SOLUTIONS

THERMODYNAMICS PRACTICE PROBLEMS FOR NON-TECHNICAL MAJORS

Thermodynamic Properties

1. If an object has a weight of 10 lbf on the moon, what would the same object weigh on Jupiter?

$$g_{Jupiter} = 75\frac{\text{ft}}{\text{sec}^2} \qquad g_{Moon} = 5.4\frac{\text{ft}}{\text{sec}^2} \qquad g_c = 32\frac{\text{lbm-ft}}{\text{lbf-sec}^2}$$

$$|\overline{W}| = \frac{mg}{g_c} \Rightarrow m = \frac{|\overline{W}|_{moon}\, g_c}{g_{moon}} = \frac{10\times 32}{5.4} = 59.26 \text{ lbm}$$

$$|\overline{W}|_{Jupiter} = \frac{mg_{Jupiter}}{g_c} = \frac{59.26\times 75}{32} = \boxed{139 \text{ lbf}}$$

2. An object that weighs 50 lbf on earth is moved to Saturn where its new weight is 105 lbf. What is the acceleration due to gravity on Saturn?

$$g_{Earth} = 32\frac{\text{ft}}{\text{sec}^2} \qquad g_c = 32\frac{\text{lbm-ft}}{\text{lbf-sec}^2}$$

$50\, lbf \text{ } on\, earth \Rightarrow 50\, lbm$

$$|\overline{W}| = \frac{mg}{g_c} \Rightarrow g = \frac{|\overline{W}|g_c}{m} = \frac{105\times 32}{50} = \boxed{67.2\frac{ft}{\text{sec}^2}}$$

3. Define, using equations, specific volume (v) and density (ρ). What is the mathematical relationship between these two terms?

$$v = \frac{V}{m}, \quad \rho = \frac{m}{V}, \quad v = \frac{1}{\rho} \text{ or } \rho = \frac{1}{v}$$

Temperature and Pressure Measurements

4. (a) Define temperature.
   (b) What is the absolute temperature scale corresponding to Fahrenheit?
   (c) Convert 100° F to that absolute scale.

(a) Temperature: a measure of molecular activity of a substance.

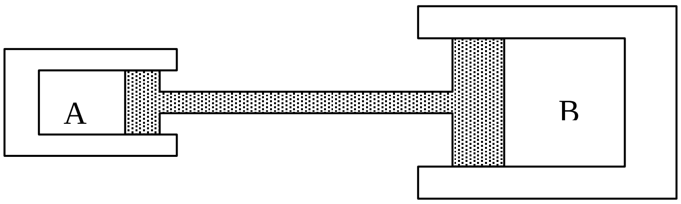
(b) Rankine

(c) °R = °F + 460 $\Rightarrow$ 100° F converts to 560° R

5. Define pressure.

Pressure: a measure of force exerted per unit area on the boundaries of a system.

6. If $P_A=P_B$, in which direction will the piston move? Explain, using equations.

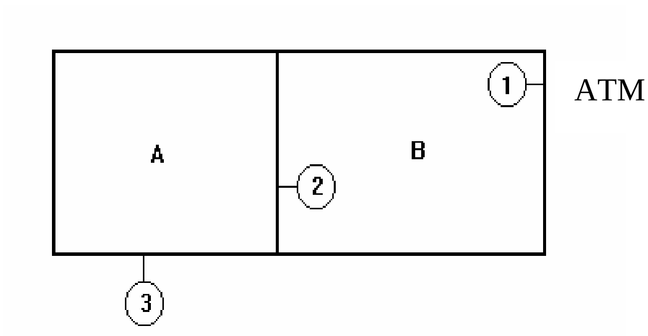


$$P=\frac{F}{A}$$

$$A_B > A_A \Rightarrow \overset{\leftrightarrow}{P}=\frac{F}{A\uparrow} \Rightarrow F\uparrow \Rightarrow F_B > F_A$$

Piston will move to the left.

7. Given: $P_1 = 4$ psig, $P_{ATM} = 15$ psia, and $P_2 = 10$ psig
Find P_A and P_B.

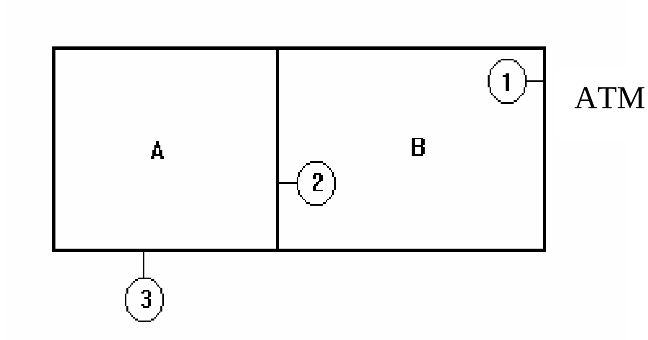


$$P_{gage} = P_{system} - P_{reference}$$

$$P_1 = P_{ATM} - P_B \Rightarrow P_B = 15 \text{ psia} - 4 \text{ psia} = \boxed{11 \text{ psia}}$$

$$P_2 = P_A - P_B \Rightarrow P_A = 10 \text{ psig} + 11 \text{ psia} = \boxed{21 \text{ psia}}$$

8. Given: P_{ATM} = 15 psia, P_2 =6 psiv, and P_3 = 7 psig
   Find P_A and P_B.

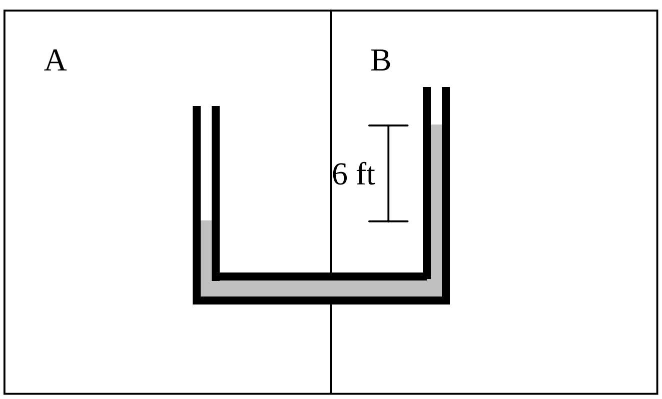


$$P_{gage} = P_{system} - P_{reference}$$

$$P_3 = P_A - P_{ATM} \Rightarrow P_A = 15\text{ psia} + 7\text{ psia} = \boxed{22\text{ psia}}$$

$$P_2 = P_A - P_B \Rightarrow P_B = 22\text{ psia} - (-6)\text{ psi} = \boxed{28\text{ psia}}$$

9. Given the conversion factor 1 inch H_2O = 0.0361 psid and that the manometer below employs water, find the difference in pressure between compartments A and B.



$$\Delta P = \frac{6\text{ ft}}{} \left| \frac{12\text{ in}}{1\text{ ft}} \right| \frac{0.0361\text{psid}}{1\text{in}} = \boxed{2.6\text{ psid}}$$

<u>Energy, Work, and Heat</u>

10. Define energy.

Energy: the capacity of a system to perform work or produce heat.

11. Define, using equations, the total kinetic energy, total potential energy, and enthalpy.

$$PE = \frac{mgz}{g_c}$$

$$KE = \frac{mv^2}{2g_c}$$

$$h = u + Pv$$

12. Given the following information about a system, calculate specific enthalpy (in Btu/lbm).

P=100 psia $\quad v = 1.6\frac{\text{ft}^3}{\text{lbm}} \quad$ u = 600 $\frac{\text{Btu}}{\text{lbm}}$ $\quad$ Note: 778 ft-lbf=1 Btu

$$h = u + Pv$$

$$h = 600\frac{Btu}{lbm} + (100\frac{\cancel{lbf}}{\cancel{in}^2})(1.6\frac{\cancel{ft}^3}{lbm})(\frac{144\,\cancel{in}^2}{\cancel{ft}^2})(\frac{Btu}{778\,\cancel{ft}-\cancel{lbf}}) = \boxed{629.6\frac{Btu}{lbm}}$$

13. Given the following information about a system, calculate specific internal energy (in Btu/lbm).

P=200 psia $\quad v = 2.8\frac{\text{ft}^3}{\text{lbm}} \quad$ h=1000 $\frac{\text{Btu}}{\text{lbm}}$ $\quad$ Note: 778 ft-lbf=1Btu

$$h = u + Pv \Rightarrow u = h - Pv$$

$$u = 1000\frac{Btu}{lbm} - (200\frac{\cancel{lbf}}{\cancel{in}^2})(2.8\frac{\cancel{ft}^3}{lbm})(\frac{144\,\cancel{in}^2}{\cancel{ft}^2})(\frac{Btu}{778\,\cancel{ft}-\cancel{lbf}}) = \boxed{896.3\frac{Btu}{lbm}}$$

14. A 5 lbm system was taken from 50° F to 150° F. How much energy in the form of heat was added to the system to produce this temperature increase?

$$c_p = 1.6\frac{\text{Btu}}{\text{lbm-F}}$$

$$Q = mc_p(T_{hot} - T_{cold})$$

$$Q = 5\,\cancel{lbm} \times 1.6\frac{\text{Btu}}{\cancel{lbm}\,\cancel{F}} \times (150 - 50)\cancel{F} = \boxed{800\,\text{Btu}}$$

15. A 10 lbm metal ball has a temperature of 200° F when it is placed in a 50 lbm bath of water at room temperature (72° F). Heat transfer occurs between the two substances until equilibrium is reached. Find this equilibrium temperature.

$$c_{p_{Water}} = 1.0\frac{\text{Btu}}{\text{lbm-F}} \qquad c_{p_{Metal}} = 4.3\frac{\text{Btu}}{\text{lbm-F}}$$

$$Q_{Out_{Ball}} = Q_{In_{Water}}$$

$$m_{ball} c_{ball} (T_{ball_{initial}} - T_{eq}) = m_{water} c_{water} (T_{eq} - T_{water_{initial}})$$

$$T_{eq} = \frac{(mcT)_{ball} + (mcT)_{water}}{(mc)_{ball} + (mc)_{water}}$$

$$T_{eq} = \frac{\frac{10\ \cancel{lbm}}{} \frac{4.3\ \cancel{Btu}}{\cancel{lbm}-\cancel{F}} \frac{200\ \cancel{F}}{} + \frac{50\ \cancel{lbm}}{} \frac{1.0\ \cancel{Btu}}{\cancel{lbm}-\cancel{F}} \frac{72\ \cancel{F}}{}}{\frac{50\ \cancel{lbm}}{} \frac{1.0\cancel{Btu}}{\cancel{lbm}-F} + \frac{10\ \cancel{lbm}}{} \frac{4.3\ \cancel{Btu}}{\cancel{lbm}-F}}$$

$$\boxed{T_{eq} = 131.2F}$$

16. During a phase change, the specific entropy of a 20 lbm system increases from $0.31\frac{Btu}{lbm-R}$ to $1.61\frac{Btu}{lbm-R}$ while the temperature of the substance is a constant 212°F.
Find the heat transfer into this system.
Hint: Must convert temperature to Rankine.

$$Q = m\,T\,\Delta s = \frac{20\ \cancel{lbm}}{} \left| \frac{(212+460)\ \cancel{R}}{} \right| \frac{(1.61-0.31)\ Btu}{\cancel{lbm}\ \cancel{R}} \Bigg| = \boxed{17{,}472\ Btu}$$

17. A nuclear power plant is found to generate 80 MW of power. A typical Honda civic is capable of producing 150 HP. How many Honda Civic's would be required to generate the equivalent power of this nuclear power plant?
Use the energy and power equivalences found in the DOE Fundamentals Handbook (see Pages 23 and 24 of the "Energy, Work, and Heat" module).

$$\frac{80\ \cancel{MW}}{} \left| \frac{1000\ \cancel{KW}}{1\ \cancel{MW}} \right| \frac{3{,}413\ \cancel{BTU}}{1\ \cancel{KW}\cdot \cancel{hr}} \left| \frac{1\ \cancel{HP}\cdot \cancel{hr}}{2{,}545\ \cancel{BTU}} \right| \frac{1\ \text{Honda Civic}}{150\ \cancel{HP}} = 715.23 \approx \boxed{716\ \text{Honda Civics}}$$

Thermodynamic Systems and Processes

18. Define isolated system, closed system, and open system.

Isolated system – A system that is not influenced in any way by its surroundings (mass and energy do not cross the system boundary).
Closed System – A system which has no transfer of mass with its surroundings, but that may have a transfer of energy.
Open System – A system that may have a transfer of both mass and energy with its surroundings

19. Can a system be in steady state yet have the fluid passing through it undergoing a phase change? Reconcile your answer with the definition of steady state.

Yes. Steady state occurs in a system when the fluid properties at a given point remain constant with respect to time. A fluid undergoing a phase change will have properties that change from point to point. However, to determine if the system is in steady state, we must concentrate on a single point over time.

Change of Phase

20. Describe the difference between an intensive and an extensive property. Give 2 examples of each type of property.

Intensive properties are independent of the amount of mass present. Extensive properties are a function of the amount of mass present. Examples of intensive properties are pressure, temperature, and density. Examples of extensive properties are volume, weight, and energy.

21. A system contains 250 lbm of saturated liquid and 10 lbm of saturated vapor. What is the quality of the system?

$$X = \frac{m_{vapor}}{m_{liquid} + m_{vapor}} = \frac{10lbm}{250lbm + 10lbm} = \boxed{0.038 \ or \ 3.8\%}$$

Property Diagrams and Steam Tables

22. Steam enters a turboexpander as a saturated vapor at 500 psia and is expanded at constant entropy to 5 psia. Using the Mollier diagram in Appendix A (Figure A-1), find the Δh for this process.

From the Mollier diagram: $1205 - 895 = \boxed{310 \frac{\text{Btu}}{\text{lbm}}}$

23. Use the excerpt from the steam tables in Appendix A (Figure A-2) to find h, v, and s for water:

Saturated liquid, P = 350 psia

$h = 409.8 \frac{Btu}{lbm}$ $\quad v = 0.01912 \frac{ft^3}{lbm}$ $\quad s = 0.6059 \frac{Btu}{lbm - R}$

Saturated vapor, P = 400 psia

$h = 1204.6 \frac{Btu}{lbm}$ $\quad v = 1.16095 \frac{ft^3}{lbm}$ $\quad s = 1.4847 \frac{Btu}{lbm - R}$

Saturated liquid, T = 468 F

$h = 450.7 \frac{Btu}{lbm}$ $\quad v = 0.01976 \frac{ft^3}{lbm}$ $\quad s = 0.6502 \frac{Btu}{lbm - R}$

Superheated steam, P = 400 psia and T=700 F

$h = 1363.4 \frac{Btu}{lbm}$ $\quad v = 1.6499 \frac{ft^3}{lbm}$ $\quad s = 1.6406 \frac{Btu}{lbm - R}$

24. Use the steam tables and the concept of quality to find h and ν for water at a pressure of 260 psia if entropy is known to be $0.725\ \frac{Btu}{lbm-R}$.

$$s_{WV} = s_f + Xs_{fg} \Rightarrow X = \frac{s_{WV} - s_f}{s_{fg}} = \frac{0.725 - 0.5722}{0.9508} = 16\%$$

$$h_{WV} = h_f + Xh_{fg} = 379.9 + 0.16 \times 821.6 = \boxed{511.4 \frac{Btu}{lbm}}$$

$$\nu_{WV} = \nu_f + X\nu_{fg} = 0.01870 + 0.16 \times 1.75548 = \boxed{0.29958 \frac{ft^3}{lbm}}$$

25. Calculate specific internal energy for a 200 psia system of saturated liquid. Hint: Review the definition of enthalpy.

$$h = u + P\nu \Rightarrow u = h - P\nu$$

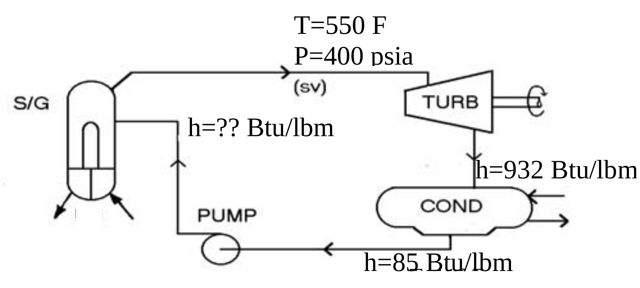
$$u = 355.5\frac{Btu}{lbm} - (200\frac{\cancel{lbf}}{\cancel{in}^2})(0.01839\frac{\cancel{ft}^3}{lbm})(\frac{144\cancel{in}^2}{\cancel{ft}^2})(\frac{Btu}{778\cancel{ft} - \cancel{lbf}}) = \boxed{354.82\frac{Btu}{lbm}}$$

<u>First Law of Thermodynamics</u>

26. State the First Law of Thermodynamics.

Energy can neither be created nor destroyed, only altered in form.

27. The following schematic of a simple Rankine cycle consists of steam leaving a boiler at T=550 F and P=400 psia and passes through a turboexpander where it does work and exhausts with an enthalpy of 932 Btu/lbm. The exhaust is then condensed to an enthalpy of 85 Btu/lbm before being pumped back into the boiler.



Given $\dot{W}_{turb} = 4.15 \times 10^6\ \frac{Btu}{lbm}$ and $\dot{Q}_{boiler} = 1.43 \times 10^7\ \frac{Btu}{lbm}$, find the mass flow rate of the system ($\dot{m}_{system}$), the total heat transfer out at the condenser ($\dot{Q}_{Cond}$), and the enthalpy of the fluid after leaving the pump and before entering the boiler.

$$\dot{W}_{turb} = \dot{m}_{system}(\Delta h)_{turb} \Rightarrow \dot{m}_{system} = \frac{\dot{W}_{turb}}{(\Delta h)_{turb}}$$

$$\Rightarrow \dot{m}_{system} = \frac{4.15\times10^{6}\,\frac{\cancel{Btu}}{hr}}{(1277.5-932)\frac{\cancel{Btu}}{lbm}} = \boxed{1.2\times10^{4}\,\frac{lbm}{hr}}$$

$$\dot{Q}_{condenser} = \dot{m}_{system}(\Delta h)_{condenser} = 1.2\times10^{4}\,\frac{\cancel{lbm}}{hr}(932-85)\frac{Btu}{\cancel{lbm}} = \boxed{1.02\times10^{7}\,\frac{Btu}{hr}}$$

$$\dot{Q}_{boiler} = \dot{m}_{system}(\Delta h)_{boiler} \Rightarrow \Delta h_{boiler} = \frac{\dot{Q}_{boiler}}{\dot{m}_{system}} = \frac{1.43\times10^{7}\,\frac{Btu}{\cancel{hr}}}{1.2\times10^{4}\,\frac{lbm}{\cancel{hr}}} = 1191.67\,\frac{Btu}{lbm}$$

$$\Delta h_{boiler} = h_{steam} - h_{water\ entering\ boiler} \Rightarrow h_{water\ entering\ boiler} = 1277.5-1191.67 = \boxed{85.8\,\frac{Btu}{lbm}}$$

Second Law of Thermodynamics

28. What is the maximum possible cycle efficiency of a heat engine operating between a heat source at 400 F and a heat sink at 32 F?

$$\eta_{\max} = 1-\frac{T_C}{T_H} = 1-\frac{(32+460)}{(400+460)} = 1-.572 = \boxed{42.8\%}$$

29. An inventor claims to have invented a device which absorbs 2500 Btu of heat and produces 2000 Btu of work. If the heat sink for the device is ice water (32 F), what would be the minimum source temperature?

$$\eta_{actual} = \frac{W_{net}}{Q_{in}} = \frac{2000Btu}{2500Btu} = 80\% \qquad \eta_{\max} = 1-\frac{T_{C\text{ (given)}}}{T_{H\text{ (need to solve)}}}$$

Setting $\eta_{\max}$ equal to η_{actual} gives $T_{H\text{ (minimum)}}$

$$0.80 = 1-\frac{(32+460)R}{T_{H\text{ (minimum)}}} \quad\Rightarrow\quad T_{H\text{ (minimum)}} = \frac{(32+460)R}{1-0.80} = 2460\ R = \boxed{2000\ F}$$

30. What is the efficiency of a turbine which receives dry, saturated steam at 100 psia and exhausts a wet vapor at 1 psia, while producing 230 Btu/lbm of real work?

$$\eta_{turbine} = \frac{w_{real}}{w_{ideal}} = \frac{230\,\frac{Btu}{lbm}}{h_{stm} - h_{exh_{ideal}}}$$

$h_{sat.stm@100\ psia} = 1188\,\frac{Btu}{lbm}$ from Mollier diagram or steam table

$h_{exh_{ideal}@1\ psia} = 895\,\frac{Btu}{lbm}$ from intersection of constant entropy process line with 1 psia line on Mollier diagram.

$$\eta_{turbine} = \frac{230\,\frac{Btu}{lbm}}{(1188 - 895)\,\frac{Btu}{lbm}} = .785 = \boxed{78.5\%}$$

Compression Processes

31. State the ideal gas law. Explain the meaning of each symbol.

$Pv = RT$ where P is the gas pressure in absolute units, v is the specific volume of the gas, R is a constant for a given gas, and T is the absolute temperature of the gas.

32. When can a fluid be considered incompressible? Give an everyday example of such a fluid.

A fluid is considered incompressible when it is in the liquid state, or when it is a gas at high speed. (Speed greater than 1/3 the speed of sound in the gas.) Liquid water is an everyday fluid which is considered to be nearly incompressible.