Tutorial - 1

MIN-106: Engineering Thermodynamics Autumn 2019-20

Department of Mechanical and Industrial Engineering, IIT Roorkee

Topic: Basic Concepts

1 The water in a tank pressurized by air and the pressure is measured by a multi-fluid manometer as shown in Fig. 1. Determine the gage pressure of air in the tank if $h_1 = 0.2$ *m,* $h_2 = 0.3$ *m, and* $h_3 = 0.46$ *m.* Take the densities of mercury, water, and oil are 13,600, 1000, and 850 kg/m^3, respectively. Ans: 56.9 kPa

2 A gas is contained in a vertical frictionless piston-cylinder device as shown in Fig 2. The piston has a mass of 4 kg and a cross sectional area of 35 cm^2. A compressed spring above the piston exerts a force of 60 N on the piston. If the atmospheric pressure is 95 kPa, determine the pressure inside the cylinder. Ans: 123.4 kPa

3 Both a gauge and a manometer is attached to a gas tank to measure its pressure as shown in Fig 3. If the reading on the pressure gauge is 80 kPa, determine the distance between the fluid levels of the manometer if the fluid is (a) mercury (ρ = *13,600* kg/m^3) and (b) water (ρ = *13,600* kg/m^3). Ans: 0.6 m, and 8.16 m

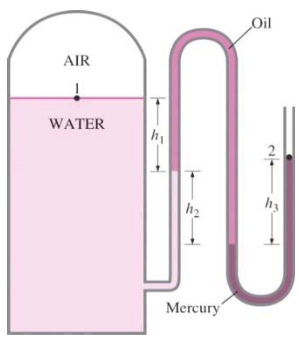


Fig. 1

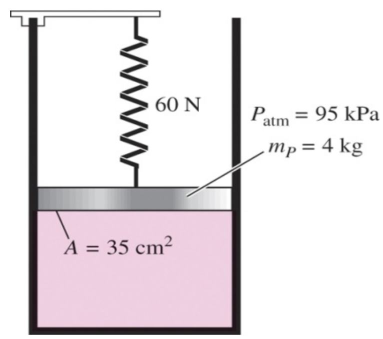


Fig. 2

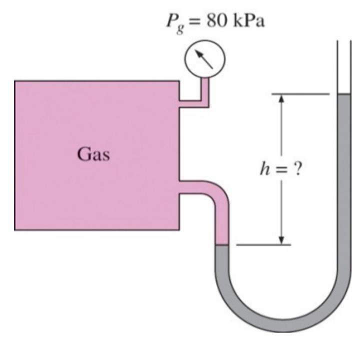


Fig. 3

4 Fresh and seawater flowing in parallel horizontal pipelines are connected to each other by a double U-tube manometer as shown in Fig. 4. Determined the pressure difference between the two pipelines. The densities of seawater and mercury are given to be ρ_{sea} = *1035* kg/m^3 and ρ_{Hg} = *13,600* kg/m^3. We take the density of water to be ρ_w =1000 kg/m^3. Can the air column be ignored in the analysis? Ans: 3.39 kPa

5 A glass tube open to the atmosphere is attached to a water pipe as shown in Fig. 5. The water pressure at the bottom of the tube is 115 kPa and the local atmospheric pressure is 92 kPa. Determine how high the water will rise in the tube, in mm. The density of water is given to be ρ = 1000 kg/m^3. Ans: 2.34 m

6 Water pipe is connected to a double-U manometer whose free arm is open to the atmosphere as shown in Fig. 6. The local atmospheric pressure is 92 kPa. Determined the absolute pressure at the center of the pipe. The specific gravities of mercury and oil are given to be 13.6 and 0.80, respectively. Take the density of water to be ρ_w = 1000 kg/m^3.

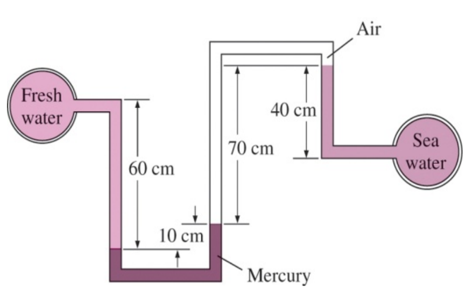


Fig. 4

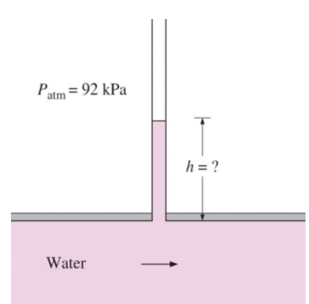


Fig. 5

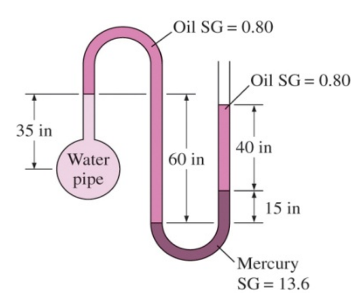


Fig. 6

MIN-106: Engineering Thermodynamics

Department of Mechanical and Industrial Engineering, IIT Roorkee

Topic: Properties of pure substances

1. Determine whether water at each of the following states is a compressed liquid, a superheated vapor, or a mixture of saturated liquid and vapor.

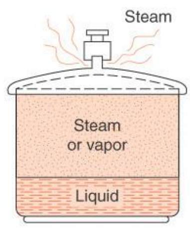
   a. 10 MPa, 0.003 m^3/kg b. 1 MPa, 190°C

   c. 200°C, 0.1 m^3/kg d. 200 kPa, 10°C

2. Find the phase, quality x if applicable and the missing property P or T.

   a. H_2O T = 120°C, v = 0.5 m^3 /kg b. H_2O P = 100 kPa, v = 1.8 m^3/kg

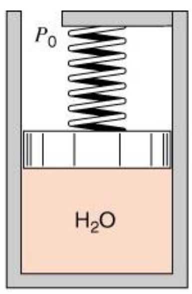
3. A sealed rigid vessel has volume of 1 m^3 and contains 2 kg of water at 100°C. The vessel is now heated. If a safety pressure valve is installed, at what pressure should the valve is set to have a maximum temperature of 200°C? (**431.3 kPa**)



4. A pressure cooker has the lid screwed on tight. A small opening with A = 5 mm2 is covered with a petcock that can be lifted to let steam escape. How much mass should the petcock have to allow boiling at 120oC with an outside atmosphere at 101.3 kPa?

5. A pressure cooker (closed tank) contains water at 100°C with the liquid volume being 1/10 of the vapor volume. It is heated until the pressure reaches 2.0 MPa. Find the final temperature. Has the final state more or less vapor than the initial state? (**More vapor, 212.4°C**)

6. A piston/cylinder arrangement is loaded with a linear spring and the outside atmosphere. It contains water at 5 MPa, 400°C with the volume being 0.1 m^3. If the piston is at the bottom, the spring exerts a force such that P_{lift} = 200 kPa. The system now cools until the pressure reaches 1200 kPa. Find the mass of water, the final state (T_2, v_2) and plot the *P–v* diagram for the process. (**0.01204 m3/kg, 188°C**)



7. Argon is kept in a rigid 5 m3 tank at −30°C, 3 MPa. Determine the mass using the compressibility factor. What is the error (%) if the ideal gas model is used? **308.75 kg, 4% Error.**

8. What is the percent error in specific volume if the ideal gas model is used to represent the behavior of superheated ammonia at 40°C, 500 kPa? What if the generalized compressibility chart is used instead? **v = 0.2923 m3/kg, 4.5% and 1.4% Error.**

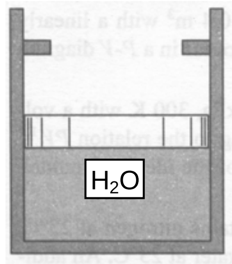
Tutorial –3

MIN 106: Engineering Thermodynamics (Autumn 2019-2020)

Department of Mechanical and Industrial Engineering, IIT Roorkee

Topic: Heat and work

1. A steam radiator in a room at 25°C has saturated water vapor at 110 kPa flowing through it, when the inlet and exit valves are closed. What is the pressure and the quality of the water, when it has cooled to 25°C? How much work is done? **(3.169 kPa, 0.0361, 0)**
2. A piston/cylinder contains 1 kg of liquid water at 20°Cand 300 kPa. Initially the piston floats, similar to the setup in figure, with a maximum enclosed volume of 0.002 m^3 if the piston touches the stops. Now heat is added so a final pressure of 600 kPa is reached. Find the final volume and the work in the process. **(0.30 kJ)**

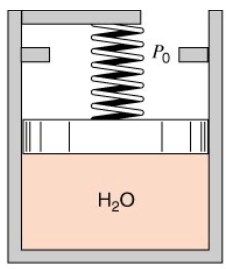


3. A cylinder having an initial volume of 3m^3 contains 0.1 kg of water at 40°C. The water is then compressed in an isothermal quasi-equilibrium process until it has a quality of 50%. Calculate the work done in the process. Assume the water vapor is an ideal gas. **(-13.4 kJ)**
4. A piston cylinder contains 1 kg of liquid water at 20°C and 300 kPa. There is a linear spring mounted on the piston such that when the water is heated the pressure reaches 3 MPa with a volume of 0.1 m^3.

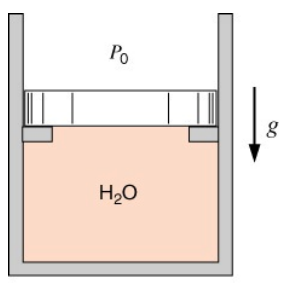
   a) Find the final temperature **(404°C)**

   b) Plot the process in a P-v diagram.

   c) Find the work in the process **(163.35 kJ)**
5. Air goes through a polytropic process from 125 kPa, 325 K to 300 kPa and 500 K. Find the polytropic exponent **n** and the specific work in the process. **(1.969, -51.8 kJ/kg)**
6. Two kilograms of water is contained in a piston/cylinder with a mass less piston loaded with a linear spring and the outside atmosphere. Initially the spring force is zero and $P_1 = P_o$ = 100 kPa with a volume of 0.2 m^3. If the piston just hits the upper stops the volume is 0.8 m^3 and T = 600°C. Heat is now added until the pressure reaches 1.2 MPa. Find the final temperature, show the P–V diagram and find the work done during the process. **(770°C, 330 kJ)**



7. A piston/cylinder contains 1 kg of water at 20°C with a volume of 0.1 m^3. Initially the piston rests on some stops with the top surface open to the atmosphere, P_o and a mass so a water pressure of 400 kPa will lift it. To what temperature should the water be heated to lift the piston? If it is heated to saturated vapor find the final temperature, volume and the work, ${}_1W_2$. **(143.6°C, 145 kJ)**



8. A piston cylinder setup similar to Problem 7 contains 0.1 kg saturated liquid and vapor water at 100 kPa with quality 25%. The mass of the piston is such that a pressure of 500 kPa will float it. The water is heated to 300°C. Find the final pressure, volume and the work, ${}_1W_2$. **(500 kPa, 0.05226 m^3, 4.91 kJ)**

Autumn 2019-20

MIN 106 ENGINEERING THERMODYNAMICS
Tutorial Sheet 4
First Law of Thermodynamics (Closed Systems)

I **F**ive kg of steam contained within a piston-cylinder assembly undergoes an expansion from state 1, where the specific internal energy is u_1 = 2709.9 kJ/kg to state 2, where u_2 = 2659.6 kJ/kg. During the process, there is heat transfer to the steam with a magnitude of 80 kJ. Also a paddle wheel transfers energy to the steam by work in the amount of 18.5 kJ. There is no significant change in the kinetic and potential energy of the steam. Determine the energy transfer by work from the steam to the piston during the process, in kJ.
(350 kJ)

II A gas expands in a piston cylinder assembly from P_1 = 8 bar, V_1 = 0.02m^3 to P_2 = 2 bar in a process during which the relation between the pressure and volume is $PV^{1.2}$ = constant. The mass of the gas is 0.25 kg. If the specific internal energy of the gas decreases by 55 kJ/kg during the process, determine the heat transfer, in kJ. Kinetic and potential energy effects are negligible.
(2.75 kJ)

III Air is contained in a vertical piston-cylinder assembly by a piston of mass 50 kg and having a face area of 0.01 m^2. The mass of air is 5 g and initially the air occupies a volume of 5 liters. The atmosphere exerts a pressure of 100 kPa on the top of the piston. The volume of the air slowly decreases to 0.002 m^3 as the specific internal energy of the air decreases by 260 kJ/kg. Neglecting friction between the piston and the cylinder wall, determine the heat transfer to the air, in kJ
(-1.747)

IV A gas undergoes a thermodynamic cycle consisting of three processes:
Process 1-2: Constant volume, V = 0.028 m^3, $U_2 - U_1$ = 26.4 kJ
Process 2-3: Expansion with PV = constant, $U_3 = U_2$
Process 3-1: Constant Pressure, P = 1.4 bar, W_{31} = -10.5 kJ
There are no significant changes in kinetic or potential energy.
(a) Sketch the cycle on a P-V diagram.
(b) Calculate the net work for the cycle
(c) Calculate the heat transfer for process 2-3, in kJ
(d) Calculate the heat transfer for process 3 – 1, in kJ
Is this a power cycle or a refrigeration cycle?
(W_{cycle} = 8.28kJ, Q_{23} = 18.78kJ, Q_{31} = -36.9 kJ, the cycle is a power cycle)

V A constant pressure piston/cylinder assembly contains 0.2 kg of water as saturated vapor at 400 kPa. It is now cooled so that the water occupies half the original volume. Find the heat transfer in the process.
(-213.9 kJ)

VI A piston cylinder arrangement contains water of quality 0.7 in the initial volume of 0.1 m^3, where the piston applies a constant pressure of 200 kPa. The system is now heated to a final temperature of 200^o C. Determine the work and heat transfer in the process.
(W=14.83 kJ, Q=132.9kJ)

VII A cylinder having a piston restrained by a linear spring (of spring constant 15 kN/m) contains 0.5 kg of saturated vapor water at 120°C, as shown in Fig. 2. Heat is transferred to the water, causing the piston to rise. If the piston cross-sectional area is 0.05 m^2, and the pressure varies linearly with volume until a final pressure of 500 kPa is reached. Find the final temperature in the cylinder and the heat transfer for the process.

(803°C, 587 kJ)

VIII Air in a piston/cylinder at 200 kPa, 600 K, is expanded in a constant-pressure process to twice the initial volume (state 2), shown in Fig. 3. The piston is then locked with a pin and heat is transferred to a final temperature of 600 K. Find P, T, and h for states 2 and 3, and find the work and heat transfer in both processes.

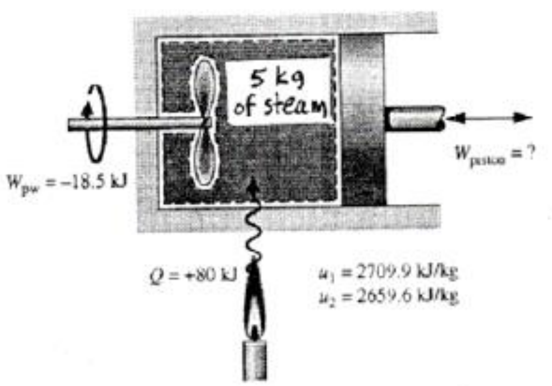
(200kPa, 1200K, h_2 = 1277.8 kJ/kg, h_3 = 607.5 kJ/kg, w_{23} = 0, q_{23} = -498.3 kJ/kg)

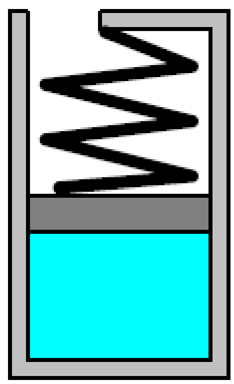
IX A piston/cylinder contains 0.001 m3 air at 300 K, 150 kPa. The air is now compressed in a process in which $P\,V^{1.25} = C$ to a final pressure of 600 kPa. Find the work performed by the air and the heat transfer.

(0.192 kJ, 0.072kJ)

X Air is expanded from 400 kPa, 600 K in a polytropic process to 150 kPa, 400 K in a piston cylinder arrangement. Find the polytropic exponent n and the work and heat transfer per kg air. Take the value of c_v = 0.717 kJ/kgK

(1.7047, work = 81.45 kJ/kg, q = -61.95 kJ/kg)





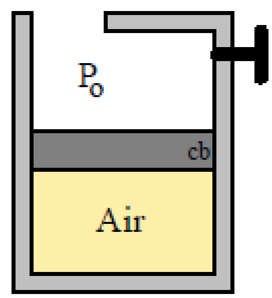


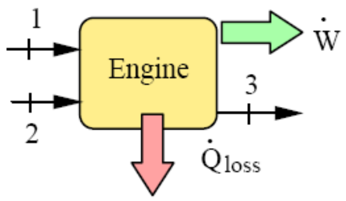
FIG 1 **FIG 2** **FIG 3**

MIN-106 : Engineering Thermodynamics (Autumn 2019-20)

Department of Mechanical and Industrial Engineering, IIT Roorkee

Topic: *First law of Thermodynamics for open systems*

1. Steam at 500 kPa, 300°C is used to heat cold water at 15°C to 75°C for domestic hot water supply. How much steam per kg liquid water is needed if the steam should not condense? **(0.795)**
2. A nozzle receives 0.1 kg/s steam at 1 MPa, 400°C with negligible kinetic energy. The exit is at 500 kPa, 350°C and the flow is adiabatic. Find the nozzle exit velocity and the exit area. **(438.7 m/s, 1.3 cm^2)**
3. Water at 1.5 MPa, 150°C, is throttled adiabatically through a valve to 200 kPa. The inlet velocity is 5 m/s, and the inlet and exit pipe diameters are the same. Determine the state (neglecting kinetic energy in the energy equation) and the velocity of the water at the exit. (x_e = **0.0579, 240 m/s)**
4. A liquid water turbine receives 2 kg/s water at 2000 kPa, 20°C and velocity of 15 m/s. The exit is at 100 kPa, 20°C and very low velocity. Find the specific work and the power produced. **(1.99 kJ/kg, 3.985 kW)**
5. Consider a water pump that receives liquid water at 15°C, 100 kPa and delivers it to a same diameter short pipe having a nozzle with exit diameter of 1 cm to the atmosphere at 100 kPa. Neglect the kinetic energy in the pipes and assume constant u for the water. Find the exit velocity and the mass flow rate if the pump draws a power of 1 kW. **(29.43 m/s, 2.31 kg/s)**
6. A large expansion engine has two low velocity flows of water entering. High pressure steam enters at point 1 with 2.0 kg/s at 2 MPa, 500°C and 0.5 kg/s cooling water at 120 kPa, 30°C enters at point 2. A single flow exits at point 3 with 150 kPa, 80% quality, through a 0.15 m diameter exhaust pipe. There is a heat loss of 300 kW. Find the exhaust velocity and the power output of the engine. **(131.2 m/s, 1056 kW)**



7. An initially empty bottle is filled with water from a line at 0.8 MPa, 350°C. Assume no heat transfer and that the bottle is closed when the pressure reaches the line pressure. If the final mass is 0.75 kg find the final temperature and the volume of the bottle. **(520°C, 0.342 m^3)**
8. A rigid 100-L tank contains air at 1 MPa, 200°C. A valve on the tank is now opened and air flows out until the pressure drops to 100 kPa. During this process, heat is transferred from a heat source at 200°C, such that when the valve is closed, the temperature inside the tank is 50°C. What is the heat transfer? **(+25.7 kJ)**
9. A 1-m^3, 40-kg rigid steel tank contains air at 500 kPa, and both tank and air are at 20°C. The tank is connected to a line flowing air at 2 MPa, 20°C. The valve is opened, allowing air to flow into the tank until the pressure reaches 1.5 MPa and is then closed. Assume the air and tank are always at the same temperature and the final temperature is 35°C. Find the final air mass and the heat transfer. **(16.96 kg, – 468.9 kJ)**
10. A 200 liter tank initially contains water at 100 kPa and a quality of 1%. Heat is transferred to the water thereby raising its pressure and temperature. At a pressure of 2 MPa a safety valve opens and saturated vapor at 2 MPa flows out. The process continues, maintaining 2 MPa inside until the quality in the tank is 90%, then stops. Determine the total mass of water that flowed out and the total heat transfer. **(8.90 kg, 25.46 MJ)**

MIN 106 ENGINEERING THERMODYNAMICS

Tutorial Sheet VI

Second Law of Thermodynamics

I Does a heat engine that has a thermal efficiency of 100% necessarily violate (a) the first law and (b) the second law of thermodynamics? Explain.

II Are the efficiencies of all the work-producing devices, including the hydroelectric power plants, limited by Kelvin-Planck statement of the second law? Explain.

III For each of the cases below determine if the heat engine satisfies the first law (energy equation) and if it violates the second law.

a. $\dot{Q}_H = 6$ kW, $\dot{Q}_L = 4$ kW, $\dot{W} = 2$ kW

b. $\dot{Q}_H = 6$ kW, $\dot{Q}_L = 0$ kW, $\dot{W} = 6$ kW

c. $\dot{Q}_H = 6$ kW, $\dot{Q}_L = 2$ kW, $\dot{W} = 5$ kW

d. $\dot{Q}_H = 6$ kW, $\dot{Q}_L = 6$ kW, $\dot{W} = 0$ kW

IV Assume we have a refrigerator operating at steady state using 500 W of electric power with a COP of 2.5. What is the net effect on the kitchen air?

V A car engine takes atmospheric air in at 20oC, no fuel, and exhausts the air at –20oC producing work in the process. What do the first and the second laws say about that?

VI A steam power plant with a power output of 150 MW consumes coal at a rate of 60 tons/h. If the heating value of the coal is 30,000 kJ/kg, determine the overall efficiency of this plant. **(Ans.: 30%)**

VII A commercial heat pump removes 10,000 kJ/h from the source, rejects 15,090 kJ/h to the sink, and requires 1.5 kW of power. What is the coefficient of performance of this heat pump? **(Ans. 2.79)**

VIII A household refrigerator that has a power input of 450 W and a COP of 2.5 is used to cool five large (10 kg each) watermelons to 8°C. If the watermelons are initially at 20°C, determine how long it will take for the refrigerator to cool them. The watermelons can be treated as water whose specific heat is 4.2 kJ/kg.°C. Is your answer realistic or optimistic? Explain. **(Ans.: 2240 seconds)**

IX A heat pump is used to maintain a house at a constant temperature of 23°C. The house is rejecting heat to the outside air through the walls and the windows at a rate of 60,000 kJ/h while the energy generated within the house from people, lights, and appliances amounts to 4000 kJ/h. for a COP of 2.5, determine the required power input to the heat pump. **(Ans. 6.22 kW)**

X Refrigerant enters the condenser of a residential heat pump at 800 kPa and 35°C at a rate of 0.018 kg/s and leaves at 800 kPa as a saturated liquid. If the compressor consumes 1.2 kW of power, determine (a) the COP of the heat pump, and (b) the rate of heat absorption from the outside air. **(Ans.: (a) 2.64, (b) 1.96 kW)**

XI Refrigerant enters the evaporator coils placed at the back of the freezer section of a household refrigerator at 120 kPa with a quality of 20% and leaves at 120 kPa and -20°C. If the compressor consumes 450 W of power and the COP of the refrigerator is 1.2, determine (a) the mass flow rate of the refrigerant and (b) the rate of heat rejected to the kitchen air. **(Ans. (a) 0.00311 kg/s (b) 990 W)**

XII A completely reversible heat engine operates with a source of 800 K and a sink at 280 K. At what rate must heat (kJ/h) be supplied to this engine for it to produce 4kW of power? **(Ans. 22150 kJ/h)**

XIII A geothermal power plant uses geothermal water extracted at 160°C at a rate of 440 kg/s as the heat source and produces 22 MW of net power. If the environment temperature is 25°C, determine (a) the actual thermal efficiency, (b) the maximum possible thermal efficiency, and (c) the actual rate of heat rejection from this power plant. **(Ans.: 8.8%, 31.2%, 229.1 MW)**

XIV The structure of a house is such that it loses heat at a rate of 5400 kJ/h per oC difference between the indoors and outdoors. A heat pump that requires power input of 6kW is used to maintain this house at 21°C. Determine the lowest outdoor temperature for which the heat pump can meet the heating requirements of this house. **(Ans. -13.3°C)**

XV A Carnot heat engine receives heat from a reservoir at 900oC at a rate of 800 kJ/min and rejects the waste heat to the ambient air at 27oC. The entire work output of the heat engine is used to drive a refrigerator that removes heat from the refrigerated space at -5oC and transfers it to the same ambient air at 27oC. Determine (a) the maximum rate of heat removal from the refrigerated space, and (b) the total rate of the heat rejection to the ambient air. **(Ans. 4982 kJ/min, 5782 kJ/min)**

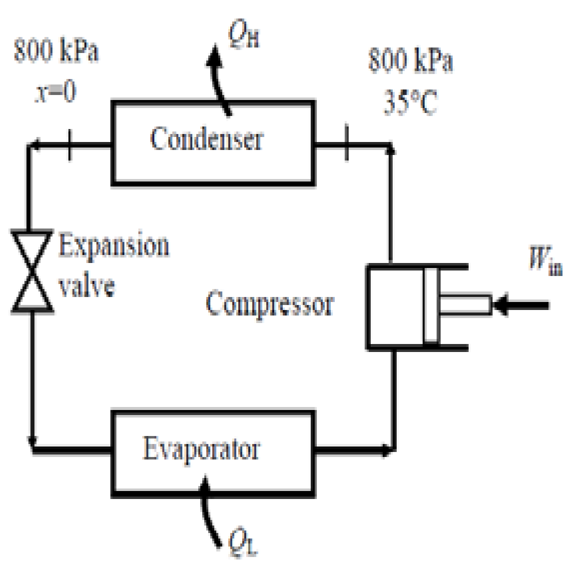


Fig Problem X

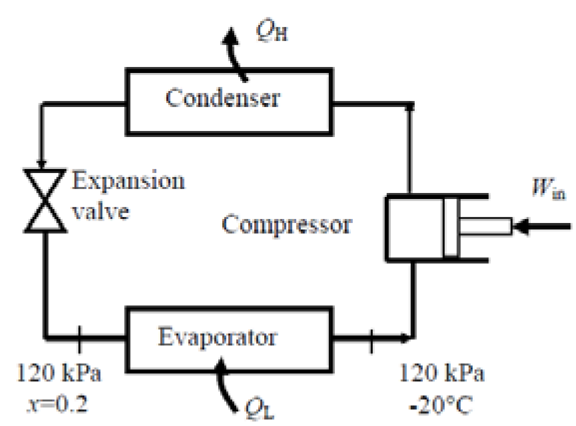


Fig Problem XI

Tutorial - VII

MIN-106 : Engineering Thermodynamics (Autumn 2019-20)

Department of Mechanical and Industrial Engineering, IIT Roorkee

Topic: Entropy

1. A cylinder fitted with a movable piston contains water at 3 MPa, 50% quality, at which point the volume is 20L. The water now expands to 1.2 MPa as a result of receiving 600 kJ of heat from a large source at 300◦C. It is claimed that the water does 124 kJ of work during this process. Is this possible? (Possible)

2. Two 5 kg blocks of steel, one at 250◦C the other at 25◦C, come in thermal contact. Find the final temperature and the total entropy generation in the process? (137.5◦C, 0.1794 kJ/K)

3. A rigid tank contains 2 kg of air at 200 kPa and ambient temperature, 20◦C. An electric current now passes through a resistor inside the tank. After a total of 100 kJ of electrical work has crossed the boundary, the air temperature inside is 80◦C. Is this possible? C_v = 0.717 kJ/kg K, R = 0.287 kJ/kg K (possible)

4. A reversible heat engine exchanges heat with three reservoirs A, B and C and produces 1400 kJ of work output. Reservoir A supplies 3000 kJ of heat at 500 K to the engine. If the temperatures of reservoirs B and C are 400 K and 300 K respectively, how much heat the reservoirs B and C exchange with the engine and in what direction?
   (Q2 = 800 kJ, Q3 = 2400 kJ)

5. Consider a Carnot-cycle heat engine with water as the working fluid. The heat transfer to the water occurs at 300°C, during which process the water changes from saturated liquid to saturated vapor. The heat is rejected from the water at 40°C. Show the cycle on a T–s diagram and find the quality of the water at the beginning and end of the heat rejection process. Determine the net work output per kilogram of water and the cycle thermal efficiency. (0.6678, 0.3489, 637.3 kJ/kg)

6. A piston cylinder loaded so it gives constant pressure has 0.75 kg saturated vapor water at 200 kPa. It is now cooled so the volume becomes half the initial volume by heat transfer to the ambient at 20oC. Find the work, the heat transfer and the total entropy generation. (-66.22 kJ, -824.1 kJ, 0.716 kJ/K)

7. A piston/cylinder contains 1 kg water at 150 kPa, 20°C. The piston is loaded so pressure is linear in volume. Heat is added from a 600°C source until the water is at 1 MPa, 500°C. Find the heat transfer and the total change in entropy. (3243.4 kJ, 3.751 kJ/K)

8. Nitrogen at 200°C, 300 kPa is in a piston cylinder, volume 5 L, with the piston locked with a pin. The forces on the piston require a pressure inside of 200 kPa to balance it without the pin. The pin is removed and the piston quickly comes to its equilibrium position without any heat transfer. Find the final P, T and V and the entropy generation due to this partly unrestrained expansion. (200 kPa, 428.13 K, 0.00679 m^3, 0.000173 kJ/K)

MIN-106: Engineering Thermodynamics
Department of Mechanical and Industrial Engineering
Autumn 2019-2020

Topic: Exergy analysis

1. Consider a thermal energy reservoir at 1500 K that can supply heat at a rate of 150,000 kJ/h. Determine the exergy of this supplied energy, assuming an environmental temperature of 25 °C.

(Answer: 33.4KW)

2. How much of the 100 kJ of thermal energy at 800 K can be converted to useful work? Assume the environment to be at 25 °C.

(Answer: 62.75 kJ)

3. A piston–cylinder device initially contains 2 L of air at 100 kPa and 25 °C. Air is now compressed to a final state of 600 kPa and 150 °C. The useful work input is 1.2 kJ. Assuming the surroundings are at 100 kPa and 25 °C, determine (*a*) the exergy of the air at the initial and the final states, (*b*) the minimum work that must be supplied to accomplish this compression process, and (*c*) the second-law efficiency of this process.

(Answer: (a) 0.171 kJ, (b) 0.171 kJ, 9c) 14.3%)

4. A rigid tank is divided into two equal parts by a partition. One part of the tank contains 1.5 kg of compressed liquid water at 300 kPa and 60 °C and the other side is evacuated. Now the partition is removed, and the water expands to fill the entire tank. If the final pressure in the tank is 15 kPa, determine the exergy destroyed during this process. Assume the surroundings to be at 25 °C and 100 kPa.

(*Answer:* 3.67 kJ)

5. Steam is throttled from 8 MPa and 450 °C to 6 MPa. Determine the wasted work potential during this throttling process. Assume the surroundings to be at 25 °C.

(*Answer:* 36.6 kJ/kg)

6. Steam enters a diffuser at 10 kPa and 50 °C with a velocity of 300 m/s and exits as saturated vapor at 50 °C and 70 m/s. The exit area of the diffuser is 3 m^2. Determine (*a*) the mass flow rate of the steam and (*b*) the wasted work potential during this process. Assume the surroundings to be at 25 °C.

(*Answer:* 238.3 kW)

7. Steam enters an adiabatic turbine at 6 MPa, 600 °C, and 80 m/s and leaves at 50 kPa, 100°C, and 140 m/s. If the power output of the turbine is 5 MW, determine (*a*) the reversible power output and (*b*) the second-law efficiency of the turbine. Assume the surroundings to be at 25 °C.

(*Answers:* (*a*) 5.84 MW, (*b*) 85.6 percent)

AUTUMN 2019-20

MIN 106 ENGINEERING THERMODYNAMICS

Tutorial Sheet 9

Topic: Air Standard Cycles

I. The compression ratio of an air-standard Otto cycle is 9.5. Prior to the isentropic compression process, the air is at 100 kPa, 35°C, and 600 cm^3. The temperature at the end of the isentropic expansion process is 800 K. Using specific heat values at room temperature; determine (a) the highest temperature and pressure in the cycle; (b) the amount of heat transferred in, in kJ; (c) the thermal efficiency; and (d) the mean effective pressure.

[(a)1969 K, 6072 kPa, (b) 0.59 kJ, (c) 59.4%, (d) 652 kPa]

II. An ideal Otto cycle has a compression ratio of 7. At the beginning of the compression process, P_1 = 90 kPa, T_1 = 27°C, and V_1 = 0.004 m^3. The maximum cycle temperature is 1127°C. For each repetition of the cycle, calculate the heat rejection and the net work production. Also calculate the thermal efficiency and mean effective pressure for this cycle. Use constant specific heats at room temperature.

[1.03 kJ, 1.21 kJ, 54.1%, 354 kPa]

III. An ideal Diesel cycle has a compression ratio of 20 and uses air as the working fluid. The state of air at the beginning of the compression process is 95 kPa and 20°C. If the maximum temperature in the cycle is not to exceed 2200 K, determine (a) the thermal efficiency (b) mean effective pressure. Assume specific heats for air at room-temperature.

[63.5%, 933 kPa]

IV. Two engines are to operate on Otto and Diesel cycles with the following data: Maximum temperature 1400 K, exhaust temperature 700 K, air flow rate 1 kg/min. State of air at the beginning of compression 0.1 MPa, 300K. Estimate the compression ratios, the maximum pressures, efficiencies, and rate of work outputs

[Otto- 5.656, 2.64 MPa, 2872 kJ/kg, 50%; Diesel-7.456, 1.665 MPa, 446.45 kJ/kg, 60.8%]

V. In air standard diesel cycle, the compression ratio is 16, and at the beginning of isentropic compression, the temperature is 15°C and the pressure is 0.1 MPa. Heat is added until the temperature at the end of the constant pressure process is 1480°C. Calculate (a) the cut off ratio, (b) the heat supplied per kg of air, (c) the cycle efficiency, and (d) the mean effective pressure**.**

[2.01, 343.2 kJ/kg, 61.2%, 698.45 kPa]

Tutorial – X

MIN 106: Engineering Thermodynamics (Autumn 2019-20)

Department of Mechanical and Industrial Engineering, IIT Roorkee

Topic: Brayton Cycle and Vapor Power Cycle

1) Consider an ideal air-standard Brayton cycle in which the air into the compressor is at 100 kPa, 20°C, and the pressure ratio across the compressor is 12:1. The maximum temperature in the cycle is 1100°C, and the air flow rate is 10 kg/s. Assume constant specific heat for the air (1.004 kJ/kg-K). Determine the compressor work, the turbine work, and the thermal efficiency of the cycle. **[3048 kW, 7013 kW, 0.509]**

2) A large stationary Brayton cycle gas-turbine power plant delivers a power output of 100 MW to an electric generator. The minimum temperature in the cycle is 300 K, and the maximum temperature is 1600 K. The minimum pressure in the cycle is 100 kPa, and the compressor pressure ratio is 14 to 1. Calculate the power output of the turbine. What fraction of the turbine output is required to drive the compressor? What is the thermal efficiency of the cycle? **[166.32 MW, 0.399, 0.530]**

3) Repeat Problem#2, but assume that the compressor has an isentropic efficiency of 85% and the turbine an isentropic efficiency of 88%. **[214.2 MW, 0.533, 0.386]**

4) A simple ideal Rankine cycle with water as the working fluid operates between the pressure limits of 15 MPa in the boiler and 100 kPa in the condenser. Saturated steam enters the turbine. Determine the work produced by the turbine, the heat transferred in the boiler, and thermal efficiency of the cycle. **[676 kJ/kg, 2178 kJ/kg, 30.4%]**

5) Consider a coal-fired steam power plant that produces 300 MW of electric power. The power plant operates on a simple ideal Rankine cycle with turbine inlet conditions of 5 MPa and 450^{o}C and a condenser pressure of 25 kPa. The coal has a heating value (energy released when the fuel is burned) of 29,300 kJ/kg. Assuming that 75 percent of this energy is transferred to the steam in the boiler and that the electric generator has an efficiency of 96 percent, determine (a) the overall plant efficiency (the ratio of net electric power output to the energy input as fuel) and (b) the required rate of coal supply. **[24.5%, 150 t/h]**

6) (a) Consider a steam power plant that operates on a simple ideal Rankine cycle and has a net power output of 45 MW. Steam enters the turbine at 7 MPa and 500'C and is cooled in the condenser at a pressure of 10 kPa by running cooling water from a lake through the tubes of the condenser at a rate of 2000 kg/s. Show the cycle on a T-s diagram and determine (a) the thermal efficiency of the cycle, (b) the mass flow rate of the steam, and (c) the temperature rise of the cooling water. **[38.9%, 36 kg/s, 8.4^{o}C]**

(b) Repeat the above problem assuming an isentropic efficiency of 87% for both the turbine and the pump. **[33.8%, 41.4 kg/s, 10.5^{o}C]**

7) Consider an ideal steam reheat cycle where steam enters the high-pressure turbine at 3.0 MPa, 400°C, and then expands to 0.8 MPa. It is then reheated to 400°C and expands to 10 kPa in the low-pressure turbine. Calculate the cycle thermal efficiency and the moisture content of the steam leaving the low-pressure turbine. **[0.923, 36.2%]**

8) A smaller power plant produces 25 kg/s steam at 3 MPa, 600oC in the boiler. It cools the condenser with ocean water so the condenser exit is at 45^{o}C. There is a reheat done at 500 kPa up to 400^{o}C and then expansion in the low pressure turbine. Find the net power output and the total heat transfer in the boiler. **[34,820 kW, 91 737 kW]**

MIN 106: Engineering Thermodynamics (Autumn 2019-20)

Department of Mechanical and Industrial Engineering, IIT Roorkee

Topic: Refrigeration cycle and Airconditioning

1) Refrigerant-134a is the working fluid in an ideal compression refrigeration cycle. The refrigerant leaves the evaporator at -20°C and has a condenser pressure of 0.9 MPa. The mass flow rate is 3 kg/min. Find rate of heat removal, COP_R and $COP_{R,\,Carnot}$ for the same T_{max} and T_{min}. **[6.84 kW, 3.44, 3.97]**

2) A refrigerator uses refrigerant-134a as the working fluid and operates on an ideal vapor-compression cycle between 0.14 and 0.8 MPa. The mass flow rate of refrigerant is 0.06 kg/s. Determine (a) the rate of heat removal from the refrigerated space and the power input to compressor, (b) the power input to compressor (c) the rate of heat rejection to the environment and (d) the coefficient of performance. **[8.62kW, 2.17 kW, (b) 10.79 kW, (c) 3.97]**

3) A refrigerator uses refrigerant-134a as the working fluid and operates on an ideal vapor-compression cycle between 0.12 and 0.7 MPa. The mass flow rate of refrigerant is 0.05 kg/s. Show the cycle on a *T-s* diagram. Determine (a) the rate of heat removal from the refrigerated space and the power input to compressor, (b) the rate of heat rejection to the environment and (c) the coefficient of performance. **[(a)7.41 kW, 1.83 kW, (b) 9.23 kW, (c) 4.06]**

4) Refrigerant-134a enters the compressor of a refrigerator at 140 kPa and -10°C at a rate of 0.3 m^3/min and leaves at 1 MPs. The isentropic efficiency of the compressor is 78 percent. The refrigerant enters the throttling valve at 0.95 MPa and 30°C and leaves the evaporator as saturated vapor at -18.5°C. Show the cycle on a *T-s* diagram and determine (a) the power input to the compressor, (b) the rate of heat removal from the refrigerated space, and (c) the pressure drop and rate of heat gain in the line between the evaporator and the compressor. **[(a)1.88 kW, (b) 4.99 kW, (c) 1.65 kPa, 0.241 kW]**

5) A refrigerator operates on the ideal vapor-compression refrigeration cycle with refrigerant-134a as the working fluid. The condenser operates at 1.6 MPa and the evaporator at -6 °C. If an adiabatic, reversible expansion device were available and used to expand the liquid leaving the condenser, how much would the COP improve by using this device instead of the throttling device. **[2.77 to 3.04; 9.7%]**