 | 5.8210 |
| 290 | 7441.8 | 0.001366 | 0.025554 | 1279.7 | 1296.9 | 2576.5 | 1289.8 | 1476.9 | 2766.7 | 3.1608 | 2.6225 | 5.7834 |
| 295 | 7999.0 | 0.001384 | 0.023528 | 1306.0 | 1264.5 | 2570.5 | 1317.1 | 1441.6 | 2758.7 | 3.2076 | 2.5374 | 5.7450 |
| 300 | 8587.9 | 0.001404 | 0.021659 | 1332.7 | 1230.9 | 2563.6 | 1344.8 | 1404.8 | 2749.6 | 3.2548 | 2.4511 | 5.7059 |
| 305 | 9209.4 | 0.001425 | 0.019932 | 1360.0 | 1195.9 | 2555.8 | 1373.1 | 1366.3 | 2739.4 | 3.3024 | 2.3633 | 5.6657 |
| 310 | 9865.0 | 0.001447 | 0.018333 | 1387.7 | 1159.3 | 2547.1 | 1402.0 | 1325.9 | 2727.9 | 3.3506 | 2.2737 | 5.6243 |
| 315 | 10,556 | 0.001472 | 0.016849 | 1416.1 | 1121.1 | 2537.2 | 1431.6 | 1283.4 | 2715.0 | 3.3994 | 2.1821 | 5.5816 |
| 320 | 11,284 | 0.001499 | 0.015470 | 1445.1 | 1080.9 | 2526.0 | 1462.0 | 1238.5 | 2700.6 | 3.4491 | 2.0881 | 5.5372 |
| 325 | 12,051 | 0.001528 | 0.014183 | 1475.0 | 1038.5 | 2513.4 | 1493.4 | 1191.0 | 2684.3 | 3.4998 | 1.9911 | 5.4908 |
| 330 | 12,858 | 0.001560 | 0.012979 | 1505.7 | 993.5 | 2499.2 | 1525.8 | 1140.3 | 2666.0 | 3.5516 | 1.8906 | 5.4422 |
| 335 | 13,707 | 0.001597 | 0.011848 | 1537.5 | 945.5 | 2483.0 | 1559.4 | 1086.0 | 2645.4 | 3.6050 | 1.7857 | 5.3907 |
| 340 | 14,601 | 0.001638 | 0.010783 | 1570.7 | 893.8 | 2464.5 | 1594.6 | 1027.4 | 2622.0 | 3.6602 | 1.6756 | 5.3358 |
| 345 | 15,541 | 0.001685 | 0.009772 | 1605.5 | 837.7 | 2443.2 | 1631.7 | 963.4 | 2595.1 | 3.7179 | 1.5585 | 5.2765 |
| 350 | 16,529 | 0.001741 | 0.008806 | 1642.4 | 775.9 | 2418.3 | 1671.2 | 892.7 | 2563.9 | 3.7788 | 1.4326 | 5.2114 |
| 355 | 17,570 | 0.001808 | 0.007872 | 1682.2 | 706.4 | 2388.6 | 1714.0 | 812.9 | 2526.9 | 3.8442 | 1.2942 | 5.1384 |
| 360 | 18,666 | 0.001895 | 0.006950 | 1726.2 | 625.7 | 2351.9 | 1761.5 | 720.1 | 2481.6 | 3.9165 | 1.1373 | 5.0537 |
| 365 | 19,822 | 0.002015 | 0.006009 | 1777.2 | 526.4 | 2303.6 | 1817.2 | 605.5 | 2422.7 | 4.0004 | 0.9489 | 4.9493 |
| 370 | 21,044 | 0.002217 | 0.004953 | 1844.5 | 385.6 | 2230.1 | 1891.2 | 443.1 | 2334.3 | 4.1119 | 0.6890 | 4.8009 |
| 373.95 | 22,064 | 0.003106 | 0.003106 | 2015.7 | 0 | 2015.7 | 2084.3 | 0 | 2084.3 | 4.4070 | 0 | 4.4070 |

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# Table 2: Saturated Water – Pressure Table

Saturated water—Pressure table

| | | Specific volume, m³/kg | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg · K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Press., $P$ kPa | Sat. temp., $T_{sat}$ °C | 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, $s_g$ |
| 1.0 | 6.97 | 0.001000 | 129.19 | 29.302 | 2355.2 | 2384.5 | 29.303 | 2484.4 | 2513.7 | 0.1059 | 8.8690 | 8.9749 |
| 1.5 | 13.02 | 0.001001 | 87.964 | 54.686 | 2338.1 | 2392.8 | 54.688 | 2470.1 | 2524.7 | 0.1956 | 8.6314 | 8.8270 |
| 2.0 | 17.50 | 0.001001 | 66.990 | 73.431 | 2325.5 | 2398.9 | 73.433 | 2459.5 | 2532.9 | 0.2606 | 8.4621 | 8.7227 |
| 2.5 | 21.08 | 0.001002 | 54.242 | 88.422 | 2315.4 | 2403.8 | 88.424 | 2451.0 | 2539.4 | 0.3118 | 8.3302 | 8.6421 |
| 3.0 | 24.08 | 0.001003 | 45.654 | 100.98 | 2306.9 | 2407.9 | 100.98 | 2443.9 | 2544.8 | 0.3543 | 8.2222 | 8.5765 |
| 4.0 | 28.96 | 0.001004 | 34.791 | 121.39 | 2293.1 | 2414.5 | 121.39 | 2432.3 | 2553.7 | 0.4224 | 8.0510 | 8.4734 |
| 5.0 | 32.87 | 0.001005 | 28.185 | 137.75 | 2282.1 | 2419.8 | 137.75 | 2423.0 | 2560.7 | 0.4762 | 7.9176 | 8.3938 |
| 7.5 | 40.29 | 0.001008 | 19.233 | 168.74 | 2261.1 | 2429.8 | 168.75 | 2405.3 | 2574.0 | 0.5763 | 7.6738 | 8.2501 |
| 10 | 45.81 | 0.001010 | 14.670 | 191.79 | 2245.4 | 2437.2 | 191.81 | 2392.1 | 2583.9 | 0.6492 | 7.4996 | 8.1488 |
| 15 | 53.97 | 0.001014 | 10.020 | 225.93 | 2222.1 | 2448.0 | 225.94 | 2372.3 | 2598.3 | 0.7549 | 7.2522 | 8.0071 |
| 20 | 60.06 | 0.001017 | 7.6481 | 251.40 | 2204.6 | 2456.0 | 251.42 | 2357.5 | 2608.9 | 0.8320 | 7.0752 | 7.9073 |
| 25 | 64.96 | 0.001020 | 6.2034 | 271.93 | 2190.4 | 2462.4 | 271.96 | 2345.5 | 2617.5 | 0.8932 | 6.9370 | 7.8302 |
| 30 | 69.09 | 0.001022 | 5.2287 | 289.24 | 2178.5 | 2467.7 | 289.27 | 2335.3 | 2624.6 | 0.9441 | 6.8234 | 7.7675 |
| 40 | 75.86 | 0.001026 | 3.9933 | 317.58 | 2158.8 | 2476.3 | 317.62 | 2318.4 | 2636.1 | 1.0261 | 6.6430 | 7.6691 |
| 50 | 81.32 | 0.001030 | 3.2403 | 340.49 | 2142.7 | 2483.2 | 340.54 | 2304.7 | 2645.2 | 1.0912 | 6.5019 | 7.5931 |
| 75 | 91.76 | 0.001037 | 2.2172 | 384.36 | 2111.8 | 2496.1 | 384.44 | 2278.0 | 2662.4 | 1.2132 | 6.2426 | 7.4558 |
| 100 | 99.61 | 0.001043 | 1.6941 | 417.40 | 2088.2 | 2505.6 | 417.51 | 2257.5 | 2675.0 | 1.3028 | 6.0562 | 7.3589 |
| 101.325 | 99.97 | 0.001043 | 1.6734 | 418.95 | 2087.0 | 2506.0 | 419.06 | 2256.5 | 2675.6 | 1.3069 | 6.0476 | 7.3545 |
| 125 | 105.97 | 0.001048 | 1.3750 | 444.23 | 2068.8 | 2513.0 | 444.36 | 2240.6 | 2684.9 | 1.3741 | 5.9100 | 7.2841 |
| 150 | 111.35 | 0.001053 | 1.1594 | 466.97 | 2052.3 | 2519.2 | 467.13 | 2226.0 | 2693.1 | 1.4337 | 5.7894 | 7.2231 |
| 175 | 116.04 | 0.001057 | 1.0037 | 486.82 | 2037.7 | 2524.5 | 487.01 | 2213.1 | 2700.2 | 1.4850 | 5.6865 | 7.1716 |
| 200 | 120.21 | 0.001061 | 0.88578 | 504.50 | 2024.6 | 2529.1 | 504.71 | 2201.6 | 2706.3 | 1.5302 | 5.5968 | 7.1270 |
| 225 | 123.97 | 0.001064 | 0.79329 | 520.47 | 2012.7 | 2533.2 | 520.71 | 2191.0 | 2711.7 | 1.5706 | 5.5171 | 7.0877 |
| 250 | 127.41 | 0.001067 | 0.71873 | 535.08 | 2001.8 | 2536.8 | 535.35 | 2181.2 | 2716.5 | 1.6072 | 5.4453 | 7.0525 |
| 275 | 130.58 | 0.001070 | 0.65732 | 548.57 | 1991.6 | 2540.1 | 548.86 | 2172.0 | 2720.9 | 1.6408 | 5.3800 | 7.0207 |
| 300 | 133.52 | 0.001073 | 0.60582 | 561.11 | 1982.1 | 2543.2 | 561.43 | 2163.5 | 2724.9 | 1.6717 | 5.3200 | 6.9917 |
| 325 | 136.27 | 0.001076 | 0.56199 | 572.84 | 1973.1 | 2545.9 | 573.19 | 2155.4 | 2728.6 | 1.7005 | 5.2645 | 6.9650 |
| 350 | 138.86 | 0.001079 | 0.52422 | 583.89 | 1964.6 | 2548.5 | 584.26 | 2147.7 | 2732.0 | 1.7274 | 5.2128 | 6.9402 |
| 375 | 141.30 | 0.001081 | 0.49133 | 594.32 | 1956.6 | 2550.9 | 594.73 | 2140.4 | 2735.1 | 1.7526 | 5.1645 | 6.9171 |
| 400 | 143.61 | 0.001084 | 0.46242 | 604.22 | 1948.9 | 2553.1 | 604.66 | 2133.4 | 2738.1 | 1.7765 | 5.1191 | 6.8955 |
| 450 | 147.90 | 0.001088 | 0.41392 | 622.65 | 1934.5 | 2557.1 | 623.14 | 2120.3 | 2743.4 | 1.8205 | 5.0356 | 6.8561 |
| 500 | 151.83 | 0.001093 | 0.37483 | 639.54 | 1921.2 | 2560.7 | 640.09 | 2108.0 | 2748.1 | 1.8604 | 4.9603 | 6.8207 |
| 550 | 155.46 | 0.001097 | 0.34261 | 655.16 | 1908.8 | 2563.9 | 655.77 | 2096.6 | 2752.4 | 1.8970 | 4.8916 | 6.7886 |
| 600 | 158.83 | 0.001101 | 0.31560 | 669.72 | 1897.1 | 2566.8 | 670.38 | 2085.8 | 2756.2 | 1.9308 | 4.8285 | 6.7593 |
| 650 | 161.98 | 0.001104 | 0.29260 | 683.37 | 1886.1 | 2569.4 | 684.08 | 2075.5 | 2759.6 | 1.9623 | 4.7699 | 6.7322 |
| 700 | 164.95 | 0.001108 | 0.27278 | 696.23 | 1875.6 | 2571.8 | 697.00 | 2065.8 | 2762.8 | 1.9918 | 4.7153 | 6.7071 |
| 750 | 167.75 | 0.001111 | 0.25552 | 708.40 | 1865.6 | 2574.0 | 709.24 | 2056.4 | 2765.7 | 2.0195 | 4.6642 | 6.6837 |

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Saturated water—Pressure table (*Continued*)

| | | Specific volume, $m^3/kg$ | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg · K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Press., $P$ kPa | Sat. temp., $T_{sat}$ °C | 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, $s_g$ |
| 800 | 170.41 | 0.001115 | 0.24035 | 719.97 | 1856.1 | 2576.0 | 720.87 | 2047.5 | 2768.3 | 2.0457 | 4.6160 | 6.6616 |
| 850 | 172.94 | 0.001118 | 0.22690 | 731.00 | 1846.9 | 2577.9 | 731.95 | 2038.8 | 2770.8 | 2.0705 | 4.5705 | 6.6409 |
| 900 | 175.35 | 0.001121 | 0.21489 | 741.55 | 1838.1 | 2579.6 | 742.56 | 2030.5 | 2773.0 | 2.0941 | 4.5273 | 6.6213 |
| 950 | 177.66 | 0.001124 | 0.20411 | 751.67 | 1829.6 | 2581.3 | 752.74 | 2022.4 | 2775.2 | 2.1166 | 4.4862 | 6.6027 |
| 1000 | 179.88 | 0.001127 | 0.19436 | 761.39 | 1821.4 | 2582.8 | 762.51 | 2014.6 | 2777.1 | 2.1381 | 4.4470 | 6.5850 |
| 1100 | 184.06 | 0.001133 | 0.17745 | 779.78 | 1805.7 | 2585.5 | 781.03 | 1999.6 | 2780.7 | 2.1785 | 4.3735 | 6.5520 |
| 1200 | 187.96 | 0.001138 | 0.16326 | 796.96 | 1790.9 | 2587.8 | 798.33 | 1985.4 | 2783.8 | 2.2159 | 4.3058 | 6.5217 |
| 1300 | 191.60 | 0.001144 | 0.15119 | 813.10 | 1776.8 | 2589.9 | 814.59 | 1971.9 | 2786.5 | 2.2508 | 4.2428 | 6.4936 |
| 1400 | 195.04 | 0.001149 | 0.14078 | 828.35 | 1763.4 | 2591.8 | 829.96 | 1958.9 | 2788.9 | 2.2835 | 4.1840 | 6.4675 |
| 1500 | 198.29 | 0.001154 | 0.13171 | 842.82 | 1750.6 | 2593.4 | 844.55 | 1946.4 | 2791.0 | 2.3143 | 4.1287 | 6.4430 |
| 1750 | 205.72 | 0.001166 | 0.11344 | 876.12 | 1720.6 | 2596.7 | 878.16 | 1917.1 | 2795.2 | 2.3844 | 4.0033 | 6.3877 |
| 2000 | 212.38 | 0.001177 | 0.099587 | 906.12 | 1693.0 | 2599.1 | 908.47 | 1889.8 | 2798.3 | 2.4467 | 3.8923 | 6.3390 |
| 2250 | 218.41 | 0.001187 | 0.088717 | 933.54 | 1667.3 | 2600.9 | 936.21 | 1864.3 | 2800.5 | 2.5029 | 3.7926 | 6.2954 |
| 2500 | 223.95 | 0.001197 | 0.079952 | 958.87 | 1643.2 | 2602.1 | 961.87 | 1840.1 | 2801.9 | 2.5542 | 3.7016 | 6.2558 |
| 3000 | 233.85 | 0.001217 | 0.066667 | 1004.6 | 1598.5 | 2603.2 | 1008.3 | 1794.9 | 2803.2 | 2.6454 | 3.5402 | 6.1856 |
| 3500 | 242.56 | 0.001235 | 0.057061 | 1045.4 | 1557.6 | 2603.0 | 1049.7 | 1753.0 | 2802.7 | 2.7253 | 3.3991 | 6.1244 |
| 4000 | 250.35 | 0.001252 | 0.049779 | 1082.4 | 1519.3 | 2601.7 | 1087.4 | 1713.5 | 2800.8 | 2.7966 | 3.2731 | 6.0696 |
| 5000 | 263.94 | 0.001286 | 0.039448 | 1148.1 | 1448.9 | 2597.0 | 1154.5 | 1639.7 | 2794.2 | 2.9207 | 3.0530 | 5.9737 |
| 6000 | 275.59 | 0.001319 | 0.032449 | 1205.8 | 1384.1 | 2589.9 | 1213.8 | 1570.9 | 2784.6 | 3.0275 | 2.8627 | 5.8902 |
| 7000 | 285.83 | 0.001352 | 0.027378 | 1258.0 | 1323.0 | 2581.0 | 1267.5 | 1505.2 | 2772.6 | 3.1220 | 2.6927 | 5.8148 |
| 8000 | 295.01 | 0.001384 | 0.023525 | 1306.0 | 1264.5 | 2570.5 | 1317.1 | 1441.6 | 2758.7 | 3.2077 | 2.5373 | 5.7450 |
| 9000 | 303.35 | 0.001418 | 0.020489 | 1350.9 | 1207.6 | 2558.5 | 1363.7 | 1379.3 | 2742.9 | 3.2866 | 2.3925 | 5.6791 |
| 10,000 | 311.00 | 0.001452 | 0.018028 | 1393.3 | 1151.8 | 2545.2 | 1407.8 | 1317.6 | 2725.5 | 3.3603 | 2.2556 | 5.6159 |
| 11,000 | 318.08 | 0.001488 | 0.015988 | 1433.9 | 1096.6 | 2530.4 | 1450.2 | 1256.1 | 2706.3 | 3.4299 | 2.1245 | 5.5544 |
| 12,000 | 324.68 | 0.001526 | 0.014264 | 1473.0 | 1041.3 | 2514.3 | 1491.3 | 1194.1 | 2685.4 | 3.4964 | 1.9975 | 5.4939 |
| 13,000 | 330.85 | 0.001566 | 0.012781 | 1511.0 | 985.5 | 2496.6 | 1531.4 | 1131.3 | 2662.7 | 3.5606 | 1.8730 | 5.4336 |
| 14,000 | 336.67 | 0.001610 | 0.011487 | 1548.4 | 928.7 | 2477.1 | 1571.0 | 1067.0 | 2637.9 | 3.6232 | 1.7497 | 5.3728 |
| 15,000 | 342.16 | 0.001657 | 0.010341 | 1585.5 | 870.3 | 2455.7 | 1610.3 | 1000.5 | 2610.8 | 3.6848 | 1.6261 | 5.3108 |
| 16,000 | 347.36 | 0.001710 | 0.009312 | 1622.6 | 809.4 | 2432.0 | 1649.9 | 931.1 | 2581.0 | 3.7461 | 1.5005 | 5.2466 |
| 17,000 | 352.29 | 0.001770 | 0.008374 | 1660.2 | 745.1 | 2405.4 | 1690.3 | 857.4 | 2547.7 | 3.8082 | 1.3709 | 5.1791 |
| 18,000 | 356.99 | 0.001840 | 0.007504 | 1699.1 | 675.9 | 2375.0 | 1732.2 | 777.8 | 2510.0 | 3.8720 | 1.2343 | 5.1064 |
| 19,000 | 361.47 | 0.001926 | 0.006677 | 1740.3 | 598.9 | 2339.2 | 1776.8 | 689.2 | 2466.0 | 3.9396 | 1.0860 | 5.0256 |
| 20,000 | 365.75 | 0.002038 | 0.005862 | 1785.8 | 509.0 | 2294.8 | 1826.6 | 585.5 | 2412.1 | 4.0146 | 0.9164 | 4.9310 |
| 21,000 | 369.83 | 0.002207 | 0.004994 | 1841.6 | 391.9 | 2233.5 | 1888.0 | 450.4 | 2338.4 | 4.1071 | 0.7005 | 4.8076 |
| 22,000 | 373.71 | 0.002703 | 0.003644 | 1951.7 | 140.8 | 2092.4 | 2011.1 | 161.5 | 2172.6 | 4.2942 | 0.2496 | 4.5439 |
| 22,064 | 373.95 | 0.003106 | 0.003106 | 2015.7 | 0 | 2015.7 | 2084.3 | 0 | 2084.3 | 4.4070 | 0 | 4.4070 |



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# Table 3: Superheated Water Properties

Superheated water

| *T* °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 | *v* m³/kg | *u* kJ/kg | *h* kJ/kg | *s* kJ/kg · K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *P* = 0.01 MPa (45.81°C)* | | | | *P* = 0.05 MPa (81.32°C) | | | | *P* = 0.10 MPa (99.61°C) | | | |
| Sat.† | 14.670 | 2437.2 | 2583.9 | 8.1488 | 3.2403 | 2483.2 | 2645.2 | 7.5931 | 1.6941 | 2505.6 | 2675.0 | 7.3589 |
| 50 | 14.867 | 2443.3 | 2592.0 | 8.1741 | | | | | | | | |
| 100 | 17.196 | 2515.5 | 2687.5 | 8.4489 | 3.4187 | 2511.5 | 2682.4 | 7.6953 | 1.6959 | 2506.2 | 2675.8 | 7.3611 |
| 150 | 19.513 | 2587.9 | 2783.0 | 8.6893 | 3.8897 | 2585.7 | 2780.2 | 7.9413 | 1.9367 | 2582.9 | 2776.6 | 7.6148 |
| 200 | 21.826 | 2661.4 | 2879.6 | 8.9049 | 4.3562 | 2660.0 | 2877.8 | 8.1592 | 2.1724 | 2658.2 | 2875.5 | 7.8356 |
| 250 | 24.136 | 2736.1 | 2977.5 | 9.1015 | 4.8206 | 2735.1 | 2976.2 | 8.3568 | 2.4062 | 2733.9 | 2974.5 | 8.0346 |
| 300 | 26.446 | 2812.3 | 3076.7 | 9.2827 | 5.2841 | 2811.6 | 3075.8 | 8.5387 | 2.6389 | 2810.7 | 3074.5 | 8.2172 |
| 400 | 31.063 | 2969.3 | 3280.0 | 9.6094 | 6.2094 | 2968.9 | 3279.3 | 8.8659 | 3.1027 | 2968.3 | 3278.6 | 8.5452 |
| 500 | 35.680 | 3132.9 | 3489.7 | 9.8998 | 7.1338 | 3132.6 | 3489.3 | 9.1566 | 3.5655 | 3132.2 | 3488.7 | 8.8362 |
| 600 | 40.296 | 3303.3 | 3706.3 | 10.1631 | 8.0577 | 3303.1 | 3706.0 | 9.4201 | 4.0279 | 3302.8 | 3705.6 | 9.0999 |
| 700 | 44.911 | 3480.8 | 3929.9 | 10.4056 | 8.9813 | 3480.6 | 3929.7 | 9.6626 | 4.4900 | 3480.4 | 3929.4 | 9.3424 |
| 800 | 49.527 | 3665.4 | 4160.6 | 10.6312 | 9.9047 | 3665.2 | 4160.4 | 9.8883 | 4.9519 | 3665.0 | 4160.2 | 9.5682 |
| 900 | 54.143 | 3856.9 | 4398.3 | 10.8429 | 10.8280 | 3856.8 | 4398.2 | 10.1000 | 5.4137 | 3856.7 | 4398.0 | 9.7800 |
| 1000 | 58.758 | 4055.3 | 4642.8 | 11.0429 | 11.7513 | 4055.2 | 4642.7 | 10.3000 | 5.8755 | 4055.0 | 4642.6 | 9.9800 |
| 1100 | 63.373 | 4260.0 | 4893.8 | 11.2326 | 12.6745 | 4259.9 | 4893.7 | 10.4897 | 6.3372 | 4259.8 | 4893.6 | 10.1698 |
| 1200 | 67.989 | 4470.9 | 5150.8 | 11.4132 | 13.5977 | 4470.8 | 5150.7 | 10.6704 | 6.7988 | 4470.7 | 5150.6 | 10.3504 |
| 1300 | 72.604 | 4687.4 | 5413.4 | 11.5857 | 14.5209 | 4687.3 | 5413.3 | 10.8429 | 7.2605 | 4687.2 | 5413.3 | 10.5229 |
| | *P* = 0.20 MPa (120.21°C) | | | | *P* = 0.30 MPa (133.52°C) | | | | *P* = 0.40 MPa (143.61°C) | | | |
| Sat. | 0.88578 | 2529.1 | 2706.3 | 7.1270 | 0.60582 | 2543.2 | 2724.9 | 6.9917 | 0.46242 | 2553.1 | 2738.1 | 6.8955 |
| 150 | 0.95986 | 2577.1 | 2769.1 | 7.2810 | 0.63402 | 2571.0 | 2761.2 | 7.0792 | 0.47088 | 2564.4 | 2752.8 | 6.9306 |
| 200 | 1.08049 | 2654.6 | 2870.7 | 7.5081 | 0.71643 | 2651.0 | 2865.9 | 7.3132 | 0.53434 | 2647.2 | 2860.9 | 7.1723 |
| 250 | 1.19890 | 2731.4 | 2971.2 | 7.7100 | 0.79645 | 2728.9 | 2967.9 | 7.5180 | 0.59520 | 2726.4 | 2964.5 | 7.3804 |
| 300 | 1.31623 | 2808.8 | 3072.1 | 7.8941 | 0.87535 | 2807.0 | 3069.6 | 7.7037 | 0.65489 | 2805.1 | 3067.1 | 7.5677 |
| 400 | 1.54934 | 2967.2 | 3277.0 | 8.2236 | 1.03155 | 2966.0 | 3275.5 | 8.0347 | 0.77265 | 2964.9 | 3273.9 | 7.9003 |
| 500 | 1.78142 | 3131.4 | 3487.7 | 8.5153 | 1.18672 | 3130.6 | 3486.6 | 8.3271 | 0.88936 | 3129.8 | 3485.5 | 8.1933 |
| 600 | 2.01302 | 3302.2 | 3704.8 | 8.7793 | 1.34139 | 3301.6 | 3704.0 | 8.5915 | 1.00558 | 3301.0 | 3703.3 | 8.4580 |
| 700 | 2.24434 | 3479.9 | 3928.8 | 9.0221 | 1.49580 | 3479.5 | 3928.2 | 8.8345 | 1.12152 | 3479.0 | 3927.6 | 8.7012 |
| 800 | 2.47550 | 3664.7 | 4159.8 | 9.2479 | 1.65004 | 3664.3 | 4159.3 | 9.0605 | 1.23730 | 3663.9 | 4158.9 | 8.9274 |
| 900 | 2.70656 | 3856.3 | 4397.7 | 9.4598 | 1.80417 | 3856.0 | 4397.3 | 9.2725 | 1.35298 | 3855.7 | 4396.9 | 9.1394 |
| 1000 | 2.93756 | 4054.8 | 4642.3 | 9.6599 | 1.95824 | 4054.5 | 4642.0 | 9.4726 | 1.46859 | 4054.3 | 4641.7 | 9.3396 |
| 1100 | 3.16848 | 4259.6 | 4893.3 | 9.8497 | 2.11226 | 4259.4 | 4893.1 | 9.6624 | 1.58414 | 4259.2 | 4892.9 | 9.5295 |
| 1200 | 3.39938 | 4470.5 | 5150.4 | 10.0304 | 2.26624 | 4470.3 | 5150.2 | 9.8431 | 1.69966 | 4470.2 | 5150.0 | 9.7102 |
| 1300 | 3.63026 | 4687.1 | 5413.1 | 10.2029 | 2.42019 | 4686.9 | 5413.0 | 10.0157 | 1.81516 | 4686.7 | 5412.8 | 9.8828 |
| | *P* = 0.50 MPa (151.83°C) | | | | *P* = 0.60 MPa (158.83°C) | | | | *P* = 0.80 MPa (170.41°C) | | | |
| Sat. | 0.37483 | 2560.7 | 2748.1 | 6.8207 | 0.31560 | 2566.8 | 2756.2 | 6.7593 | 0.24035 | 2576.0 | 2768.3 | 6.6616 |
| 200 | 0.42503 | 2643.3 | 2855.8 | 7.0610 | 0.35212 | 2639.4 | 2850.6 | 6.9683 | 0.26088 | 2631.1 | 2839.8 | 6.8177 |
| 250 | 0.47443 | 2723.8 | 2961.0 | 7.2725 | 0.39390 | 2721.2 | 2957.6 | 7.1833 | 0.29321 | 2715.9 | 2950.4 | 7.0402 |
| 300 | 0.52261 | 2803.3 | 3064.6 | 7.4614 | 0.43442 | 2801.4 | 3062.0 | 7.3740 | 0.32416 | 2797.5 | 3056.9 | 7.2345 |
| 350 | 0.57015 | 2883.0 | 3168.1 | 7.6346 | 0.47428 | 2881.6 | 3166.1 | 7.5481 | 0.35442 | 2878.6 | 3162.2 | 7.4107 |
| 400 | 0.61731 | 2963.7 | 3272.4 | 7.7956 | 0.51374 | 2962.5 | 3270.8 | 7.7097 | 0.38429 | 2960.2 | 3267.7 | 7.5735 |
| 500 | 0.71095 | 3129.0 | 3484.5 | 8.0893 | 0.59200 | 3128.2 | 3483.4 | 8.0041 | 0.44332 | 3126.6 | 3481.3 | 7.8692 |
| 600 | 0.80409 | 3300.4 | 3702.5 | 8.3544 | 0.66976 | 3299.8 | 3701.7 | 8.2695 | 0.50186 | 3298.7 | 3700.1 | 8.1354 |
| 700 | 0.89696 | 3478.6 | 3927.0 | 8.5978 | 0.74725 | 3478.1 | 3926.4 | 8.5132 | 0.56011 | 3477.2 | 3925.3 | 8.3794 |
| 800 | 0.98966 | 3663.6 | 4158.4 | 8.8240 | 0.82457 | 3663.2 | 4157.9 | 8.7395 | 0.61820 | 3662.5 | 4157.0 | 8.6061 |
| 900 | 1.08227 | 3855.4 | 4396.6 | 9.0362 | 0.90179 | 3855.1 | 4396.2 | 8.9518 | 0.67619 | 3854.5 | 4395.5 | 8.8185 |
| 1000 | 1.17480 | 4054.0 | 4641.4 | 9.2364 | 0.97893 | 4053.8 | 4641.1 | 9.1521 | 0.73411 | 4053.3 | 4640.5 | 9.0189 |
| 1100 | 1.26728 | 4259.0 | 4892.6 | 9.4263 | 1.05603 | 4258.8 | 4892.4 | 9.3420 | 0.79197 | 4258.3 | 4891.9 | 9.2090 |
| 1200 | 1.35972 | 4470.0 | 5149.8 | 9.6071 | 1.13309 | 4469.8 | 5149.6 | 9.5229 | 0.84980 | 4469.4 | 5149.3 | 9.3898 |
| 1300 | 1.45214 | 4686.6 | 5412.6 | 9.7797 | 1.21012 | 4686.4 | 5412.5 | 9.6955 | 0.90761 | 4686.1 | 5412.2 | 9.5625 |

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Superheated water (*Continued*)

| T °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 | v m³/kg | u kJ/kg | h kJ/kg | s kJ/kg · K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P = 1.00 MPa (179.88°C) | | | | P = 1.20 MPa (187.96°C) | | | | P = 1.40 MPa (195.04°C) | | | |
| Sat. | 0.19437 | 2582.8 | 2777.1 | 6.5850 | 0.16326 | 2587.8 | 2783.8 | 6.5217 | 0.14078 | 2591.8 | 2788.9 | 6.4675 |
| 200 | 0.20602 | 2622.3 | 2828.3 | 6.6956 | 0.16934 | 2612.9 | 2816.1 | 6.5909 | 0.14303 | 2602.7 | 2803.0 | 6.4975 |
| 250 | 0.23275 | 2710.4 | 2943.1 | 6.9265 | 0.19241 | 2704.7 | 2935.6 | 6.8313 | 0.16356 | 2698.9 | 2927.9 | 6.7488 |
| 300 | 0.25799 | 2793.7 | 3051.6 | 7.1246 | 0.21386 | 2789.7 | 3046.3 | 7.0335 | 0.18233 | 2785.7 | 3040.9 | 6.9553 |
| 350 | 0.28250 | 2875.7 | 3158.2 | 7.3029 | 0.23455 | 2872.7 | 3154.2 | 7.2139 | 0.20029 | 2869.7 | 3150.1 | 7.1379 |
| 400 | 0.30661 | 2957.9 | 3264.5 | 7.4670 | 0.25482 | 2955.5 | 3261.3 | 7.3793 | 0.21782 | 2953.1 | 3258.1 | 7.3046 |
| 500 | 0.35411 | 3125.0 | 3479.1 | 7.7642 | 0.29464 | 3123.4 | 3477.0 | 7.6779 | 0.25216 | 3121.8 | 3474.8 | 7.6047 |
| 600 | 0.40111 | 3297.5 | 3698.6 | 8.0311 | 0.33395 | 3296.3 | 3697.0 | 7.9456 | 0.28597 | 3295.1 | 3695.5 | 7.8730 |
| 700 | 0.44783 | 3476.3 | 3924.1 | 8.2755 | 0.37297 | 3475.3 | 3922.9 | 8.1904 | 0.31951 | 3474.4 | 3921.7 | 8.1183 |
| 800 | 0.49438 | 3661.7 | 4156.1 | 8.5024 | 0.41184 | 3661.0 | 4155.2 | 8.4176 | 0.35288 | 3660.3 | 4154.3 | 8.3458 |
| 900 | 0.54083 | 3853.9 | 4394.8 | 8.7150 | 0.45059 | 3853.3 | 4394.0 | 8.6303 | 0.38614 | 3852.7 | 4393.3 | 8.5587 |
| 1000 | 0.58721 | 4052.7 | 4640.0 | 8.9155 | 0.48928 | 4052.2 | 4639.4 | 8.8310 | 0.41933 | 4051.7 | 4638.8 | 8.7595 |
| 1100 | 0.63354 | 4257.9 | 4891.4 | 9.1057 | 0.52792 | 4257.5 | 4891.0 | 9.0212 | 0.45247 | 4257.0 | 4890.5 | 8.9497 |
| 1200 | 0.67983 | 4469.0 | 5148.9 | 9.2866 | 0.56652 | 4468.7 | 5148.5 | 9.2022 | 0.48558 | 4468.3 | 5148.1 | 9.1308 |
| 1300 | 0.72610 | 4685.8 | 5411.9 | 9.4593 | 0.60509 | 4685.5 | 5411.6 | 9.3750 | 0.51866 | 4685.1 | 5411.3 | 9.3036 |
| | P = 1.60 MPa (201.37°C) | | | | P = 1.80 MPa (207.11°C) | | | | P = 2.00 MPa (212.38°C) | | | |
| Sat. | 0.12374 | 2594.8 | 2792.8 | 6.4200 | 0.11037 | 2597.3 | 2795.9 | 6.3775 | 0.09959 | 2599.1 | 2798.3 | 6.3390 |
| 225 | 0.13293 | 2645.1 | 2857.8 | 6.5537 | 0.11678 | 2637.0 | 2847.2 | 6.4825 | 0.10381 | 2628.5 | 2836.1 | 6.4160 |
| 250 | 0.14190 | 2692.9 | 2919.9 | 6.6753 | 0.12502 | 2686.7 | 2911.7 | 6.6088 | 0.11150 | 2680.3 | 2903.3 | 6.5475 |
| 300 | 0.15866 | 2781.6 | 3035.4 | 6.8864 | 0.14025 | 2777.4 | 3029.9 | 6.8246 | 0.12551 | 2773.2 | 3024.2 | 6.7684 |
| 350 | 0.17459 | 2866.6 | 3146.0 | 7.0713 | 0.15460 | 2863.6 | 3141.9 | 7.0120 | 0.13860 | 2860.5 | 3137.7 | 6.9583 |
| 400 | 0.19007 | 2950.8 | 3254.9 | 7.2394 | 0.16849 | 2948.3 | 3251.6 | 7.1814 | 0.15122 | 2945.9 | 3248.4 | 7.1292 |
| 500 | 0.22029 | 3120.1 | 3472.6 | 7.5410 | 0.19551 | 3118.5 | 3470.4 | 7.4845 | 0.17568 | 3116.9 | 3468.3 | 7.4337 |
| 600 | 0.24999 | 3293.9 | 3693.9 | 7.8101 | 0.22200 | 3292.7 | 3692.3 | 7.7543 | 0.19962 | 3291.5 | 3690.7 | 7.7043 |
| 700 | 0.27941 | 3473.5 | 3920.5 | 8.0558 | 0.24822 | 3472.6 | 3919.4 | 8.0005 | 0.22326 | 3471.7 | 3918.2 | 7.9509 |
| 800 | 0.30865 | 3659.5 | 4153.4 | 8.2834 | 0.27426 | 3658.8 | 4152.4 | 8.2284 | 0.24674 | 3658.0 | 4151.5 | 8.1791 |
| 900 | 0.33780 | 3852.1 | 4392.6 | 8.4965 | 0.30020 | 3851.5 | 4391.9 | 8.4417 | 0.27012 | 3850.9 | 4391.1 | 8.3925 |
| 1000 | 0.36687 | 4051.2 | 4638.2 | 8.6974 | 0.32606 | 4050.7 | 4637.6 | 8.6427 | 0.29342 | 4050.2 | 4637.1 | 8.5936 |
| 1100 | 0.39589 | 4256.6 | 4890.0 | 8.8878 | 0.35188 | 4256.2 | 4889.6 | 8.8331 | 0.31667 | 4255.7 | 4889.1 | 8.7842 |
| 1200 | 0.42488 | 4467.9 | 5147.7 | 9.0689 | 0.37766 | 4467.6 | 5147.3 | 9.0143 | 0.33989 | 4467.2 | 5147.0 | 8.9654 |
| 1300 | 0.45383 | 4684.8 | 5410.9 | 9.2418 | 0.40341 | 4684.5 | 5410.6 | 9.1872 | 0.36308 | 4684.2 | 5410.3 | 9.1384 |
| | P = 2.50 MPa (223.95°C) | | | | P = 3.00 MPa (233.85°C) | | | | P = 3.50 MPa (242.56°C) | | | |
| Sat. | 0.07995 | 2602.1 | 2801.9 | 6.2558 | 0.06667 | 2603.2 | 2803.2 | 6.1856 | 0.05706 | 2603.0 | 2802.7 | 6.1244 |
| 225 | 0.08026 | 2604.8 | 2805.5 | 6.2629 | | | | | | | | |
| 250 | 0.08705 | 2663.3 | 2880.9 | 6.4107 | 0.07063 | 2644.7 | 2856.5 | 6.2893 | 0.05876 | 2624.0 | 2829.7 | 6.1764 |
| 300 | 0.09894 | 2762.2 | 3009.6 | 6.6459 | 0.08118 | 2750.8 | 2994.3 | 6.5412 | 0.06845 | 2738.8 | 2978.4 | 6.4484 |
| 350 | 0.10979 | 2852.5 | 3127.0 | 6.8424 | 0.09056 | 2844.4 | 3116.1 | 6.7450 | 0.07680 | 2836.0 | 3104.9 | 6.6601 |
| 400 | 0.12012 | 2939.8 | 3240.1 | 7.0170 | 0.09938 | 2933.6 | 3231.7 | 6.9235 | 0.08456 | 2927.2 | 3223.2 | 6.8428 |
| 450 | 0.13015 | 3026.2 | 3351.6 | 7.1768 | 0.10789 | 3021.2 | 3344.9 | 7.0856 | 0.09198 | 3016.1 | 3338.1 | 7.0074 |
| 500 | 0.13999 | 3112.8 | 3462.8 | 7.3254 | 0.11620 | 3108.6 | 3457.2 | 7.2359 | 0.09919 | 3104.5 | 3451.7 | 7.1593 |
| 600 | 0.15931 | 3288.5 | 3686.8 | 7.5979 | 0.13245 | 3285.5 | 3682.8 | 7.5103 | 0.11325 | 3282.5 | 3678.9 | 7.4357 |
| 700 | 0.17835 | 3469.3 | 3915.2 | 7.8455 | 0.14841 | 3467.0 | 3912.2 | 7.7590 | 0.12702 | 3464.7 | 3909.3 | 7.6855 |
| 800 | 0.19722 | 3656.2 | 4149.2 | 8.0744 | 0.16420 | 3654.3 | 4146.9 | 7.9885 | 0.14061 | 3652.5 | 4144.6 | 7.9156 |
| 900 | 0.21597 | 3849.4 | 4389.3 | 8.2882 | 0.17988 | 3847.9 | 4387.5 | 8.2028 | 0.15410 | 3846.4 | 4385.7 | 8.1304 |
| 1000 | 0.23466 | 4049.0 | 4635.6 | 8.4897 | 0.19549 | 4047.7 | 4634.2 | 8.4045 | 0.16751 | 4046.4 | 4632.7 | 8.3324 |
| 1100 | 0.25330 | 4254.7 | 4887.9 | 8.6804 | 0.21105 | 4253.6 | 4886.7 | 8.5955 | 0.18087 | 4252.5 | 4885.6 | 8.5236 |
| 1200 | 0.27190 | 4466.3 | 5146.0 | 8.8618 | 0.22658 | 4465.3 | 5145.1 | 8.7771 | 0.19420 | 4464.4 | 5144.1 | 8.7053 |
| 1300 | 0.29048 | 4683.4 | 5409.5 | 9.0349 | 0.24207 | 4682.6 | 5408.8 | 8.9502 | 0.20750 | 4681.8 | 5408.0 | 8.8786 |



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# Table 4: Saturated and Superheated R-134a Properties

Saturated refrigerant-134a—Pressure table

| | | Specific volume, m³/kg | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg · K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Press., $P$ kPa | Sat. temp., $T_{sat}$ °C | 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, $s_g$ |
| 60 | −36.95 | 0.0007098 | 0.31121 | 3.798 | 205.32 | 209.12 | 3.841 | 223.95 | 227.79 | 0.01634 | 0.94807 | 0.96441 |
| 70 | −33.87 | 0.0007144 | 0.26929 | 7.680 | 203.20 | 210.88 | 7.730 | 222.00 | 229.73 | 0.03267 | 0.92775 | 0.96042 |
| 80 | −31.13 | 0.0007185 | 0.23753 | 11.15 | 201.30 | 212.46 | 11.21 | 220.25 | 231.46 | 0.04711 | 0.90999 | 0.95710 |
| 90 | −28.65 | 0.0007223 | 0.21263 | 14.31 | 199.57 | 213.88 | 14.37 | 218.65 | 233.02 | 0.06008 | 0.89419 | 0.95427 |
| 100 | −26.37 | 0.0007259 | 0.19254 | 17.21 | 197.98 | 215.19 | 17.28 | 217.16 | 234.44 | 0.07188 | 0.87995 | 0.95183 |
| 120 | −22.32 | 0.0007324 | 0.16212 | 22.40 | 195.11 | 217.51 | 22.49 | 214.48 | 236.97 | 0.09275 | 0.85503 | 0.94779 |
| 140 | −18.77 | 0.0007383 | 0.14014 | 26.98 | 192.57 | 219.54 | 27.08 | 212.08 | 239.16 | 0.11087 | 0.83368 | 0.94456 |
| 160 | −15.60 | 0.0007437 | 0.12348 | 31.09 | 190.27 | 221.35 | 31.21 | 209.90 | 241.11 | 0.12693 | 0.81496 | 0.94190 |
| 180 | −12.73 | 0.0007487 | 0.11041 | 34.83 | 188.16 | 222.99 | 34.97 | 207.90 | 242.86 | 0.14139 | 0.79826 | 0.93965 |
| 200 | −10.09 | 0.0007533 | 0.099867 | 38.28 | 186.21 | 224.48 | 38.43 | 206.03 | 244.46 | 0.15457 | 0.78316 | 0.93773 |
| 240 | −5.38 | 0.0007620 | 0.083897 | 44.48 | 182.67 | 227.14 | 44.66 | 202.62 | 247.28 | 0.17794 | 0.75664 | 0.93458 |
| 280 | −1.25 | 0.0007699 | 0.072352 | 49.97 | 179.50 | 229.46 | 50.18 | 199.54 | 249.72 | 0.19829 | 0.73381 | 0.93210 |
| 320 | 2.46 | 0.0007772 | 0.063604 | 54.92 | 176.61 | 231.52 | 55.16 | 196.71 | 251.88 | 0.21637 | 0.71369 | 0.93006 |
| 360 | 5.82 | 0.0007841 | 0.056738 | 59.44 | 173.94 | 233.38 | 59.72 | 194.08 | 253.81 | 0.23270 | 0.69566 | 0.92836 |
| 400 | 8.91 | 0.0007907 | 0.051201 | 63.62 | 171.45 | 235.07 | 63.94 | 191.62 | 255.55 | 0.24761 | 0.67929 | 0.92691 |
| 450 | 12.46 | 0.0007985 | 0.045619 | 68.45 | 168.54 | 237.00 | 68.81 | 188.71 | 257.53 | 0.26465 | 0.66069 | 0.92535 |
| 500 | 15.71 | 0.0008059 | 0.041118 | 72.93 | 165.82 | 238.75 | 73.33 | 185.98 | 259.30 | 0.28023 | 0.64377 | 0.92400 |
| 550 | 18.73 | 0.0008130 | 0.037408 | 77.10 | 163.25 | 240.35 | 77.54 | 183.38 | 260.92 | 0.29461 | 0.62821 | 0.92282 |
| 600 | 21.55 | 0.0008199 | 0.034295 | 81.02 | 160.81 | 241.83 | 81.51 | 180.90 | 262.40 | 0.30799 | 0.61378 | 0.92177 |
| 650 | 24.20 | 0.0008266 | 0.031646 | 84.72 | 158.48 | 243.20 | 85.26 | 178.51 | 263.77 | 0.32051 | 0.60030 | 0.92081 |
| 700 | 26.69 | 0.0008331 | 0.029361 | 88.24 | 156.24 | 244.48 | 88.82 | 176.21 | 265.03 | 0.33230 | 0.58763 | 0.91994 |
| 750 | 29.06 | 0.0008395 | 0.027371 | 91.59 | 154.08 | 245.67 | 92.22 | 173.98 | 266.20 | 0.34345 | 0.57567 | 0.91912 |
| 800 | 31.31 | 0.0008458 | 0.025621 | 94.79 | 152.00 | 246.79 | 95.47 | 171.82 | 267.29 | 0.35404 | 0.56431 | 0.91835 |
| 850 | 33.45 | 0.0008520 | 0.024069 | 97.87 | 149.98 | 247.85 | 98.60 | 169.71 | 268.31 | 0.36413 | 0.55349 | 0.91762 |

Superheated refrigerant-134a

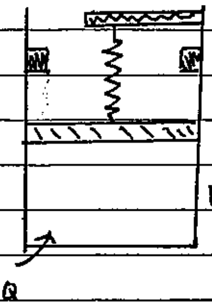
| $T$ °C | $v$ m³/kg | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K | $v$ m³/kg | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K | $v$ m³/kg | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ = 0.06 MPa ($T_{sat}$ = −36.95°C) | | | | $P$ = 0.10 MPa ($T_{sat}$ = −26.37°C) | | | | $P$ = 0.14 MPa ($T_{sat}$ = −18.77°C) | | | |
| Sat. | 0.31121 | 209.12 | 227.79 | 0.9644 | 0.19254 | 215.19 | 234.44 | 0.9518 | 0.14014 | 219.54 | 239.16 | 0.9446 |
| −20 | 0.33608 | 220.60 | 240.76 | 1.0174 | 0.19841 | 219.66 | 239.50 | 0.9721 | | | | |
| −10 | 0.35048 | 227.55 | 248.58 | 1.0477 | 0.20743 | 226.75 | 247.49 | 1.0030 | 0.14605 | 225.91 | 246.36 | 0.9724 |
| 0 | 0.36476 | 234.66 | 256.54 | 1.0774 | 0.21630 | 233.95 | 255.58 | 1.0332 | 0.15263 | 233.23 | 254.60 | 1.0031 |
| 10 | 0.37893 | 241.92 | 264.66 | 1.1066 | 0.22506 | 241.30 | 263.81 | 1.0628 | 0.15908 | 240.66 | 262.93 | 1.0331 |
| 20 | 0.39302 | 249.35 | 272.94 | 1.1353 | 0.23373 | 248.79 | 272.17 | 1.0918 | 0.16544 | 248.22 | 271.38 | 1.0624 |
| 30 | 0.40705 | 256.95 | 281.37 | 1.1636 | 0.24233 | 256.44 | 280.68 | 1.1203 | 0.17172 | 255.93 | 279.97 | 1.0912 |
| 40 | 0.42102 | 264.71 | 289.97 | 1.1915 | 0.25088 | 264.25 | 289.34 | 1.1484 | 0.17794 | 263.79 | 288.70 | 1.1195 |
| 50 | 0.43495 | 272.64 | 298.74 | 1.2191 | 0.25937 | 272.22 | 298.16 | 1.1762 | 0.18412 | 271.79 | 297.57 | 1.1474 |
| 60 | 0.44883 | 280.73 | 307.66 | 1.2463 | 0.26783 | 280.35 | 307.13 | 1.2035 | 0.19025 | 279.96 | 306.59 | 1.1749 |
| 70 | 0.46269 | 288.99 | 316.75 | 1.2732 | 0.27626 | 288.64 | 316.26 | 1.2305 | 0.19635 | 288.28 | 315.77 | 1.2020 |
| 80 | 0.47651 | 297.41 | 326.00 | 1.2997 | 0.28465 | 297.08 | 325.55 | 1.2572 | 0.20242 | 296.75 | 325.09 | 1.2288 |
| 90 | 0.49032 | 306.00 | 335.42 | 1.3260 | 0.29303 | 305.69 | 334.99 | 1.2836 | 0.20847 | 305.38 | 334.57 | 1.2553 |
| 100 | 0.50410 | 314.74 | 344.99 | 1.3520 | 0.30138 | 314.46 | 344.60 | 1.3096 | 0.21449 | 314.17 | 344.20 | 1.2814 |
| | $P$ = 0.18 MPa ($T_{sat}$ = −12.73°C) | | | | $P$ = 0.20 MPa ($T_{sat}$ = −10.09°C) | | | | $P$ = 0.24 MPa ($T_{sat}$ = −5.38°C) | | | |
| Sat. | 0.11041 | 222.99 | 242.86 | 0.9397 | 0.09987 | 224.48 | 244.46 | 0.9377 | 0.08390 | 227.14 | 247.28 | 0.9346 |
| −10 | 0.11189 | 225.02 | 245.16 | 0.9484 | 0.09991 | 224.55 | 244.54 | 0.9380 | | | | |
| 0 | 0.11722 | 232.48 | 253.58 | 0.9798 | 0.10481 | 232.09 | 253.05 | 0.9698 | 0.08617 | 231.29 | 251.97 | 0.9519 |
| 10 | 0.12240 | 240.00 | 262.04 | 1.0102 | 0.10955 | 239.67 | 261.58 | 1.0004 | 0.09026 | 238.98 | 260.65 | 0.9831 |
| 20 | 0.12748 | 247.64 | 270.59 | 1.0399 | 0.11418 | 247.35 | 270.18 | 1.0303 | 0.09423 | 246.74 | 269.36 | 1.0134 |
| 30 | 0.13248 | 255.41 | 279.25 | 1.0690 | 0.11874 | 255.14 | 278.89 | 1.0595 | 0.09812 | 254.61 | 278.16 | 1.0429 |
| 40 | 0.13741 | 263.31 | 288.05 | 1.0975 | 0.12322 | 263.08 | 287.72 | 1.0882 | 0.10193 | 262.59 | 287.06 | 1.0718 |
| 50 | 0.14230 | 271.36 | 296.98 | 1.1256 | 0.12766 | 271.15 | 296.68 | 1.1163 | 0.10570 | 270.71 | 296.08 | 1.1001 |
| 60 | 0.14715 | 279.56 | 306.05 | 1.1532 | 0.13206 | 279.37 | 305.78 | 1.1441 | 0.10942 | 278.97 | 305.23 | 1.1280 |
| 70 | 0.15196 | 287.91 | 315.27 | 1.1805 | 0.13641 | 287.73 | 315.01 | 1.1714 | 0.11310 | 287.36 | 314.51 | 1.1554 |
| 80 | 0.15673 | 296.42 | 324.63 | 1.2074 | 0.14074 | 296.25 | 324.40 | 1.1983 | 0.11675 | 295.91 | 323.93 | 1.1825 |
| 90 | 0.16149 | 305.07 | 334.14 | 1.2339 | 0.14504 | 304.92 | 333.93 | 1.2249 | 0.12038 | 304.60 | 333.49 | 1.2092 |
| 100 | 0.16622 | 313.88 | 343.80 | 1.2602 | 0.14933 | 313.74 | 343.60 | 1.2512 | 0.12398 | 313.44 | 343.20 | 1.2356 |

**END OF PAPER**

April/May 2018



Q1)



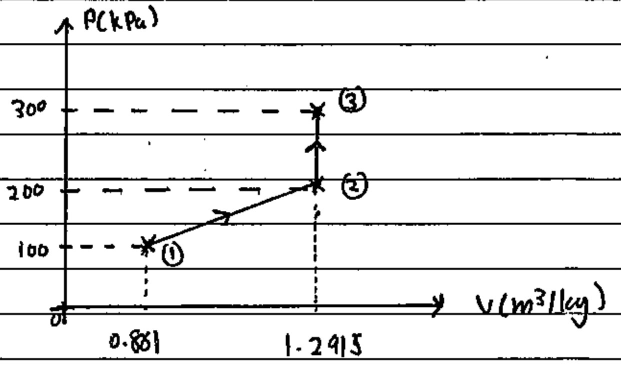

2kg

$R = 0.287$ kJ/kg·K

$C_v = 0.718$ kJ/kg·K

$P_1 = 100$ kPa

$T = 300$ K




State ②: $P_2 = 200$ kPa, $V_2 = 1.5V_1$

State ③: $V_3 = V_2$, $P_3 = 300$ kPa

(b) $pV = nRT$

$pV = mR_mT$

$V_1 = \frac{mR_mT}{p}$

$\therefore V_1 = \frac{2(0.287)(300)}{100}$

$= 1.722 m^3$

$V_2 = 1.5V_1 = 2.583 m^3$

$= V_3$

$v_1 = \frac{V_1}{m} = \frac{1.722}{2} = 0.861$ m³/kg

$v_2 = v_3 = \frac{2.583}{2} = 1.2915$ m³/kg

$\therefore T = \frac{pV}{mR_m}$

Hence at intermediate state, $T_2 = \frac{(200)(2.583)}{2(0.287)}$

$= 900$ K

final temperature, $T_3 = \frac{300(2.583)}{2(0.287)}$

$= 1350$ K

(c) W for expansion = Area under curve

$= 2(1.2915 - 0.861)\left(\frac{200+100}{2}\right)$

$= 129.15$ kJ

Q to raise T $= C_v(m)(\Delta T)$

$= 0.718(2)(1350 - 300)$

$= 1507.8$ kJ

$\therefore$ Total heat to reach final state = Work to expand against atmosphere + spring + Q to raise T

$= 129.15 + 1507.8$

$= 1636.95$ kJ

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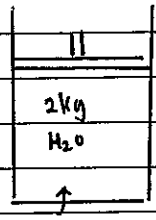
(d)




100 kPa 30°C

at 30°C, $u_1 = 125.73$ kJ/kg
$v_1 = v_f = 0.001004$ kJ/kg } ~~compressed liquid.~~

as piston is free moving, it expands at constant pressure of 100 kPa.

at 100kPa, $v_f = 0.001043$ m³/kg

State ② $v_g = 1.6941$ m³/kg.

~~xxx~~ quality, x $u_f = 417.40$ kJ/kg

$P_2 = 100$kPa $u_g = 2505.6$ kJ/kg

∴ Work done against atmosphere $= p\Delta V$

$= 100(2)(v_2 - v_1)$

$= 200(0.001043 + x(1.6941 - 0.001043) - 0.001004)$

$= 200(3.9\times10^{-5} + 1.693057x)$

$\Delta U = U_2 - U_1$

$= 2(417.40 + x(2505.6 - 417.40) - 125.73)$

$= 2(291.67 + 2088.2x)$

∴ total $Q = p\Delta V + \Delta U$

$1636.95 = 200(3.9\times10^{-5} + 1.693057x) + 2(291.67 + 2088.2x)$

$1636.95 = 0.0078 + 338.6114x + 583.34 + 4176.4x$

$x = 0.23335$

∴ Work done $= 200[3.9\times10^{-5} + 1.693057(0.23335)]$

$= 79.024 \approx 79.0$ kJ (+ve as expansion)

as $x = 0.233$ ⇒ final state in saturated liquid-vapor mixture.

∴ $P_2 = 100$kPa $T_2 = 99.61$°C

(e) When same amount of heat is added to 2kg of R-134a at 100kPa and 30°C, the heat will cause the piston to expand at constant ~~xxxx~~ pressure against atmosphere, as well as result in a increase in internal energy, u.

at 100kPa, $T_{sat} = -26.37$°C. Hence, as $T > T_{sat}$, initial state of R-134a would be ~~x~~ superheated vapour. We would thus also expect final state to be in superheated vapour region.

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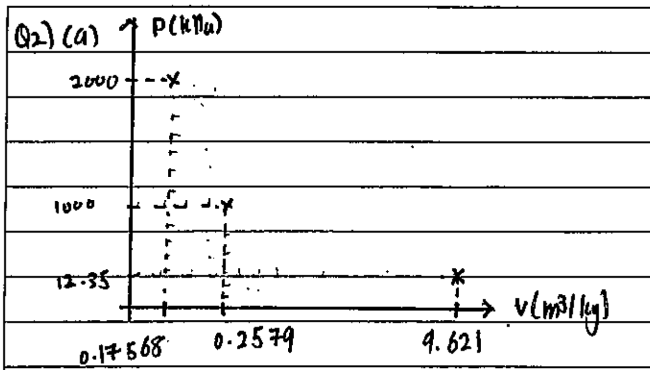
(2)

Q2) (a)




① 20 bar = 2000 kPa, $T_1$ = 500°C, $\dot{m}_1$ = 20 kg/s → $v_1$ = 0.17568 m³/kg, $h_1$ = 3468.3 kJ/kg

② 10 bar = 1000 kPa, $T_2$ = 300°C, $\dot{m}_2$ = 10 kg/s → $v_2$ = 0.25794 m³/kg, $h_2$ = 3051.6 kJ/kg

③ $T_3$ = 50°C, x = 0.80 → $v_3$ = 4.621 m³/kg, $h_3$ = 2114.408 m³/kg

(b) $\dot{Q} - \dot{W} = \dot{m}(\Delta h + \Delta KE + \Delta PE)$.

Assuming no heat loss and no change in KE and PE,

$-\dot{W} = \dot{m}(\Delta h)$

$\dot{W} = -\sum \dot{m}(\Delta h)$

$= -[10(3051.6) + (10)(2114.908) - 20(3468.3)]$

$= 17700\,W$

$\approx 17.7\,kW$

+ve $\dot{W}$ indicate output, ∴ power output = 17.7 kW

(c) saturated liquid at 10 bar ⇒ $P_4$ = 1000 kPa

x = 0

$h_4 = h_f$ = 762.51 kJ/kg.

$\dot{Q} - \dot{W} = \dot{m}(\Delta h + \Delta KE + \Delta PE)$

$\dot{Q} = \dot{m}\Delta h$

$= 10(762.51 - 3051.6)$

$= -22\,840\,J$ (-ve as heat loss)

∴ Total heat provided = 22.4 kJ

ratio = $\frac{17.7}{22.84} \times 100\%$

= 77.32 ≈ 77.3%

(d) now, ② $P_2$ = 1600 kPa, $T_2$ = 400°C → h = 3254.4 kJ/kg

∴ power output, $\dot{W} = -\sum \dot{m}\Delta h$

$= -[10(3254.4) + 10(2114.408) - 20(3468.3)]$

= 15.667 kW

heat output = 10(762.51 − 3254.4) = −24.923 kJ.

∴ ratio = (15.667)/(24.923) × 100% = 62.863

≈ 62.8%

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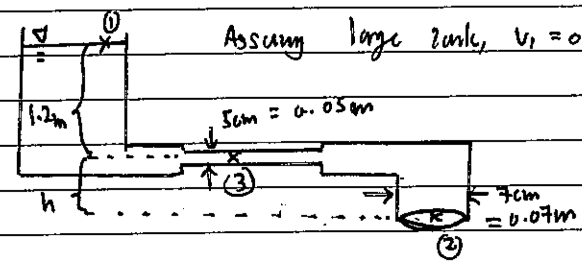
Q3) (a)




Assume large tank, $V_1 = 0$

$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$

$\rho g(1.2+h) = \frac{1}{2}\rho V_2^2$

$2g(1.2+h) = V_2^2$

$V_2 = \sqrt{2g(1.2+h)}$

By conservation of mass,

$A_2 V_2 = A_3 V_3$

$\pi\left(\frac{D}{2}\right)^2 V_2 = \pi\left(\frac{D_3}{2}\right)^2 V_3$

$D^2 V_2 = D_3^2 V_3$

$V_3 = V_2\left(\frac{D_2}{D_3}\right)^2 = \sqrt{2g(1.2+h)}\left(\frac{D_2}{D_3}\right)^2$

relating point ② and ③,

$P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2 = P_3 + \frac{1}{2}\rho V_3^2 + \rho g h_3$

$(P_2 - P_3) + \frac{1}{2}\rho V_2^2 = \frac{1}{2}\rho V_3^2 + \rho g h$

$50\times10^3 + \frac{1}{2}(1000)\left(\sqrt{2g(1.2+h)}\right)^2 = \frac{1}{2}(1000)\left[\sqrt{2g(1.2+h)}\left(\frac{0.07}{0.05}\right)^2\right]^2 + 1000(9.81)h$

$50\times10^3 + 500(19.62(1.2+h)) = 500[19.62(1.2+h)(3.8416)] + 9810h$

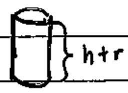
$50\times10^3 + 9810(1.2+h) - 37686(1.2+h) - 9810h = 0$

solving for h, $h = 0.439123$

$\approx 0.439\,m$

(b) 40 tonnes = 40 000 kg

upthrust will be due to volume of displaced fluid.




$\therefore \sum F_y = 0.$

$U - W = 0$

$W = U$

$40\,000(9.81) = \rho g \forall$

$40\,000(9.81) = 1000(9.81)\left(\pi(2.5)^2(h+2.5) - \frac{1}{2}\left(\frac{4}{3}\right)\pi(2.5)^3\right)$

$40 = 6.25\pi(h+2.5) - 32.7249$

$h + 2.5 = 3.7038$

$h = 1.2038$

$\approx 1.20\,m$

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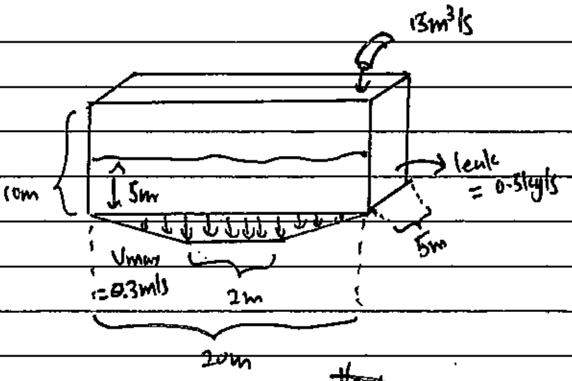
③

Q4) (a)

$\frac{d}{dt}\int_{cv} \rho \, d\forall + \int_{cs} \rho V\cdot n \, dA = 0$

$\frac{d}{dt}\int_{cv} \rho \, d\forall + \int_{in} \rho(-V_{in})\, dA + \int_{out} \rho (V_{out}) dA + 0.5 = 0$




Hence,

$\frac{d}{dt}\int_{cv} \rho \, d\forall = \int_{in} \rho V_{in} \, dA - \int_{out} \rho V_{out} \, dA - 0.5 \quad -①$

Average $V_{out(Avg)} = \frac{2\times 0.3 + \frac{1}{2}\times 18 \times 0.3}{20}$

$= 0.165 \text{ m/s}$

$\forall_{water} = 20 \times 5 \times 5 = 500 \text{ m}^3$

Hence from ①, $\frac{d}{dt}\int_{cv} \rho \, d\forall = \int_{in} \rho V_{in} \, dA - \int_{out} \rho V_{out(Avg)} \, dA - 0.5$

$= \rho V_{in} A - \rho V_{out(Avg)} A - 0.5$

$= 1000(13) - 1000(0.165)(20\times 5) - 0.5$

$= -1500.5 \text{ kg/s}$

Hence, water in tank is decreasing

$\frac{d}{dt}\int_{cv} \rho \, d\forall = -1500.5$

$\rho \int_{500}^{0} d\forall = \int_0^t -1500.5 \, dt$

$1000(-500) = -1500.5t$

$t = 333.222$

$\approx 333 s$

**DISCLAIMER:** *The solutions are done by students who scored A or above in this subject. MAE Club and Campus supplies are not liable or responsible for any errors in the contents of these solutions. Students are advised to take the solutions as a guide rather than absolute answers to exam paper.*

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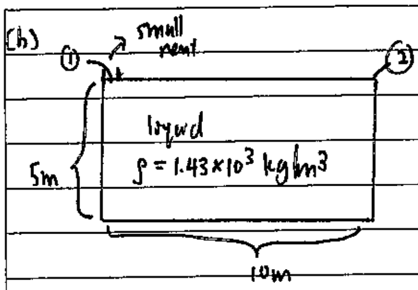
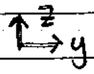
(b)




$$\frac{\partial p}{\partial x} = -\rho a_x \qquad \frac{\partial p}{\partial y} = -\rho a_y \qquad \frac{\partial p}{\partial z} = -\rho(g + a_z)$$

$$\therefore\ \partial p = \frac{\partial p}{\partial x}\partial x + \frac{\partial p}{\partial y}\partial y + \frac{\partial p}{\partial z}\partial z$$

$$\partial p = -\rho a_y dy - \rho(g + a_z) dz$$




$$= -\rho a_y dy - \rho g\, dz \quad (\text{as } a_z = 0)$$

As liquid is trapped it will not be able to shift within the container. Hence, for liquid to vaporize, it will need to drop from Patm to 30kPa. Hence, the location to vaporize first will need to have the lowest ~~pressure~~ initial pressure.
Thus top right corner will vaporize first, as pressure at bottom is higher due to mass of liquid, while top left will always be Patm.

Hence, from $\partial p = -\rho a_y dy - \rho g\, dz$, taking ① as reference.

$$P_1 - P_2 = -\rho a_y (y_1 - y_2) - \rho g (z_1 - z_2)$$

$$(101.3 - 30)\times1000 = -\rho a_y (0 - 10) - 0$$

$$71300 = -1.43\times10^3 (-10)\, a_y$$

$$a_y = 4.98601$$

$\approx$ **4.99 m/s²** (rightwards as we define positive $y$ in right)

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***Should there be any mistake identified, please proceed to the Facebook link encoded in the QR code to feedback or submit correct answers. The link is: http://bit.ly/2lW2C32***

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**NANYANG TECHNOLOGICAL UNIVERSITY**

**SEMESTER 1 EXAMINATION 2018-2019**

**MA2003 – INTRODUCTION TO THERMO-FLUIDS**

November/December 2018 Time allowed: 2½ hours

**INSTRUCTIONS**

1. This paper contains **FOUR (4)** questions and comprises **ELEVEN (11)** pages including **SIX (6)** pages of Appendices.
2. Answer **ALL FOUR** questions.
3. This is a **CLOSED-BOOK** examination.
4. Marks for each question are as indicated.
5. Relevant Thermodynamics tables and formulas for second moment of inertia are provided in the Appendix (pages 6 to 11).

---

1. The pressurized tank as shown in Figure 1 consists of two subsystems A and B. The tank is completely insulated. The cylindrical shaped subsystem A is a piston-cylinder-spring-stopper arrangement and initially contains 0.1 $m^3$ of liquid – vapour mixture with a quality of 70 percent at the pressure of 1000 kPa. The frictionless piston is free to move and has a cross-sectional area of 0.2 $m^2$. The semi-sphere-shaped subsystem B is filled with 2 kg of air at the pressure and temperature of 1000 kPa and 450 K, respectively. There is a partition between subsystems A and B. Air and water cannot pass through the partition. In the subsystem A, the heavy piston sits on the stopper and a spring with the spring constant of 200 kN/m is attached on the piston from the top of the cylinder (Fig. 1). The subsystem A is now brought in thermal contact with a heat source of $\boldsymbol{Q}$. The piston does not move initially even though the $\boldsymbol{Q}$ amount of heat is applied to the subsystem A. When the pressure of the subsystem A reaches 1500 kPa, the piston moves up and compresses the spring. The final pressure of subsystem A is found to be 2000 kPa. 1/4 of total heat $\boldsymbol{Q}$ is transferred from subsystem A to subsystem B through the partition. You may assume air as ideal gas. For air, the ideal gas constant (R) and the specific heat at constant volume (cv) are given as 0.287 kJ/kg.K and 0.721 kJ/kg.K.

(a) Calculate the initial temperature and mass of water-vapour mixture at subsystem A. (3 marks)

(b) Calculate the distance travelled by the piston from initial to final state. (3 marks)

Note: Question 1 continues on page 2.
Figure 1 appears on page 2.



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(c) Calculate the work done by subsystem A up to its final state. Show the process in P-v diagram

(8 marks)

(d) Calculate the amount of heat, $Q$. to the system. What is the final temperature of subsystem A?

(8 marks)

(e) What are the final temperature and pressure of subsystem B? (8 marks)

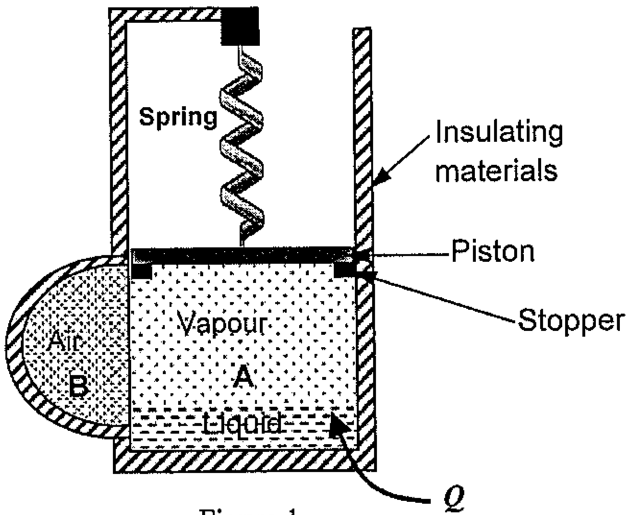


Figure 1

2. In a steam power plant, the steam is generated from the Boiler, and a throttling valve is used to control the flow of steam to the turbine as shown schematically in Figure 2. At first, the steam enters into the throttling valve with pressure and temperature of 6 MPa and 500 °C, respectively (point 1), and leaves at the pressure of 3 MPa (point 2). The heat loss from the throttling valve is negligible. Next, the steam directly goes to the adiabatic steam turbine, where the steam expands up to the final pressure of 100 kPa under saturated vapour conditions (point 3). The kinetic and potential energy changes throughout the process are negligible. The pressure drops and heat loss at the connection between main components are also negligible. All state points are shown in Figure 2.

(a) Calculate the temperature at state point 2. (5 marks)

(b) Calculate the amount of power generated by the turbine in terms of kJ/kg. (5 marks)

(c) If the flow velocities at the inlet and outlet of the turbine are same, determine the required ratio of pipe cross-sectional area between the outlet and the inlet of the turbine ($A_o/A_i$).

(5 marks)

(d) Show the state points on T-v diagram. (5 marks)

Note: Figure 2 appears on page 3.

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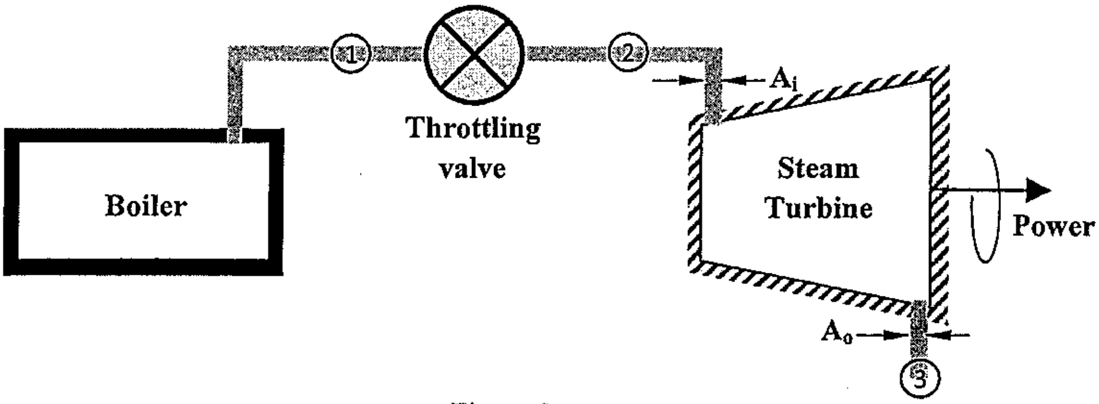


Figure 2

3. A 1-m-wide (dimension into paper) tank is fully filled with water of density $\rho$ up to the small opening at the top right surface exposed to the atmosphere as shown in Figure 3.

(a) Assume that the tank is at rest. In terms of the given parameters, determine:

(i) The magnitude and location of the total horizontal force, $F_H$ and $h$, exerted by the water on the surface AB, and

(5 marks)

(ii) The magnitude and location of the total vertical force, $F_V$ and $l$, exerted by the water on the surface AB.

(5 marks)

(b) Assume that the tank now moves horizontally at a constant acceleration $a_x$. In terms of the given parameters, determine:

(i) Pressures at A and B (gauge), (2 marks)

(ii) The total horizontal and vertical forces $F_H$ and $F_V$ on surface AB. (6 marks)

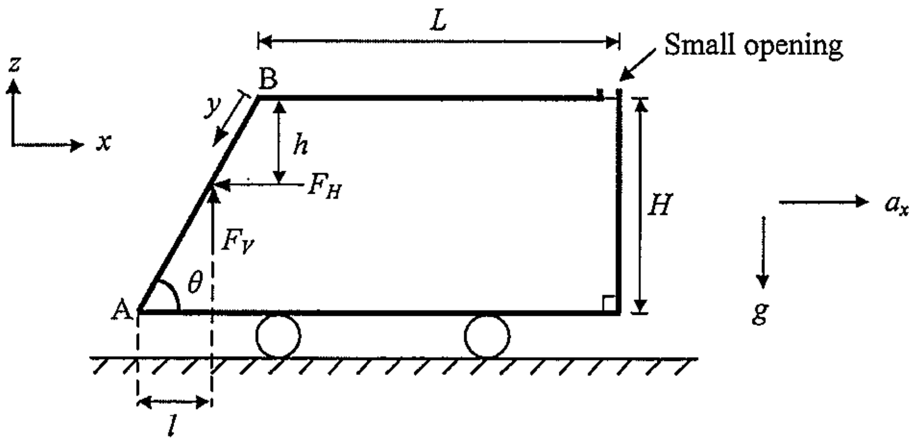


Figure 3

Note: Question 3 continues on page 4



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(c) A block with density $\rho_b$ and dimensions shown in Figure 4 is partially submerged in a fluid of density $\rho_w$.

(i) Determine the height $H$ in terms of the given parameters

(3 marks)

(ii) Determine the ratio of $\rho_b/\rho_w$ in order to obtain a stable configuration. Please provide necessary calculations to justify your answer.

(4 marks)

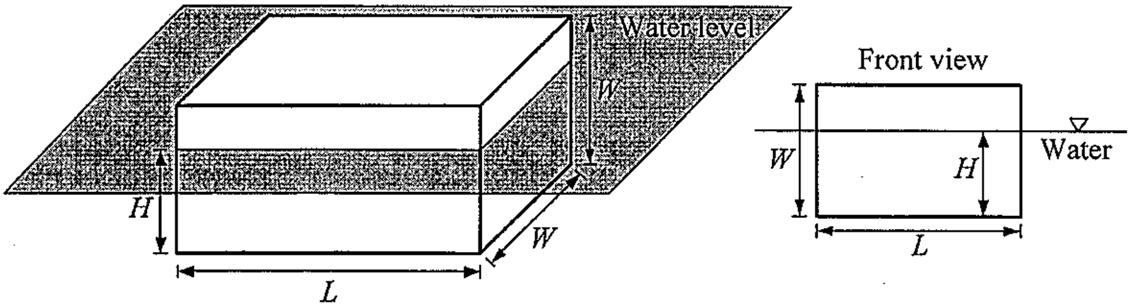


Figure 4

4 (a) Water of density $\rho$ is flowing through 2 channels as shown in Figure 5 (left). A triangular wedge is placed between the two channels such that the water from the top and bottom channels do not mix. The triangular compartment above the wedge connected to the top channel through a small opening is fully filled with water at rest. The channels and wedge all have rectangular cross section area with width of (dimension into paper) 1 m. The flow is assumed to be steady and ideal. The velocity across the section area is uniform. The net vertical force exerted by the water on the wedge is zero.

(i) Determine the velocity $V_3$ in terms of $V_1$, $L_1$, and $L_3$. (2 marks)

(ii) Determine the gauge pressure at the bottom surface of the wedge in terms of $V_1$, $L_1$, $L_3$, $\rho$, and $g$.

(3 marks)

(iii) Determine the velocity $V_4$ in terms of $V_1$, $L_1$, $L_2$, $L_3$, $L_4$, $H$, and $g$.

(8 marks)

Please draw your streamlines and show your working clearly in your answer book.

Note: Question 4 continues on page 5.
Figure 5 appears on page 5.

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The system is used to water the plant as shown in Figure 5 (right). The total mass of the water in flowerpot is defined as $M$. While the channels continuously infuse water into the flowerpot, the plant absorbs the water at the rate $\dot{m}_p = C_0 - C_1 e^{-M/\tau}$ and the water inside the flowerpot evaporates at the rate $\dot{m}_v = C_2 M$. At time $t = 0$, the soil in the flowerpot contains water of mass $M_0$. The water starts to leak out from the small opening when the mass of the water insides flowerpot reaches $M_1$ ($M_1 > M_0$). Note that $C_0$, $C_1$, $C_2$ and $\tau$ are constants.

(b) In terms of $V_3$, $V_4$, and the given parameters,

(i) determine the time taken for the mass in the flowerpot from $t = 0$ to reach $M_1$,

(4 marks)

(ii) if the system reaches a steady state at $M = M_2$, where $M_2 > M_1$, determine $\dot{m}_e$,

(4 marks)

(iii) if the channels stop providing water at the point where $M = M_2$, determine the total time taken for the mass in the flowerpot to reach $0.1\ M_0$. You may assume $\dot{m}_e$ is a constant when $M > M_1$.

(4 marks)

Wherever applicable, you are not required to solve the integrals. Please leave your solutions in integral form with the integration limits clearly written.

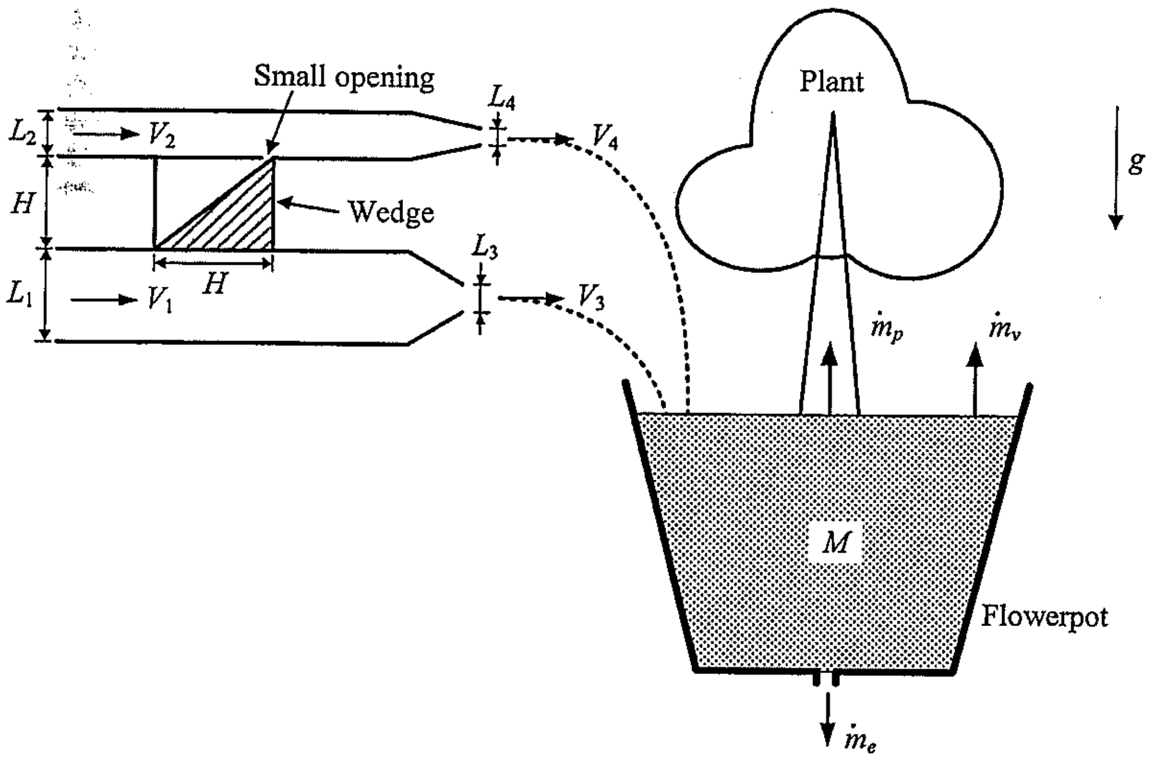


Figure 5



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# APPENDIX

## Table 1- Pressure Table for water

Saturated water—Pressure table

| | | Specific volume, $m^3/kg$ | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg · K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Press., $P$ kPa | Sat. temp., $T_{sat}$ °C | 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, $s_g$ |
| 1.0 | 6.97 | 0.001000 | 129.19 | 29.302 | 2355.2 | 2384.5 | 29.303 | 2484.4 | 2513.7 | 0.1059 | 8.8690 | 8.9749 |
| 1.5 | 13.02 | 0.001001 | 87.964 | 54.686 | 2338.1 | 2392.8 | 54.688 | 2470.1 | 2524.7 | 0.1956 | 8.6314 | 8.8270 |
| 2.0 | 17.50 | 0.001001 | 66.990 | 73.431 | 2325.5 | 2398.9 | 73.433 | 2459.5 | 2532.9 | 0.2606 | 8.4621 | 8.7227 |
| 2.5 | 21.08 | 0.001002 | 54.242 | 88.422 | 2315.4 | 2403.8 | 88.424 | 2451.0 | 2539.4 | 0.3118 | 8.3302 | 8.6421 |
| 3.0 | 24.08 | 0.001003 | 45.654 | 100.98 | 2306.9 | 2407.9 | 100.98 | 2443.9 | 2544.8 | 0.3543 | 8.2222 | 8.5765 |
| 4.0 | 28.96 | 0.001004 | 34.791 | 121.39 | 2293.1 | 2414.5 | 121.39 | 2432.3 | 2553.7 | 0.4224 | 8.0510 | 8.4734 |
| 5.0 | 32.87 | 0.001005 | 28.185 | 137.75 | 2282.1 | 2419.8 | 137.75 | 2423.0 | 2560.7 | 0.4762 | 7.9176 | 8.3938 |
| 7.5 | 40.29 | 0.001008 | 19.233 | 168.74 | 2261.1 | 2429.8 | 168.75 | 2405.3 | 2574.0 | 0.5763 | 7.6738 | 8.2501 |
| 10 | 45.81 | 0.001010 | 14.670 | 191.79 | 2245.4 | 2437.2 | 191.81 | 2392.1 | 2583.9 | 0.6492 | 7.4996 | 8.1488 |
| 15 | 53.97 | 0.001014 | 10.020 | 225.93 | 2222.1 | 2448.0 | 225.94 | 2372.3 | 2598.3 | 0.7549 | 7.2522 | 8.0071 |
| 20 | 60.06 | 0.001017 | 7.6481 | 251.40 | 2204.6 | 2456.0 | 251.42 | 2357.5 | 2608.9 | 0.8320 | 7.0752 | 7.9073 |
| 25 | 64.96 | 0.001020 | 6.2034 | 271.93 | 2190.4 | 2462.4 | 271.96 | 2345.5 | 2617.5 | 0.8932 | 6.9370 | 7.8302 |
| 30 | 69.09 | 0.001022 | 5.2287 | 289.24 | 2178.5 | 2467.7 | 289.27 | 2335.3 | 2624.6 | 0.9441 | 6.8234 | 7.7675 |
| 40 | 75.86 | 0.001026 | 3.9933 | 317.58 | 2158.8 | 2476.3 | 317.62 | 2318.4 | 2636.1 | 1.0261 | 6.6430 | 7.6691 |
| 50 | 81.32 | 0.001030 | 3.2403 | 340.49 | 2142.7 | 2483.2 | 340.54 | 2304.7 | 2645.2 | 1.0912 | 6.5019 | 7.5931 |
| 75 | 91.76 | 0.001037 | 2.2172 | 384.36 | 2111.8 | 2496.1 | 384.44 | 2278.0 | 2662.4 | 1.2132 | 6.2426 | 7.4558 |
| 100 | 99.61 | 0.001043 | 1.6941 | 417.40 | 2088.2 | 2505.6 | 417.51 | 2257.5 | 2675.0 | 1.3028 | 6.0562 | 7.3589 |
| 101.325 | 99.97 | 0.001043 | 1.6734 | 418.95 | 2087.0 | 2506.0 | 419.06 | 2256.5 | 2675.6 | 1.3069 | 6.0476 | 7.3545 |
| 125 | 105.97 | 0.001048 | 1.3750 | 444.23 | 2068.8 | 2513.0 | 444.36 | 2240.6 | 2684.9 | 1.3741 | 5.9100 | 7.2841 |
| 150 | 111.35 | 0.001053 | 1.1594 | 466.97 | 2052.3 | 2519.2 | 467.13 | 2226.0 | 2693.1 | 1.4337 | 5.7894 | 7.2231 |
| 175 | 116.04 | 0.001057 | 1.0037 | 486.82 | 2037.7 | 2524.5 | 487.01 | 2213.1 | 2700.2 | 1.4850 | 5.6865 | 7.1716 |
| 200 | 120.21 | 0.001061 | 0.88578 | 504.50 | 2024.6 | 2529.1 | 504.71 | 2201.6 | 2706.3 | 1.5302 | 5.5968 | 7.1270 |
| 225 | 123.97 | 0.001064 | 0.79329 | 520.47 | 2012.7 | 2533.2 | 520.71 | 2191.0 | 2711.7 | 1.5706 | 5.5171 | 7.0877 |
| 250 | 127.41 | 0.001067 | 0.71873 | 535.08 | 2001.8 | 2536.8 | 535.35 | 2181.2 | 2716.5 | 1.6072 | 5.4453 | 7.0525 |
| 275 | 130.58 | 0.001070 | 0.65732 | 548.57 | 1991.6 | 2540.1 | 548.86 | 2172.0 | 2720.9 | 1.6408 | 5.3800 | 7.0207 |
| 300 | 133.52 | 0.001073 | 0.60582 | 561.11 | 1982.1 | 2543.2 | 561.43 | 2163.5 | 2724.9 | 1.6717 | 5.3200 | 6.9917 |
| 325 | 136.27 | 0.001076 | 0.56199 | 572.84 | 1973.1 | 2545.9 | 573.19 | 2155.4 | 2728.6 | 1.7005 | 5.2645 | 6.9650 |
| 350 | 138.86 | 0.001079 | 0.52422 | 583.89 | 1964.6 | 2548.5 | 584.26 | 2147.7 | 2732.0 | 1.7274 | 5.2128 | 6.9402 |
| 375 | 141.30 | 0.001081 | 0.49133 | 594.32 | 1956.6 | 2550.9 | 594.73 | 2140.4 | 2735.1 | 1.7526 | 5.1645 | 6.9171 |
| 400 | 143.61 | 0.001084 | 0.46242 | 604.22 | 1948.9 | 2553.1 | 604.66 | 2133.4 | 2738.1 | 1.7765 | 5.1191 | 6.8955 |
| 450 | 147.90 | 0.001088 | 0.41392 | 622.65 | 1934.5 | 2557.1 | 623.14 | 2120.3 | 2743.4 | 1.8205 | 5.0356 | 6.8561 |
| 500 | 151.83 | 0.001093 | 0.37483 | 639.54 | 1921.2 | 2560.7 | 640.09 | 2108.0 | 2748.1 | 1.8604 | 4.9603 | 6.8207 |
| 550 | 155.46 | 0.001097 | 0.34261 | 655.16 | 1908.8 | 2563.9 | 655.77 | 2096.6 | 2752.4 | 1.8970 | 4.8916 | 6.7886 |
| 600 | 158.83 | 0.001101 | 0.31560 | 669.72 | 1897.1 | 2566.8 | 670.38 | 2085.8 | 2756.2 | 1.9308 | 4.8285 | 6.7593 |
| 650 | 161.98 | 0.001104 | 0.29260 | 683.37 | 1886.1 | 2569.4 | 684.08 | 2075.5 | 2759.6 | 1.9623 | 4.7699 | 6.7322 |
| 700 | 164.95 | 0.001108 | 0.27278 | 696.23 | 1875.6 | 2571.8 | 697.00 | 2065.8 | 2762.8 | 1.9918 | 4.7153 | 6.7071 |
| 750 | 167.75 | 0.001111 | 0.25552 | 708.40 | 1865.6 | 2574.0 | 709.24 | 2056.4 | 2765.7 | 2.0195 | 4.6642 | 6.6837 |

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Saturated water—Pressure table (*Continued*)

| | | *Specific volume,* m³/kg | | *Internal energy,* kJ/kg | | | *Enthalpy,* kJ/kg | | | *Entropy,* kJ/kg · K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Press., *P* kPa | Sat. temp., $T_{sat}$ °C | 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, $s_g$ |
| 800 | 170.41 | 0.001115 | 0.24035 | 719.97 | 1856.1 | 2576.0 | 720.87 | 2047.5 | 2768.3 | 2.0457 | 4.6160 | 6.6616 |
| 850 | 172.94 | 0.001118 | 0.22690 | 731.00 | 1846.9 | 2577.9 | 731.95 | 2038.8 | 2770.8 | 2.0705 | 4.5705 | 6.6409 |
| 900 | 175.35 | 0.001121 | 0.21489 | 741.55 | 1838.1 | 2579.6 | 742.56 | 2030.5 | 2773.0 | 2.0941 | 4.5273 | 6.6213 |
| 950 | 177.66 | 0.001124 | 0.20411 | 751.67 | 1829.6 | 2581.3 | 752.74 | 2022.4 | 2775.2 | 2.1166 | 4.4862 | 6.6027 |
| 1000 | 179.88 | 0.001127 | 0.19436 | 761.39 | 1821.4 | 2582.8 | 762.51 | 2014.6 | 2777.1 | 2.1381 | 4.4470 | 6.5850 |
| 1100 | 184.06 | 0.001133 | 0.17745 | 779.78 | 1805.7 | 2585.5 | 781.03 | 1999.6 | 2780.7 | 2.1785 | 4.3735 | 6.5520 |
| 1200 | 187.96 | 0.001138 | 0.16326 | 796.96 | 1790.9 | 2587.8 | 798.33 | 1985.4 | 2783.8 | 2.2159 | 4.3058 | 6.5217 |
| 1300 | 191.60 | 0.001144 | 0.15119 | 813.10 | 1776.8 | 2589.9 | 814.59 | 1971.9 | 2786.5 | 2.2508 | 4.2428 | 6.4936 |
| 1400 | 195.04 | 0.001149 | 0.14078 | 828.35 | 1763.4 | 2591.8 | 829.96 | 1958.9 | 2788.9 | 2.2835 | 4.1840 | 6.4675 |
| 1500 | 198.29 | 0.001154 | 0.13171 | 842.82 | 1750.6 | 2593.4 | 844.55 | 1946.4 | 2791.0 | 2.3143 | 4.1287 | 6.4430 |
| 1750 | 205.72 | 0.001166 | 0.11344 | 876.12 | 1720.6 | 2596.7 | 878.16 | 1917.1 | 2795.2 | 2.3844 | 4.0033 | 6.3877 |
| 2000 | 212.38 | 0.001177 | 0.099587 | 906.12 | 1693.0 | 2599.1 | 908.47 | 1889.8 | 2798.3 | 2.4467 | 3.8923 | 6.3390 |
| 2250 | 218.41 | 0.001187 | 0.088717 | 933.54 | 1667.3 | 2600.9 | 936.21 | 1864.3 | 2800.5 | 2.5029 | 3.7926 | 6.2954 |
| 2500 | 223.95 | 0.001197 | 0.079952 | 958.87 | 1643.2 | 2602.1 | 961.87 | 1840.1 | 2801.9 | 2.5542 | 3.7016 | 6.2558 |
| 3000 | 233.85 | 0.001217 | 0.066667 | 1004.6 | 1598.5 | 2603.2 | 1008.3 | 1794.9 | 2803.2 | 2.6454 | 3.5402 | 6.1856 |
| 3500 | 242.56 | 0.001235 | 0.057061 | 1045.4 | 1557.6 | 2603.0 | 1049.7 | 1753.0 | 2802.7 | 2.7253 | 3.3991 | 6.1244 |
| 4000 | 250.35 | 0.001252 | 0.049779 | 1082.4 | 1519.3 | 2601.7 | 1087.4 | 1713.5 | 2800.8 | 2.7966 | 3.2731 | 6.0696 |
| 5000 | 263.94 | 0.001286 | 0.039448 | 1148.1 | 1448.9 | 2597.0 | 1154.5 | 1639.7 | 2794.2 | 2.9207 | 3.0530 | 5.9737 |
| 6000 | 275.59 | 0.001319 | 0.032449 | 1205.8 | 1384.1 | 2589.9 | 1213.8 | 1570.9 | 2784.6 | 3.0275 | 2.8627 | 5.8902 |
| 7000 | 285.83 | 0.001352 | 0.027378 | 1258.0 | 1323.0 | 2581.0 | 1267.5 | 1505.2 | 2772.6 | 3.1220 | 2.6927 | 5.8148 |
| 8000 | 295.01 | 0.001384 | 0.023525 | 1306.0 | 1264.5 | 2570.5 | 1317.1 | 1441.6 | 2758.7 | 3.2077 | 2.5373 | 5.7450 |
| 9000 | 303.35 | 0.001418 | 0.020489 | 1350.9 | 1207.6 | 2558.5 | 1363.7 | 1379.3 | 2742.9 | 3.2866 | 2.3925 | 5.6791 |
| 10,000 | 311.00 | 0.001452 | 0.018028 | 1393.3 | 1151.8 | 2545.2 | 1407.8 | 1317.6 | 2725.5 | 3.3603 | 2.2556 | 5.6159 |
| 11,000 | 318.08 | 0.001488 | 0.015988 | 1433.9 | 1096.6 | 2530.4 | 1450.2 | 1256.1 | 2706.3 | 3.4299 | 2.1245 | 5.5544 |
| 12,000 | 324.68 | 0.001526 | 0.014264 | 1473.0 | 1041.3 | 2514.3 | 1491.3 | 1194.1 | 2685.4 | 3.4964 | 1.9975 | 5.4939 |
| 13,000 | 330.85 | 0.001566 | 0.012781 | 1511.0 | 985.5 | 2496.6 | 1531.4 | 1131.3 | 2662.7 | 3.5606 | 1.8730 | 5.4336 |
| 14,000 | 336.67 | 0.001610 | 0.011487 | 1548.4 | 928.7 | 2477.1 | 1571.0 | 1067.0 | 2637.9 | 3.6232 | 1.7497 | 5.3728 |
| 15,000 | 342.16 | 0.001657 | 0.010341 | 1585.5 | 870.3 | 2455.7 | 1610.3 | 1000.5 | 2610.8 | 3.6848 | 1.6261 | 5.3108 |
| 16,000 | 347.36 | 0.001710 | 0.009312 | 1622.6 | 809.4 | 2432.0 | 1649.9 | 931.1 | 2581.0 | 3.7461 | 1.5005 | 5.2466 |
| 17,000 | 352.29 | 0.001770 | 0.008374 | 1660.2 | 745.1 | 2405.4 | 1690.3 | 857.4 | 2547.7 | 3.8082 | 1.3709 | 5.1791 |
| 18,000 | 356.99 | 0.001840 | 0.007504 | 1699.1 | 675.9 | 2375.0 | 1732.2 | 777.8 | 2510.0 | 3.8720 | 1.2343 | 5.1064 |
| 19,000 | 361.47 | 0.001926 | 0.006677 | 1740.3 | 598.9 | 2339.2 | 1776.8 | 689.2 | 2466.0 | 3.9396 | 1.0860 | 5.0256 |
| 20,000 | 365.75 | 0.002038 | 0.005862 | 1785.8 | 509.0 | 2294.8 | 1826.6 | 585.5 | 2412.1 | 4.0146 | 0.9164 | 4.9310 |
| 21,000 | 369.83 | 0.002207 | 0.004994 | 1841.6 | 391.9 | 2233.5 | 1888.0 | 450.4 | 2338.4 | 4.1071 | 0.7005 | 4.8076 |
| 22,000 | 373.71 | 0.002703 | 0.003644 | 1951.7 | 140.8 | 2092.4 | 2011.1 | 161.5 | 2172.6 | 4.2942 | 0.2496 | 4.5439 |
| 22,064 | 373.95 | 0.003106 | 0.003106 | 2015.7 | 0 | 2015.7 | 2084.3 | 0 | 2084.3 | 4.4070 | 0 | 4.4070 |

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# Table 2- Superheated vapour Table for water

Superheated water (*Continued*)

| T °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 | v m³/kg | u kJ/kg | h kJ/kg | s kJ/kg · K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *P* = 1.00 MPa (179.88°C) | | | | *P* = 1.20 MPa (187.96°C) | | | | *P* = 1.40 MPa (195.04°C) | | | |
| Sat. | 0.19437 | 2582.8 | 2777.1 | 6.5850 | 0.16326 | 2587.8 | 2783.8 | 6.5217 | 0.14078 | 2591.8 | 2788.9 | 6.4675 |
| 200 | 0.20602 | 2622.3 | 2828.3 | 6.6956 | 0.16934 | 2612.9 | 2816.1 | 6.5909 | 0.14303 | 2602.7 | 2803.0 | 6.4975 |
| 250 | 0.23275 | 2710.4 | 2943.1 | 6.9265 | 0.19241 | 2704.7 | 2935.6 | 6.8313 | 0.16356 | 2698.9 | 2927.9 | 6.7488 |
| 300 | 0.25799 | 2793.7 | 3051.6 | 7.1246 | 0.21386 | 2789.7 | 3046.3 | 7.0335 | 0.18233 | 2785.7 | 3040.9 | 6.9553 |
| 350 | 0.28250 | 2875.7 | 3158.2 | 7.3029 | 0.23455 | 2872.7 | 3154.2 | 7.2139 | 0.20029 | 2869.7 | 3150.1 | 7.1379 |
| 400 | 0.30661 | 2957.9 | 3264.5 | 7.4670 | 0.25482 | 2955.5 | 3261.3 | 7.3793 | 0.21782 | 2953.1 | 3258.1 | 7.3046 |
| 500 | 0.35411 | 3125.0 | 3479.1 | 7.7642 | 0.29464 | 3123.4 | 3477.0 | 7.6779 | 0.25216 | 3121.8 | 3474.8 | 7.6047 |
| 600 | 0.40111 | 3297.5 | 3698.6 | 8.0311 | 0.33395 | 3296.3 | 3697.0 | 7.9456 | 0.28597 | 3295.1 | 3695.5 | 7.8730 |
| 700 | 0.44783 | 3476.3 | 3924.1 | 8.2755 | 0.37297 | 3475.3 | 3922.9 | 8.1904 | 0.31951 | 3474.4 | 3921.7 | 8.1183 |
| 800 | 0.49438 | 3661.7 | 4156.1 | 8.5024 | 0.41184 | 3661.0 | 4155.2 | 8.4176 | 0.35288 | 3660.3 | 4154.3 | 8.3458 |
| 900 | 0.54083 | 3853.9 | 4394.8 | 8.7150 | 0.45059 | 3853.3 | 4394.0 | 8.6303 | 0.38614 | 3852.7 | 4393.3 | 8.5587 |
| 1000 | 0.58721 | 4052.7 | 4640.0 | 8.9155 | 0.48928 | 4052.2 | 4639.4 | 8.8310 | 0.41933 | 4051.7 | 4638.8 | 8.7595 |
| 1100 | 0.63354 | 4257.9 | 4891.4 | 9.1057 | 0.52792 | 4257.5 | 4891.0 | 9.0212 | 0.45247 | 4257.0 | 4890.5 | 8.9497 |
| 1200 | 0.67983 | 4469.0 | 5148.9 | 9.2866 | 0.56652 | 4468.7 | 5148.5 | 9.2022 | 0.48558 | 4468.3 | 5148.1 | 9.1308 |
| 1300 | 0.72610 | 4685.8 | 5411.9 | 9.4593 | 0.60509 | 4685.5 | 5411.6 | 9.3750 | 0.51866 | 4685.1 | 5411.3 | 9.3036 |
| | *P* = 1.60 MPa (201.37°C) | | | | *P* = 1.80 MPa (207.11°C) | | | | *P* = 2.00 MPa (212.38°C) | | | |
| Sat. | 0.12374 | 2594.8 | 2792.8 | 6.4200 | 0.11037 | 2597.3 | 2795.9 | 6.3775 | 0.09959 | 2599.1 | 2798.3 | 6.3390 |
| 225 | 0.13293 | 2645.1 | 2857.8 | 6.5537 | 0.11678 | 2637.0 | 2847.2 | 6.4825 | 0.10381 | 2628.5 | 2836.1 | 6.4160 |
| 250 | 0.14190 | 2692.9 | 2919.9 | 6.6753 | 0.12502 | 2686.7 | 2911.7 | 6.6088 | 0.11150 | 2680.3 | 2903.3 | 6.5475 |
| 300 | 0.15866 | 2781.6 | 3035.4 | 6.8864 | 0.14025 | 2777.4 | 3029.9 | 6.8246 | 0.12551 | 2773.2 | 3024.2 | 6.7684 |
| 350 | 0.17459 | 2866.6 | 3146.0 | 7.0713 | 0.15460 | 2863.6 | 3141.9 | 7.0120 | 0.13860 | 2860.5 | 3137.7 | 6.9583 |
| 400 | 0.19007 | 2950.8 | 3254.9 | 7.2394 | 0.16849 | 2948.3 | 3251.6 | 7.1814 | 0.15122 | 2945.9 | 3248.4 | 7.1292 |
| 500 | 0.22029 | 3120.1 | 3472.6 | 7.5410 | 0.19551 | 3118.5 | 3470.4 | 7.4845 | 0.17568 | 3116.9 | 3468.3 | 7.4337 |
| 600 | 0.24999 | 3293.9 | 3693.9 | 7.8101 | 0.22200 | 3292.7 | 3692.3 | 7.7543 | 0.19962 | 3291.5 | 3690.7 | 7.7043 |
| 700 | 0.27941 | 3473.5 | 3920.5 | 8.0558 | 0.24822 | 3472.6 | 3919.4 | 8.0005 | 0.22326 | 3471.7 | 3918.2 | 7.9509 |
| 800 | 0.30865 | 3659.5 | 4153.4 | 8.2834 | 0.27426 | 3658.8 | 4152.4 | 8.2284 | 0.24674 | 3658.0 | 4151.5 | 8.1791 |
| 900 | 0.33780 | 3852.1 | 4392.6 | 8.4965 | 0.30020 | 3851.5 | 4391.9 | 8.4417 | 0.27012 | 3850.9 | 4391.1 | 8.3925 |
| 1000 | 0.36687 | 4051.2 | 4638.2 | 8.6974 | 0.32606 | 4050.7 | 4637.6 | 8.6427 | 0.29342 | 4050.2 | 4637.1 | 8.5936 |
| 1100 | 0.39589 | 4256.6 | 4890.0 | 8.8878 | 0.35188 | 4256.2 | 4889.6 | 8.8331 | 0.31667 | 4255.7 | 4889.1 | 8.7842 |
| 1200 | 0.42488 | 4467.9 | 5147.7 | 9.0689 | 0.37766 | 4467.6 | 5147.3 | 9.0143 | 0.33989 | 4467.2 | 5147.0 | 8.9654 |
| 1300 | 0.45383 | 4684.8 | 5410.9 | 9.2418 | 0.40341 | 4684.5 | 5410.6 | 9.1872 | 0.36308 | 4684.2 | 5410.3 | 9.1384 |
| | *P* = 2.50 MPa (223.95°C) | | | | *P* = 3.00 MPa (233.85°C) | | | | *P* = 3.50 MPa (242.56°C) | | | |
| Sat. | 0.07995 | 2602.1 | 2801.9 | 6.2558 | 0.06667 | 2603.2 | 2803.2 | 6.1856 | 0.05706 | 2603.0 | 2802.7 | 6.1244 |
| 225 | 0.08026 | 2604.8 | 2805.5 | 6.2629 | | | | | | | | |
| 250 | 0.08705 | 2663.3 | 2880.9 | 6.4107 | 0.07063 | 2644.7 | 2856.5 | 6.2893 | 0.05876 | 2624.0 | 2829.7 | 6.1764 |
| 300 | 0.09894 | 2762.2 | 3009.6 | 6.6459 | 0.08118 | 2750.8 | 2994.3 | 6.5412 | 0.06845 | 2738.8 | 2978.4 | 6.4484 |
| 350 | 0.10979 | 2852.5 | 3127.0 | 6.8424 | 0.09056 | 2844.4 | 3116.1 | 6.7450 | 0.07680 | 2836.0 | 3104.9 | 6.6601 |
| 400 | 0.12012 | 2939.8 | 3240.1 | 7.0170 | 0.09938 | 2933.6 | 3231.7 | 6.9235 | 0.08456 | 2927.2 | 3223.2 | 6.8428 |
| 450 | 0.13015 | 3026.2 | 3351.6 | 7.1768 | 0.10789 | 3021.2 | 3344.9 | 7.0856 | 0.09198 | 3016.1 | 3338.1 | 7.0074 |
| 500 | 0.13999 | 3112.8 | 3462.8 | 7.3254 | 0.11620 | 3108.6 | 3457.2 | 7.2359 | 0.09919 | 3104.5 | 3451.7 | 7.1593 |
| 600 | 0.15931 | 3288.5 | 3686.8 | 7.5979 | 0.13245 | 3285.5 | 3682.8 | 7.5103 | 0.11325 | 3282.5 | 3678.9 | 7.4357 |
| 700 | 0.17835 | 3469.3 | 3915.2 | 7.8455 | 0.14841 | 3467.0 | 3912.2 | 7.7590 | 0.12702 | 3464.7 | 3909.3 | 7.6855 |
| 800 | 0.19722 | 3656.2 | 4149.2 | 8.0744 | 0.16420 | 3654.3 | 4146.9 | 7.9885 | 0.14061 | 3652.5 | 4144.6 | 7.9156 |
| 900 | 0.21597 | 3849.4 | 4389.3 | 8.2882 | 0.17988 | 3847.9 | 4387.5 | 8.2028 | 0.15410 | 3846.4 | 4385.7 | 8.1304 |
| 1000 | 0.23466 | 4049.0 | 4635.6 | 8.4897 | 0.19549 | 4047.7 | 4634.2 | 8.4045 | 0.16751 | 4046.4 | 4632.7 | 8.3324 |
| 1100 | 0.25330 | 4254.7 | 4887.9 | 8.6804 | 0.21105 | 4253.6 | 4886.7 | 8.5955 | 0.18087 | 4252.5 | 4885.6 | 8.5236 |
| 1200 | 0.27190 | 4466.3 | 5146.0 | 8.8618 | 0.22658 | 4465.3 | 5145.1 | 8.7771 | 0.19420 | 4464.4 | 5144.1 | 8.7053 |
| 1300 | 0.29048 | 4683.4 | 5409.5 | 9.0349 | 0.24207 | 4682.6 | 5408.8 | 8.9502 | 0.20750 | 4681.8 | 5408.0 | 8.8786 |

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Superheated water (*Continued*)

| T °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 | v m³/kg | u kJ/kg | h kJ/kg | s kJ/kg · K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *P* = 4.0 MPa (250.35°C) | | | | *P* = 4.5 MPa (257.44°C) | | | | *P* = 5.0 MPa (263.94°C) | | | |
| Sat. | 0.04978 | 2601.7 | 2800.8 | 6.0696 | 0.04406 | 2599.7 | 2798.0 | 6.0198 | 0.03945 | 2597.0 | 2794.2 | 5.9737 |
| 275 | 0.05461 | 2668.9 | 2887.3 | 6.2312 | 0.04733 | 2651.4 | 2864.4 | 6.1429 | 0.04144 | 2632.3 | 2839.5 | 6.0571 |
| 300 | 0.05887 | 2726.2 | 2961.7 | 6.3639 | 0.05138 | 2713.0 | 2944.2 | 6.2854 | 0.04535 | 2699.0 | 2925.7 | 6.2111 |
| 350 | 0.06647 | 2827.4 | 3093.3 | 6.5843 | 0.05842 | 2818.6 | 3081.5 | 6.5153 | 0.05197 | 2809.5 | 3069.3 | 6.4516 |
| 400 | 0.07343 | 2920.8 | 3214.5 | 6.7714 | 0.06477 | 2914.2 | 3205.7 | 6.7071 | 0.05784 | 2907.5 | 3196.7 | 6.6483 |
| 450 | 0.08004 | 3011.0 | 3331.2 | 6.9386 | 0.07076 | 3005.8 | 3324.2 | 6.8770 | 0.06332 | 3000.6 | 3317.2 | 6.8210 |
| 500 | 0.08644 | 3100.3 | 3446.0 | 7.0922 | 0.07652 | 3096.0 | 3440.4 | 7.0323 | 0.06858 | 3091.8 | 3434.7 | 6.9781 |
| 600 | 0.09886 | 3279.4 | 3674.9 | 7.3706 | 0.08766 | 3276.4 | 3670.9 | 7.3127 | 0.07870 | 3273.3 | 3666.9 | 7.2605 |
| 700 | 0.11098 | 3462.4 | 3906.3 | 7.6214 | 0.09850 | 3460.0 | 3903.3 | 7.5647 | 0.08852 | 3457.7 | 3900.3 | 7.5136 |
| 800 | 0.12292 | 3650.6 | 4142.3 | 7.8523 | 0.10916 | 3648.8 | 4140.0 | 7.7962 | 0.09816 | 3646.9 | 4137.7 | 7.7458 |
| 900 | 0.13476 | 3844.8 | 4383.9 | 8.0675 | 0.11972 | 3843.3 | 4382.1 | 8.0118 | 0.10769 | 3841.8 | 4380.2 | 7.9619 |
| 1000 | 0.14653 | 4045.1 | 4631.2 | 8.2698 | 0.13020 | 4043.9 | 4629.8 | 8.2144 | 0.11715 | 4042.6 | 4628.3 | 8.1648 |
| 1100 | 0.15824 | 4251.4 | 4884.4 | 8.4612 | 0.14064 | 4250.4 | 4883.2 | 8.4060 | 0.12655 | 4249.3 | 4882.1 | 8.3566 |
| 1200 | 0.16992 | 4463.5 | 5143.2 | 8.6430 | 0.15103 | 4462.6 | 5142.2 | 8.5880 | 0.13592 | 4461.6 | 5141.3 | 8.5388 |
| 1300 | 0.18157 | 4680.9 | 5407.2 | 8.8164 | 0.16140 | 4680.1 | 5406.5 | 8.7616 | 0.14527 | 4679.3 | 5405.7 | 8.7124 |
| | *P* = 6.0 MPa (275.59°C) | | | | *P* = 7.0 MPa (285.83°C) | | | | *P* = 8.0 MPa (295.01°C) | | | |
| Sat. | 0.03245 | 2589.9 | 2784.6 | 5.8902 | 0.027378 | 2581.0 | 2772.6 | 5.8148 | 0.023525 | 2570.5 | 2758.7 | 5.7450 |
| 300 | 0.03619 | 2668.4 | 2885.6 | 6.0703 | 0.029492 | 2633.5 | 2839.9 | 5.9337 | 0.024279 | 2592.3 | 2786.5 | 5.7937 |
| 350 | 0.04225 | 2790.4 | 3043.9 | 6.3357 | 0.035262 | 2770.1 | 3016.9 | 6.2305 | 0.029975 | 2748.3 | 2988.1 | 6.1321 |
| 400 | 0.04742 | 2893.7 | 3178.3 | 6.5432 | 0.039958 | 2879.5 | 3159.2 | 6.4502 | 0.034344 | 2864.6 | 3139.4 | 6.3658 |
| 450 | 0.05217 | 2989.9 | 3302.9 | 6.7219 | 0.044187 | 2979.0 | 3288.3 | 6.6353 | 0.038194 | 2967.8 | 3273.3 | 6.5579 |
| 500 | 0.05667 | 3083.1 | 3423.1 | 6.8826 | 0.048157 | 3074.3 | 3411.4 | 6.8000 | 0.041767 | 3065.4 | 3399.5 | 6.7266 |
| 550 | 0.06102 | 3175.2 | 3541.3 | 7.0308 | 0.051966 | 3167.9 | 3531.6 | 6.9507 | 0.045172 | 3160.5 | 3521.8 | 6.8800 |
| 600 | 0.06527 | 3267.2 | 3658.8 | 7.1693 | 0.055665 | 3261.0 | 3650.6 | 7.0910 | 0.048463 | 3254.7 | 3642.4 | 7.0221 |
| 700 | 0.07355 | 3453.0 | 3894.3 | 7.4247 | 0.062850 | 3448.3 | 3888.3 | 7.3487 | 0.054829 | 3443.6 | 3882.2 | 7.2822 |
| 800 | 0.08165 | 3643.2 | 4133.1 | 7.6582 | 0.069856 | 3639.5 | 4128.5 | 7.5836 | 0.061011 | 3635.7 | 4123.8 | 7.5185 |
| 900 | 0.08964 | 3838.8 | 4376.6 | 7.8751 | 0.076750 | 3835.7 | 4373.0 | 7.8014 | 0.067082 | 3832.7 | 4369.3 | 7.7372 |
| 1000 | 0.09756 | 4040.1 | 4625.4 | 8.0786 | 0.083571 | 4037.5 | 4622.5 | 8.0055 | 0.073079 | 4035.0 | 4619.6 | 7.9419 |
| 1100 | 0.10543 | 4247.1 | 4879.7 | 8.2709 | 0.090341 | 4245.0 | 4877.4 | 8.1982 | 0.079025 | 4242.8 | 4875.0 | 8.1350 |
| 1200 | 0.11326 | 4459.8 | 5139.4 | 8.4534 | 0.097075 | 4457.9 | 5137.4 | 8.3810 | 0.084934 | 4456.1 | 5135.5 | 8.3181 |
| 1300 | 0.12107 | 4677.7 | 5404.1 | 8.6273 | 0.103781 | 4676.1 | 5402.6 | 8.5551 | 0.090817 | 4674.5 | 5401.0 | 8.4925 |
| | *P* = 9.0 MPa (303.35°C) | | | | *P* = 10.0 MPa (311.00°C) | | | | *P* = 12.5 MPa (327.81°C) | | | |
| Sat. | 0.020489 | 2558.5 | 2742.9 | 5.6791 | 0.018028 | 2545.2 | 2725.5 | 5.6159 | 0.013496 | 2505.6 | 2674.3 | 5.4638 |
| 325 | 0.023284 | 2647.6 | 2857.1 | 5.8738 | 0.019877 | 2611.6 | 2810.3 | 5.7596 | | | | |
| 350 | 0.025816 | 2725.0 | 2957.3 | 6.0380 | 0.022440 | 2699.6 | 2924.0 | 5.9460 | 0.016138 | 2624.9 | 2826.6 | 5.7130 |
| 400 | 0.029960 | 2849.2 | 3118.8 | 6.2876 | 0.026436 | 2833.1 | 3097.5 | 6.2141 | 0.020030 | 2789.6 | 3040.0 | 6.0433 |
| 450 | 0.033524 | 2956.3 | 3258.0 | 6.4872 | 0.029782 | 2944.5 | 3242.4 | 6.4219 | 0.023019 | 2913.7 | 3201.5 | 6.2749 |
| 500 | 0.036793 | 3056.3 | 3387.4 | 6.6603 | 0.032811 | 3047.0 | 3375.1 | 6.5995 | 0.025630 | 3023.2 | 3343.6 | 6.4651 |
| 550 | 0.039885 | 3153.0 | 3512.0 | 6.8164 | 0.035655 | 3145.4 | 3502.0 | 6.7585 | 0.028033 | 3126.1 | 3476.5 | 6.6317 |
| 600 | 0.042861 | 3248.4 | 3634.1 | 6.9605 | 0.038378 | 3242.0 | 3625.8 | 6.9045 | 0.030306 | 3225.8 | 3604.6 | 6.7828 |
| 650 | 0.045755 | 3343.4 | 3755.2 | 7.0954 | 0.041018 | 3338.0 | 3748.1 | 7.0408 | 0.032491 | 3324.1 | 3730.2 | 6.9227 |
| 700 | 0.048589 | 3438.8 | 3876.1 | 7.2229 | 0.043597 | 3434.0 | 3870.0 | 7.1693 | 0.034612 | 3422.0 | 3854.6 | 7.0540 |
| 800 | 0.054132 | 3632.0 | 4119.2 | 7.4606 | 0.048629 | 3628.2 | 4114.5 | 7.4085 | 0.038724 | 3618.8 | 4102.8 | 7.2967 |
| 900 | 0.059562 | 3829.6 | 4365.7 | 7.6802 | 0.053547 | 3826.5 | 4362.0 | 7.6290 | 0.042720 | 3818.9 | 4352.9 | 7.5195 |
| 1000 | 0.064919 | 4032.4 | 4616.7 | 7.8855 | 0.058391 | 4029.9 | 4613.8 | 7.8349 | 0.046641 | 4023.5 | 4606.5 | 7.7269 |
| 1100 | 0.070224 | 4240.7 | 4872.7 | 8.0791 | 0.063183 | 4238.5 | 4870.3 | 8.0289 | 0.050510 | 4233.1 | 4864.5 | 7.9220 |
| 1200 | 0.075492 | 4454.2 | 5133.6 | 8.2625 | 0.067938 | 4452.4 | 5131.7 | 8.2126 | 0.054342 | 4447.7 | 5127.0 | 8.1065 |
| 1300 | 0.080733 | 4672.9 | 5399.5 | 8.4371 | 0.072667 | 4671.3 | 5398.0 | 8.3874 | 0.058147 | 4667.3 | 5394.1 | 8.2819 |

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## Table 3: Ideal gas properties of air

Ideal-gas properties of air

| $T$ K | $h$ kJ/kg | $P_r$ | $u$ kJ/kg | $v_r$ | $s°$ kJ/kg · K | $T$ K | $h$ kJ/kg | $P_r$ | $u$ kJ/kg | $v_r$ | $s°$ kJ/kg · K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 200 | 199.97 | 0.3363 | 142.56 | 1707.0 | 1.29559 | 580 | 586.04 | 14.38 | 419.55 | 115.7 | 2.37348 |
| 210 | 209.97 | 0.3987 | 149.69 | 1512.0 | 1.34444 | 590 | 596.52 | 15.31 | 427.15 | 110.6 | 2.39140 |
| 220 | 219.97 | 0.4690 | 156.82 | 1346.0 | 1.39105 | 600 | 607.02 | 16.28 | 434.78 | 105.8 | 2.40902 |
| 230 | 230.02 | 0.5477 | 164.00 | 1205.0 | 1.43557 | 610 | 617.53 | 17.30 | 442.42 | 101.2 | 2.42644 |
| 240 | 240.02 | 0.6355 | 171.13 | 1084.0 | 1.47824 | 620 | 628.07 | 18.36 | 450.09 | 96.92 | 2.44356 |
| 250 | 250.05 | 0.7329 | 178.28 | 979.0 | 1.51917 | 630 | 638.63 | 19.84 | 457.78 | 92.84 | 2.46048 |
| 260 | 260.09 | 0.8405 | 185.45 | 887.8 | 1.55848 | 640 | 649.22 | 20.64 | 465.50 | 88.99 | 2.47716 |
| 270 | 270.11 | 0.9590 | 192.60 | 808.0 | 1.59634 | 650 | 659.84 | 21.86 | 473.25 | 85.34 | 2.49364 |
| 280 | 280.13 | 1.0889 | 199.75 | 738.0 | 1.63279 | 660 | 670.47 | 23.13 | 481.01 | 81.89 | 2.50985 |
| 285 | 285.14 | 1.1584 | 203.33 | 706.1 | 1.65055 | 670 | 681.14 | 24.46 | 488.81 | 78.61 | 2.52589 |
| 290 | 290.16 | 1.2311 | 206.91 | 676.1 | 1.66802 | 680 | 691.82 | 25.85 | 496.62 | 75.50 | 2.54175 |
| 295 | 295.17 | 1.3068 | 210.49 | 647.9 | 1.68515 | 690 | 702.52 | 27.29 | 504.45 | 72.56 | 2.55731 |
| 298 | 298.18 | 1.3543 | 212.64 | 631.9 | 1.69528 | 700 | 713.27 | 28.80 | 512.33 | 69.76 | 2.57277 |
| 300 | 300.19 | 1.3860 | 214.07 | 621.2 | 1.70203 | 710 | 724.04 | 30.38 | 520.23 | 67.07 | 2.58810 |
| 305 | 305.22 | 1.4686 | 217.67 | 596.0 | 1.71865 | 720 | 734.82 | 32.02 | 528.14 | 64.53 | 2.60319 |
| 310 | 310.24 | 1.5546 | 221.25 | 572.3 | 1.73498 | 730 | 745.62 | 33.72 | 536.07 | 62.13 | 2.61803 |
| 315 | 315.27 | 1.6442 | 224.85 | 549.8 | 1.75106 | 740 | 756.44 | 35.50 | 544.02 | 59.82 | 2.63280 |
| 320 | 320.29 | 1.7375 | 228.42 | 528.6 | 1.76690 | 750 | 767.29 | 37.35 | 551.99 | 57.63 | 2.64737 |
| 325 | 325.31 | 1.8345 | 232.02 | 508.4 | 1.78249 | 760 | 778.18 | 39.27 | 560.01 | 55.54 | 2.66176 |
| 330 | 330.34 | 1.9352 | 235.61 | 489.4 | 1.79783 | 780 | 800.03 | 43.35 | 576.12 | 51.64 | 2.69013 |
| 340 | 340.42 | 2.149 | 242.82 | 454.1 | 1.82790 | 800 | 821.95 | 47.75 | 592.30 | 48.08 | 2.71787 |
| 350 | 350.49 | 2.379 | 250.02 | 422.2 | 1.85708 | 820 | 843.98 | 52.59 | 608.59 | 44.84 | 2.74504 |
| 360 | 360.58 | 2.626 | 257.24 | 393.4 | 1.88543 | 840 | 866.08 | 57.60 | 624.95 | 41.85 | 2.77170 |
| 370 | 370.67 | 2.892 | 264.46 | 367.2 | 1.91313 | 860 | 888.27 | 63.09 | 641.40 | 39.12 | 2.79783 |
| 380 | 380.77 | 3.176 | 271.69 | 343.4 | 1.94001 | 880 | 910.56 | 68.98 | 657.95 | 36.61 | 2.82344 |
| 390 | 390.88 | 3.481 | 278.93 | 321.5 | 1.96633 | 900 | 932.93 | 75.29 | 674.58 | 34.31 | 2.84856 |
| 400 | 400.98 | 3.806 | 286.16 | 301.6 | 1.99194 | 920 | 955.38 | 82.05 | 691.28 | 32.18 | 2.87324 |
| 410 | 411.12 | 4.153 | 293.43 | 283.3 | 2.01699 | 940 | 977.92 | 89.28 | 708.08 | 30.22 | 2.89748 |
| 420 | 421.26 | 4.522 | 300.69 | 266.6 | 2.04142 | 960 | 1000.55 | 97.00 | 725.02 | 28.40 | 2.92128 |
| 430 | 431.43 | 4.915 | 307.99 | 251.1 | 2.06533 | 980 | 1023.25 | 105.2 | 741.98 | 26.73 | 2.94468 |
| 440 | 441.61 | 5.332 | 315.30 | 236.8 | 2.08870 | 1000 | 1046.04 | 114.0 | 758.94 | 25.17 | 2.96770 |
| 450 | 451.80 | 5.775 | 322.62 | 223.6 | 2.11161 | 1020 | 1068.89 | 123.4 | 776.10 | 23.72 | 2.99034 |
| 460 | 462.02 | 6.245 | 329.97 | 211.4 | 2.13407 | 1040 | 1091.85 | 133.3 | 793.36 | 23.29 | 3.01260 |
| 470 | 472.24 | 6.742 | 337.32 | 200.1 | 2.15604 | 1060 | 1114.86 | 143.9 | 810.62 | 21.14 | 3.03449 |
| 480 | 482.49 | 7.268 | 344.70 | 189.5 | 2.17760 | 1080 | 1137.89 | 155.2 | 827.88 | 19.98 | 3.05608 |
| 490 | 492.74 | 7.824 | 352.08 | 179.7 | 2.19876 | 1100 | 1161.07 | 167.1 | 845.33 | 18.896 | 3.07732 |
| 500 | 503.02 | 8.411 | 359.49 | 170.6 | 2.21952 | 1120 | 1184.28 | 179.7 | 862.79 | 17.886 | 3.09825 |
| 510 | 513.32 | 9.031 | 366.92 | 162.1 | 2.23993 | 1140 | 1207.57 | 193.1 | 880.35 | 16.946 | 3.11883 |
| 520 | 523.63 | 9.684 | 374.36 | 154.1 | 2.25997 | 1160 | 1230.92 | 207.2 | 897.91 | 16.064 | 3.13916 |
| 530 | 533.98 | 10.37 | 381.84 | 146.7 | 2.27967 | 1180 | 1254.34 | 222.2 | 915.57 | 15.241 | 3.15916 |
| 540 | 544.35 | 11.10 | 389.34 | 139.7 | 2.29906 | 1200 | 1277.79 | 238.0 | 933.33 | 14.470 | 3.17888 |
| 550 | 555.74 | 11.86 | 396.86 | 133.1 | 2.31809 | 1220 | 1301.31 | 254.7 | 951.09 | 13.747 | 3.19834 |
| 560 | 565.17 | 12.66 | 404.42 | 127.0 | 2.33685 | 1240 | 1324.93 | 272.3 | 968.95 | 13.069 | 3.21751 |
| 570 | 575.59 | 13.50 | 411.97 | 121.2 | 2.35531 | | | | | | |

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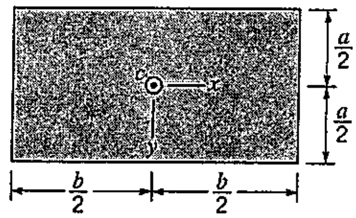
## Table 4: Formulas for second moment of area and centroid



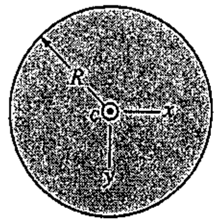

$A = ba$

$I_{xc} = \frac{1}{12} ba^3$

$I_{yc} = \frac{1}{12} ab^3$

$I_{xyc} = 0$

(*a*) Rectangle

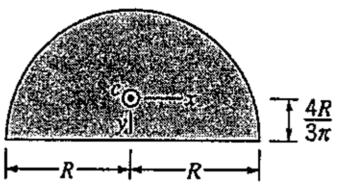



$A = \pi R^2$

$I_{xc} = I_{yc} = \frac{\pi R^4}{4}$

$I_{xyc} = 0$

(*b*) Circle



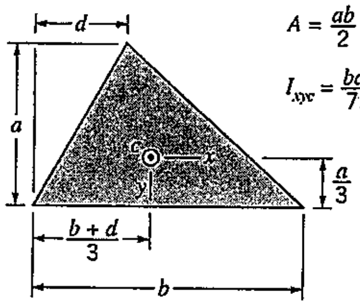

$A = \frac{\pi R^2}{2}$

$I_{xc} = 0.1098R^4$

$I_{yc} = 0.3927R^4$

$I_{xyc} = 0$

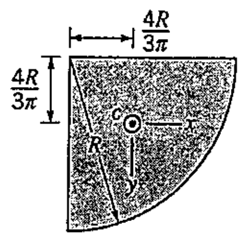
(*c*) Semicircle




$A = \frac{ab}{2}$ $\quad I_{xc} = \frac{ba^3}{36}$

$I_{xyc} = \frac{ba^2}{72}(b - 2d)$

(*d*) Triangle




$A = \frac{\pi R^2}{4}$

$I_{xc} = I_{yc} = 0.05488R^4$

$I_{xyc} = -0.01647R^4$

(*e*) Quarter circle

**END OF PAPER**



36

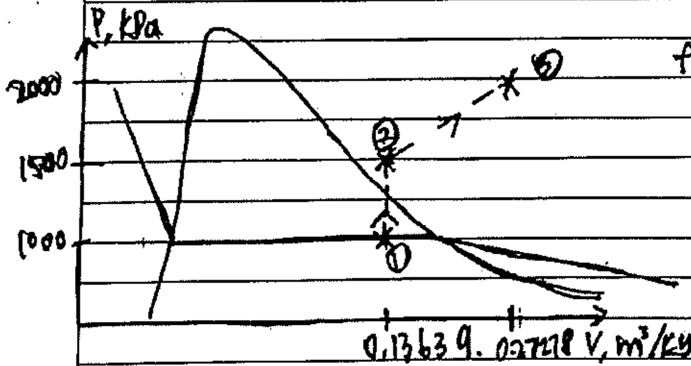
MA2003 18/19 Sem 1

a) Initial temperature of mixture at subsystem A
= Saturation temperature at 1000 kPa
= 179.88°C

$x = 0.70$
$\Rightarrow 0.70 = \frac{v - v_f}{v_g - v_f}$, $v_f = 0.001127\ m^3/kg$ $v_g = 0.19436\ m^3/kg$
$\Rightarrow v = 0.13639\ m^3/kg$.
mass of mixture $= \frac{\text{volume of mixture}}{v} = \frac{0.1}{0.13639}\ kg = 0.73320\ kg$

b) Force exerted by spring at final state $= (2000 - 1500) \times 10^3 \times 0.2\ N$.
$= 1 \times 10^5\ N$
$= kx$
$\Rightarrow x = \frac{1 \times 10^5}{200 \times 10^3} = 0.5\ m$

c) work done by subsystem A up to final state
$= (1500 \times 10^3)(0.2)(0.5)\ J + (\frac{1}{2})(200 \times 10^3)(0.5)^2\ J$
(work done by A against weight of piston and atmospheric pressure; work done by A against spring)
$= 1.75 \times 10^5\ J$




final $v = \frac{0.1 + 0.2 \times 0.5}{0.73320}\ m^3/kg$
$= 0.27278\ m^3/kg$

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d) $V_{final} = 0.27228\ m^3/kg$
$P_{final} = 2000\ kPa$

By interpolation, $T_{final} = 911.42\ °C$

$u_{final} = 3873.65\ kJ/kg$

$u_{initial} = [0.7(1821.4) + 761.39]\ kJ/kg$
$= 2036.37\ kJ/kg$

$\Delta u = 1837.30\ kJ/kg$

change in internal energy of A $= 1837.30 \times 0.73320\ kJ$
$= 1347.10\ kJ$

heat supplied to A = increase in internal energy of A + work done by A

$\Rightarrow \frac{3}{4} Q = 1347.10\ kJ + 1.75 \times 10^5\ J$
$= 1.52 \times 10^6\ J$

$Q = 2.03 \times 10^6\ J$

e) $\frac{1}{4} Q = 0.50737 \times 10^6\ J$

increase in temperature of B $= \frac{0.50737 \times 10^6}{(721)(2)}\ K$
$= 351.85\ K$

final temperature of B $= (450 + 351.85)\ K$
$= 801.85\ K$

$PV = RmT$

$V = \frac{(287)(450)}{(1000 \times 10^3)}\ m^3/kg = 0.12915\ m^3/kg$

$P_{final} = \frac{(287)(801.85)}{0.12915}\ Pa = 1782\ kPa$

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2. a.) since heat loss from throttling valve is negligible and work done by valve is zero, $h_{initial}$ and $h_{final}$ across the valve are the same.

From table, h @ 6MPa and 500°C = 3423.1 kJ/kg
= h at state 2

By interpolation, @ 3MPa and h = 3423.1 kJ/kg,
T = 484.60 K.

b.) h at state 3 = 2675.0 kJ/kg (@ 100kPa and saturated vapour conditions).

⇒ power generated by turbine = (3423.1 − 2675.0) kJ/kg
= 748.1 kJ/kg

c.) By conservation of mass, $\rho_0 A_0 V_0 = \rho_i A_i V_i$

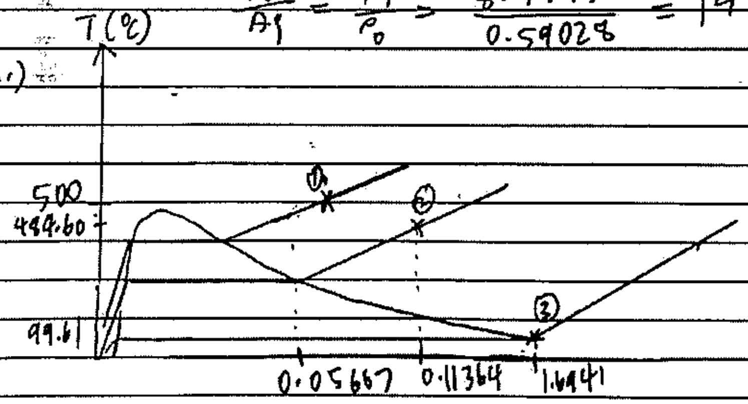
$\rho_0 A_0 = \rho_i A_i$ ∵ $V_0 = V_i$

$\rho_0 = \frac{1}{v_3} = \frac{1}{1.6941}$ kg/m³ = 0.59028 kg/m³

$\rho_i = \frac{1}{v_2} = \frac{1}{0.11362}$ kg/m³ = 8.7997 kg/m³

$\frac{A_0}{A_i} = \frac{\rho_i}{\rho_0} = \frac{8.7997}{0.59028} = 14.908$

d.)

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P(2)

3.a i) average pressure $= \rho g(\frac{H}{2})$

$F_H = \rho g(\frac{H}{2})(H)(1)$

$= \frac{\rho g H^2}{2}$

location of total horizontal force, $h$

$= \frac{2}{3}H$

ii) $F_V = \frac{1}{2}(H)(\frac{H}{\tan\theta})(1)(\rho)(g)$

$= \frac{\rho g H^2}{2\tan\theta}$

$l = \frac{1}{3}(\frac{H}{\tan\theta}) = \frac{H}{3\tan\theta}$

b i) $dp = -\rho a_x dx - \rho g dz$

$P_A - P_2 = -\rho a_x(x_A - x_2) - \rho g(z_A - z_2)$.

Let point 2 be the position where the small opening is located

$\Rightarrow P_A = -\rho a_x(-L - \frac{H}{\tan\theta}) - \rho g(-H)$

$= \rho a_x(L + \frac{H}{\tan\theta}) + \rho g H$

$P_B - P_2 = -\rho a_x(x_B - x_2) - \rho g(z_B - z_2)$

$P_B = -\rho a_x(-L) = \rho a_x L$

ii) average pressure acting on surface AB is at the midpoint of AB.

Let the midpoint be M.

$P_M = -\rho a_x(x_M - x_2) - \rho g(z_M - z_2)$

$= -\rho a_x(-L - \frac{H}{2\tan\theta}) - \rho g(\frac{-H}{2})$

$= \rho a_x(L + \frac{H}{2\tan\theta}) + \rho g(\frac{H}{2})$.

$\Rightarrow$ Total force acting on AB $= [\rho a_x(L + \frac{H}{2\tan\theta}) + \rho g(\frac{H}{2})][\frac{H}{\tan\theta}][1]$

$\Rightarrow$ Total horizontal force $F_H = \sin\theta\,[\rho a_x(L + \frac{H}{2\tan\theta}) + \rho g(\frac{H}{2})][\frac{H}{\tan\theta}]$.

Total vertical force $F_V = \cos\theta\,[\rho a_x(L + \frac{H}{2\tan\theta}) + \rho g(\frac{H}{2})][\frac{H}{\tan\theta}]$

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c.) i) Since block is floating, weight of block = weight of displaced fluid.

$$\Rightarrow (W^2L)(\rho_b)(g) = (WLH)(\rho_w)(g)$$

$$H = \frac{W^2 L \rho_b}{W L \rho_w} = W\left(\frac{\rho_b}{\rho_w}\right)$$

ii) For configuration to be stable, $\overline{GM} = \frac{I_o}{V} - \overline{CG} > 0$

$$\overline{CG} = \frac{W}{2} - \frac{H}{2}$$

$$V = LHW$$

$$I_o = \frac{1}{12}(L)(W)^3 \quad \text{(assume that } L > W\text{)}.$$

$$\Rightarrow \frac{\frac{1}{12}(L)(W)^3}{LHW} - \left(\frac{W}{2} - \frac{H}{2}\right) > 0$$

$$\frac{1}{12}\frac{W^2}{H} - \frac{W}{2} + \frac{H}{2} > 0.$$

$$\frac{1}{12}\frac{W^2}{W\left(\frac{\rho_b}{\rho_w}\right)} - \frac{W}{2} + \frac{W}{2}\left(\frac{\rho_b}{\rho_w}\right) > 0$$

$$\frac{W}{12}\left(\frac{\rho_w}{\rho_b}\right) - \frac{W}{2} + \frac{W}{2}\left(\frac{\rho_b}{\rho_w}\right) > 0$$

Let $\frac{\rho_b}{\rho_w}$ be $k$.

$$\frac{W}{12}\left(\frac{1}{k}\right) - \frac{W}{2} + \frac{W}{2}(k) > 0.$$

$$\frac{1}{k} - 6 + 6k > 0.$$

solving, $k < 0.21132$ or $k > 0.78867$

$$\Rightarrow 0 < \frac{\rho_b}{\rho_w} < 0.21132 \quad \text{or} \quad \frac{\rho_b}{\rho_w} > 0.78867.$$

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P(3)

4a) i) Using conservation of mass,

$(L_1)(1)(\rho)(V_1) = (L_3)(1)(\rho)(V_3)$.

$V_3 = (V_1)(\frac{L_1}{L_3})$

ii) using Bernoulli's eqn and letting the bottom surface of wedge be point S,

$P_S + \frac{1}{2}\rho V_S^2 + \rho g z_S = P_3 + \frac{1}{2}\rho V_3^2 + \rho g z_3$.

$\Rightarrow P_S + \frac{1}{2}\rho V_1^2 + \rho g(z_S - z_3) = \frac{1}{2}\rho V_3^2$ ($P_3$ = atmospheric pressure)

$P_S + \frac{1}{2}\rho V_1^2 + \rho g(\frac{L_1}{2}) = \frac{1}{2}\rho V_3^2$

$P_S = \frac{1}{2}\rho V_3^2 - \frac{1}{2}\rho V_1^2 - \rho g(\frac{L_1}{2})$

(gauge)

$= \frac{1}{2}\rho (V_1)^2(\frac{L_1}{L_3})^2 - \frac{1}{2}\rho V_1^2 - \rho g(\frac{L_1}{2})$

$= \frac{1}{2}\rho (V_1)^2 \left[(\frac{L_1}{L_3})^2 - 1\right] - \rho g(\frac{L_1}{2})$

iii) using Bernoulli's equation,

$P_2 + \frac{1}{2}\rho V_2^2 + \rho g z_2 = P_4 + \frac{1}{2}\rho V_4^2 + \rho g z_4$

$P_2 + \frac{1}{2}\rho V_2^2 = \frac{1}{2}\rho V_4^2$ $\because z_2 = z_4$, $P_4$ = atmospheric pressure

By conservation of mass, $V_2 = V_4(\frac{L_4}{L_2})$.

$\Rightarrow P_2 + \frac{1}{2}\rho (V_4)^2(\frac{L_4}{L_2})^2 = \frac{1}{2}\rho (V_4)^2$

Let small opening be point O.

$P_2 + \frac{1}{2}\rho V_2^2 + \rho g z_2 = P_0 + \frac{1}{2}\rho V_0^2 + \rho g z_0$

$P_0 = P_2 + \rho g(\frac{L_2}{2})$, $\because V_2 = V_0$, $z_2 - z_0 = \frac{L_2}{2}$

Average pressure exerted on wedge by water in triangular compartment

$= P_0 + (\frac{H}{2})(g)(\rho)$

$\Rightarrow$ downwards vertical force exerted on wedge by water in triangular compartment

$= [P_0 + (\frac{H}{2})(g)(\rho)][H][1]$

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upwards vertical force exerted on wedge by water in bottom channel

$= (P_5)(H)(1)$.

Since net vertical force on wedge is zero,

$\rightarrow [P_0 + (\frac{H}{2})(g)(\rho)]H = (P_5)(H)$

$\Rightarrow P_0 = P_5 - \frac{H}{2} g \rho$

$\therefore P_2 = P_0 - \rho g (\frac{L_2}{2})$ $\quad \because P_2 = \frac{1}{2}\rho(V_4)^2 - \frac{1}{2}\rho(V_4)^2(\frac{L_4}{L_2})^2$

$P_0 - \rho g (\frac{L_2}{2}) + \frac{1}{2}\rho(V_4)^2(\frac{L_4}{L_2})^2 = \frac{1}{2}\rho(V_4)^2$

$P_0 - \rho g (\frac{L_2}{2}) = (V_4)^2 (\frac{1}{2}\rho)[1 - (\frac{L_4}{L_2})^2]$

$$V_4 = \sqrt{\frac{P_0 - \rho g (\frac{L_2}{2})}{(\frac{1}{2}\rho)(1 - (\frac{L_4}{L_2})^2)}}$$

$$= \sqrt{\frac{P_5 - \frac{H}{2} g\rho - \rho g (\frac{L_2}{2})}{(\frac{1}{2}\rho)(1 - (\frac{L_4}{L_2})^2)}}$$

$$= \sqrt{\frac{\frac{1}{2}\rho(V_1)^2[(\frac{L_1}{L_3})^2 - 1] - \rho g(\frac{L_1}{2}) - \frac{H}{2} g\rho - \rho g (\frac{L_2}{2})}{(\frac{1}{2}\rho)(1 - (\frac{L_4}{L_2})^2)}}$$

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P(4)

$$= \sqrt{\frac{(V_1)^2\left[\left(\frac{L_1}{L_3}\right)^2-1\right]-gL_1-Hg-gL_2}{1-\left(\frac{L_4}{L_2}\right)^2}}$$

(please draw the streamlines yourself)

b) i) $\dot{M} = (V_4)(L_4)(1)\rho + (V_3)(L_3)(1)(\rho) - \dot{m}_p - \dot{m}_v$

$$= \rho(V_4L_4+V_3L_3) - C_0 + C_1e^{-\frac{M}{\tau}} - C_2M$$

$$\frac{1}{\rho(V_4L_4+V_3L_3) - C_0 + C_1e^{-\frac{M}{\tau}} - C_2M}\frac{dM}{dt} = 1$$

$\Rightarrow$ time taken, $T = \int_{M_0}^{M_1} \frac{1}{\rho(V_4L_4+V_3L_3)-C_0+C_1e^{-\frac{M}{\tau}}-C_2M}\,dM$

ii) at steady state, $\frac{dM}{dt}=0$ i.e. rate of inflow = rate of outflow

$$\Rightarrow \rho(V_4L_4+V_3L_3) = C_0 - C_1e^{-\frac{M_2}{\tau}} + C_2M_2 + \dot{m}_e$$

$$\dot{m}_e = \rho(V_4L_4+V_3L_3) - C_0 + C_1e^{-\frac{M_2}{\tau}} - C_2M_2$$

iii) Time taken for mass to reach 0.1 $M_0$

$$= \int_{M_2}^{M_1} \frac{1}{-C_0+C_1e^{-\frac{M}{\tau}}-C_2M-[\rho(V_4L_4+V_3L_3)-C_0+C_1e^{-\frac{M_2}{\tau}}-C_2M_2]}\,dM$$

$$+ \int_{M_1}^{0.1M_0} \frac{1}{-C_0+C_1e^{-\frac{M}{\tau}}-C_2M}\,dM$$

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NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2018-2019

MA2003 – INTRODUCTION TO THERMO-FLUIDS

April/May 2019 Time allowed: 2½ hours

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **SIX (6)** pages including **ONE (1)** page of appendix.
2. Answer **ALL** questions.
3. Marks for each question are as indicated.
4. This is a **CLOSED-BOOK** examination.

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1. A frictionless piston-cylinder device contains 0.01 kg saturated liquid-vapor mixture of water at 125 kPa. The piston has a mass of 80 kg and a diameter of 200 mm. The position of the piston at the initial state is shown in Figure 1. Heat is then added to the system and the piston goes up until the piston pushes the stopper with 3.9252 kN of force. The local atmospheric pressure is 100 kPa. Determine:

(a) the quality of the liquid-vapor mixture and the volume of water in liquid phase at the initial state;

(10 marks)

(b) the phase of the final state and the final temperature;

(10 marks)

(c) the work done when the system changes from the initial state to the final state and the heat added.

(10 marks)

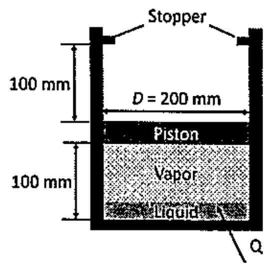


Figure 1



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2. Air at 22°C and 50 kPa steadily enters a nozzle whose inlet area is 0.4 $m^2$ with a velocity of 200 m/s. The air leaves the nozzle with a velocity of 400 m/s while losing heat at a rate of 10 kW, as shown in Figure 2. The gas constant of air is $R$ = 0.287 kJ/kg·K. Determine:

(a) the specific volume and mass flow rate of the air entering the nozzle;

(8 marks)

(b) the specific enthalpy and temperature of the air leaving the nozzle.

(12 marks)

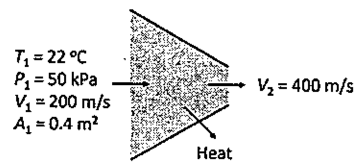


Figure 2

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3 (a) A tank with an attached manometer contains oil (SG=0.85) at 20°C. The atmospheric pressure is 115 kPa. There is a stopcock located 1.25 m from the surface of the oil in the manometer. The stopcock is closed, trapping the air in the manometer, and oil is added to the tank to the level of the stopcock. Find the increase in elevation of the oil in the manometer assuming the air in the manometer is compressed isothermally.

(5 marks)

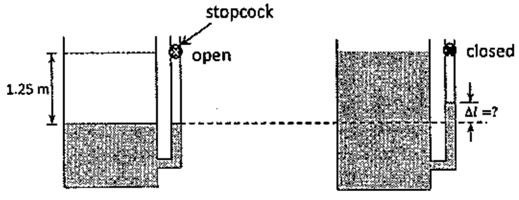


Figure 3

(b) A system of oil and water is given below. The water is discharged to the standard atmosphere. Neglecting the losses, for what nozzel diameter $D$ will cavitation occur? Atmospheric pressure is 101.3 kPa (abs), and the water vapor pressure is 2 kPa (abs). Figure is not drawn to scale.

(10 marks)

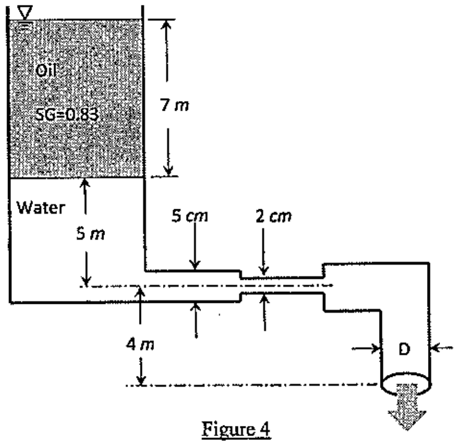


Figure 4

Note: Question 3 continues on page 4.



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(c) The tank of water in the following figure is full and open to the atmosphere at point A. If it is accelerated to the right, for what acceleration will the pressure at point B be (1) zero gage and (2) zero absolute? Assume no spilling out. Atmospheric pressure is 101.3 kPa.

(10 marks)

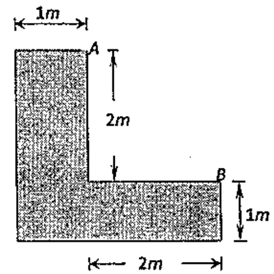


Figure 5

4 (a) Determine force $P$ needed to just start opening the 5-m wide gate. Force $P$ is perpendicular to the gate and is located at the end of the gate. The seawater has a specific weight of 10.3 kN/m$^3$.

(10 marks)

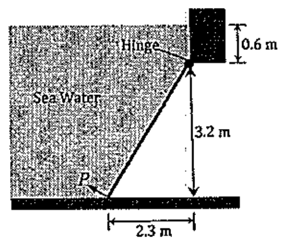


Figure 6

Note: Question 4 continues on page 5.

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(b) Consider the following figure as a model for the steady flow through the showerhead. Assume water enters via section 1 at 20 kg/min. The average velocity at section 2 is 0.02 m/s. The showerhead contains 50 holes of 2-mm diameter. The diameter of the showerhead is 14 cm. Assuming the shower flow is uniform, what is the exit velocity from the showerhead holes?

(15 marks)

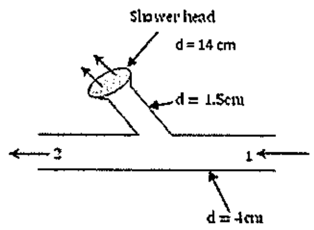


Figure 7



42

1a) $v = \frac{\frac{\pi(0.2)^2}{4} \times 0.1}{0.01} = 0.31415\ m^3/kg$

$X = \frac{0.31415 - 0.001048}{1.3750 - 0.001048} = 0.2278$

$X = 22.78\%$

volume of water $= (1 - 0.2278)(0.001048)(0.01)$

$= 0.0000080917 m^3$

1b) $P = \frac{F}{A} = \frac{3.9252 \times 1000 + 80 \times 9.81}{0.031415} = 149928\ Pa = 150 kPa$

Final v = Initial v x 2 since volume just doubled

$= 0.31415 \times 2$

$= 0.6283\ m^3/kg$

Since v between $v_f$ and $v_g$ at 150kPa from table,

state is liquid vapour mixture

$X = \frac{0.6283 - 0.001053}{1.1594 - 0.001053} = 0.5415$

T = 111.35°C State is liquid vapour mixture with 54.15% quality.

1c) From initial state to just touching is constant pressure process.

∴ use change in enthalpy

X when just touch stopper $= \frac{0.6283 - 0.001048}{1.3750 - 0.001048} = 0.45653$

$m(h_2 - h_1) = Q_{in}$

$0.01(0.45653 - 0.2278)(2240.6)(1000) = 5124J$

~~Workdone = 125000(0.31415) = 39268.75J~~

Workdone $= 125000 \times \frac{\pi \times 0.2^2}{4} = 3926J$

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From touching stopper to increase pressure to 150kPa, constant volume, use internal energy.

$m(u_2-u_1) = Q_{in}$ $W=0$

$0.01\,(0.5415(2052.3) + 466.97 - 444.23 - 0.45653(2068.8)) \times 1000$

$= 1895.91\text{J}$

$Q_{in} = 1895.91 + ~~5142~~\ 5124$

$= 7019.91\text{J}$

2a) $Pv = R_m T$

$v = \frac{287(22+273)}{50000}$

$= 1.6933\,m^3/kg$

$\dot{m} = \frac{200 \times 0.4}{1.6933}$

$= 47.24\,kgs^{-1}$

2b) Assume $W=0$ Assume steady state and steady flow conditions

Assume GPE = 0

$\dot{m}_{in} = \dot{m}_{out}$

$-10000 = \dot{m}\left(h_{out} - h_{in} + \frac{V_{out}^2}{2} - \frac{V_{in}^2}{2}\right)$

Find $h_{in}$ from table: $295.17 \times 1000$

$\frac{-10000}{47.24} = h_{out} - 295170 + \frac{400^2}{2} - \frac{200^2}{2}$

$h_{out} = 234958\,J/kg$

From table this value between 230 and 240

Linear interpolation

$T = \frac{234958 - 230.02 \times 1000}{(240.02 - 230.02)(1000)} + 230 = 234.938K$

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3a) $PV = nRT$

Since isothermic, T is constant and nRT is constant.

Therefore, $P \propto \frac{1}{V}$

On the other hand Volume is proportional to height of the small tube since diameter constant

$V \propto \frac{1.25 - \Delta l}{1.25}$

Combining these 2

$P \propto \frac{1.25}{1.25 - \Delta l}$ the more $\Delta l$ the higher P

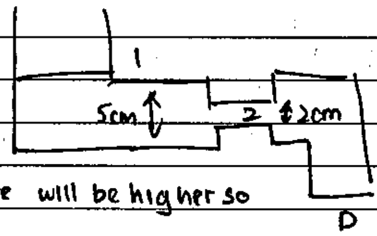
$$0.85(1000)(9.81)(1.25) + 115000 = 115000\left(\frac{1.25}{1.25 - \Delta l}\right) + \Delta l(0.85)(1000)(9.81)$$

$$156778 - 125423\Delta l = 115000(1.25) + \Delta l\, 10423.125 - (\Delta l)^2\, 8338.5$$

Solving for $\Delta l$ :

$\Delta l = 0.096m$ or $16.194m$ (Rejected)

3b)




P at point 1 = $0.83(7)(1000)(9.81)$

(gage) $= 56996.1 Pa$

Assume $v$ at point $1 = 0$

Since 5cm and 2cm are same height,

cavitation will happen at 2cm area because V there will be higher so pressure will be lower than at 5cm area.

Use Bernoulli at 1 and D

$$\frac{56996.1}{1000(9.81)} + 0 + 9 = 0 + \frac{V_D^2}{2g} + 0$$

$V_D^2 = 17.046ms^{-1}$

Since volume flow rate must be constant throughout as water won't accumulate at certain areas,

$$17.046 \times \frac{D^2}{4} \times \pi = V_2^2 \times \pi \times \frac{(0.02)^2}{4}$$

$V_2 = 42615D^2$

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Using Bernoulli at 1 and 2, now use absolute as there are pressures below atmospheric

$$\frac{56996.1+101300}{1000(9.81)}+0+5=\frac{2000}{1000\times 9.81}+\frac{(42615D^2)^2}{9.81\times 2}$$

Solving for D

$$410.9622=(42615D^2)^2$$

$$D=0.0218\,m$$

3c) $\int dp = -\int \rho a_y \, dy - \int \rho g \, dz$

(1) Putting everything about A below and B on top for integration

$$\int_0^0 dp = -\int_0^2 1000 a_y - \int_0^{-2} 1000(9.81)$$

$$0 = -2000 a_y + 2000(9.81)$$

$$a_y = 9.81\,ms^{-2}$$

(2) For second part, since B is zero absolute, we can just put B as $-101300$ and A is 0 instead of reintegrating

$\int_0^{-101300} dp$ ← since it is just the difference, so just replace 0 with $-101300$

$$-101300 = -2000 a_y + 2000(9.81)$$

$$a_y = 51.631\,ms^{-2}$$

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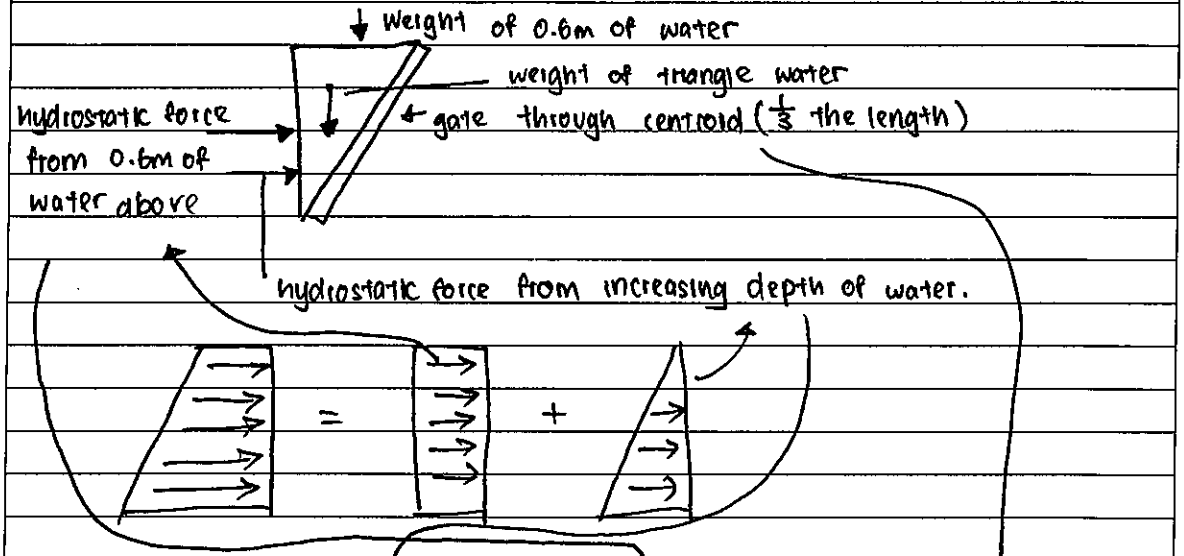
4a) Setting up control volume




Moment from all these forces = Moment from P

$$\frac{P(2.3)}{5} = 2.2(10300)(3.2)\left(\frac{2}{3}\right) + 0.6(10300)(1.6) + \frac{2.3(3.2)}{2}(10300)(2.3)\left(\frac{2}{3}\right)$$

$$+\ 0.6(2.3)(10300)\frac{(2.3)}{2}$$ ← weight of 0.6m of water

(5) ← Just put thickness here instead of every term

Solve for P,

P = 111 087N

4b) Volume of water in = Volume of water out

Water in = 20kg/min = $\frac{1}{3}$ kg/s = 0.00033333 m³/s

Water out from 2 = $0.02 \times \frac{0.04^2}{4} \times \pi = 0.000025132\ m^3/s$

Water out from shower = 0.00033333 − 0.000025132

$V \times 50 \times \frac{0.002^2}{4} \times \pi = 0.00033333 - 0.000025132$

$V = 1.9618\ ms^{-1}$

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