TD 1

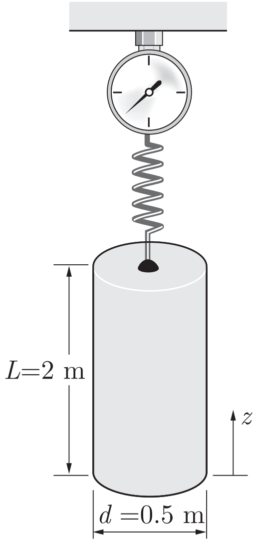
BASIC CONCEPTS AND ENERGY ANALYSIS

TD 1.1 Density of liquid water is $\rho = \left(1008 - \frac{T}{2}\right)\,\text{kg/m}^3$ with T in $^\circ$C. If the temperature increases 10°C, how much will be the change in per meter depth of water ?

(A) 0.001 m (B) 0.005 m

(C) 0.05 m (D) 0.010 m

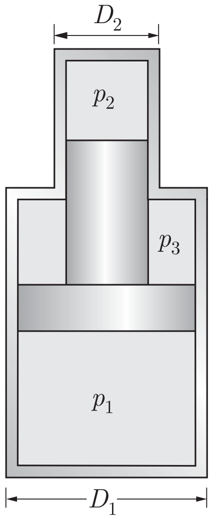
TD 1.2 A cylinder of 2 m in length and 0.5 m in diameter is suspended from a spring scale at a location shown in figure where the acceleration due to gravity is $9.78\,\text{m/s}^2$. If the metal density of cylinder varies with position z according to $\rho = 7800 - 360\left(\frac{z}{L}\right)^2$, then the reading of the scale will be



(A) 36395 N (B) 24586 N

(C) 32446 N (D) 29496 N

TD 1.3 Consider the piston cylinder arrangement as shown in figure. The piston diameters are $D_1 = 10$ cm and $D_2 = 4$ cm. If $p_1 = 1000$ kPa and $p_3 = 500$ kPa, what will be the pressure in chamber 2 ?



(A) 2538 kPa (B) 4532 kPa
(C) 2965 kPa (D) 3625 kPa

TD 1.4 A steel cylinder of mass 2 kg contains 4 liter of water at 25°C, 200 kPa. What will be the total mass and volume of the system, respectively ?

(Take $\rho_{steel} = 7820\ kg/m^3$, $\rho_{water} = 997\ kg/m^3$)

(A) 4.491 kg, 3.20 L (B) 7.784 kg, 5.33 L
(C) 3.249 kg, 2.42 L (D) 5.988 kg, 4.26 L

TD 1.5 The following table lists temperatures and specific volumes of water vapor at two pressures:

$p = 1.0$ MPa		$p = 1.5$ MPa	
T (°C)	ν (m^3/kg)	T (°C)	ν (m^3/kg)
200	0.2060	200	0.1325
240	0.2275	240	0.1483
280	0.2480	280	0.1627

Using the data provided here, what will be the specific volume at $T = 240$°C, $p = 1.25$ MPa and the temperature at $p = 1.5$ MPa, $\nu = 0.1555\ m^3/kg$?

(A) 0.280 m^3/kg, 300°C (B) 0.141 m^3/kg, 230°C
(C) 0.225 m^3/kg, 210°C (D) 0.188 m^3/kg, 260°C

TD 1.6 A vacuum gauge connected to a tank reads 15 kPa at a location where the barometric reading is 750 mm Hg. What is the absolute pressure in the tank ? Take $\rho_{Hg} = 13,590\ kg/m^3$.

(A) 80 kPa (B) 95 kPa
(C) 85 kPa (D) 75 kPa

TD 1.7 A 2.5 kJ of work is to be delivered on a rod from a pneumatic piston. If the air pressure is limited to 500 kPa, what diameter cylinder should we have to restrict the rod motion to the maximum of 0.5 m ?

(A) 0.113 m (B) 0.090 m
(C) 0.254 m (D) 0.165 m

TD 1.8 The barometric readings at the top and at the bottom of a building are 730 mm Hg and 755 mm Hg, respectively. If the densities of air and mercury to be 1.18 kg/m^3 and 13600 kg/m^3, respectively, then the height of the building will be

(A) 287.6 m (B) 244.5 m
(C) 345.2 m (D) 264.6 m

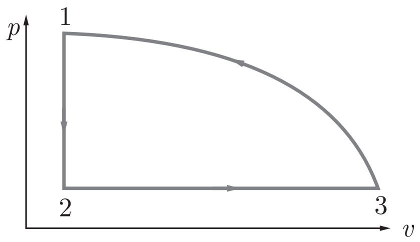
TD 1.9 A gas contained within a piston-cylinder assembly undergoes a thermodynamic cycle consisting of three processes:

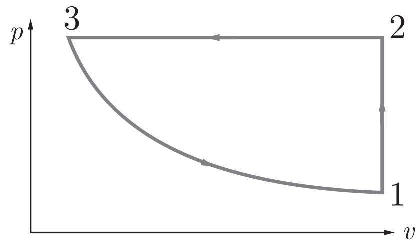
Process 1-2; Compression with pv constant from $p_1 = 1$ bar, $v_1 = 1.0\ m^3$ to $v_2 = 0.2\ m^3$

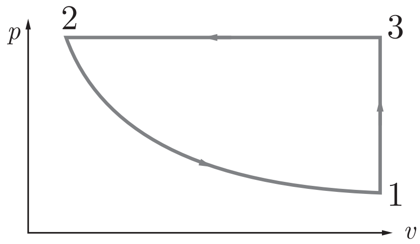
Process 2-3; Constant-pressure expansion to $v_3 = 1.0\ m^3$

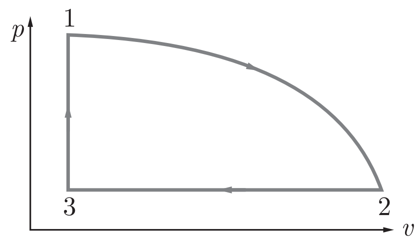
Process 3-1; Constant volume

Which one of the following is the correct cycle on a p-v diagram labelled with each numbered state ?

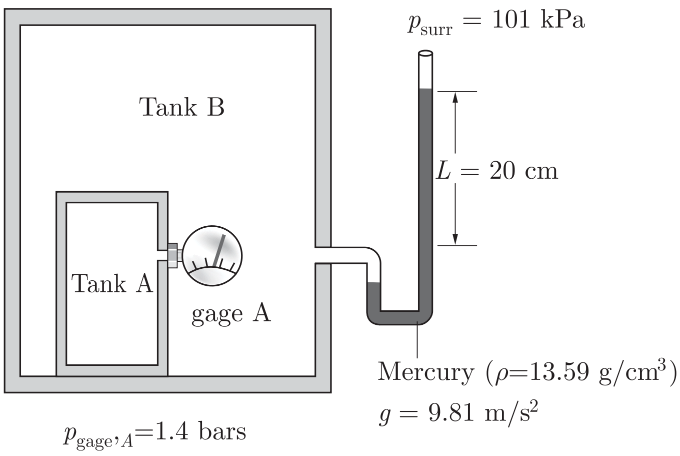
(A) 

(B) 

(C) 

(D) 

TD 1.10 Given figure shows a tank within a tank and both contains air. Pressure gage A is located inside tank B and reads 1.4 bar. The U-tube manometer connected to tank B contains mercury. The atmospheric pressure surrounding tank B is 101 kPa. Using data on the diagram, the absolute pressures inside tank A and tank B, respectively, are

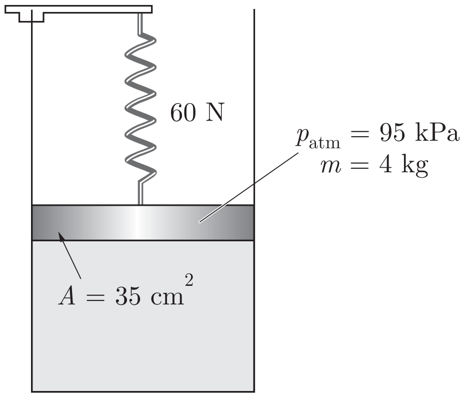


(A) 2.68 bar, 1.28 bar
(B) 2.94 bar, 1.56 bar
(C) 2.34 bar, 1.10 bar
(D) 3.20 bar, 2.10 bar

TD 1.11 A car of mass 1775 kg travels with a velocity of 100 km/h. What will be the kinetic energy and height in the standard gravitational field to have a potential energy that equals the kinetic energy ?

(A) 684.9 kJ, 39.3 m
(B) 753.4 kJ, 43.3 m
(C) 583.2 kJ, 33.5 m
(D) 856.2 kJ, 49.17 m

TD 1.12 Consider a vertical, frictionless piston-cylinder device shown in figure. It contains gas. 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, the pressure inside the cylinder will be



(A) 89.07 kPa (B) 123.4 kPa

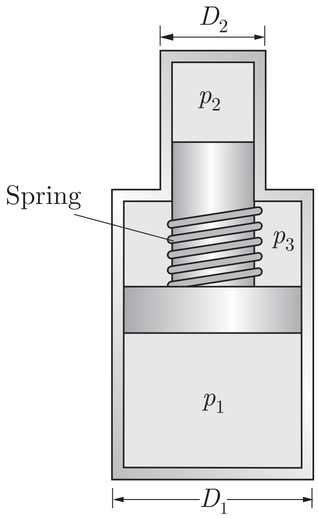
(C) 66.65 kPa (D) 56.7 kPa

TD 1.13 The depth of a swimming pool varies linearly along its length from 1 m to 4 m. The atmospheric pressure is 0.98 bar, the density of the water is 998.2 kg/m^3 and the local acceleration of gravity is 9.81 m/s^2. What will be the total force on the bottom of this 100×50 m swimming pool and the pressure on the floor at the center of the pool ?

(A) 7.66×10^5 kN, 153.2 kPa (B) 4.9×10^5 kN, 127.4 kPa

(C) 6.13×10^5 kN, 122.5 kPa (D) 1.23×10^5 kN, 137.2 kPa

TD 1.14 In the system shown, the spring has a spring constant of 8 kN/cm. The pressures are $p_1 = 5000$ kPa, $p_2 = 10000$ kPa and $p_3 = 1000$ kPa. If the piston diameters are $D_1 = 8$ cm and $D_2 = 3$ cm, how far will the spring be deflected ?



(A) 2.15 cm (B) 1.38 cm

(C) 1.98 cm (D) 1.72 cm

TD 1.15 A 1 m^3 container is filled with 400 kg of granite stone ($\rho = 2750$ kg/m^3), 200 kg dry sand ($\rho = 1500$ kg/m^3) and 0.2 m^3 of liquid 25°C water ($\rho = 997$ kg/m^3). What are the average specific volume and density of the masses when exclude air mass and volume ?

(A) 0.000750 m^3/kg, 1333.3 kg/m^3 (B) 0.000599 m^3/kg, 1669.5 kg/m^3

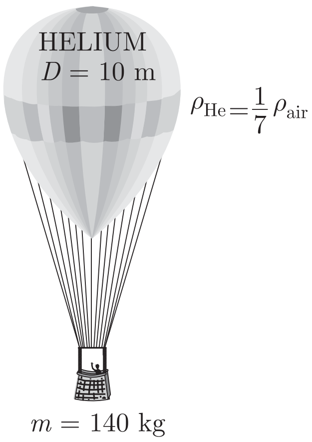
(C) 0.000509 m^3/kg, 1964.6 kg/m^3 (D) 0.000838 m^3/kg, 1193.3 kg/m^3

TD 1.16 An airplane whose mass is 5000 kg is flying with a velocity of 150 m/s at an altitude of 10000 m both measured relative to the surface of the earth. The acceleration of gravity can be taken as constant at $g = 9.78\ \text{m/s}^2$. What will be the total (kinetic plus potential) energy of the airplane and the final velocity when the kinetic energy is increased by $10000\ \text{kJ}$ with no change in elevation ?

(A) $595.2\ \text{MJ}, 180.3\ \text{m/s}$ (B) $545.25\ \text{MJ}, 162.8\ \text{m/s}$

(C) $676.6\ \text{MJ}, 201.5\ \text{m/s}$ (D) $510.32\ \text{MJ}, 143.3\ \text{m/s}$

TD 1.17 A helium gas filled balloon, whose weight is about one-seventh of air weight , is shown in figure. Assume the density of air is $\rho = 1.16\ \text{kg/m}^3$ and neglect the weight of the ropes and the cage. If the balloon has a diameter of 10 m and carries two people, 70 kg each, what will be the acceleration of the balloon when it is first released ?



(A) $13.5\ \text{m/sec}^2$ (B) $16.5\ \text{m/sec}^2$

(C) $17.5\ \text{m/sec}^2$ (D) $19.5\ \text{m/sec}^2$

TD 1.18 A vertical hydraulic piston cylinder system has a $125\ \text{mm}$ piston diameter and fluid inside the cylinder. An outside ambient pressure of 1 bar is working on piston. Assuming standard gravity, what will be the piston mass that create a inside pressure of $1500\ \text{kPa}$?

(A) $2101\ \text{kg}$ (B) $1489\ \text{kg}$

(C) $1969\ \text{kg}$ (D) $1751\ \text{kg}$

TD 1.19 One-fourth kg of a gas contained within a piston-cylinder assembly undergoes a constant-pressure process at $5\ \text{bar}$ beginning at $\nu_1 = 0.20\ \text{m}^3/\text{kg}$. For the gas as the system, the work is $-15\ \text{kJ}$. What will be the final volume of the gas, in m^3 ?

(A) $0.02\ \text{m}^3$ (B) $0.20\ \text{m}^3$

(C) $0.04\ \text{m}^3$ (D) $0.06\ \text{m}^3$

TD 1.20 The specific weight of a system is a/an

(A) extensive property (B) physical property

(C) intensive property (D) none of these

TD 1.21 A swimmer dive $15\ \text{m}$ down in the ocean and later climb a hill up to $250\ \text{m}$ elevation. The atmosphere pressure at the beach is 1025 milibar . If the density of water is about $1000\ \text{kg/m}^3$ and the density of air is $1.18\ \text{kg/m}^3$, what pressure do swimmer feel for at each place ?

(A) $p_{\text{ocean}} = 280\ \text{kPa}$, $p_{\text{hill}} = 109\ \text{kPa}$

(B) $p_{\text{ocean}} = 250\ \text{kPa}$, $p_{\text{hill}} = 99.61\ \text{kPa}$

(C) $p_{\text{ocean}} = 300\ \text{kPa}$, $p_{\text{hill}} = 123.7\ \text{kPa}$

(D) $p_{\text{ocean}} = 225\,\text{kPa}$, $p_{\text{hill}} = 89.65\,\text{kPa}$

TD 1.22 A gas is compressed from $v_1 = 0.3\,\text{m}^3$, $p_1 = 1\,\text{bar}$ to $v_2 = 0.1\,\text{m}^3$, $p_2 = 3\,\text{bar}$. If the pressure and volume are related linearly during the process, what will be the work ?

(A) 50 kJ (B) 45 kJ

(C) 40 kJ (D) 35 kJ

TD 1.23 The number of moles of a substance contained in a system is a/an

(A) extensive property (B) intensive property

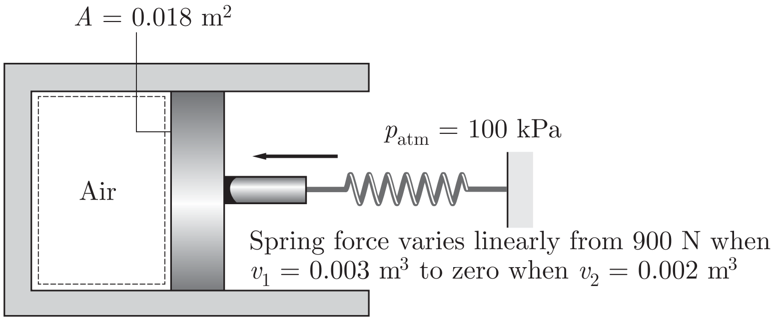
(C) chemical property (D) none of these

TD 1.24 Liquid water with density ρ is filled on top of a thin piston in a cylinder with cross-sectional area A and total height H. Air is let in under the piston so it pushes up, spilling the water over the edge. What will be the air pressure at the piston elevation h from the bottom ?

(A) $p = p_0 - (H - h)\rho g$ (B) $p = (H - h)\rho g - p_0$

(C) $p = p_0 + (H - h)\rho$ (D) $p = p_0 + (H - h)\rho g$

TD 1.25 Warm air is contained in a piston-cylinder assembly oriented horizontally as shown in figure. The air cools slowly from an initial volume of $0.003\,\text{m}^3$ to a final volume of $0.002\,\text{m}^3$. During the process, the spring exerts a force that varies linearly from an initial value of 900 N to a final value of zero. The atmospheric pressure is 100 kPa and the area of the piston face is $0.018\,\text{m}^2$. Friction between the piston and the cylinder wall can be neglected. For the air, what will be the work ?



(A) 100 J (B) 150 J

(C) 175 J (D) 125 J

TD 1.26 The variation of pressure with density in a gas layer is given by the relation $p = C\rho^n$, where C and n are constants. What will be the relation for pressure as a function of elevation z ? Take the pressure and density at $z = 0$ to be p_0 and ρ_0, respectively.

(A) $p = p_0\left(1 - \dfrac{n}{n-1}\dfrac{\rho_0 gz}{p_0}\right)^n$ (B) $p = p_0\left(1 + \dfrac{n-1}{n}\dfrac{\rho_0 gz}{p_0}\right)^{n/(n-1)}$

(C) $p = p_0\left(1 - \dfrac{n-1}{n}\dfrac{\rho_0 gz}{p_0}\right)^{n/(n-1)}$ (D) $p = p_0\left(1 - \dfrac{n-1}{n}\dfrac{\rho_0 gz}{p_0}\right)^{1/(n-1)}$

TD 1.27 Two piston-cylinder arrangements, A and B as shown, have their gas chambers connected by a pipe. The cross-sectional areas are $A_A = 75\,\text{cm}^2$ and $A_B = 25\,\text{cm}^2$

. The piston mass in A being $m_A = 25$ kg and the outside pressure is 100 kPa. What will be the mass m_B so that none of the pistons have to rest on the bottom ?

(A) 9.37 kg
(B) 6.66 kg
(C) 8.33 kg
(D) 10.41 kg

TD 1.28 Air undergoes two processes in series:
Process 1-2; Polytropic compression with $n = 1.3$ from $p_1 = 100$ kPa, $\nu_1 = 0.04\,\text{m}^3/\text{kg}$ to $\nu_2 = 0.02\,\text{m}^3/\text{kg}$.
Process 2-3; Constant-pressure process to $\nu_3 = \nu_1$.
What will be the work per unit mass of air ?

(A) 1.848 kJ/kg
(B) 1.234 kJ/kg
(C) 2.932 kJ/kg
(D) 2.341 kJ/kg

TD 1.29 A pot of water is boiling on a stove supplying 325 W to the water. If the increase in enthalpy during vaporization is $h_{fg} = 2257$ kJ/kg, what will be the rate of mass vaporizing assuming a constant pressure process ?

(A) 0.173 gm/s
(B) 0.144 gm/s
(C) 0.108 gm/s
(D) 0.089 gm/s

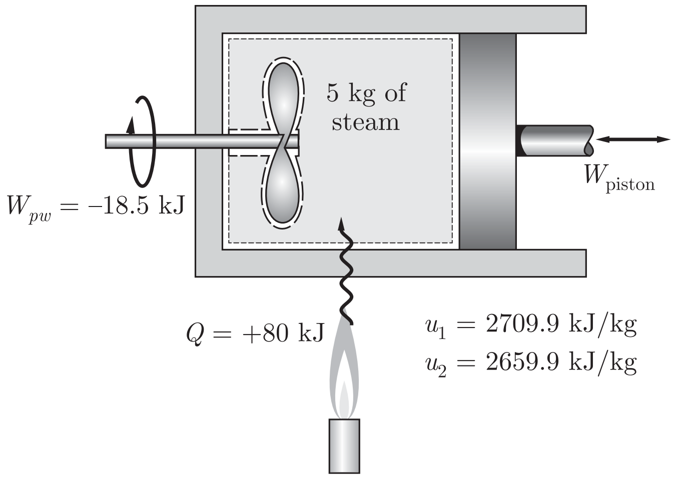
TD 1.30 A closed system of mass 20 kg undergoes a process in which there is a heat transfer of 1000 kJ from the system to the surroundings. The work done on the system is 200 kJ. If the initial specific internal energy of the system is 300 kJ/kg, what is the final specific internal energy ? Neglect changes in kinetic and potential energy.

(A) 290 kJ/kg
(B) 180 kJ/kg
(C) 260 kJ/kg
(D) 240 kJ/kg

TD 1.31 A seminar hall is to be air-conditioned with window air-conditioning units of 5 kW cooling capacity. The hall contains 40 peoples. A person at rest may be assumed to dissipate heat at a rate of about 360 kJ/h. There are 10 light bulbs in the room, each with a rating of 100 W and the rate of heat transfer to the classroom through the walls and the windows is 15000 kJ/h. If the room air is to be maintained at a constant temperature of 21°C, the number of window air-conditioning units required will be

(A) 4
(B) 5
(C) 3
(D) 2

TD 1.32 In the figure shown, 5 kg of steam contained within a piston-cylinder assembly, undergoes an expansion from state 1 to state 2. During the process, 80 kJ of heat is transferred to the steam. Also, a paddle wheel transfers energy to the steam by work in the amount of 18.5 kJ. Neglect changes in kinetic and potential energy of the steam. The energy transfer by work from the steam to the piston during this process will be



(A) 320 kJ (B) 350 kJ
(C) 390 kJ (D) 250 kJ

TD 1.33 Consider a room that contains a 100 W light bulb, a 110 W TV set, a 200 W refrigerator and a 1000 W iron. Assuming no heat transfer through the walls. If the room is initially at the outdoor temperature of 20°C, what will be the rate of increase of the energy content of the room when all of these electric devices are on ?
(A) 1410 W (B) 1622 W
(C) 1128 W (D) 1270 W

TD 1.34 A gas expands in a piston-cylinder assembly from $p_1 = 8$ bar, $v_1 = 0.02\ \text{m}^3$ to $p_2 = 2$ bar in a process during which the relation between pressure and volume is $pv^{1.2}$ = constant. The mass of the gas is 0.25 kg and kinetic and potential energy effects are negligible. If the specific internal energy of the gas decreases by 55 kJ/kg during the process, what will be the heat transfer, in kJ ?
(A) 2.35 (B) 4.25
(C) 3.20 (D) 2.75

TD 1.35 A motor of 75 hp shaft output has worn out and is replaced by a high-efficiency motor of same power. The old motor had an efficiency of 91% while the new motor has an efficiency of 95.4 percent. Due to higher efficiency under full-load conditions, the reduction in the heat gain of the room will be
(A) 3120 W (B) 2212 W
(C) 2836 W (D) 3404 W

TD 1.36 Consider a rigid well-insulated tank which contains 2 kg of air with a volume of $0.6\ \text{m}^3$. The tank is fitted with a paddle wheel that transfers energy to the air at a constant rate of 10 W for 1 h. If the changes in kinetic or potential energies are negligible, the specific volume at the final state and the energy transfer by work respectively, are
(A) $0.10\ \text{m}^3/\text{kg}$, 21 kJ (B) $0.5\ \text{m}^3/\text{kg}$, 27 kJ
(C) $0.3\ \text{m}^3/\text{kg}$, 36 kJ (D) $0.7\ \text{m}^3/\text{kg}$, 41 kJ

TD 1.37 Consider a hydraulic turbine-generator at a site 70 m below the free surface of a large water reservoir which can supply water at a rate of 1500 kg/s steadily. The mechanical power output of the turbine is 800 kW and the electric power generation is 750 kW. If the losses in the pipes are negligible, the turbine efficiency and the combined turbine-generator efficiency of this plant, respectively, are

(A) 72.7%, 77.6%
(B) 77.6%, 72.7%
(C) 65.6%, 71.2%
(D) 71.2%, 65.6%

TD 1.38 In a vertical piston-cylinder assembly, piston has a mass of 50 kg and a face area of $0.01\,m^2$. Initially, 5 gof air occupies a volume of 5 liters. 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. The atmosphere exerts a pressure of 100 kPa on the top of the piston. If the friction between the piston and the cylinder wall is negligible, the heat transfer to the air will be

(A) 1.28 kJ
(B) 1.75 kJ
(C) 1.93 kJ
(D) 1.50 kJ

TD 1.39 A gas undergoes a thermodynamic cycle consisting of three processes:
Process 1-2; Compression with $pv =$ constant, from $p_1 = 1\,\text{bar}$, $v_1 = 1.6\,m^3$ to $v_2 = 0.2\,m^3$, $U_2 - U_1 = 0$.
Process 2-3; Constant pressure to $v_3 = v_1$.
Process 3-1; Constant volume, $U_1 - U_3 = -3549\,\text{kJ}$.
If the changes in kinetic or potential energies are negligible, what will be the work for the cycle ?

(A) 787.3 kJ
(B) 1344 kJ
(C) 1452.7 kJ
(D) 1120 kJ

TD 1.40 Consider a circular windmills with a 7 m-diameter rotor in a 10 m/s wind on a day when the atmospheric pressure is 100 kPa and the temperature is 20°C. The wind speed behind the windmill is measured at 9 m/s. Assuming the air is incompressible, what will be the diameter of the wind channel downstream from the rotor and the power produced by this windmill ?

(A) 4.43 m, 2.61 kW
(B) 5.54 m, 3.26 kW
(C) 7.38 m, 4.35 kW
(D) 8.85 m, 5.22 kW

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TD 2

PROPERTIES OF PURE SUBSTANCES

TD 2.1 A tank of $0.05\,m^3$ volume contains $2\,kg$ liquid-vapor mixture (two-phase) of carbon dioxide at $-40^\circ C$. If the values of specific volume for saturated liquid and saturated vapor CO_2 at $-40^\circ C$ are $\nu_f = 0.000896\,m^3/kg$ and $\nu_g = 0.03824\,m^3/kg$, respectively, the quality of the mixture will be

(A) 69.3% (B) 64.5%

(C) 46.5% (D) 54.6%

TD 2.2 Consider a piston-cylinder arrangement which contains air at $250\,kPa$, $300^\circ C$. The 50-kg piston has a diameter of $0.1\,m$ and initially pushes against the stops. The atmospheric pressure is $100\,kPa$ and $20^\circ C$. The cylinder now cools as heat is transferred to the ambient. At what temperature does the piston begin to move down ?

(A) 186.3 K (B) 93.1 K

(C) 372.5 K (D) 279.4 K

TD 2.3 A $0.14\,m^3$ weighted piston-cylinder device contains $2\,kg$ of fluid at a temperature of $-26.4^\circ C$. The container is now heated until the temperature is $100^\circ C$. If the saturated pressure at $-26.4^\circ C$ is $100\,kPa$ and the specific volume at the final state is $0.30138\,m^3/kg$, what will be the final volume of the fluid ?

(A) $0.07\,m^3$ (B) $0.30138\,m^3$

(C) $0.60276\,m^3$ (D) $0.14\,m^3$

TD 2.4 A water sample at $100\,kPa$ has specific volumes as $\nu_f = 0.001043\,m^3/kg$ and $\nu_g = 1.6940\,m^3/kg$. If the sample has the quality of 10%, the volume fraction of the vapor will be

(A) 0.550 (B) 0.995

(C) 0.746 (D) 0.498

TD 2.5 Consider a $1\,m^3$ of a two-phase liquid vapor mixture of Refrigerant 22 at 1 bar with a quality of 75%. If the values of specific volume for saturated liquid and saturated vapor at 1 bar are $\nu_f = 0.7093 \times 10^{-3}\,m^3/kg$ and $\nu_g = 0.2152\,m^3/kg$, respectively, what will be the mass of the mixture ?

(A) 9.3 kg (B) 3.1 kg

(C) 6.2 kg (D) 4.65 kg

TD 2.6 A rigid container of $14\,L$ contains $10\,kg$ of refrigerant at $300\,kPa$. Now the container is heated until the pressure is $600\,kPa$. The thermodynamic properties of the refrigerant are shown in table. What will be the enthalpies in the container before heating and after heating, respectively ?

Pressure (kPa)	Temperature (°C)	Specific volume (m^3/kg)		Enthalpy (kJ/kg)		
		ν_f	ν_g	h_f	h_{fg}	h_g

280	-1.25	0.0007699	0.072352	50.18	199.54	249.72
320	2.46	0.0007772	0.063604	55.16	196.71	251.88
600	21.55	0.0008199	0.034295	81.51	180.90	262.40

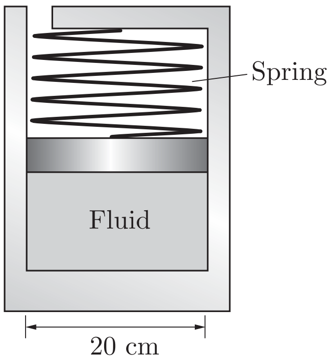
(A) 423 kJ, 545 kJ (B) 545 kJ, 846 kJ
(C) 846 kJ, 545 kJ (D) 545 kJ, 423 kJ

TD 2.7 Consider the table given below.

Temperature (°C)	Pressure (kPa)	Specific volume (m^3/kg)		
		Sat. liquid ν_f	Evap. ν_{fg}	Sat. vapor ν_g
190	1254.4	0.001141	0.15539	0.15654
200	1553.8	0.001156	0.12620	0.12736
179.91	1000	0.001127	0.19332	0.19444

What will be the state of water at (a) 1 MPa, 190°C and (b) 200°C, 0.1 m^3/kg , respectively ?
(A) Compressed liquid and superheated vapor
(B) Compressed liquid and mixture of liquid and vapor
(C) Superheated vapor and mixture of liquid and vapor
(D) Both are superheated vapor

TD 2.8 0.5 kg of water vapor initially at 4 MPa and 400°C, is filled in a spring-loaded piston-cylinder device as shown in figure. Initially, the specific volume is 0.07343 m^3/kg and the spring exerts no force against the piston. The water now undergoes a process until its volume is one-half of the original volume. If the spring constant is $k = 0.9$ kN/cm, the final pressure of the water will be



(A) 1163 kPa (B) 581.5 kPa
(C) 1744.5 kPa (D) 2326 kPa

TD 2.9 A two-phase liquid-vapor mixture of a substance has a pressure of 150 bar and occupies a volume of 0.2 m^3. If the masses of saturated liquid and vapor present are 3.8 kg and 4.2 kg, respectively, the mixture specific volume in m^3/kg will be
(A) 0.025 m^3/kg (B) 0.052 m^3/kg
(C) 0.048 m^3/kg (D) 0.5 m^3/kg

TD 2.10 A steel tank contains 6 kg of propane (liquid + vapor) at 20°C with a volume of

$0.015\,m^3$. The critical specific volume of propane is $\nu_c = 0.00454\,m^3/kg$. The tank is now slowly heated. What will happen to the liquid level inside when (a) mass is 6 kg and (b) mass is 1 kg instead of 6 kg, respectively ?

(A) Level rises to the top in both cases

(B) Level drops to the bottom in both cases

(C) Level drops to the bottom and rises to the top

(D) Level rises to the top and drops to the bottom

TD 2.11 A piston-cylinder assembly initially contains water vapor at 10 bar and 400°C for which specific volume is $\nu = 0.3066\,m^3/kg$. The water is cooled at constant volume until its temperature is 150°C. At 150°C, $p_{sat.} = 475.8\,kPa$ $\nu_f = 0.0010905\,m^3/kg$, $\nu_{fg} = 0.39169\,m^3/kg$ and $\nu_g = 0.39278\,m^3/kg$. The water is then condensed isothermally to saturated liquid. Considering the water as the system, what is the work, in kJ/kg ?

(A) 36.35 (B) 72.7

(C) 145.4 (D) 109.05

TD 2.12 Consider a piston-cylinder arrangement which contains air at 250 kPa, 300°C. The 50-kg piston has a diameter of 0.1 m and initially pushes against the stops. The atmospheric pressure is 100 kPa and 20°C. The cylinder now cools as heat is transferred to the ambient. At what temperature does the piston begin to move down ?

(A) 186.3 K (B) 93.1 K

(C) 372.5 K (D) 279.4 K

TD 2.13 A pressure cooker 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. The thermodynamic properties of saturated water are given in table below.

Saturated Water				
Temperature (°C)	Pressure (kPa)	Specific volume (m^3/kg)		
		Sat. liquid ν_f	Evap. ν_{fg}	Sat. vapor ν_g
100	101.3	0.001044	1.67185	1.67290
212.42	2000	0.001177	0.09845	0.09963

What will be the final condition (more or less vapor than initial state) and final temperature of liquid ?

(A) More vapor, 212.4°C (B) More vapor, 150.4°C

(C) Less vapor, 212.4°C (D) Less vapor, 150.4°C

TD 2.14 A stainless steel pan of 25 cm internal diameter contains water. The water is boiled at 1 atm pressure on an electric range. It is observed that the water level in the pan drops by 10 cm in 45 min. If the properties of water at 1 atm and at saturation temperature of 100°C are $h_{fg} = 2256.5\,kJ/kg$ and $\nu_f = 0.001043\,m^3/kg$ then the rate of heat transfer to the pan will be

(A) 3.93 kW (B) 4.92 kW

(C) 1.96 kW (D) 2.95 kW

TD 2.15 Consider 2 kg of Refrigerant 22, undergoes a process for which the pressure-volume relation is $pv^{1.05}$ = constant. The initial state of the refrigeration is fixed by $p_1 = 2$ bar, $T_1 = -20^\circ C$ for which specific volume is $\nu_1 = 0.11520\,m^3/kg$ and the final pressure is $p_2 = 10$ bar. What will be the work for the process ?

(A) 36.7 kJ (B) 146.8 kJ
(C) 55.05 kJ (D) 73.4 kJ

TD 2.16 A $0.5\,m^3$ vessel contains 10 kg of refrigerant at $-20^\circ C$. Considering the related data given in table, total internal energy and the volume occupied by the liquid phase, respectively, are

Temperature (°C)	Pressure (kPa)	Specific volume (m^3/kg)		Specific internal energy (kJ/kg)		
		ν_f	ν_g	u_f	u_{fg}	u_g
-20	132.82	0.0007362	0.14729	25.39	193.45	218.84

(A) 904 kJ, 4.9 L (B) 678 kJ, 6.1 L
(C) 452 kJ, 3.7 L (D) 847 kJ, 7.35 L

TD 2.17 Consider a 10 m diameter spherical helium balloon at ambient temperature of 15°C and pressure of 100 kPa. It can lift a total mass that equals the mass of displaced atmospheric air. How much mass of the balloon fabric and cage can then be lifted ? Take the gas constant for the helium is 2.0771.

(A) 720.5 kg (B) 545.5 kg
(C) 87.5 kg (D) 633 kg

TD 2.18 Considering the table for water as given below. What will be the quality and the specific internal energy, respectively of water at $p = 3$ bar, $\nu = 0.5\,m^3/kg$?

Pressure (kPa)	Temperature (°C)	Specific volume (m^3/kg)			Specific Internal energy (kJ/kg)		
		ν_f	ν_{fg}	ν_g	u_f	u_{fg}	u_g
300	133.55	0.001073	0.60475	0.60582	561.13	1982.43	2543.55

(A) 82.5%, 2192 kJ/kg (B) 82.5%, 1648 kJ/kg
(C) 61.9%, 1648 kJ/kg (D) 61.9%, 2192 kJ/kg

TD 2.19 Consider a rigid vessel of $0.3\,m^3$, which initially contains saturated liquid vapor mixture of water at 150°C. The water is now heated until it reaches the critical state where specific volume becomes $\nu_{cr.} = 0.003106\,m^3/kg$. At 150°C, the specific volume of liquid is $\nu_f = 0.001091\,m^3/kg$ and that for gas is $\nu_g = 0.39248\,m^3/kg$. What will be the mass of the liquid water and the volume occupied by the liquid at the initial state ?

(A) 96.6 kg, $0.298\,m^3$ (B) 96.6 kg, $0.105\,m^3$
(C) 96.1 kg, $0.105\,m^3$ (D) 96.1 kg, $0.298\,m^3$

TD 2.20 Two tanks filled with propane are connected to each other by a valve. A $1\,m^3$ rigid tank has propane at 100 kPa, 300 K and the other $0.5\,m^3$ tank has propane at 250 kPa, 400 K. The valve is opened and the two tanks come to a uniform state at 325 K. What will be the final pressure ? The gas constant for the propane

is $R = 0.1886$ kJ/kg-K.
(A) 151 kPa (B) 129 kPa
(C) 140 kPa (D) 172 kPa

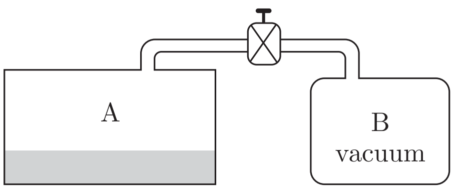
TD 2.21 The pressure in an automobile tire varies with the temperature of the air in the tire. The pressure gage reads 210 kPa, when the air temperature is 25°C. The volume of the tire is $0.025\ m^3$ and the atmospheric pressure is 100 kPa. If the air temperature in the tire rises to 50°C, what will be the pressure rise in the tire and the amount of air that must be bled off to restore pressure to its original value at this temperature ?
(A) 336 kPa, 0.0836 kg (B) 646 kPa, 0.0906 kg
(C) 310 kPa, 0.1742 kg (D) 26 kPa, 0.007 kg

TD 2.22 A closed rigid tank contains saturated liquid water which is cooled to a final state where the temperature is 50°C and the masses of saturated vapor and liquid present are 0.03 and 1999.97 kg, respectively. The kinetic and potential energy effects are negligible. What will be the heat transfer for the process ?

Temperature (°C)	Pressure (kPa)	Specific volume (m^3/kg)		Specific internal energy (kJ/kg)	
		v_f	v_g	u_f	u_g
50	12.350	0.001012	12.0318	209.32	2443.5
220	2317.8	0.001190	0.08619	940.85	2602.35
225	2547.7	0.001199	0.07849	963.72	2603.30

(A) 1157.5 MJ (B) 2315 MJ
(C) 1736 MJ (D) 1477 MJ

TD 2.23 Two tanks A and B are connected by a valve as shown in figure. Each tank has a volume of 200 L. Tank A has R-12 at 25°C ($v_f = 0.000763\ m^3/kg$, $v_g = 0.026854\ m^3/kg$), 10% liquid and 90% vapor by volume, while tank B is evacuated. The valve is now opened and saturated vapor flows from A to B until the pressure in B become equal to pressure in A, at this point the value is closed. This process occurs slowly such that all temperatures stay at 25°C throughout the process. How much has the quality changed in tank A during the process ?

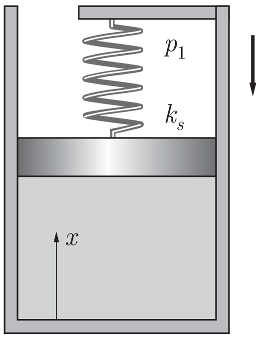


(A) 27.18% (B) 20.36%
(C) 47.54% (D) 6.82%

TD 2.24 Consider a process for which the pressure-volume relation is $pv^n =$ constant. The initial and final states of the working fluid are $p_1 = 200$ kPa, $T_1 = -10°C$ and $p_2 = 1000$ kPa, $T_2 = 50°C$, respectively. The kinetic and potential energy effects are negligible. If the specific volumes of initial and final states are $v_1 = 0.09938\ m^3/kg$ and $v_2 = 0.02171\ m^3/kg$, respectively, what will be the work for the process ?
(A) 31.62 kJ/kg (B) 23.72 kJ/kg

(C) 15.81 kJ/kg (D) 7.905 kJ/kg

TD 2.25 Consider a piston-cylinder arrangement which contains water at 105°C, 85% quality with a volume of 1 L. Heating of system causes the piston to rise and encounter a linear spring with spring constant of 100 N/mm as shown in figure. At this point the volume is 1.5 L and piston diameter is 150 mm. The heating continues, so the piston compresses the spring. What will be the cylinder temperature when the pressure reaches 200 kPa ?



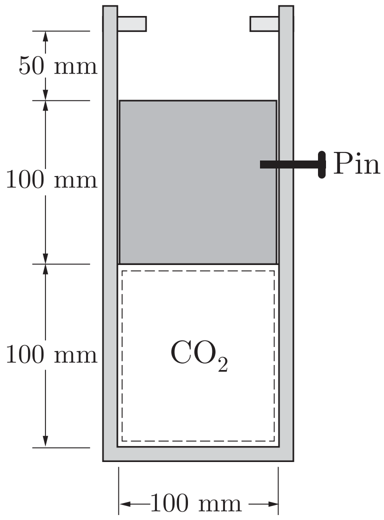
Saturated water				
Temperature (°C)	Pressure (kPa)	Specific volume (m^3/kg)		
		ν_f	ν_{fg}	ν_g
105	120.8	0.001047	1.41831	1.41936
Superheated vapor water				
		ν (m^3/kg)		
600	200	2.01297		
700	200	2.2443		

(A) 160.25°C (B) 641°C
(C) 320.5°C (D) 480.75°C

TD 2.26 A refrigerant undergoes a constant pressure process at 2.5 bar from $T_1 = 30$°C to saturated vapor. If at $T_1 = 30$°C, specific volume is $\nu_1 = 0.57745\ m^3/kg$ and at saturated state $\nu_2 = \nu_g = 0.4821\ m^3/kg$, what will be the work for the process in kJ/kg of refrigerant ?
(A) 264.9 (B) 11.9
(C) 23.84 (D) 17.8

TD 2.27 A rigid vessel of 0.2 m^3 contains 0.1 kg of helium at 350 kPa. The vessel is heated until the pressure is 700 kPa. The gas constant of helium is $R = 2.0769$ kJ/kg-K. As a result of this heating, the temperature change of helium will be
(A) 505 K (B) 337 K
(C) 168 K (D) 674 K

TD 2.28 In the figure shown, a cylinder has a thick piston initially held by a pin. The cylinder contains carbon dioxide at 200 kPa and ambient temperature of 290 K . The pin is now removed, allowing the piston to move and after a while the gas returns to ambient temperature. If the metal piston has a density of 8000 kg/m^3 and the atmospheric pressure is 101 kPa, what will be the final pressure when the piston is at the stops ?



(A) 133 kPa (B) 167 kPa
(C) 105 kPa (D) 149 kPa

TD 2.29 A $0.2\,m^3$ closed, rigid tank contains water at an initial pressure of 5 bar and a quality of 50%. Heat transfer occurs until the tank contains only saturated vapor. If the specific volume of liquid is $\nu_f = 0.0010926\,m^3/kg$ and that for gas is $\nu_g = 0.3749\,m^3/kg$, the final mass of vapor in the tank will be
(A) 1.064 kg (B) 0.532 kg
(C) 0.798 kg (D) 1.33 kg

TD 2.30 Carbon dioxide gas at 3 MPa and 500 K flows steadily in a pipe at a rate of 0.4 kmol/s. If the temperature of CO_2 drops to 450 K at the exit of the pipe, the density of carbon dioxide at initial state and the volume flow rate at the exit of the pipe, respectively, are
(A) $15.88\,kg/m^3, 0.374\,m^3/s$ (B) $20.9\,kg/m^3, 0.249\,m^3/s$
(C) $7.94\,kg/m^3, 0.125\,m^3/s$ (D) $31.76\,kg/m^3, 0.498\,m^3/s$

TD 2.31 Five kilograms of water, initially a saturated vapor at 100 kPa, are cooled to saturated liquid while the pressure is maintained constant. The kinetic and potential energies are negligible. The thermodynamic properties of saturated vapor are given in table. What will be the heat transfer for the process ?

Pressure (kPa)	Specific volume (m^3/kg)			Specific internal energy (kJ/kg)		
	ν_f	ν_{fg}	ν_g	u_f	u_{fg}	u_g
100	0.001043	1.6929	1.694	417.33	2088.72	2506.06

(A) 8.48 MJ (B) 11.3 MJ
(C) 2.83 MJ (D) 5.65 MJ

TD 2.32 A 13 kg well-insulated copper tank contains 4 kg of liquid water initially at 50°C . The initial temperature of the copper is 27°C. An electrical resistor of negligible mass, transfers 100 kJ of energy to the contents of the tank. The potential and kinetic effects are negligible. At the equilibrium point of the tank and its contents, what will be the final temperature ?

(Data: $c_c = 0.385\,\text{kJ/kg-K}$ and $c_w = 4.179\,\text{kJ/kg-K}$)

(A) 161.2°C (B) 49.3°C

(C) 241.7°C (D) 322.3°C

TD 2.33 Consider a diesel engine with cylinder conditions of $950\,\text{K}$ and $75\,\text{cm}^3$ before combustion and $150\,\text{cm}^3$ after it. If the engine operates with an air-fuel ratio of $22\,\text{kg air/kg fuel}$, what will be the temperature after the combustion process ?

(A) $1817\,\text{K}$ (B) $454\,\text{K}$

(C) $1363\,\text{K}$ (D) $950\,\text{K}$

TD 2.34 Consider two rigid tanks of same volume of $0.5\,\text{m}^3$. One tank contains hydrogen at 20°C, $600\,\text{kPa}$ and is connected to another tank that holds hydrogen at 30°C , $150\,\text{kPa}$ by a valve. Now the valve is opened and the system is allowed to reach thermal equilibrium with the surroundings, which are at 15°C. What will be the final pressure in the tank ? The gas constant for H_2 is $4.124\,\text{kJ/kg-K}$.

(A) $182.9\,\text{kPa}$ (B) $91.4\,\text{kPa}$

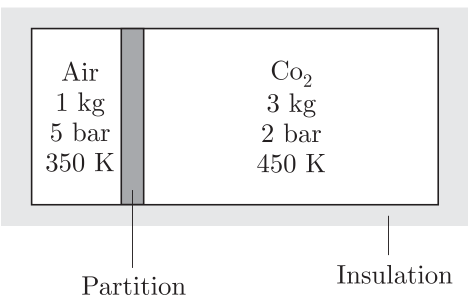
(C) $365.8\,\text{kPa}$ (D) $274.4\,\text{kPa}$

TD 2.35 A tank contains air at $1\,\text{MPa}$ and room temperature of 20°C. It is used to fill an initially empty balloon to a pressure of $200\,\text{kPa}$, at this point the radius is $2\,\text{m}$. Assume the pressure in the balloon is linearly proportional to its radius and the system is in isothermal equilibrium throughout the process. The mass of air in the balloon and the minimum required volume of the tank respectively, are

(A) $8.4\,\text{m}^3$ (B) $2.1\,\text{m}^3$

(C) $4.2\,\text{m}^3$ (D) $6.3\,\text{m}^3$

TD 2.36 Consider a rigid, well-insulated container shown in figure. One kilogram of air, initially at $5\,\text{bar}$, $350\,\text{K}$ and $3\,\text{kg}$ of carbon dioxide (CO_2), initially at $2\,\text{bar}$, $450\,\text{K}$, are confined to opposite sides of this container. The partition is free to move and allows conduction from one gas to the other without energy storage in the partition itself. Assuming the air and carbon dioxide as ideal gases and constant specific heats as $c_{v,air} = 0.726\,\text{kJ/kg-K}$, $c_{v,CO_2} = 0.750\,\text{kJ/kg-K}$ and molar masses as $M_{air} = 28.97\,\text{kg/kmol}$, $M_{CO_2} = 44.01\,\text{kg/kmol}$, what will be the final equilibrium temperature and the final pressure, respectively ?



(A) $425.6\,\text{K}, 1.231\,\text{bar}$ (B) $212.8\,\text{K}, 2.462\,\text{bar}$

(C) $212.8\,\text{K}, 1.231\,\text{bar}$ (D) $425.6\,\text{K}, 2.462\,\text{bar}$

TD 2.37 What will be the pressure of water at 200°C and specific volume of $1.5\,\text{m}^3/\text{kg}$?.

Saturated Water

Temperature °C	Pressure kPa	Specific Volume (m^3/kg)		
		ν_f	ν_{fg}	ν_g
200	1553.8	0.001156	0.12620	0.12736
Superheated Vapour Water				
200	100	2.17226		
200	200	1.08034		

(A) 121.2 kPa (B) 80.8 kPa
(C) 40.4 kPa (D) 161.6 kPa

TD 2.38 Consider a closed rigid tank fitted with an electric resistor. The tank contains 2 kg of a gas with molecular weight 28 . The resistor draws a constant current of 10 amp at a voltage of 12 V for 10 min. At the equilibrium, the temperature of the gas is increased by 40.3°C. Heat transfer to the surrounding is estimated to occur at a constant rate of 20 W and the kinetic and potential energy effects are negligible. If the gas behaves as ideal gas, an average value of the specific heat c_p , of the gas, will be
(A) 1.041 kJ/kg-K (B) 0.2603 kJ/kg-K
(C) 0.5205 kJ/kg-K (D) 0.7807 kJ/kg-K

TD 2.39 Air is compressed adiabatically form $p_1 = 1$ bar, $T_1 = 300$ K to $p_2 = 15$ bar, $\nu_2 = 0.1227\ m^3/kg$. After this air is cooled at constant volume to $T_3 = 300$ K and at this temperature the specific heat remains constant at $c_v = 0.718$ kJ/kg-K. Neglect the kinetic and potential energy effects. Assuming ideal gas behavior, the work for the first process and the heat transfer for the second process, respectively, are
(A) 245 kJ/kg, 676 kJ/kg (B) Both are 676 kJ/kg
(C) Both are 245 kJ/kg (D) 676 kJ/kg, 245 kJ/kg

TD 2.40 2 kg of water initially at 80°C and a quality of 0.6 is contained in a closed rigid tank. Heat transfer occurs until the tank contains only saturated vapor. If the kinetic and potential energy effects are negligible, the amount the energy transfer by heat is

Temperature (°C)	Pressure (kPa)	Specific volume (m^3/kg)		Specific internal energy (kJ/kg)	
		ν_f	ν_g	u_f	u_g
80	47.39	0.001029	3.40715	334.84	2482.19
90	70.14	0.001036	2.36056	376.82	2494.52
95	84.55	0.001040	1.98186	397.86	2500.56

(A) 876.3 kJ (B) 1752.6 kJ
(C) 438.15 kJ (D) 1314.4 kJ

TD 2.41 A rigid tank and a piston-cylinder assembly oriented vertically are connected together by a valve. The tank initially contains 3 kg of air at 500 kPa, 290 K and the piston-cylinder assembly contains 0.05 m^3 of air initially at 200 kPa, 290 K. Although the valve is closed, a slow leak allows air to flow into the cylinder until the tank pressure falls to 200 kPa. A constant pressure of 200 kPa and constant

TD 3

ENERGY ANALYSIS OF CLOSED SYSTEM

TD 3.1 Consider the following two general expression:

1. $\left(\frac{\partial u}{\partial p}\right)_T = -T\left(\frac{\partial v}{\partial T}\right)_p - p\left(\frac{\partial v}{\partial p}\right)_T$

2. $\left(\frac{\partial h}{\partial v}\right)_T = v\left(\frac{\partial p}{\partial v}\right)_T + T\left(\frac{\partial T}{\partial p}\right)_v$

Which of the above expression is/are true ?

(A) Only 1 (B) Only 2

(C) Both 1 and 2 (D) None of these

TD 3.2 Consider a heat engine that receives 5 kW at 800 K and 10 kW at 1000 K and rejecting energy by heat transfer at 600 K. Assuming reversible process , what will be the power output ?

(A) 15 kW (B) 5.25 kW

(C) 9.75 kW (D) 4.75 kW

TD 3.3 Air undergoes a change of state from 100 kPa and 20°C to 600 kPa and 300°C using the equation of state $p(v-a) = RT$. If $a = 0.10\,\text{m}^3/\text{kg}$, what will be the change in the internal energy of air ? Take $c_v = 0.731\,\text{kJ/kg-K}$.

(A) 256.25 kJ/kg (B) 205 kJ/kg

(C) 307.5 kJ/kg (D) 358.75 kJ/kg

TD 3.4 A refrigerant enters in a compressor at 100 kPa, −20°C and exits at 1 MPa, 40°C . Referring the following table properties with the room at 20°C, the minimum compressor work will be

Pressure (kPa)	Temperature (°C)	h (kJ/kg)	s (kJ/kg-K)
100	-20	387.22	1.7665
1000	40	420.25	1.7148

(A) 48.18 kJ/kg (B) 36.2 kJ/kg

(C) 12.1 kJ/kg (D) 24.09 kJ/kg

TD 3.5 Air undergoes a change of state from 100 kPa and 20°C to 600 kPa and 300°C using the equation of state $p(v-a) = RT$ where $a = 0.10\,\text{m}^3/\text{kg}$What will be the change in the entropy of air ? Take $c_p = 1.018\,\text{kJ/kg-K}$ and $R = 0.287\,\text{kJ/kg-K}$.

(A) 0.423 kJ/kg-K (B) 0.338 kJ/kg-K

(C) 0.169 kJ/kg-K (D) 0.254 kJ/kg-K

TD 3.6 For the equation of state of a gas

$$v = \frac{RT}{p} - \frac{a}{T} + b$$

where a and b are constants, what will be the equation for the Joule-Thomson coefficient inversion line ?

(A) $T = \frac{2b}{a}$ (B) $T = \frac{a}{2b}$

(C) $T = \frac{2a}{b}$ (D) $T = \frac{b}{2a}$

Common Data For Q. 7 and 8

A rock bed ($c = 0.89$ kJ/kg-K) consists of 6000 kg granite at 70°C. A small house with lumped mass of 12000 kg wood ($c = 1.26$ kJ/kg-K) and 1000 kg iron ($c = 0.46$ kJ/kg-K) is at 15°C. They are now brought to a uniform final temperature with no external heat transfer by connecting the house and rock bed through some heat engines. Assume that the process is reversible.

TD 3.7 The final temperature will be

(A) 75.4 K (B) 150.6 K

(C) 301.3 K (D) 226 K

TD 3.8 What will be the work done in the process ?

(A) 9824 kJ (B) 19648 kJ

(C) 14736 kJ (D) 4912 kJ

TD 3.9 Steam initially at 4.5 MPa, 300°C is throttled to the final state of 2.5 MPa, 274°C. The average Joule-Thomson coefficient will be

(A) 16.25°C/MPa (B) 9.75°C/MPa

(C) 19.5°C/MPa (D) 13°C/MPa

TD 3.10 At 20°C, the volume expansivity of water is $\beta = 0.207 \times 10^{-6} K^{-1}$. If this value remains constant, the change in volume of 1 m^3 of water as it is heated from 10°C to 30°C at constant pressure, will be

(A) 4.14 cm^3 (B) 5.2 cm^3

(C) 3.1 cm^3 (D) 6.21 cm^3

TD 3.11 Consider a constant pressure piston-cylinder arrangement which contains 2 kg of water at 5 MPa and 100°C. Now heat is added from a reservoir at 700°C to the water until it reaches 700°C. Refer the given table. What will be the total irreversibility in the process ?

Temperature (°C)	Enthalpy (h) kJ/kg	Entropy (s) kJ/kg-K
100	422.71	1.303
700	3900.13	7.5122

(A) 393 kJ (B) 6954.8 kJ

(C) 3477.4 kJ (D) 1571 kJ

TD 3.12 Consider a substance whose Joule-Thomson coefficient is negative, is throttled to a lower pressure. During this process

(A) The entropy of the substance will remains constant.

(B) The temperature of the substance will decrease.

(C) The temperature of the substance will increase.

(D) The enthalpy of the substance will decrease.

TD 3.13 A rigid tank is connected by a value to a piston-cylinder device with zero clearance. The tank contains $0.4\,m^3$ of air at $400\,kPa$ and $30^\circ C$. A pressure of $200\,kPa$ is required to raise the piston. Now the valve is opened slightly and air is allowed to flow into the cylinder until the pressure in the tank drops to $200\,kPa$. If heat is exchanged with the surroundings such that the entire air remains at $30^\circ C$ all times, the heat transfer of this process will be

(A) $100\,kJ$ (B) $60\,kJ$

(C) $120\,kJ$ (D) $80\,kJ$

TD 3.14 A hospital requires supply of steam at $100\,kPa$, $150^\circ C$ and at a rate of $15\,kg/s$. To fulfill this requirement, a supply of steam at $150\,kPa$, $250^\circ C$ from a boiler is mixed with a tap water at $100\,kPa$, $15^\circ C$ in a mixing chamber. Using the data given in table, the rate of irreversibility of the mixing process will be

Temperature ($^\circ C$)	Pressure (kPa)	Enthalpy (kJ/kg)	Entropy (kJ/kg-K)
15	100	62.99	0.2245
150	100	2776.4	7.6133
250	150	2972.7	7.8437

(A) $1268\,kW$ (B) $634\,kW$

(C) $317\,kW$ (D) $951\,kW$

TD 3.15 A vertical piston-cylinder device of $12\,cm$ diameter, contains an ideal gas at the ambient conditions of $1\,bar$ and $24^\circ C$. Initially, the inner face of the piston is $20\,cm$ from the base of the cylinder. Now an external shaft connected to the piston exerts a force corresponding to a boundary work input of $0.1\,kJ$. If the process remains isothermal during the process, the final pressure in the cylinder and the distance that the piston is displaced, respectively, are

(A) $233.4\,kPa$, $8.87\,cm$ (B) $272.3\,kPa$, $5.35\,cm$

(C) $155.6\,kPa$, $7.1\,cm$ (D) $116.7\,kPa$, $10.65\,cm$

TD 3.16 Carbon dioxide is compressed from $0.3\,m^3$ to $0.1\,m^3$. During the process, the pressure and volume are related by $p = av^{-2}$, where $a = 8\,kPa\text{-}m^6$. What will be the work done on the carbon dioxide during this process ?

(A) $26.7\,kJ$ (B) $39.9\,kJ$

(C) $53.3\,kJ$ (D) $66.8\,kJ$

Common Data For Q. 17 and 18

Air enters the turbocharger compressor of an automotive engine at $100\,kPa$, $30^\circ C$ and exits at $170\,kPa$. Now the air is cooled by $50^\circ C$ in an intercooler before entering the engine. The isentropic efficiency of the compressor is 75%.

TD 3.17 What will be the temperature of the air entering the engine ?

(A) $96.1^\circ C$ (B) $369.1^\circ C$

(C) $46.1^\circ C$ (D) $319.1^\circ C$

TD 3.18 The irreversibility of the compression-cooling process is

(A) $19.9\,kJ/kg$ (B) $29.85\,kJ/kg$

(C) $14.9\,kJ/kg$ (D) $24.87\,kJ/kg$

Common Data For Q. 19 and 20

Consider a piston-cylinder device which contains an ideal gas. The gas undergoes two successive cooling processes by rejecting heat to the surroundings. First the gas is cooled at constant pressure until $T_2 = \frac{3}{4}T_1$. Then the piston is held stationary while the gas is further cooled to $T_3 = \frac{1}{2}T_1$, where all temperatures are in K.

TD 3.19 The ratio of the final volume to the initial volume of the gas and the work done on the gas by the piston respectively, are

(A) 0.25, $c_p T_1/2$
(B) 0.50, $c_v T_1/2$
(C) 0.67, $(c_v + c_p) T_1/4$
(D) 0.75, $RT_1/4$

TD 3.20 What is the total heat transferred from the gas ?

(A) $RT_1/4$
(B) $c_v T_1/2$
(C) $c_p T_1/2$
(D) $(c_v + c_p) T_1/4$

Common Data For Q. 21 and 22

A 200 L capacity rigid container is divided into two equal volumes by a partition. Both partitions are filled with nitrogen. One side is at 2 MPa, 300°C and the other at 1 MPa, 50°C. Suddenly the partition breaks and the nitrogen comes to a uniform state at 100°C. Assume the surroundings are at 25°C. The gas constant for the nitrogen is $R = 0.2968$ kJ/kg-K and the specific heats at the constant volume and pressure are $c_v = 0.745$ kJ/kg-K and $c_p = 1.042$ kJ/kg-K, respectively.

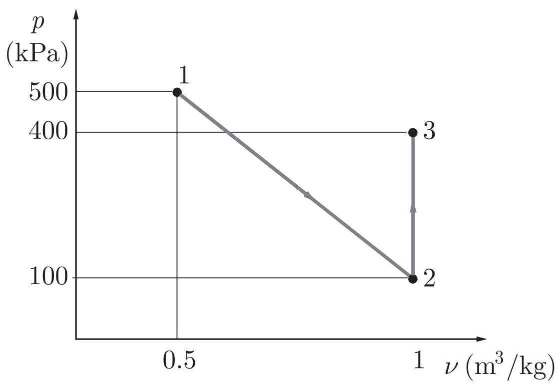
TD 3.21 The actual heat transfer in the process will be

(A) 272.8 kJ
(B) 136.4 kJ
(C) 170.5 kJ
(D) 238.7 kJ

TD 3.22 What will be the irreversibility in the process ?

(A) 116 kJ
(B) 58 kJ
(C) 130.5 kJ
(D) 101.5 kJ

TD 3.23 Consider the $p-v$ curve shown in figure. For the system consisting of 2 kg of nitrogen, the total work for process 1-3 will be



(A) 150 kJ
(B) 300 kJ
(C) 225 kJ
(D) 375 kJ

TD 3.24 A spring-loaded piston-cylinder device occupies 0.5 kg water that is initially at 1 MPa and 10 percent quality. At this state the specific volume of liquid and vapor are $\nu_f = 0.001127$ kg/m^3 and $\nu_g = 0.19436$ kg/m^3, respectively. This device is now cooled until the water is saturated liquid at 100°C where $p = 101.42$ kPa and $\nu_f = 0.001043\,\text{m}^3/\text{kg}$. What will be the total work produced during this process ?

(A) 4.01 kJ (B) 5.34 kJ

(C) 6.67 kJ (D) 8.01 kJ

TD 3.25 Consider a well-insulated rigid tank. It contains 5 kg of a saturated liquid-vapor mixture of water at 100 kPa. Initially, three-quarters of the mass is in the liquid phase. An electric resistor placed in the tank is connected to a 110 V source and a current of 8 A flows through the resistor when the switch is turned on. What will be the time that it will take to vaporize all the liquid in the tank ?

Pressure (kPa)	Specific Volume (m^3/kg)		Internal energy (kJ/kg)	
	ν_f	ν_g	u_f	u_g
100	0.001043	1.6941	417.40	2505.6
440	0.001087	0.42431	618.45	2556.2

(A) 153.1 minutes (B) 115 minutes

(C) 76.5 minutes (D) 191 minutes

TD 3.26 For a gas with an equation of state as $p(v-b) = RT$, match List-I (properties of an isothermal process) with List-II (corresponding changes). Choose the best set of the changes in an isothermal process for u, h and s.

	List-I		List-II
a.	$u_2 - u_1$	**1.**	$b(p_2 - p_1)$
b.	$h_2 - h_1$	**2.**	$R\ln(v_2 - b)/(v_1 - b)$
c.	$s_2 - s_1$	**3.**	Zero

Codes:

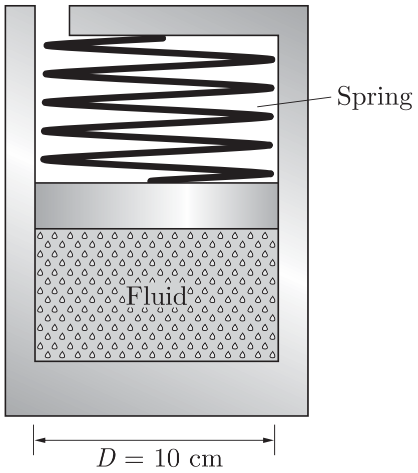
	a	b	c
(A)	1	2	3
(B)	3	2	1
(C)	3	1	2
(D)	2	3	1

TD 3.27 Consider the flow of nitrogen in a pipe with velocity 300 m/s at 500 kPa, 300°C. What will be its availability with respect to an ambient at 100 kPa, 20°C ? Take $c_p = 1.042$ kJ/kg-K and $R = 0.2968$ kJ/kg-K.

(A) 544 kJ/kg (B) 476 kJ/kg

(C) 272 kJ/kg (D) 408 kJ/kg

TD 3.28 A mass of 10 gm of nitrogen is contained in the spring loaded piston-cylinder device as shown in figure. When the spring exerts no force against the piston, the nitrogen is at 120 kPa and 27°C. The device is now heated until its volume is 10 percent greater than the original volume. If the spring constant is 1 kN/m, what will be the change in the specific internal energy and enthalpy of the nitrogen ? Take $R = 0.2968\,\text{kPam}^3$/kg-K, $c_v = 0.743$ kJ/kg-K and $c_p = 1.039$ kJ/kg-K.



(A) 65.5 kJ/kg, 46.8 kJ/kg (B) 46.8 kJ/kg, 65.5 kJ/kg
(C) 93.6 kJ/kg, 65.5 kJ/kg (D) 46.8 kJ/kg, 32.75 kJ/kg

TD 3.29 A closed system containing of air undergoes an isothermal process from 600 kPa and 200°C to 80 kPa. What will be the initial volume of this system and the heat transfer during this process, respectively ?

(Take $R = 0.287$ kJ/kg-K)

(A) 0.4525 m^3, 547 kJ (B) 0.5656 m^3, 410.5 kJ
(C) 0.3394 m^3, 683.75 kJ (D) 0.6787 m^3, 273.5 kJ

TD 3.30 Consider a polytropic expansion process for which $pv^{1.667} =$ constant. Helium gas expands in this process from initial pressure p_1 to final pressure p_2 where $p_1 > p_2$. The work will

(A) be positive (B) be negative
(C) be zero (D) not be determined

TD 3.31 Argon is compressed in a polytropic process from 120 kPa and 30°C to 1200 kPa in a piston-cylinder device. If the equation of state is $pv^{1.2}$, what will be the work produced and heat transferred during this compression process, respectively ? Take $R = 0.2081$ kJ/kg-K and $c_v = 0.3122$ kJ/kg-K.

(A) 147.5 kJ/kg, 110.7 kJ/kg (B) 103.3 kJ/kg, 129.3 kJ/kg
(C) 103.3 kJ/kg, 147.5 kJ/kg (D) 147.5 kJ/kg, 103.3 kJ/kg

TD 3.32 Consider a piston-cylinder device. A mass of 15 kg of air is heated from 25°C ($h_1 = 298.18$ kJ/kg) to 77°C ($h_2 = 350.49$ kJ/kg) by passing current through a resistance heater inside the cylinder. The pressure inside the cylinder is held constant at 300 kPa during the process. If a heat loss of 60 kJ occurs in this process, the electric energy supplied will be

(A) 0.294 kWh (B) 0.352 kWh
(C) 0.235 kWh (D) 0.412 kWh

TD 3.33 A piston cylinder contains 3 kg of air at 20°C and 300 kPa. If it is heated up in a constant pressure process to 600 K, the work in the process will be

(A) 767 kJ (B) 198.2 kJ
(C) 384.5 kJ (D) 264.2 kJ

TD 3.34 Consider a piston-cylinder device, with a set of stops on the top. It is initially contains 3 kg of air at 200 kPa and 27°C. Heat is now transferred to the air and the piston rises until it hits the stops, at which point the volume is twice the initial volume. More heat is transferred until the pressure inside the cylinder also doubles and the temperature reaches to $927^{\circ}C$. If the initial and final internal energies are $214.07\,kJ/kg$ and $933.33\,kJ/kg$ respectively, what will be the amount of heat transfer for this process ?

(A) 2416 kJ (B) 258 kJ

(C) 2158 kJ (D) 1208 kJ

TD 3.35 What will be the expression for the work produced by an ideal gas as it undergoes a polytropic process in a closed system from initial state 1 to final state 2 ?

(A) $\frac{RT_1}{1-n}\left[\left(\frac{p_2}{p_1}\right)^{(n-1)/n}+1\right]$ (B) $\frac{RT_1}{1-n}\left[\left(\frac{p_2}{p_1}\right)^{(n-1)/n}-1\right]$

(C) $\frac{RT_1}{1+n}\left[\left(\frac{p_2}{p_1}\right)^{(n-1)/n}-1\right]$ (D) $\frac{RT_1}{1+n}\left[\left(\frac{p_2}{p_1}\right)^{(n-1)/n}+1\right]$

TD 3.36 Water at $500^{\circ}C$, $3\,MPa$ with specific volume $\nu = 0.11619\,kg/m^3$ is cooled in a polytropic process to $200^{\circ}C$, $1\,MPa$ with specific volume $\nu = 0.20596\,kg/m^3$. What will be the specific work in this process ?

(A) 155.2 kJ/kg (B) 310.4 kJ/kg

(C) 232.8 kJ/kg (D) 271.6 kJ/kg

TD 3.37 Consider a piston-cylinder device which initially contains helium gas at $150\,kPa$, $20^{\circ}C$ and $0.5\,m^3$. If the helium is compressed in a polytropic process $\left(pv^n = \text{constant}\right)$ to $400\,kPa$ and $140^{\circ}C$, the heat loss during this process will be

(Take $R = 2.0769\,kJ/kg\text{-}K$, $c_v = 3.1156\,kJ/kg\text{-}K$)

(A) 57.2 kJ (B) 22.4 kJ

(C) 28.6 kJ (D) 11.2 kJ

TD 3.38 12 kg of an ideal gas with molar mass of 25, is contained in a frictionless piston-cylinder device and a rigid tank. Each is at the same temperature, pressure and volume. It is desired to raise the temperatures of both systems by $15^{\circ}C$. If the cylinder is maintained at constant pressure to achieve this result, what will be the amount of extra heat that must be supplied to the gas in the cylinder ?

(A) 59.9 kJ (B) 45 kJ

(C) 14.9 kJ (D) 29.95 kJ

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TD 4

MASS AND ENERGY ANALYSIS OF CONTROL VOLUME

TD 4.1 A 17500 kg aeroplane takeoff from an aircraft carrier. It is assisted by a steam driven piston-cylinder device with an average pressure of 1250 kPa. The airplane should be accelerated from zero to a speed of 30 m/s with 30% of the energy coming from the steam piston. What will be the required piston displacement volume ?

(A) $3.30\,m^3$ (B) $2.36\,m^3$
(C) $1.89\,m^3$ (D) $2.85\,m^3$

TD 4.2 In a one-inlet, one-exit control volume, air enters at 8 bar, 600 K and 40 m/s through a flow area of $20\,cm^2$. This air exits at 2 bar, 400 K and 350 m/s. If the air behaves as an ideal gas and for steady state operation, the mass flow rate and the exit flow area respectively, are

(A) 0.651 kg/s, $4.58\,cm^2$ (B) 0.372 kg/s, $6.1\,cm^2$
(C) 0.558 kg/s, $7.63\,cm^2$ (D) 0.744 kg/s, $3.05\,cm^2$

TD 4.3 A $0.5\,m^3$ rigid insulated tank contains compressed air initially at 4000 kPa and 20°C. Enough air is now released from the tank to reduce the pressure to 2000 kPa. Due to this release, what will be the temperature of the remaining air in the tank ?

(Take $c_p = 1.005$ kJ/kg K, $c_v = 0.718$ kJ/kg K, $R = 0.287$ kJ/kg-K)

(A) 32 K (B) 241 K
(C) 293 K (D) 305 K

TD 4.4 A $0.2\,m^3$ rigid tank equipped with a pressure regulator contains steam at 2 MPa and 300°C. The steam in the tank is now heated. The regulator keeps the steam pressure constant by letting out some steam, but the temperature inside rises. Use the data given in the table. The amount of heat transferred, when the steam temperature reaches 500°C, will be

Temperature (°C)	Pressure (MPa)	Specific volume m^3/kg	Internal energy kJ/kg	Enthalpy kJ/kg
300	2	0.12551	2773.2	3024.2
500	2	0.17568	3116.9	3468.3

(A) 455.1 kJ (B) 303.4 kJ
(C) 606.8 kJ (D) 151.7 kJ

TD 4.5 In a steady state process, a stream of liquid water at 20°C, 1 bar ($M = 18.02$) is mixed with a stream of ethylene glycol ($M = 62.07$). It forms a refrigerant mixture that is 50% glycol by mass. The density of ethylene glycol is 1.115 times that of water and the velocity in each pipe is 2.5 m/s. If the water molar flow rate is 4.2 kmol/ min, what will be the molar flow rate of the entering ethylene glycol and the diameter of glycol supply pipe, respectively ?

(A) $1.22\,\text{kmol/min}$, $2.4\,\text{cm}$ (B) $1.83\,\text{kmol/min}$, $1.8\,\text{cm}$
(C) $1.52\,\text{kmol/min}$, $1.2\,\text{cm}$ (D) $2.15\,\text{kmol/min}$, $3\,\text{cm}$

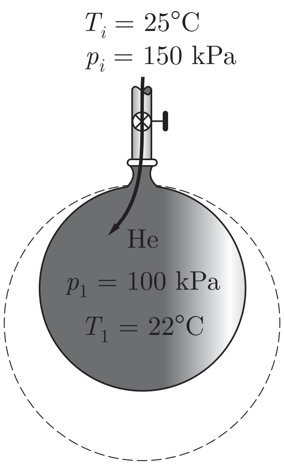
TD 4.6 In a constant pressure process, 2 kg of water at 200 kPa with a quality of 25% has its temperature raised 20°C. Consider the table shown below, what will be the heat transfer in the process ?

State	Specific Volume (kJ/kg)		Internal Energy (kJ/kg)	
	ν_f	ν_g	u_f	u_g
Saturated water at 200 kPa, 120.23°C	0.001061	0.88573	504.47	2529.49
	Specific volume (kJ/kg)		Internal energy (kJ/kg)	
Superheated vapour at 200 kPa, 150°C	0.95964		2576.87	

(A) 3386.5 kJ (B) 1693.2 kJ
(C) 846.6 kJ (D) 2539.8 kJ

TD 4.7 A large reservoir that supplied helium gas at 150 kPa and 25°C is connected to a balloon by a valve as shown in figure. The balloon initially contains 65 m^3 of helium gas at atmospheric conditions of 100 kPa, 22°C. Now the valve is opened and helium is allowed to enter the balloon until pressure equilibrium with the helium at the supply line is reached. If the volume of the balloon increases linearly with pressure and no heat transfer takes place during this process, what will be the final temperature in the balloon ?

(Take $R = 2.0769\,\text{kJ/kg-K}$, $c_p = 5.1926\,\text{kJ/kg-K}$, $c_v = 3.1156\,\text{kJ/kg-K}$)



(A) 295 K (B) 333.6 K
(C) 298 K (D) 276 K

TD 4.8 Air at steady state enters in a control volume operating at 1.05 bar, 300 K with a volumetric flow rate of 12 m^3/min and exits at 12 bar, 400 K. The enthalpies at the inlet and exit are 300.19 kJ/kg and 400.98 kJ/kg respectively. The kinetic and potential energy effects are negligible. If heat transfer occurs at a rate of 20 kW from the control volume to the surroundings, what will be the power, in kW ?

(A) 33.5 (B) 66.9
(C) 55.75 (D) 44.6

TD 4.9 Two tanks of 1 m^3 each, are connected by a valve and line. The tank A is filled with refrigerant at 20°C with quality of 15% and tank B is evacuated. The valve is opened and saturated vapor flows from A into B until the pressures become equal. The process occurs slowly enough that all temperatures stay at 20°C during the process. Using the data given in table, the total heat transfer to the refrigerant during the process, will be

Temperature (°C)	Pressure (kPa)	Specific volume (m^3/kg)		Internal energy (kJ/kg)	
		ν_f	ν_g	u_f	u_g
20	572.8	0.000817	0.03606	227.03	389.19

(A) 2325 kJ
(B) 5812 kJ
(C) 3487 kJ
(D) 4650 kJ

Common Data For Q. 10 and 11

Air flows steadily in a pipe at 300 kPa, 77°C and 25 m/s with a mass flow rate of 18 kg/ min. For the air, the gas constant and specific heat at constant pressure are $R = 0.287$ kJ/kg-K, $c_p = 1.008$ kJ/kg-K, respectively.

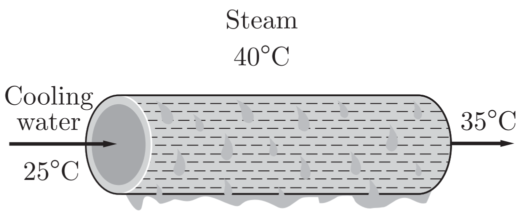
TD 4.10 The diameter of the pipe and the rate of flow energy, respectively are
(A) 7.15 cm, 30 kW
(B) 71.5 cm, 45 kW
(C) 0.715 cm, 15 kW
(D) 0.0715 cm, 60 kW

TD 4.11 What will be the rate of energy transport by mass ?
(A) 53 kW
(B) 79.5 kW
(C) 106 kW
(D) 132.5 kW

TD 4.12 Consider an engine which consists of a 100 kg cast iron block with a 20 kg aluminum head, 20 kg steel parts, 5 kg engine oil and 6 kg glycerine (antifreeze). Everything begins at 5°C. As the engine starts, if it absorbs a net of 7000 kJ before it reaches a steady uniform temperature then how hot it becomes ?
Take $c_{Fe} = 0.42$, $c_{Al} = 0.9$, $c_{gly} = 2.42$, $c_{st} = 0.46$ and $c_o = 1.9$ all units of kJ/kg-K.
(A) 40°C
(B) 60°C
(C) 80°C
(D) 5°C

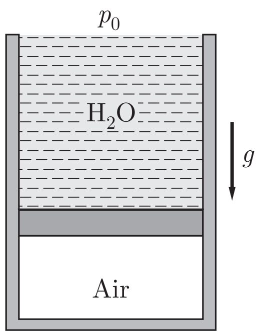
TD 4.13 At the steady state, steam enters in a nozzle at a rate of 100 m/s and at 30 bar, 320°C with $h = 3043.4$ kJ/kg. The exit pressure and temperature are 10 bar and 200°C, respectively with $h = 2827.9$ kJ/kg. The mass flow rate is 2 kg/s. Neglect heat transfer and potential energy. If the specific volumes at inlet and exit are 0.0850 m^3/kg and 0.2060 m^3/kg, respectively, what will be the exit velocity and the exit flow area ?
(A) 498 m/s, 3.1 cm^2
(B) 830 m/s, 4.65 cm^2
(C) 664 m/s, 6.2 cm^2
(D) 996 m/s, 7.75 cm^2

TD 4.14 The figure shows a 5 m long and 3 cm diameter thin horizontal copper tube. Steam at 40°C condenses on the outside of this tube by cooling water that enters the tube at 25°C at an average velocity of 2 m/s and leaves at 35°C. At 40°C, the enthalpy of liquid and vapor mixture is $h_{fg} = 2406.0$ kJ/kg-K. What will be the rate of condensation of steam ? Take $c_p = 4.18$ kJ/kg-°C.



(A) 24.5 kg/s (B) 2.45 kg/s
(C) 0.245 kg/s (D) 0.0245 kg/s

TD 4.15 Consider a piston-cylinder arrangement shown in figure. It has a cylinder of $0.1\,m^2$ cross-sectional area, 10 m height and a massless piston at the bottom with water at $20^\circ C$ on top of it. The specific volume of the water at $20^\circ C$ is $\nu_f = 0.001002\,m^3/kg$. $0.3\,m^3$ of air at 300 K ($c_v = 0.717$ kJ/kg-K), is occupied under the piston. This air is heated so that the piston moves up and spilling the water out over the side. What will be the total heat transfer to the air when all the water has been pushed out ?



(A) 165.6 kJ (B) 220.8 kJ
(C) 276 kJ (D) 331.2 kJ

Common Data For Q. 17 and 18

In a well-insulated turbine operating at steady state, steam enters at 3 MPa , $400^\circ C$ with a volumetric flow rate of $85\,m^3/min$. Some steam is extracted from the turbine at a pressure of 0.5 MPa and a temperature of $180^\circ C$. The rest expands to a pressure of 6 kPa and a quality of 90%. The kinetic and potential energy effects can be neglected and the total power developed by the turbine is 11400 kW.

State	Specific volume (m^3/kg)		Enthalpy (kJ/kg)	
Superheated water vapor at 3 MPa, $400^\circ C$	0.0994		3230.9	
Superheated water vapor at 0.5 MPa, $180^\circ C$	0.4045		2812	
Saturated water at 6 kPa	ν_f	ν_g	h_f	h_g
	0.001067	24.2385	151.53	2567.43

TD 4.16 What will be the mass flow rate of the steam at each of the two exits, respectively ?

(A) 11.17 kg/s, 3.08 kg/s (B) 3.08 kg/s, 11.17 kg/s

(C) 14.25 kg/s, 3.08 kg/s (D) 3.08 kg/s, 14.25 kg/s

TD 4.17 What will be the diameter of the duct through which steam is extracted, when the velocity there is 20 m/s ?

(A) 28.2 cm (B) 2.82 cm

(C) 14.1 cm (D) 21.2 cm

TD 4.18 A 0.75 m diameter fan takes air in at 98 kPa, 22°C and delivers it at 105 kPa, 23°C with a velocity of 1.5 m/s. If the gas constant for air is $R = 0.287$ kJ/kg-K , the mass flow rate and the inlet velocity respectively, are

(A) 0.41 kg/s, 1.2 m/s (B) 1.64 kg/s, 2.4 m/s

(C) 1.23 kg/s, 2 m/s (D) 0.819 kg/s, 1.6 m/s

TD 4.19 Nitrogen gas enters an adiabatic diffuser at 60 kPa and 7°C ($\overline{h} = 8141$ kJ/kmol) steadily with a velocity of 200 m/s and leaves at 85 kPa and 22°C ($\overline{h} = 8580$ kJ/kmol). If the molar mass of nitrogen is $M = 28$ kg/kmol, the ratio of the inlet to exit area A_1/A_2 will be

(A) 0.315 (B) 0.469

(C) 0.781 (D) 0.625

TD 4.20 Argon gas enters an adiabatic turbine operating at steady state with a velocity of 80 m/s at 900 kPa and 450°C. It leaves at 150 kPa with a velocity of 150 m/s . The power output of the turbine is 250 kW. If the inlet area of the turbine is 60 cm^2, what will be the exit temperature of the argon ?

(Take $R = 0.2081$ kJ/kg-K, $c_p = 0.5203$ kJ/kg-°C)

(A) 133.6°C (B) 334.2°C

(C) 200.4°C (D) 267.3°C

TD 4.21 In a compressor operates at steady state, the working fluid enters with a volumetric flow rate of 0.8 m^3/min at 5 bar, 10°C whereas at the exit, the pressure is 14 bar and the temperature is 90°C. The diameters of the inlet and exit pipes are 4 cm and 2 cm, respectively. The thermodynamic properties of the fluid is given in table. If the magnitude of the heat transfer rate from the compressor to its surroundings is 5% of the compressor power input, what will be the power input, in kW ?

Pressure (MPa)	Temperature (°C)	Specific volume (m^3/kg)	Enthalpy (kJ/kg)
0.5	10	0.04934	257.22
1.4	90	0.02217	306.60

(A) 10.56 (B) 7.04

(C) 17.6 (D) 14.08

Common Data For Q. 24 and 25

The air expands adiabatically in a gas turbine from 1000 kPa and 500°C to 100 kPa and 150°C. Air enters the turbine through a 0.2 m^2 opening with a average velocity of 40 m/s and exhausts through 1 m^2 opening. Take$c_p = 1.051$ kJ/kg-K and $R = 0.287$ kJ/kg-K.

TD 4.22 The mass flow rate of air through the turbine will be

(A) 27.05 kg/s (B) 36.06 kg/s

(C) 45.07 kg/s (D) 18.03 kg/s

TD 4.23 What will be the power produced by the turbine ?

(A) 3315 kW (B) 6630 kW

(C) 13260 kW (D) 9945 kW

TD 4.24 The air in a jet engine at 1000 K, 200 kPa and 40 m/s enters in nozzle and the air exits at 500 m/s, 90 kPa. What will be the exit temperature when there is no heat loss ?

Temperature ($^\circ$C)	Enthalpy (kJ/kg)	Temperature ($^\circ$C)	Enthalpy (kJ/kg)
850	877.40	950	989.44
900	933.15	1000	1046.22

(A) 850 K (B) 890 K

(C) 900 K (D) 950 K

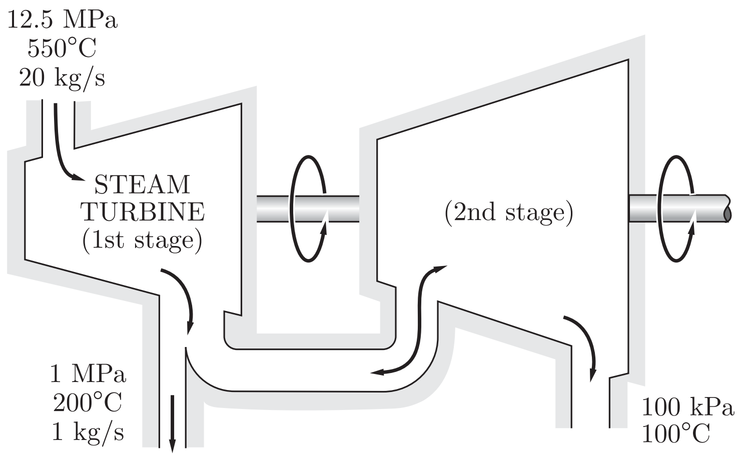
TD 4.25 Consider a feedwater heater which operates at steady state. The liquid water entering at inlet 1 at 7 bar, 42°C with a mass flow rate of 70 kg/s. Another stream of water as a two-phase liquid-vapour mixture, enters at inlet 2 at 7 bar with a quality of 98%. Finally saturated liquid at 7 bar exits the feedwater heater at 3. Ignore heat transfer with the surroundings. If the kinetic and potential energy effects are negligible and referring to the data given in table, the mass flow rate at inlet 2 will be

Temperature ($^\circ$C)	Pressure (kPa)	Specific Volume (m^3/kg)		Enthalpy (kJ/kg)	
		ν_f	ν_g	h_f	h_g
42	8.268	0.0010086	18.234	175.90	2578.6
165	700	0.0011080	0.2729	697.22	2763.5

(A) 18.0 kg/s (B) 88 kg/s

(C) 9 kg/s (D) 22 kg/s

TD 4.26 A two stage adiabatic steam turbine is shown in figure. The steam at a rate of 20 kg/s enters the turbine at 12.5 MPa and 550°C ($h = 3476.5$ kJ/kg). Steam is bled from this turbine with a mass flow rate of 1 kg/s at 1000 kPa and 200°C ($h = 2828.3$ kJ/kg) . The remaining steam leaves the turbine at 100 kPa and 100°C ($h = 2675.8$ kJ/kg). The power produced by this turbine is



(A) 15862 kW (B) 7137.9 kW
(C) 3965.5 kW (D) 12689.6 kW

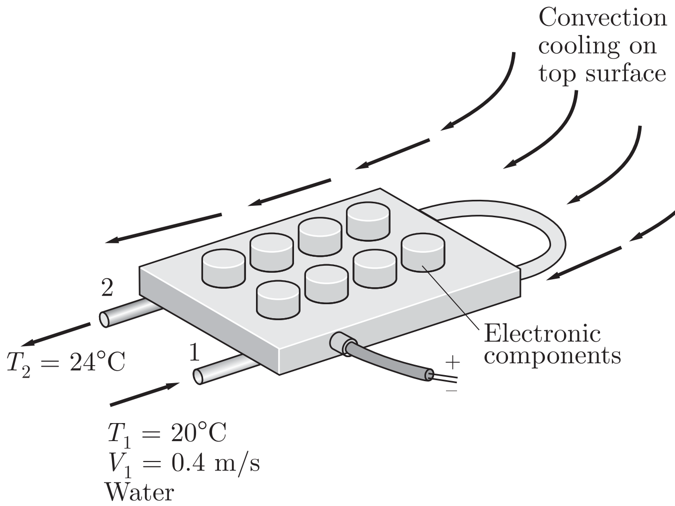
TD 4.27 Air entering in a diffuser at 100 kPa, 300 K, with a velocity of 200 m/s. The inlet and exit cross-sectional area of the diffuser are 100 mm^2 and 860 mm^2, respectively. If the exit velocity is 20 m/s, the exit pressure and temperature of the air will be

(A) 123.9 kPa (B) 93 kPa
(C) 62 kPa (D) 186 kPa

TD 4.28 In a jet engine, the front of engine acts as a diffuser and receives air at 900 km/h , -5°C, 50 kPa. It brings it to 80 m/s relative to the engine before entering the compressor. If the flow area is reduced to 80% of the inlet area, what will be the temperature and pressure in the compressor inlet ?

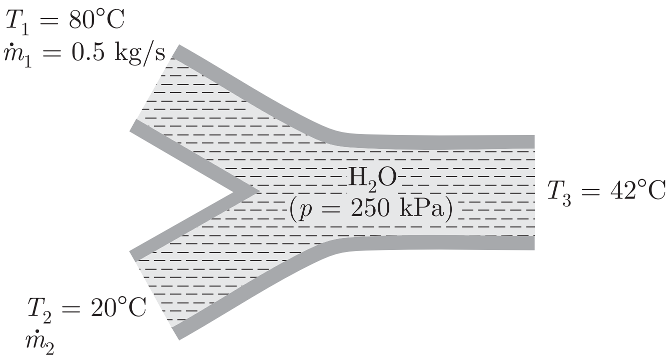
(A) 323.6 kPa (B) 161.8 kPa
(C) 215.7 kPa (D) 269.7 kPa

TD 4.29 In the figure, at steady state, water enters the tube with velocity of 0.4 m/s at 20°C. At this stage the specific volume and enthalpy of liquid are $\nu_f = 0.0010018\ \text{m}^3/\text{kg}$ and $h_f = 83.96$ kJ/kg, respectively. The water exits at 24°C, $h_f = 100.7$ kJ/kg with a negligible change in pressure. The electrical components receive 0.5 kW of electrical power and the rate of energy transfer by convection from the plate-mounted electronics is estimated to be 0.08 kW. If the kinetic and potential energy effects are negligible, the tube diameter will be



(A) 89 mm (B) 8.9 mm
(C) 0.89 mm (D) 890 mm

TD 4.30 Consider a well insulated mixing chamber shown in figure. A hot-water stream at 80°C enters this chamber steadily with a mass flow rate of 0.5 kg/s where it is mixed with a stream of cold water at 20°C. Assume all the streams are at a pressure of 250 kPa and the temperature at this pressure, is 127.41°C. If the mixture leave the chamber at 42°C, the mass flow rate of the cold-water stream will be



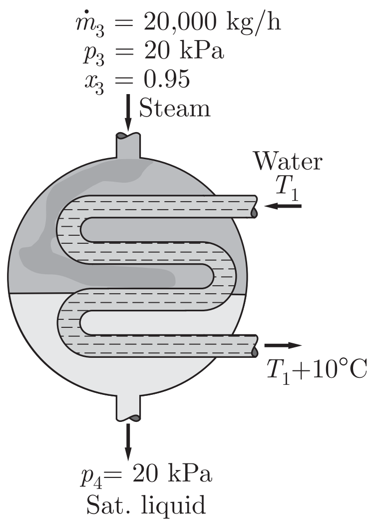
(A) 1.165 kg/s (B) 8.64 kg/s
(C) 0.864 kg/s (D) 5.62 kg/s

TD 4.31 A liquid is throttled in a line flowing at 25°C, 750 kPa to a pressure of 165 kPa . The kinetic energy is negligible. Considering the table, the ratio of exit pipe diameter to that of the inlet pipe so the velocity stays constant, respectively are

Temperature (°C)	Pressure (kPa)	Specific volume (m^3/kg)		Enthalpy (kJ/kg)	
		ν_f	ν_g	h_f	h_g
25	666.3	0.000829	0.03098	234.59	412.51
-15	165	0.000746	0.12007	180.19	389.20

(A) 12.38 (B) 38.32
(C) 6.19 (D) 19.16

TD 4.32 In the given figure, steam enters the condenser of a steam power plant with a mass flow rate of 20000 kg/h at 20 kPa and a quality of 95 percent. It is to be cooled by water from a nearby river by circulating the water through the tubes within the condenser. The river water is not allowed to experience a temperature rise above 10°C to prevent thermal pollution. The steam is to leave the condenser as saturated liquid at 20 kPa. If the enthalpy of liquid and vapor at 20 kPa are $h_f = 251.42$ kJ/kg and $h_g = 2608.9$ kJ/kg respectively, what will be the required mass flow rate of the cooling water ? Take $c_p = 4.18$ kJ/kg-°C.



(A) 223.3 kg/s (B) 297.7 kg/s
(C) 372.2 kg/s (D) 148.8 kg/s

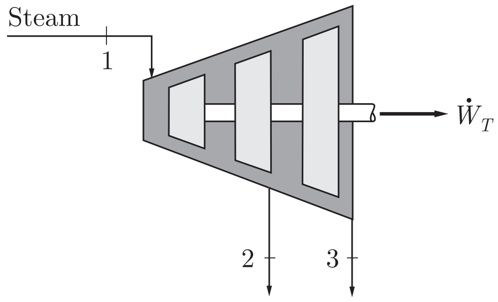
TD 4.33 Consider a wind mill with rotor diameter of 30 m. It takes 40% of the kinetic energy out as shaft work on a day with 20°C and wind speed of 30 km/h. The produced power is

(A) 246.8 kW (B) 98.6 kW
(C) 123.4 kW (D) 185.1 kW

TD 4.34 A spherical balloon of 3 m initial diameter, is filled with air at 120 kPa and 35°C . Air enters this balloon at 120 kPa and 35°C with a velocity of 2 m/s through a 1 m diameter opening. If the pressure and temperature of the air in the balloon remain the same as the air entering the balloon, how many minutes will it take to inflate this balloon to a 15 m diameter ?

(A) 9.3 minutes (B) 18.6 minutes
(C) 13.9 minutes (D) 23.3 minutes

TD 4.35 In the figure, a steam turbine receives water at 15 MPa, 600°C with a rate of 100 kg/s and enthalpy of 3582.3 kJ/kg. The water is withdrawn in the middle section at 2 MPa, 350°C with a rate of 20 kg/s and enthalpy 3137 kJ/kg. The rest exits the turbine at 75 kPa and 95% quality where the enthalpies of fluid and vapor are $h_f = 384.3$ kJ/kg and $h_g = 2662.7$ kJ/kg, respectively. Assuming no heat transfer and no changes in kinetic energy, what will be the total turbine power output ?



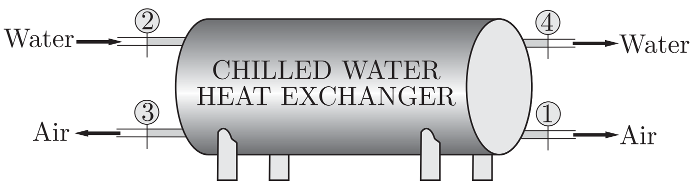
(A) 62.7 MW (B) 91.2 MW
(C) 203.9 MW (D) 358.2 MW

TD 4.36 Two streams of water are mixed steadily in an insulated container to form a third stream leaving the container. The temperature of first stream is 90°C and that of second is 50°C. The flow rates of first and second streams are 30 kg/s and 200 kg/s respectively. Using the data given in table, what will be the temperature of the third stream ?

Temperature (°C)	Entahlpy (kJ/kg)		
	h_f	h_{fg}	h_g
50	209.34	2382.0	2591.3
90	377.04	2282.5	2659.5

(A) 82.9°C (B) 41.5°C
(C) 55.3°C (D) 69.2°C

TD 4.37 A chilled water heat exchange unit shown in figure, is designed to cool $5\,m^3/s$ of air at 100 kPa, 30°C to 100 kPa, 18°C by using water at 8°C. If the mass flow rate of the water is 2 kg/s, the maximum water outlet temperature will be
(Take $R = 0.287$ kJ/kg-K, $c_{p,a} = 1.005$ kJ/kg-°C and $c_{p,w} = 4.18$ kJ/kg-°C)



(A) 16.3°C (B) 20.4°C
(C) 12.2°C (D) 24.5°C

Common Data For Q. 41 and 42

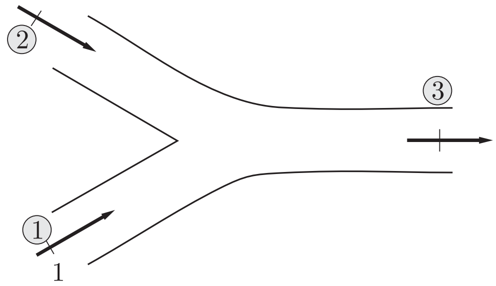
A large expansion engine has two low velocity entrance for water. High pressure steam at 2 MPa, 500°C enters through point 1 with a rate of 2.0 kg/s and cooling water at 120 kPa, 30°C enters through point 2 with a rate of 0.5 kg/s. A single flow exits with 150 kPa, 80% quality, through 0.15 m diameter exhaust pipe. There is a heat loss of 300 kW.

State	Specific Volume (m^3/kg)		Enthalpy (kJ/kg)	
Superheated Vapour water at 2 MPa, 500°C	0.17568		3467.55	
	ν_f	ν_g	h_f	h_g
Saturated water at 30°C	0.001004	32.8932	125.77	2556.25
Water vapour mixture at 150 kPa	0.001053	1.15933	467.08	2693.54

TD 4.38 What will be the exhaust velocity ?
(A) 131.2 m/s (B) 98.4 m/s
(C) 65.6 m/s (D) 164 m/s

TD 4.39 The power output of the engine is
(A) 528 kW (B) 1056 kW
(C) 792 kW (D) 1584 kW

TD 4.40 Two air streams are combined to a single flow as shown in figure. The volume flow rate of one is $1\,m^3/s$ at $20^\circ C$ and the other is $2\,m^3/s$ at $200^\circ C$ both at $100\,kPa$. They mix without any heat transfer to produce an exit flow at $100\,kPa$. If the kinetic energy is neglected, what will be the exit temperature and the volume flow rate.



(A) $3.0\,m^3/s$

(B) $4.5\,m^3/s$

(C) $1.5\,m^3/s$

(D) $2.0\,m^3/s$

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TD 5

SECOND LAW OF THERMODYNAMICS

TD 5.1 Consider a refrigerator with a COP of 1.2. It removes heat from the refrigerated space at a rate of $60\,\text{kJ/min}$. What will be the electric power consumed by the refrigerator and the rate of heat transfer to the kitchen air ?

(A) $1.04\,\text{kW}$, $60\,\text{kJ/min}$ (B) $0.83\,\text{kW}$, $110\,\text{kJ/min}$

(C) $1.25\,\text{kW}$, $50\,\text{kJ/min}$ (D) $1.45\,\text{kW}$, $93.5\,\text{kJ/min}$

TD 5.2 On a summer day, the temperature of a well sealed house is at 32°C. When the air conditioner turns on, the entire house cools to 20°C in $15\,\text{min}$. Assume the entire mass within the house is equivalent to $800\,\text{kg}$ of air for which $c_v = 0.72\,\text{kJ/kg-}^\circ\text{C}$ and $c_p = 1.0\,\text{kJ/kg-}^\circ\text{C}$. If the COP of the air-conditioning system is 2.5, what will be the power drawn by the air conditioner ?

(A) $7.68\,\text{kW}$ (B) $16.1\,\text{kW}$

(C) $19.2\,\text{kW}$ (D) $3.07\,\text{kW}$

TD 5.3 Consider a reversible power cycle. It receives energy Q_H from a reservoir at temperature T_H and rejects Q_L to a reservoir at temperature T_L. The work developed by the power cycle is used to drive a reversible heat pump that removes energy Q_L' from a reservoir at temperature T_L' and rejects energy Q_H' to a reservoir at temperature T_H'. What will the expression for the ratio Q_H'/Q_H in terms of the temperatures of the four reservoirs ?

(A) $\dfrac{T_H'(T_H + T_L)}{T_H(T_H' + T_L')}$ (B) $\dfrac{T_H'(T_H - T_L)}{T_H(T_H' - T_L')}$

(C) $\dfrac{T_H'(T_H' - T_L')}{T_H(T_H - T_L)}$ (D) $\dfrac{T_H(T_H' - T_L')}{T_H'(T_H - T_L)}$

TD 5.4 In a condenser of a residential heat pump, refrigerant-134a enters at $800\,\text{kPa}$, 35°C with a rate of $0.018\,\text{kg/s}$ and leaves at $800\,\text{kPa}$ as a saturated liquid. The enthalpies of refrigerant at the condenser inlet and exit are $h_g = 271.22\,\text{kJ/kg}$ and $h_f = 95.47\,\text{kJ/kg}$, respectively. If the compressor consumes $1.2\,\text{kW}$ of power, what will be the COP of the heat pump and the rate of heat absorption from the outside air, respectively ?

(A) 3.57, 1.2 kW (B) 1.2, 4.36 kW

(C) 2.64, 1.96 kW (D) 5.5, 3.16 kW

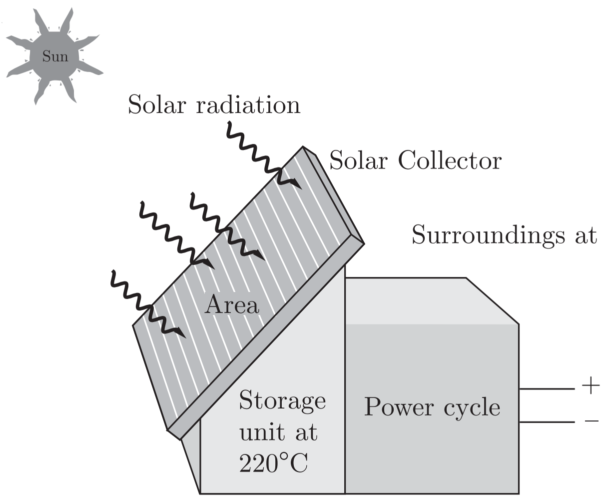
TD 5.5 A steam turbine has inlet at $4\,\text{MPa}$, 500°C and actual exit at $100\,\text{kPa}$, $x = 1.0$. Considering the properties of water and steam given in table, what will be the first law (isentropic) and second law efficiencies of the turbine, respectively ?

State	Enthalpy (kJ/kg)		Entropy (kJ/kg-K)	
Superheated vapor at $4\,\text{MPa}$, 500°C	3445.2		7.0900	
Saturated water at $100\,\text{kPa}$	h_f	h_g	s_f	s_g
	417.44	2675.46	1.3025	7.3593

(A) 90.6%, 97.7% (B) 90.6%, 88.5%
(C) 88.5%, 90.6% (D) 97.7%, 88.5%

TD 5.6 A heat engine rejects 1000 kJ/kg of heat with a thermal efficiency of 40%. How much heat does it receive ?
(A) 2500 kJ/kg (B) 1667 kJ/kg
(C) 714.3 kJ/kg (D) 1250.25 kJ/kg

TD 5.7 Consider a system for collecting solar radiation as shown. It utilizes the radiation for production of electricity by a power cycle. The solar collector receives solar radiation at the rate of 0.315 kW/m^2 and provides energy to a storage unit whose temperature remains constant at 220°C. The power cycle receives energy by heat transfer from the storage unit, generates electricity at the rate 0.5 MW and discharges energy by heat transfer to the surroundings at 20°C. For operation at steady state, what will be the minimum theoretical collector area required ?



(A) 977.25 m^2 (B) 2931.75 m^2
(C) 3909 m^2 (D) 1954.5 m^2

TD 5.8 The geothermal water extracted at 160°C and at a rate of 440 kg/s is used as the heat source in a geothermal power plant. It produces 22 MW of net power. If the environment temperature is 25°C and the specific heat of water at 160°C is 4.22 kJ/kg-K, what will be the actual thermal efficiency, the maximum possible thermal efficiency and the actual rate of heat rejection from this power plant ?
(A) 88%, 3.12%, 22 MW
(B) 8.8%, 31.2%, 228.7 MW
(C) 8.8%, 68.8%, 250.7 MW
(D) 68.8%, 31.2%, 273.1 MW

TD 5.9 In an automobile, 25 hp of power is delivered to the drive shaft by the engine . The engine has a thermal efficiency of 30% and the fuel has a heating value of 40000 kJ/kg. What will be the rate of fuel consumption and the combined power rejected through the radiator and exhaust ?
(A) 1.53 g/s, 42.9 kW (B) 2.68 g/s, 64.4 kW
(C) 3.06 g/s, 32.2 kW (D) 2.3 g/s, 53.6 kW

TD 5.10 Which of the following is the expression for the COP of a completely reversible refrigerator in terms of the thermal energy reservoir temperatures, T_L and T_H ?

(A) $\frac{T_H}{T_L - T_H}$ (B) $\frac{T_L}{T_H + T_L}$

(C) $\frac{T_L}{T_H - T_L}$ (D) $\frac{T_H}{T_H - T_L}$

TD 5.11 Air enters a compressor with a low velocity at ambient conditions of 100 kPa and 20°C at a rate of 4.5 m³/s and exits at 900 kPa, 60°C and 80 m/s. The compressor is cooled by cooling water that experiences a temperature rise of 10°C. If the isothermal efficiency of the compressor is 70 percent, the actual power input and the mass flow rate of the cooling water, respectively, are

(Take $R = 0.287$ kJ/kg-K, $c_p = 1.005$ kJ/kg-K, $c_w = 4.18$ kJ/kg-K)

(A) 988.7 kW, 5.35 kg/s (B) 1413 kW, 28.25 kg/s

(C) 2169.7 kW, 28.25 kg/s (D) 1181 kW, 5.35 kg/s

TD 5.12 In a steam power plant, the boiler added 1 MW of heat, the condenser consumes 0.58 MW of heat and the pump work is 0.02 MW. If everything could be reversed to obtain a refrigerator, what will be the plant thermal efficiency and the coefficient of performance of the refrigerator ?

(A) 44%, 1.86 (B) 42%, 1.38

(C) 46%, 2.96 (D) 40%, 2.28

TD 5.13 An automobile engine delivers 60 kW of power to the wheels while consumes fuel at a rate of 28 L/h. The fuel has a heating value of 44000 kJ/kg and a density of 0.8 g/cm³. What will be the efficiency of this engine ?

(A) 38.4% (B) 32.8%

(C) 49.3% (D) 21.9 %

TD 5.14 A refrigeration cycle at steady state, removes 18000 kJ/h of energy by heat transfer from a space maintained at −40°C and discharges energy by heat transfer to surroundings at 20°C. The coefficient of performance of the cycle is 25% of that of reversible refrigeration cycle operating between thermal reservoirs at these two temperatures. The power input to the cycle is

(A) 7.75 kW (B) 6.45 kW

(C) 9.01 kW (D) 5.15 kW

Common Data For Linked Answer Q. 17 and 18

A refrigerator removes heat from the refrigerated space at −5°C and transfers it to the ambient air at 27°C. A Carnot heat engine receives heat from a reservoir at 900°C at a rate of 800 kJ/min and rejects the waste heat to the same ambient air at 27°C. The entire work output of this heat engine is used to drive this refrigerator.

TD 5.15 The maximum rate of heat removal from the refrigerated space is

(A) 4985 kJ/min (B) 595.2 kJ/min

(C) 2492.5 kJ/min (D) 3738.7 kJ/min

TD 5.16 What will be the total rate of heat rejection to the ambient air ?

(A) 1446.25 kJ/min (B) 5785 kJ/min

(C) 2892.5 kJ/min (D) 4338.7 kJ/min

TD 5.17 In a constant-pressure heat exchanger, a refrigerant at 95°C, $x = 0.1$ flowing at 2 kg/s is brought to saturated vapor. This heat exchanger uses energy from a heat pump with a coefficient of performance of 2.5. If the enthalpy of liquid and vapor are 140.23 kJ/kg and 211.94 kJ/kg, respectively, the power required to drive this heat pump will be

(A) 38.7 kW (B) 77.4 kW

(C) 64.5 kW (D) 51.6 kW

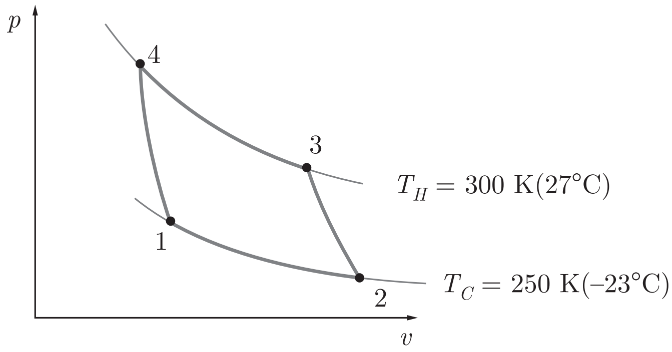
TD 5.18 A well sealed house (i.e. no air leaks) has entire mass within the house (air, furniture, etc) to be equivalent to 2000 kg of air. The house is losing heat to the outside at an average rate of 40000 kJ/h and the temperature of the house is 3°C . A heat pump with a COP of 2.4 is used to heat the house. When the heat pump is turned on, it consumes 8 kW of electric power. Take $c_{v,\text{air}} = 0.718$ kJ/kg-°C. How long it will take for the temperature in the house to rise to 22°C ?

(A) 42 min 13 sec (B) 25 min 12 sec

(C) 56 min 13 sec (D) 56 min 22 sec

Common Data For Q.21 and 22

The figure shows a Carnot refrigeration cycle which executes with one-tenth kilograms of air as an ideal gas with $k = 1.4$. The isothermal expansion occurs at -23°C with a heat transfer to the air of 3.4 kJ. The isothermal compression occurs at 27°C to a final volume of 0.01 m^3.



TD 5.19 What will be the pressures at principal states 1 and 3 ?

(A) $p_1 = 454.9$ kPa, $p_3 = 536.1$ kPa (B) $p_1 = 864$ kPa, $p_3 = 536.1$ kPa

(C) $p_1 = 536.1$ kPa, $p_3 = 454.9$ kPa (D) $p_1 = 454.9$ kPa, $p_3 = 283.2$ kPa

TD 5.20 What will be the work for this cycle ?

(A) 679 J (B) 509 J

(C) 1018 J (D) 848 J

Common Data For Linked Answer Q. 23 and 24

Consider a Carnot heat engine which receives heat at 750 K and rejects the waste heat to the environment at 300 K. The entire work output of the heat engine is used to drive a Carnot refrigerator that removes heat from the cooled space at -15°C at a rate of 400 kJ/min and rejects it to the same environment at 300 K.

TD 5.21 The rate of heat supplied to the heat engine will be

(A) 65.1 kJ/min (B) 54.25 kJ/min

(C) 130.2 kJ/min (D) 108.5 kJ/min

TD 5.22 What will be the total rate of the heat rejection to the environment ?

(A) 43.4 kJ/min (B) 508.5 kJ/min

(C) 421.7 kJ/min (D) 465.1 kJ/min

TD 5.23 Outside atmospheric air at 35°C is cooled by an air-conditioner upto 15°C with a rate of 1 kg/s. What will be the amount of power needed to operate this air-conditioner ?

(A) 3.5 kW (B) 20.08 kW

(C) 1.4 kW (D) 4.9 kW

Common Data For Linked Answer Q. 26 and 27

A bread loaf has an average mass of 450 g. These loaves are cooled from 22 to −10°C at a rate of 500 loaves per hour by refrigerated air at −30°C. The average specific and latent heats of bread to be 2.93 kJ/kg-°C and 109.3 kJ/kg, respectively. Take $R = 0.287$ kPa-m^3/kg-K and $c_{p,\,\text{air}} = 1.0$ kJ/kg-°C.

TD 5.24 What will be the rate of heat removal from the breads ?

(A) 21096 kJ/h (B) 45689 kJ/h

(C) 3497 kJ/h (D) 24593 kJ/h

TD 5.25 If the temperature rise of air is not exceed 8°C, the required volume flow rate of air is

(A) 2560.4 m^3/h (B) 1772.5 m^3/h

(C) 3348.2 m^3/h (D) 3939 m^3/h

TD 5.26 A balloon is filled with 0.5 m^3 of helium at 20°C, 1 bar. It is moving with a velocity of 15 m/s at an elevation of 0.5 km relative to an exergy reference environment. For the environment at $T_0 = 20$°C, $p_0 = 1$ bar, the specific exergy of the helium will be

(A) 8.78 kJ/kg (B) 6.27 kJ/kg

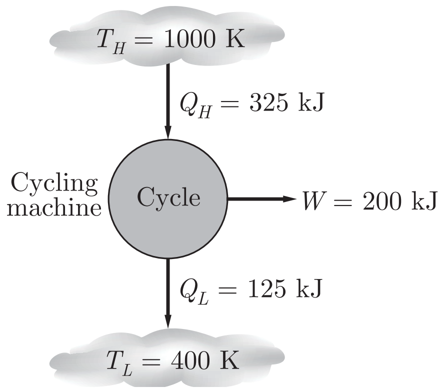
(C) 5.02 kJ/kg (D) 7.53 kJ/kg

TD 5.27 Air at 550 kPa, 425 K enters steadily in an adiabatic turbine. If the air leaves the turbine at 110 kPa and 325 K, what will be the second-law efficiency of this turbine ? Take $T_0 = 25$°C, $c_p = 1.011$ kJ/kg-K and $R = 0.287$ kJ/kg-K.

(A) 64% (B) 73%

(C) 57% (D) 86%

TD 5.28 A cyclic machine shown in figure, receives 325 kJ from a 1000 K energy reservoir. It rejects 125 kJ to 400 K energy reservoir. The cycle produces 200 kJ of work as output. This cycle is



(A) reversible (B) impossible
(C) irreversible (D) heat pump

TD 5.29 Consider two constant-volume tanks, each filled with 30 kg of air, as illustrated in figure. The tanks have temperatures of 900 K and 300 K. A heat engine places between the two tanks, extracts heat from the high-temperature tank, produces work and rejects heat to the low-temperature tank. Assume constant specific heats at room temperature, the maximum work that can be produces by the heat engine and the final temperatures of the tanks, respectively, are

(A) 8193 kJ, 130.1 K
(B) 3462 kJ, 519.6 K
(C) 4713 kJ, 519.6 K
(D) 12096 kJ, 130.1 K

TD 5.30 A refrigerator works on Cannot cycle between -8°C and 35°C with a motor-compressor of 750 W. It makes ice cubes out of a tray of 0.25 kg liquid water at 10°C. What will be the required amount of work input for the refrigerator ? Take $h_{@10^\circ C} = 41.99$ kJ/kg and $h_{@0^\circ C} = -333.6$ kJ/kg.

(A) 22.86 kJ (B) 15.24 kJ
(C) 26.67 kJ (D) 34.29 kJ

TD 5.31 Consider a 1.2 m^3 insulated rigid tank which contains 2.13 kg of carbon dioxide at 100 kPa. Now paddle-wheel work is done on the system until the pressure in the tank rises to 120 kPa. What will be the actual paddle-wheel work done during this process and the minimum paddle-wheel work with which this process (between the same end states) could be accomplished, respectively ? Take $T_0 = 298$ K, $c_v = 0.684$ kJ/kg-K and $R_{CO_2} = 0.1889$ kJ/kg-K.

(A) 87 kJ, 17.06 kJ (B) 7.58 kJ, 87 kJ
(C) 87 kJ, 7.58 kJ (D) 65.3 kJ, 7.58 kJ

TD 5.32 A storage tank of 2 m^3 is filled with water vapor at 400°C and 0.35 bar. The effects of motion and gravity are negligible. If the environment is at $T_0 = 17^\circ$C and $p_0 = 1$ atm, what will be the exergy of the contents in the tank ? Take in consideration, the data given in table.

State	Specific volume (m^3/kg)	Internal energy (kJ/kg)	Entropy (kJ/kg-K)
Superheated vapor at 0.35 bar, 400°C	8.872	2968.6	9.0291

Saturated water at 17°C	ν_f	ν_g	u_f	u_g	s_f	s_g
	0.0010012	69.044	71.38	2398.8	0.2535	8.7351

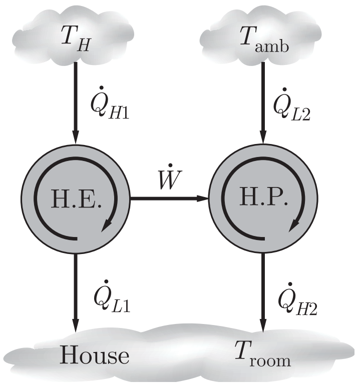
(A) 98.6 kJ (B) 281.5 kJ
(C) 182.9 kJ (D) 267.4 kJ

TD 5.33 8 kg of helium undergoes a process from an initial state of $3\,m^3/kg$ and 15°C to the final state of $0.5\,m^3/kg$ and 80°C. If the surroundings to be at 25°C and 100 kPa, what will be the increase in the useful work potential of the helium during this process ?

(Take $R = 2.0769$ kJ/kg-K, $c_v = 3.1156$ kJ/kg-K)

(A) 6980 kJ (B) 2443 kJ
(C) 5235 kJ (D) 3839 kJ

TD 5.34 In the figure, the heat pump is driven by the work output of a heat engine. If the devices are ideal and working in ideal conditions, what will be the ratio of the total power $\dot{Q}_{L1} + \dot{Q}_{H2}$ that heats the house to the power from the hot energy source $\dot{Q}_{H1}$ in terms of the temperatures ?



(A) $\dfrac{T_{room}(T_H - T_{amb.})}{T_H(T_{room} - T_{amb.})}$ (B) $\dfrac{T_{room}(T_H + T_{amb.})}{T_H(T_{room} - T_{amb.})}$

(C) $\dfrac{T_H(T_{room} - T_{amb.})}{T_{room}(T_H - T_{amb.})}$ (D) $\dfrac{T_H(T_{room} + T_{amb.})}{T_{room}(T_H + T_{amb.})}$

TD 5.35 A 50 kg iron block and 20 kg copper block, both initially at 80°C, are dropped into large tank at 15°C. As a result of heat transfer between the blocks and the tank water, thermal equilibrium is established after a while. Assuming the surroundings to be at 20°C, what will be the amount of work that could have been produced when the entire process were executed in a reversible manner ?

(Take $c_{p,\,iron} = 0.45$ kJ/kg °C and $c_{p,\,copper} = 0.386$ kJ/kg°C)

(A) 491 kJ (B) 982 kJ
(C) 196 kJ (D) 1964 kJ

Common Data For Q. 38 and 39

1 kg of water initially at 1.5 bar and 200°C cools at constant pressure with no internal irreversibilities to a final state where the water is a saturated liquid. The environment is at $T_0 = 20$°C and $p_0 = 1$ bar. Neglect the effects of motion and gravity. The thermodynamic properties of water and steam are given in the table.

State	Specific volume (m^3/kg)		Internal energy (kJ/kg)		Entropy (kJ/kg-K)	
Superheated vapor at 1.5 bar, 200°C	1.444		2656.2		7.6433	
Saturated water at 1.5 bar	ν_f	ν_g	u_f	u_g	s_f	s_g
	0.0010528	1.159	466.94	2519.7	1.4336	7.2233

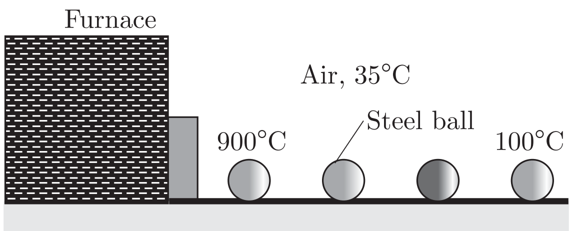
TD 5.36 For the water as the system, the work and the heat transfer, respectively, are
(A) 216.4 kJ, 2405.7 kJ
(B) 216.4 kJ, 1202.85 kJ
(C) 2405.7 kJ, 216.4 kJ
(D) 432.8 kJ, 2405.7 kJ

TD 5.37 What will be the amounts of exergy transfer accompanying work and heat transfer, respectively ?
(A) 144.2 kJ, 586.3 kJ (B) 586.3 kJ, 72.1 kJ
(C) 72.1 kJ, 293.1 kJ (D) 72.1 kJ, 586.3 kJ

TD 5.38 Hydrogen at 25 bar, 450°C enters in a turbine with a mass flow rate of 0.2 kg/s and expands to 2 bar, 160°C. The environment is at $T_0 = 25$°C and $p_0 = 1$ atm . The turbine operates at steady state with negligible heat transfer with its surroundings. Assuming the ideal gas model with $k = 1.37$ and neglecting the kinetic and potential energy effects, what will be the isentropic and exergetic turbine efficiency, respectively ?
(A) 85.2%, 93.8% (B) 85.2%, 81%
(C) 81%, 85.2% (D) 81%, 93.8%

Common Data For Q. 41 and 42

The Carbon steel balls of 8 mm diameter are annealed by heating them first to 900°C in a furnace and then allowing them to cool slowly to 100°C in ambient air at 35°C. In the process shown, 1200 balls are to be annealed per hour. Take $\rho = 7833$ kg/m^3 and $c_p = 0.465$ kJ/kg-°C.



TD 5.39 The rate of heat transfer from the balls to the air is
(A) 195 W (B) 130 W
(C) 325 W (D) 260 W

TD 5.40 What is the rate of exergy destruction due to heat loss from the balls to the air ?
(A) 182.5 W (B) 109.5 W
(C) 219 W (D) 146 W

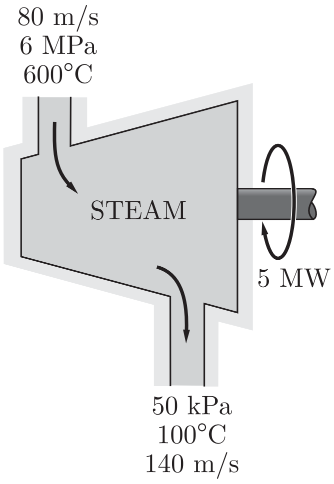
TD 5.41 A Carnot cycle heat engine operating in outer space, rejects heat only by thermal radiation. This thermal radiation is proportional to the radiator area and the fourth power of absolute temperature as $Q_{rad} = kAT^4$. For a given engine work output and given T_H, what will the ratio of T_L/T_H so that the radiator area will be minimum ?

(A) $\frac{4}{5}$ (B) $\frac{4}{3}$

(C) $\frac{2}{3}$ (D) $\frac{3}{4}$

TD 5.42 An adiabatic steam turbine with inlet and outlet conditions is shown in figure. If the power output of the turbine is 5 MW, what will be the second law efficiency of the turbine ? Assume the surroundings to be at 25°C and refer the data given in table.

Temperature (°C)	Pressure (MPa)	h (kJ/kg)	s (kJ/kg-K)
600	6	3658.8	7.1693
100	0.05	2682.4	7.6953



(A) 90.2% (B) 65.3%

(C) 86.1% (D) 76.6%

Common Data For Q. 45 and 46

Helium gas enters in an insulated nozzle with velocity of 10 m/s, operating at steady state at 1300 K, 4 bar. At the exit, the temperature and pressure of the helium are 900 K and 1.45 bar, respectively. The environment is at $T_0 = 20°C$ and $p_0 = 1$ atm. Ignore the effects of gravity and assume the ideal gas model of helium. Use $c_p = 5.1926$ kJ/kg-K, $R = 2.0769$ kJ/kg-K and $k = 1.667$.

TD 5.43 The exit velocity and the isentropic nozzle efficiency, respectively are

(A) 2038 m/s, 92.2 % (B) 1528 m/s, 46.1%

(C) 1019 m/s, 46.1% (D) 2122 m/s, 92.2%

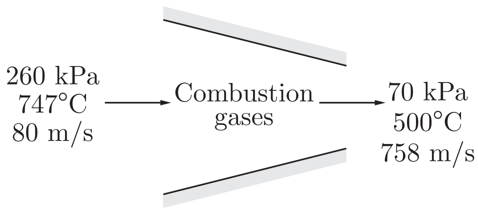
TD 5.44 What will be the rate of exergy destruction in kJ/kg of gas flowing through the nozzle ?

(A) 26.2 kJ/kg (B) 58.1 kJ/kg

(C) 37.8 kJ/kg (D) 49.4 kJ/kg

TD 5.45 In the figure shown, hot combustion gases enter the nozzle at 260 kPa, 747°C and 80 m/s and exit at 70 kPa, 500°C and 758 m/s. Assuming the nozzle to be adiabatic and the surroundings to be at 20°C, the decrease in the exergy of the gases will be

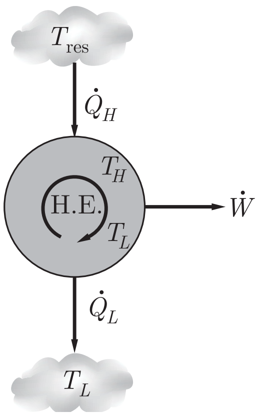
(Take $k = 1.3$, $R = 0.2654$ kJ/kg-K and $c_p = 1.15$ kJ/kg-°C)



(A) 8.56 kJ/kg (B) 6.42 kJ/kg

(C) 10.7 kJ/kg (D) 12.8 kJ/kg

TD 5.46 A Carnot heat engine is shown in figure. It receives energy from a reservoir at T_{res} through a heat exchanger where the heat transferred is given by $\dot{Q}_H = k(T_{res} - T_H)$ and T_L is the low temperature at which it rejects heat. To design the heat engine for maximum work output, what should be the high temperature, T_H, in a cycle ?



(A) $\sqrt{T_{res} T_L}$ (B) $T_{res} T_L$

(C) $(T_{res} T_L)^{1/3}$ (D) $(T_{res} T_L)^2$

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TD 6

ENTROPY

TD 6.1 In a family of four person, each person taking a 5 minute shower ever morning. The average flow rate through the shower head is 0.2 kg/s. Municipal water at 15°C is mixed by hot water at 55°C and the mixture at 42°C is being routed to the shower head. What will be the amount of entropy generated by this family per year as a result of taking daily showers ?

(A) 41016.8 kJ/K (B) 32813.5 kJ/K
(C) 16406.7 kJ/K (D) 24610.2 kJ/K

TD 6.2 Air ($c_p = 1.005$ kJ/kg-°C) enters the heat exchanger at 95 kPa and 20°C with a rate of 1.6 m^3/s. The combustion gases ($c_p = 1.10$ kJ/kg-°C) enters at 180°C with a rate of 2.2 kg/s and leave at 95°C. What will be the rate of entropy generation ?

(A) 0.455 kW/K (B) 0.91 kW/K
(C) 0.091 kW/K (D) 9.1 kW/K

TD 6.3 In an isothermal, internally reversible process, air is initially at 14 bar, 60°C and is expand to a final pressure of 2.8 bar. What will be the work ?

(A) 230.72 kJ/kg (B) 115.36 kJ/kg
(C) 153.81 kJ/kg (D) 192.26 kJ/kg

TD 6.4 In an insulated 12 cm diameter pipe, oxygen enters with a velocity of 70 m/s. The inlet state of oxygen is 240 kPa, 20°C and the exit state is 200 kPa, 18°C. For oxygen $R = 0.2598$ kJ/kg-K and $c_p = 0.918$ kJ/kg-K. The rate at which entropy is generated in the pipe, will be

(A) 0.0768 kW/K (B) 0.1537 kW/K
(C) 0.1282 kW/K (D) 0.1025 kW/K

TD 6.5 What will be the specific entropy generation when air at 1 MPa, 300 K is throttled to 0.5 MPa ?

(A) 0.3 kJ/kg-K (B) 0.1 kJ/kg-K
(C) 0.2 kJ/kg-K (D) 0.4 kJ/kg-K

TD 6.6 In an ideal gas model, nitrogen initially occupies 0.5 m^3 at 1.0 bar, 20°C and undergoes an internally reversible compression to a final state where the temperature is 200°C. During the compression $pv^{1.30} =$ constant. For nitrogen $c_p = 1.039$ kJ/kg-K and $R = 0.297$ kJ/kg-K. What will be the entropy change ?

(A) -0.0683 kJ/K (B) -0.00683 kJ/K
(C) -0.683 kJ/K (D) -6.83 kJ/K

TD 6.7 The exit velocity of a nozzle is 500 m/s. If $\eta_{nozzle} = 0.88$, what will be the ideal exit velocity ?

(A) 533 m/s (B) 266 m/s
(C) 500 m/s (D) 250 m/s

Common Data For Q. 8 and 9

1.2 cm diameter stainless-steel ball bearings are quenched in water at a rate of 1400 per minute. The balls are leaving the oven uniformly at 900°C. They are exposed to air at 30°C for a while prior to quenching and the temperature of the balls drops to 850°C. For stainless-steel use $\rho = 8085\,\text{kg/m}^3$ and $c_p = 0.480\,\text{kJ/kg-°C}$.

TD 6.8 What will be the rate of heat transfer from the balls to the air ?

(A) 4.1 kW (B) 8.2 kW
(C) 10.25 kW (D) 6.15 kW

TD 6.9 What will be the rate of entropy generation due to heat loss from the balls to the air ?

(A) 0.08955 kW/K (B) 0.597 kW/K
(C) 0.00995 kW/K (D) 1.194 kW/K

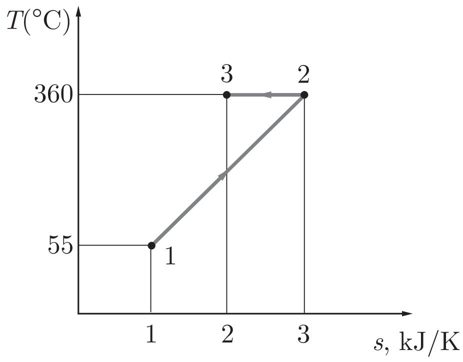
TD 6.10 A refrigerator transfers 1 kJ of heat from a cold region at -20°C to a hot region at 30°C. If the COP of the refrigerator is 4, the total entropy change of the regions will be

(A) 1.73×10^{-2} kJ/K (B) 1.73×10^{-3} kJ/K
(C) 0.1730 kJ/K (D) 1.73×10^{-4} kJ/K

TD 6.11 $1\,\text{m}^3$ of air is initially at 1 bar, 20°C. It undergoes two internally reversibly processes in series as:
Process 1–2; compression to 5 bar, 110°C during which $pv^n = \text{constant}$.
Process 2–3; adiabatic expansion to 1 bar.
What will be the net work ?

(A) 273.92 kJ (B) -153.55 kJ
(C) -33.18 kJ (D) 120.37 kJ

TD 6.12 The total heat transfer for the reversible process 1-3 shown in the figure is to be



(A) 410 kJ (B) 328 kJ
(C) 492 kJ (D) 246 kJ

TD 6.13 In a nozzle, nitrogen gas enters at 500 kPa, 200°C with a velocity of 10 m/s and is expand to produce a velocity of 300 m/s. The expansion is reversible and adiabatic. If the mass flow rate is 0.15 kg/s, the cross-sectional of the nozzle will be

(A) $2.67\,\text{cm}^2$ (B) $1.78\,\text{cm}^2$
(C) $3.12\,\text{cm}^2$ (D) $2.23\,\text{cm}^2$

TD 6.14 In an isentropic turbine with a single inlet and outlet, steam enters at 2 MPa, 360°C and leaves at 100 kPa. The thermodynamic properties of water and steam are given in table. What will be the work produced by this turbine ?

State	h_g (kJ/kg)		s_g (kJ/kg-K)	
Steam: 2 MPa, 360°C	3159.9		6.9938	
Water: 100 kPa	h_f	h_{fg}	s_f	s_{fg}
	417.51	2257.5	1.3028	6.0562

(A) 621.0 kJ/kg (B) 1579.9 kJ/kg
(C) 3159.9 kJ/kg (D) 2538.9 kJ/kg

Common Data For Linked Answer Q.15 and 16

Consider an isolated system which consists of a closed aluminium vessel of 0.1 kg that contains 1 kg of used engine oil and each initially at 55°C. This system is immersed in a 10-kg bath of liquid water which is initially at 20°C. The system is allowed to come to equilibrium.

(Data: $c_{\text{Al}} = 0.9$ kJ/kg-K, $c_{\text{oil}} = 1.91$ kJ/kg-K, $c_w = 4.18$ kJ/kg-K)

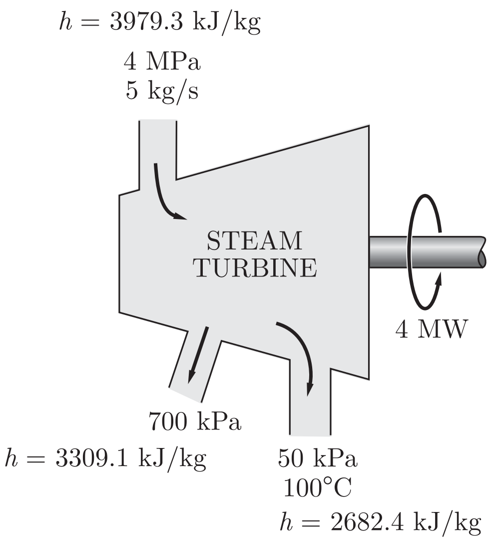
TD 6.15 What will be the final temperature when the system has come to equilibrium ?

(A) 220.9 K (B) 294.6 K
(C) 147.3 K (D) 368.2 K

TD 6.16 The amount of entropy produced will be

(A) -2.051 kJ/K (B) 0.2276 kJ/K
(C) -0.00976 kJ/K (D) 0.01283 kJ/K

TD 6.17 Given figure shows that steam at a rate of 5 kg/s, enters in an isentropic steam turbine at 4 MPa. This steam is exhausted at 50 kPa, 100°C. Five percent of this flow is diverted for feed-water heating at 700 kPa. What will be the power produced by this turbine ?



(A) 4746 kW (B) 1582 kW
(C) 6328 kW (D) 3164 kW

TD 6.18 Air with mass flow rate of 1 kg/s, enters in a reversible steady state device at 400 K, 450 kPa and leaves at 600 K, 100 kPa. Heat of 800 kW is added at 1000 K

, 100 kW is rejected at 350 K and some heat transfer takes place at 500 K. The ideal gas properties of air are given in table below.

Pressure (MPa)	Temperature (°C)	Enthalpy kJ/kg	Entropy kJ/kg-K
0.45	400	401.30	7.5764
0.1	600	607.30	7.1593

What will be the rate of work produced ?

(A) 826.5 kW (B) 495.9 kW

(C) 1157.1 kW (D) 661.2 kW

TD 6.19 An insulated tank contains 120 L of water at 25°C ($\rho = 997$ kg/m^3, $c_p = 4.18$ kJ/kg-°C). A 50 kg copper block ($c_p = 0.386$ kJ/kg-°C) initially at 80°C is dropped into water. The total entropy change for this process will be

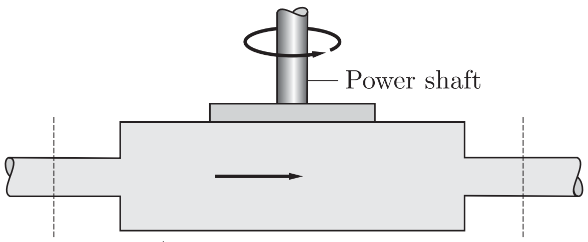
(A) 3.344 kJ/K

(B) 0.204 kJ/K

(C) 3.104 kJ/K

(D) 6.448 kJ/K

TD 6.20 Given figure provides steady-state operating data for a well-insulated device. In which air enters at one location and exits at another with a mass flow rate of 10 kg/s. For ideal gas behavior and negligible potential energy effects, the power will be



(A) 2176 kW (B) 3046.4 kW

(C) 2611.2 kW (D) 1740.8 kW

TD 6.21 Two blocks of iron and copper, both initially at 80°C, are dropped into a large lake at 15°C. The mass of the iron and copper blocks are 50 kg and 20 kg, respectively. After a while the system is in thermal equilibrium due to heat transfer between the blocks and the lake water. What will be the total entropy change for this process ?

(Data: $c_{iron} = 0.45$ kJ/kg-°C, $c_{copper} = 0.386$ kJ/kg-°C)

(A) -4.579 kJ/K (B) -1.571 kJ/K

(C) 0.670 kJ/K (D) 6.820 kJ/K

TD 6.22 A 500-L rigid tank initially contains air at 100 kPa, 15°C. Now air from a line at 12 MPa, 15°C flows into the tank until the pressure inside reaches some value p_2 then the valve is closed. This tank now eventually cools to room temperature and the pressure inside becomes 5 MPa. The process occurs rapidly and is essentially adiabatic. What will be the pressure p_2 ?

(A) 3.14 MPa (B) 6.96 MPa

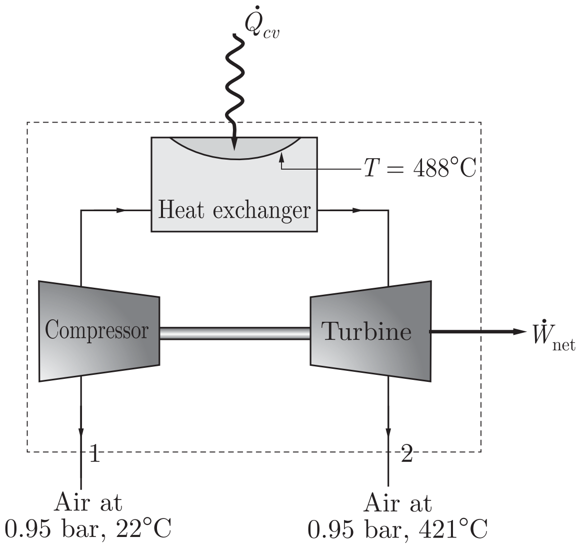
(C) 4.53 MPa (D) 6.61 MPa

TD 6.23 300 L of air initially at 120 kPa, 17°C is heated for 15 min by a 200 W resistance heater in an insulated piston–cylinder device. The pressure of air is maintained constant during this process. What will be the entropy change of air at constant specific heats ?

(A) 0.387 kJ/K (B) 0.484 kJ/K

(C) 0.290 kJ/K (D) 0.678 kJ/K

TD 6.24 Consider a gas turbine power plant that operates at steady state as shown in figure. Air enters the compressor at 3.9 kg/s with $h = 295.17$ kJ/kg, $s = 1.68515$ kJ/kg-K and exits the turbine with $h = 706.8$ kJ/kg, $s = 2.5635$ kJ/kg-K. Heat transfer occurs in heat exchanger at an average temperature of 488°C. The compressor and turbine operate adiabatically. Use the ideal gas model for the air and neglect kinetic and potential effects. What will be the maximum theoretical value for the net power that can be developed by the power plant ?



(A) 1001.5 kW (B) 751.13 kW

(C) 1752.7 kW (D) 1502.25 kW

TD 6.25 An insulated rigid has two equal parts by a partition. Initially, first part contains 5 kmol of an ideal gas at 250 kPa, 40°C and the other part is evacuated. If the partition is removed then the gas fills the entire tank, what will be the total entropy change during this process ?

(A) 14.4 kJ/K (B) 7.20 kJ/K

(C) 21.6 kJ/K (D) 28.81 kJ/K

TD 6.26 In a constant pressure process, 1 kg of air at 300 K is mixed with 1 kg air at 400 K. If the pressure is 100 kPa and $Q = 0$, the entropy generation in the process will be

(A) 0.0414 kJ/K (B) 0.414 kJ/K

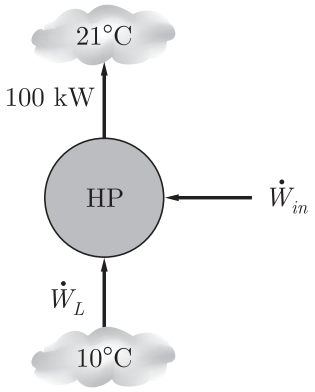
(C) 0.0207 kJ/K (D) 0.207 kJ/K

TD 6.27 In a steady state nozzle, carbon monoxide undergoes a polytropic expansion ($n = 1.2$) from 5 bar, 200°C to 1 bar. Use the ideal gas model and ignore potential energy effects. If carbon monoxide enters in nozzle at 1 m/s, the exit velocity will be

(A) 535.3 m/s (B) 1039.13 m/s

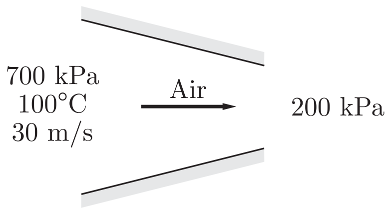
(C) 787.25 m/s (D) 629.78 m/s

TD 6.28 In given figure, a completely reversible heat pump produces heat at a rate of 100 kW to warm a house maintained at 21°C. The exterior air at 10°C serves as the source. What will be the rate of entropy change of everything in this system ?



(A) 0.304 kW/K (B) Zero
(C) −0.304 kW/K (D) 0.608 kW/K

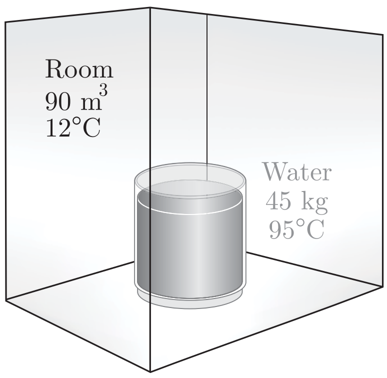
TD 6.29 An adiabatic nozzle during a polytropic process with $n = 1.3$ is shown in figure. The inlet state of air is 700 kPa, 100°C with a velocity of 30 m/s and the exit state is 200 kPa. What will be the air velocity at the nozzle exit ?



(A) 436 m/s (B) 218 m/s
(C) 872 m/s (D) 654 m/s

TD 6.30 A 5 m × 8 m × 0.3 m size concrete slab ($\rho = 2200\ \text{kg/m}^3$, $c_p = 0.88$ kJ/kg-K) is used as a thermal storage mass in a solar-heated house. If the slab cools overnight from 23°C to 18°C in an 18°C house, what will be the net entropy change associated with the process ?
(A) 395.8 kJ/K (B) 795 kJ/K
(C) 399.2 kJ/K (D) 3.4 kJ/K

TD 6.31 In figure shown, a container filled with water is placed in a well sealed and heavily insulated room. Heat transfer takes place between the water and the air in the room until the thermal equilibrium is established. Using constant specific heats, the entropy generation will be



$p = 101.3$ kPa
$c_w = 4.18$ kJ/kg.K
$c_p = 1.005$ kJ/kg.K

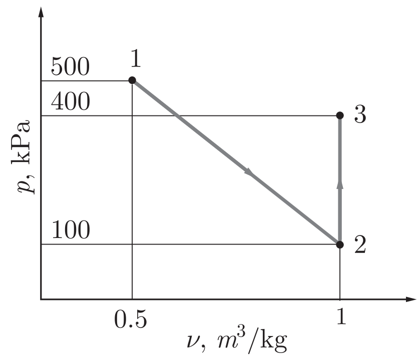
(A) 13.12 kJ/K (B) 1.76 kJ/K
(C) 14.88 kJ/K (D) 28 kJ/K

TD 6.32 A 25 kg foundry form box with sand ($c = 0.8$ kJ/kg-K) at 200°C is dumped into a 50 L water bath ($c = 4.18$ kJ/kg-K, $\nu = 0.001001\ \text{m}^3/\text{kg}$) at 15°C. Assume no heat transfer with the surroundings and no boiling away of liquid water. The net entropy change for the process will be
(A) 2.6 kJ/K (B) 4.3 kJ/K
(C) 3.5 kJ/K (D) 5.1 kJ/K

TD 6.33 In steady-flow compressor, an ideal gas enters at 100 kPa, 27°C. 10 % of the mass that entered the compressor is compressed to 400 kPa and the remaining 90 % is compressed to 600 kPa. The entire compression process is assumed to be reversible and adiabatic. The power supplied to the compressor is 32 kW. If the ideal gas has constant specific heats such that $c_v = 0.8$ kJ/kg-K and $c_p = 1.1$ kJ/kg-K, the mass flow rate of the gas into the compressor will be
(A) 0.158 kg/s (B) 0.103 kg/s
(C) 0.071 kg/s (D) 0.134 kg/s

TD 6.34 2 kg of liquid R-134a is filled in a 5 kg aluminum radiator, both at -10°C. The setup is brought indoors and heated with 220 kJ from heat source at 100°C. Specific heat for R-134a is $c_p = 1.43$ kJ/kg-K and for aluminum is $c_p = 0.90$ kJ/kg-K. What will be the total entropy generation for the process assuming that R-134a remains a liquid ?
(A) 0.253 kJ/K (B) 0.1518 kJ/K
(C) 0.2024 kJ/K (D) 0.1012 kJ/K

TD 6.35 For the reversible steady-flow process 1-3 shown in figure, the work produces will be



(A) 250 kJ/kg (B) 200 kJ/kg
(C) Zero (D) 400 kJ/kg

TD 6.36 Consider air in an 0.2 L internal combustion engine at 7 MPa, 1800 K. It now expands in a reversible polytropic process with exponent, $n = 1.5$, through a volume ratio of 8:1. What will be the work for the process ?
(A) 3.62 kJ (B) 1.81 kJ
(C) 2.72 kJ (D) 3.16 kJ

TD 6.37 A 7 kW pump raises the pressure of water from 120 kPa to 5 MPa. Neglect the kinetic energy change of water and take the specific volume of water to be $0.001\ \text{m}^3/\text{kg}$. If the elevation difference between the exit and the inlet levels is

10 m, the highest mass flow rate of liquid water this pump handle, will be

(A) 1.76 kg/s (B) 1.41 kg/s

(C) 2.12 kg/s (D) 2.46 kg/s

TD 6.38 A room is maintained at a constant temperature of 30°C by running a 2 kW heat pump. If the room loses 10 kW of heat to the colder outside ambient at 10°C, what will be the rate of entropy generated in the heat pump and the rate of entropy generated in the heat loss process, respectively ?

(A) 0.0476 kW/K, 0.0233 kW/K (B) 0.00233 kW/K, 0.00476 kW/K

(C) 0.00473 kW/K, 0.00233 kW/K (D) 0.233 kW/K, 0.476 kW/K

TD 6.39 An adiabatic turbine of 92 % isentropic efficiency expends the steam from 3 MPa, 400°C to 30 kPa. The thermodynamic properties of steam and water are given in table.

State	h_g (kJ/kg)		s_g (kJ/kg-K)	
Steam: 3 MPa, 400°C	3231.7		6.9235	
Water: 30 kPa	h_f	h_{fg}	s_f	s_{fg}
	289.27	2335.3	0.9441	6.8234

What will be the power produced by this turbine when the mass flow rate is 2 kg/s ?

(A) 1236.75 kW (B) 1649 kW

(C) 2061.25 kW (D) 2473.5 kW

Common Data For Linked Answer Q. 40 and 41

Steam at a rate of 80 m/s enters in an adiabatic turbine at 7 MPa, 600°C. It leaves at 50 kPa, 150°C with a rate of 140 m/s. The power output of the turbine is 6 MW. Steam table corresponding to this is given below.

Pressure (MPa)	Temperature (°C)	Enthalpy kJ/kg	Entropy kJ/kg-K
0.05	150	2780.2	7.9413
7	600	3650.6	7.0910

TD 6.40 What will be the mass flow rate of the steam ?

(A) 12.16 kg/s (B) 8.68 kg/s

(C) 6.95 kg/s (D) 10.42 kg/s

TD 6.41 What will be the isentropic efficiency ?

(A) 73.4 % (B) 69.3 %

(C) 83.7 % (D) 91.5 %

TD 6.42 In an adiabatic steady-flow device argon at 200 kPa, 27°C is compressed to 2 MPa. The specific heat ratio of argon is 1.667. If the argon leaves this compressor at 550°C, the isentropic efficiency of the compressor will be

(A) 67.8 % (B) 76.8 %

(C) 78.6 % (D) 86.7 %

Common Data For Linked Answer Q. 43 and 44

In an adiabatic turbine air enters at $550\,\text{kPa}$, $425\,\text{K}$ and leaves at $110\,\text{kPa}$, $325\,\text{K}$. The inlet and exit velocities of the air are $150\,\text{m/s}$ and $50\,\text{m/s}$, respectively. The air properties are $c_p = 1.011\,\text{kJ/kg-K}$ and $R = 0.287\,\text{kJ/kg-K}$. Use $T_0 = 25^\circ\text{C}$.

TD 6.43 What will be the actual work ?

(A) $83.35\,\text{kJ/kg}$ (B) $222.2\,\text{kJ/kg}$

(C) $111.1\,\text{kJ/kg}$ (D) $55.55\,\text{kJ/kg}$

TD 6.44 What will be the reversible work production for this turbine ?

(A) $125.9\,\text{kJ/kg}$ (B) $209.8\,\text{kJ/kg}$

(C) $83.95\,\text{kJ/kg}$ (D) $167.9\,\text{kJ/kg}$

TD 6.45 Air at $300\,\text{kPa}$, 180°C expands adiabatically to $100\,\text{kPa}$ in a nozzle. The inlet velocity of air is low and the nozzle isentropic efficiency is $96\,\%$. The air velocity at the exit will be

(A) $727\,\text{m/s}$ (B) $485\,\text{m/s}$

(C) $848\,\text{m/s}$ (D) $606\,\text{m/s}$

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TD 7

GAS POWER CYCLES

TD 7.1 A Carnot cycle operates between the pressure and temperature limits of 20 kPa to 2000 kPa and 300 K to 900 K, respectively. If cycle executed in a closed system with 0.003 kg of air and specific heats is assumed to be constant, the net work output per cycle will be

(A) 0.589 kJ (B) 0.441 kJ

(C) 0.883 kJ (D) 0.393 kJ

TD 7.2 In an ideal air-standard Brayton cycle, the air ($c_p = 1.005$ kJ/kg-K) enters into the compressor at 100 kPa, 20°C and the pressure ratio across the compressor is 12:1. The flow rate of air is 10 kg/s and the maximum temperature in the cycle is 1100°C. Assume constant specific heat for the air at room temperature. What will be the compressor power input and the turbine power output, respectively ?

(A) 3045 kW, 7015 kW (B) 6546 kW, 3045 kW

(C) 3858 kW, 7015 kW (D) 7015 kW, 3045 kW

TD 7.3 Consider a two-stage air compressor operates at steady state. It compresses 10 m^3/min of air from 100 kPa, 300 K to 1200 kPa. An intercooler between the two stages cools the air to 300 K at a constant pressure of 350 kPa. The compression processes are isentropic. What will be the power required to run the compressor, in kW ?

(A) 25.12 kW (B) 24.62 kW

(C) 28.43 kW (D) 49.75 kW

Common Data For Q. 4 and 5

Consider a gas turbine power plant operates on the simple Brayton cycle between the pressure limits of 100 kPa and 700 kPa. Air enters the compressor at 30°C with a rate of 12.6 kg/s and leaves at 260°C. Now, this air and diesel fuel with an air-fuel ratio of 60 are burned in the combustion chamber with a combustion efficiency of 97%. Diesel has the heating value of 42000 kJ/kg. Combustion gases leave the combustion chamber and enter the turbine whose isentropic efficiency is 85%. Treat the combustion gases as air with $c_p = 1.093$ kJ/kg-K, $c_v = 0.806$ kJ/kg-K and $k = 1.357$.

TD 7.4 What will be the back work ratio ?

(A) 0.581 (B) 0.784

(C) 0.668 (D) 0.901

TD 7.5 What will be the second-law efficiency ?

(A) 26.7% (B) 36.3 %

(C) 73.5% (D) 47.4%

TD 7.6 A Brayton cycle gas-turbine power plant operates between the temperature limits of 300 K and 1600 K and delivers a power output of 100 MW. The compressor pressure ratio is 14 to 1. What will be the thermal efficiency of the cycle ? (Use, $c_{p,\text{air}} = 1.005$ kJ/kg-K)

(A) 46% (B) 63%

(C) 37% (D) 53 %

TD 7.7 An ideal gas mixture with $k = 1.31$ and $R = 0.361$ kJ/kg-K is supplied to a converging nozzle at $p_0 = 5$ bar, $T_0 = 700$ K. This mixture discharges into a region where the pressure is 1 bar. The exit area is 30 cm^2. Assume steady isentropic flow through the nozzle. What will be the exit velocity of the gas and the mass flow rate ?

(A) 535.4 m/s, 1.997 kg/s (B) 535.4 m/s, 0.1997 kg/s

(C) 348.1 m/s, 1.997 kg/s (D) 348.1 m/s, 19.97 kg/s

TD 7.8 In a converging nozzle, air at $p_0 = 1.4$ bar, $T_0 = 280$ K expands isentropically and discharges to the atmosphere at 1 bar. The exit plane area is 0.0013 m^2. If air behaves as an ideal gas, the mass flow rate will be

(A) 40.5 kg/s (B) 0.0405 kg/s

(C) 4.05 kg/s (D) 0.405 kg/s

TD 7.9 A spark-ignition engine working on an ideal Otto cycle, uses 0.043 grams of fuel to produce 1 kJ of work. The fuel produces 42000 kJ/kg of heat. Use constant specific heats for air at room temperature. What will be the required compression ratio ?

(A) 7.52 (B) 4.53

(C) 6.63 (D) 8.78

TD 7.10 A Brayton cycle has a compression ratio of 16:1. This cycle produces 14 MW with an inlet state of 17°C, 100 kPa. If the heat added in the combustion is 960 kJ/kg, the highest temperature and the mass flow rate of air will be

(A) 640.37 K, 26.66 kg/s (B) 1595.6 K, 26.66 kg/s

(C) 1595.6 K, 22.66 kg/s (D) 640.37 K, 22.66 kg/s

TD 7.11 Air at steady state flows through a horizontal, well insulated duct of varying cross-sectional area. The inlet state of air is 15 bar, 340 K with a velocity of 20 m/s. At the exit, the pressure and the temperature are 9 bar and 300 K, respectively. The diameter of the exit is 1 cm. The net force exerted by the air on the duct in the direction of flow, will be

(A) 132.4 N (B) -1006 N

(C) 1067.8 N (D) 1138 N

TD 7.12 Consider a gas turbine engine with regeneration. The engine operates with two stages of compression and two stages of expansion. The air enters each stage of the compressor at 300 K and each stage of the turbine at 1200 K. The pressure ratio across each stage of the compressor and turbine is 3.5 and the compressor and turbine efficiencies are 78 % and 86 %, respectively. The effectiveness of the regenerator is 72 %. Assuming constant specific heats for air at room temperature, what will be the thermal efficiency of the cycle ?

(A) 43.6% (B) 39.2 %

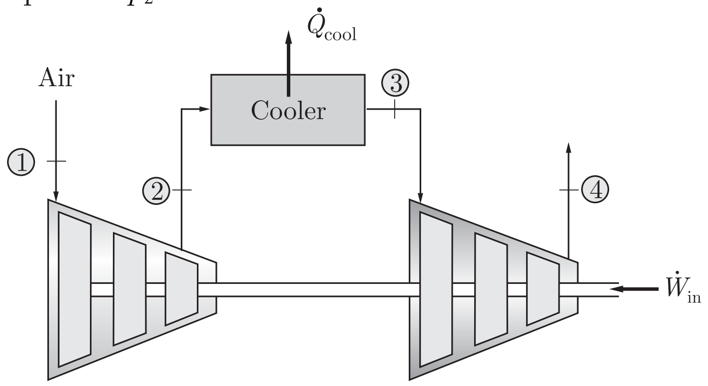
(C) 48.9% (D) 51.7%

TD 7.13 An ideal gas Carnot cycle receives heat at $1027^\circ C$. The cycle is repeated 1500 times per minute and has a compression ratio of 12. Use constant specific heats for air at room temperature. If this device is to produce 500 kW of power, the amount of heat that supplied per cycle must be

(A) 17.46 kJ/cycle (B) 20 kJ/cycle

(C) 31.75 kJ/cycle (D) 12.6 kJ/cycle

TD 7.14 A two-stage air compressor has an intercooler between the two stages as shown in figure. The inlet state is 100 kPa, 290 K and the final exit pressure is 1.6 MPa. Intercooler cools the air at constant pressure to the inlet temperature ($T_3 = T_1$). For minimum total compressor work, the optimal pressure $p_2 = \sqrt{p_1 p_4}$. What will be the specific compressor works and the intercooler heat transfer for the optimal p_2 ?



(A) $w_{C1} = w_{C2} = 141.6$ kJ/kg, $q_{ic} = 283.2$ kJ/kg

(B) $w_{C1} = 283.2$ kJ/kg, $w_{C2} = q_{ic} = 141.6$ kJ/kg

(C) $w_{C1} = w_{C2} = q_{ic} = 141.6$ kJ/kg

(D) $w_{C1} = q_{ic} = 141.6$ kJ/kg, $w_{C2} = 283.2$ kJ/kg

TD 7.15 In an air-standard Otto cycle, the pressure and temperature at the beginning of compression are $p_1 = 100$ kPa and $T_1 = 300$ K, respectively. The cycle has a compression ratio of 8.5 and the heat addition per unit mas of air is 1400 kJ/kg. The ideal-gas properties of air are given in table below.

T, (K)	u, (kJ/kg)	Relative Specific volume ν_r	T, (K)	u, (kJ/kg)	Relative Specific volume ν_r
300	214.07	621.2	1140	880.35	16.946
305	217.67	596.0	1160	897.91	16.064
680	496.62	75.50	2200	1872.4	2.012
690	504.45	72.56	2250	1921.3	1.864

The thermal efficiency of the cycle will be

(A) 74.8% (B) 37.3%

(C) 46.4% (D) 51.5 %

TD 7.16 In an ideal Otto cycle, at the beginning of the compression process $p_1 = 90$ kPa, $T_1 = 27^\circ C$ and $v_1 = 0.004\ m^3$. The maximum cycle temperature is $1127^\circ C$ and the compression ratio is 7. Use constant specific heats for air at room temperature. For each repetition of the cycle, the mean effective pressure for this cycle will be

(A) 177 kPa (B) 354 kPa

(C) 265.5 kPa (D) 442.5 kPa

TD 7.17 An ideal gas-turbine cycle with two stages of compression and two stages of expansion, is also incorporated with an ideal regenerator. The pressure ratio across each compressor stage and each turbine stage is 8 to 1. The pressure at the entrance to the first compressor is 100 kPa. The temperature at the inlet of each compressor is 20°C and at the inlet of each turbine is 1100°C. What will be the thermal efficiency of the cycle ?

(A) 56.7% (B) 49.4%

(C) 61.3 % (D) 45.9%

TD 7.18 In an air-standard diesel cycle, the beginning state of compression is 95 kPa and 300 K. At the end of the heat addition, the pressure is 7.2 MPa and the temperature is 2150 K. The ideal-gas properties of air are given in table below.

T, (K)	Relative Pressure p_r	Relative Specific volume ν_r	T, (K)	Relative Pressure p_r	Relative Specific volume ν_r
300	1.3860	621.2	980	105.2	26.73
960	97.00	28.40	2150	2837	2.175

What will be the compression ratio and the cutoff ratio, respectively ?

(A) 2.32, 21.9 (B) 23.21, 2.19

(C) 15.08, 3.61 (D) 19.72, 4.05

TD 7.19 In a SI-engine operating on the ideal Otto cycle, the minimum enclosed volume is 15% of the maximum enclosed volume. Use constant specific heats for air at room temperature. If this engine produces 90 hp, the rate of heat addition to this engine will be

(A) 126.2 kW (B) 64.1 kW

(C) 169.2 kW (D) 67.1 kW

TD 7.20 In a gasoline engine, the state before compression is 290 K, 90 kPa. It has a volumetric compression ratio of 9 and the peak cycle temperature of 1800 K . Using constant specific heat for air at room temperature, the pressure after expansion will be

(A) 1950.7 kPa (B) 232 kPa

(C) 5027.6 kPa (D) 3076.9 kPa

TD 7.21 In an air-standard diesel cycle, the state of the air at the beginning of compression is fixed by $p_1 = 95$ kPa, $T_1 = 27°$C and $v_1 = 6.0$ liters. Some other useful data are: $u_1 = 214.07$ kJ/kg, $h_2 = 869.63$ kJ/kg, $h_3 = 2280.85$ kJ/kg and $u_4 = 884.96$ kJ/kg. If the cycle is executed 1500 times per minute, the power developed and thermal efficiency of the cycle will be

(A) 153.2 kW, 55.3% (B) 122.5 kW, 52.45 %

(C) 183.7 kW, 52.45% (D) 214.5 kW, 55.3%

TD 7.22 An ideal Diesel cycle produces 200 hp of power. It has a compression ratio of 18 and a cutoff ratio of 1.5. The state of the air at the beginning of the compression is 95 kPa and 17°C. The isentropic compression efficiency is 90 % and the isentropic expansion efficiency is 95 %. Using constant specific heats at room temperature, the rate of heat addition to this cycle will be

(A) 736.1 kW (B) 72.8 kW

(C) 268.2 kW (D) 548.9 kW

TD 7.23 An air-standard Otto cycle has a heat addition of 1800 kJ/kg of air and a compression ratio of 7. The state at the beginning of the compression process is 90 kPa, 10°C. Assuming constant specific heat, the mean effective pressure of the cycle will be

(A) 1257 kPa (B) 439.9 kPa

(C) 1068.5 kPa (D) 817.05 kPa

TD 7.24 An ideal air-standard Brayton cycle has the temperature limits of 300 K and 1500 K. The pressure ratio is that which maximizes the net work developed by the cycle per unit mass of air flow. On a cold air-standard basis the thermal efficiency of the cycle will be

(A) 55.3 % (B) 69.1%

(C) 82.9% (D) 96.7%

TD 7.25 Consider an ideal diesel engine operates with air as working fluid. The state of air at the beginning of the compression process is 95 kPa and 20°C. The engine has a compression ratio of 20. If the maximum temperature in the cycle is not to exceed 1927 °C, what will be the heat rejection during the cycle ?

(A) 630.7 kJ/kg (B) 450.6 kJ/kg

(C) 315.4 kJ/kg (D) 901.2 kJ/kg

TD 7.26 Using cold air-standard analysis, the back work ratio of an ideal air-standard Brayton cycle equals to the ratio of absolute temperatures at the

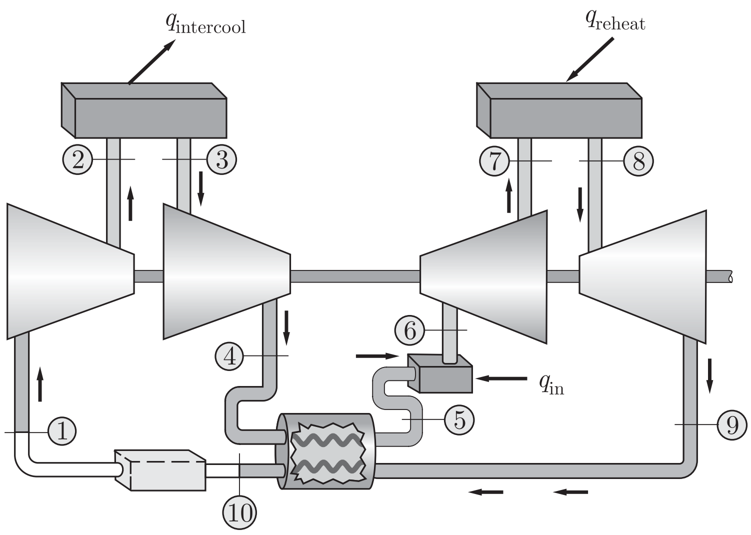
(A) turbine outlet and the compressor inlet.

(B) turbine inlet and the compressor outlet.

(C) compressor inlet and the turbine outlet.

(D) compressor outlet and the turbine inlet.

TD 7.27 A gas turbine system uses a regenerator as well as reheating and intercooling as shown in figure. This system has two stages of compression and two stages of expansion at 100 kPa and 17°C. The pressure ratio across each compressor is 4. In each combustion chamber 300 kJ/kg of heat is added to the air and the regenerator increases the temperature of the cold air by 20°C. Assume isentropic operations for all compressor and the turbine stages and constant specific at room temperature. The thermal efficiency of this system will be



(A) 49.3% (B) 37.8 %

(C) 57.6% (D) 71.7%

TD 7.28 A 2.4 L diesel engine operates on an ideal Diesel cycle has a compression ratio of 17 and a cutoff ratio of 2.2. At the beginning of the compression process air is at 55°C and 97 kPa. Using the cold air standard assumption, how much power the engine will deliver at 1500 rpm ?

(A) 46.6 kW (B) 62.9 kW

(C) 72.2 kW (D) 53.6 kW

TD 7.29 In an ideal Brayton cycle, the compressor inlet temperature is T_1 and the turbine inlet temperature is T_3. Use a cold air standard analysis. For the maximum net work developed per unit mass of air flow, the temperature T_2 at the compressor exit will be

(A) $T_2 = (T_1 T_3)^2$ (B) $T_2 = (T_1 T_3)^{1/2}$

(C) $T_2 = (T_1 T_3)^{1/3}$ (D) $T_2 = (T_1 T_3)^{k/2}$

TD 7.30 Consider a simple ideal Brayton cycle that uses air as working fluid. The cycle operates between the temperature limits of 27°C and 727°C. It has the maximum and minimum cycle pressure of 2000 kPa and 100 kPa, respectively. Use constant specific heats at room temperature. What will be the net work produced per unit mass of air each time this cycle is executed ?

(A) 420.9 kJ/kg (B) 295.4 kJ/kg

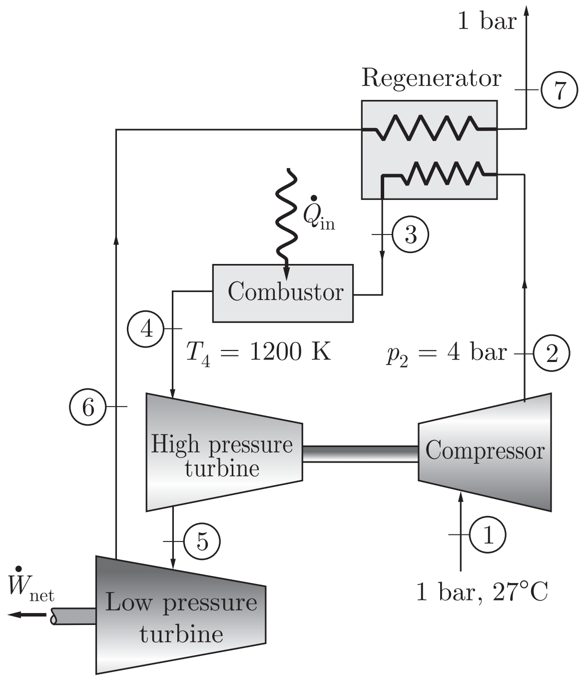
(C) 169.9 kJ/kg (D) 125.5 kJ/kg

TD 7.31 A gasoline engine has a compression ratio of 9:1 by volume and receives air at 10°C, 100 kPa. The maximum temperature of cycle is 2500 K. Use cold air properties. What will be the highest cycle pressure and specific energy added by combustion ?

(A) 7951 kPa, 2024.3 kJ/kg (B) 2167.4 kPa, 1306 kJ/kg

(C) 7951 kPa, 1306 kJ/kg (D) 2167.4 kPa, 2024.3 kJ/kg

TD 7.32 Given figure shows a regenerative gas turbine power plant. Air enters the compressor at 27°C with a mass flow rate of 0.562 kg/s and is compressed from 1 bar to 4 bar. The isentropic efficiency of the compressor and each turbine are 80 % and 87 %, respectively. The regenerator effectiveness is 90 %. All the power developed by the high-pressure turbine used to run the compressor and only the low-pressure turbine provides the net power output. The temperature at the inlet to the high pressure turbine is 1200 K



Data:

$h_1 = 300.19$ kJ/kg
$h_{2s} = 446.49$ kJ/kg
$h_4 = 1277.79$ kJ/kg
$h_{6s} = 896.40$ kJ/kg

What will be the thermal efficiency of the plant ?

(A) 43.25 % (B) 58.38%

(C) 49.73% (D) 67.03%

TD 7.33 Consider an air-standard cycle that is executed in a closed system and is composed of the following four processes:

1-2; Isentropic compression from 100 kPa, 27°C to 1 MPa.

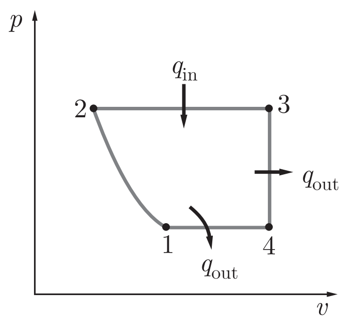
2-3; Constant pressure heat addition in amount of 2800 kJ/kg.

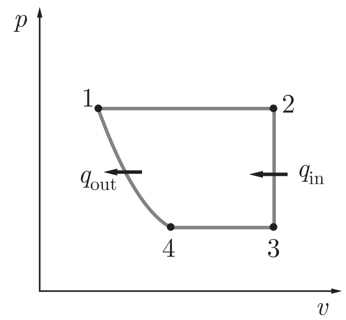
3-4; Constant volume heat rejection to 100 kPa.

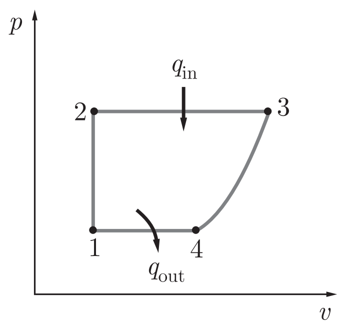
4-1; Constant pressure heat rejection to initial state.

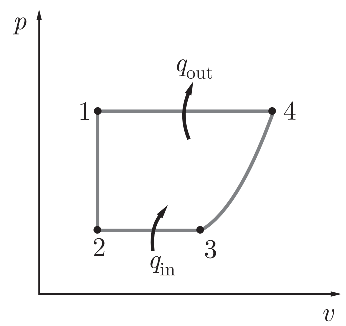
Assume constant specific heats at room temperature.

The $p-v$ diagram of cycle will be,

(A) 

(B) 

(C) 

(D) 

TD 7.34 A diesel engine has a compression ratio of 19 when running at 2000 rpm. It has a bore of 0.1 m and a stroke of 0.11 m. Each cycle takes two revolutions and has a mean effective pressure of 1400 kPa. With a total of 6 cylinders, the engine horsepower, hp will be

(A) 121 (B) 162

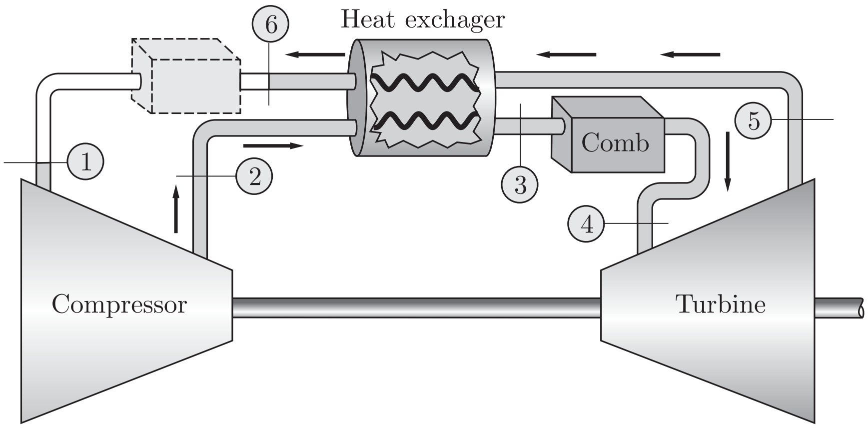
(C) 90 (D) 72

TD 7.35 A simple ideal Brayton cycle has a pressure ratio of 10. The air at the beginning of the compression is at 70 kPa and 0°C. Heat is added to the cycle at a rate of 500 kW and air passes through the engine at a rate of 1 kg/s. Using constant specific heats at room temperature, the power produced by this cycle will be

(A) 255.4 kW (B) 241.2 kW

(C) 752 kW (D) 496.6 kW

TD 7.36 In a gas turbine with a regenerator, air enters the compressor at 100 kPa and 20°C. The compressor pressure ratio is 8 and the maximum cycle temperature is 800°C. Both the compressor and the turbine is to be isentropic. If the cold air stream leaves the regenerator 10°C cooler than the hot air stream at the inlet of the regenerator, what will be the of heat rejection for this cycle when it produces 150 kW ?



(A) 252.4 kW (B) 283.1 kW

(C) 221.8 kW (D) 153 kW

TD 7.37 In a Brayton cycle with regeneration air is used as the working fluid. The cycle has a pressure ratio of 7 and have temperature limits of 310 K and 1150 K . The compressor and the turbine have isentropic efficiencies of 75% and 82% , respectively. Assume an effectiveness of 65% for the regenerator. The ideal-gas properties of air are given in table below.

T, (K)	h, (kJ/kg)	Relative pressure p_r	T, (K)	h, (kJ/kg)	Relative pressure p_r
310	310.24	1.5546	690	702.52	27.29
530	533.98	10.37	700	713.27	28.80
540	544.35	11.10	1150	1219.25	200.15

What will be the thermal efficiency of the cycle ?

(A) 22.5 % (B) 78.5%

(C) 73.5% (D) 70%

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TD 8

VAPOR AND COMBINED POWER CYCLES

Common Data For Q. 1 and 2

Consider a simple ideal Rankine cycle with water as the working fluid. The cycle operates between the pressure of 15 MPa in the boiler and 100 kPa in the condenser. Saturated steam enters the turbine and the steam quality at the outlet of the turbine is 70 percent. The thermodynamic states of water and steam are given in table.

Pressure (kPa)	Temp (°C)	Specific Volume (m^3/kg)		Entholpy (kJ/kg)		Entropy (kJ/kg-K)	
		v_f	v_g	h_f	h_g	s_f	s_g
100	99.61	0.001043	1.6941	417.51	2675	1.3028	7.3589
15000	342.16	0.001657	0.010341	1610.3	2610.8	3.6848	5.3108

TD 8.1 The thermal efficiency of the cycle is

(A) 74.2% (B) 27.4 %

(C) 47.2% (D) 37.1%

TD 8.2 The isentropic efficiency of the turbine is

(A) 87.7 % (B) 57%

(C) 39.5% (D) 74.5%

TD 8.3 In an ideal Rankine cycle, superheated water vapor enters the turbine at 80 bar, 480°C and the condenser pressure is 0.08 bar. The net power output of the cycle is 100 MW. The thermodynamic properties of steam and water are given in table.

State	h_g (kJ/kg)		s_g (kJ/kg-K)		ν_g (m^3/kg)	
Steam at 8 MPa, 480°C	3348.4		6.6586		0.040318	
Water at 8 kPa	h_f	h_{fg}	s_f	s_{fg}	ν_f	ν_g
	173.88	2403.36	0.5908	7.6403	0.0010084	18.325

What will be the rate of heat transfer to the working fluid passing through the steam generator, in MW ?

(A) 163.7 (B) 188.8

(C) 251.8 (D) 239.2

TD 8.4 In a Rankine cycle, the high pressure is determined in

(A) boiler (B) pump

(C) condenser (D) turbine or steam engine

TD 8.5 The thermal efficiency of a combined gas-steam power plant η_{cc}, in terms of the efficiency of gas cycle η_g and the efficiency of steam cycle η_s, can be expressed as

(A) $\eta_{cc} = \eta_g + \eta_s - \eta_g \eta_s$ (B) $\eta_{cc} = \eta_g - \eta_s + \eta_g \eta_s$

(C) $\eta_{cc} = \eta_g + \eta_s - 2\eta_g \eta_s$

(D) $\eta_{cc} = \eta_g + \eta_s - \sqrt{\eta_g \eta_s}$

TD 8.6 A solar energy-powered ideal Rankine cycle uses water as the working fluid. Saturated vapor leaves the solar collector at 892 kPa, 175°C and the condenser pressure is 10 kPa. The thermodynamic states of water and steam are given in the table.

State	h_g (kJ/kg)		s_g (kJ/kg-K)		ν_g (m^3/kg)	
Steam at 892 kPa, 175°C	2773.6		6.6256		0.21680	
Water at 10 kPa	h_f	h_{fg}	s_f	s_{fg}	ν_f	ν_g
	191.81	2392.8	0.6492	7.5010	0.001010	14.674

What will be the thermal efficiency of this cycle ?

(A) 0.261

(B) 0.343

(C) 0.215

(D) 0.469

TD 8.7 In an ideal Rankine cycle, water is used as the working fluid. Saturated vapor enters the turbine at 18 MPa and the condenser pressure is 6 kPa. The thermodynamic properties of steam and water are given in table.

State	h_g (kJ/kg)		s_g (kJ/kg-K)		ν_g (m^3/kg)	
Steam at 18 MPa	2509.1		5.1044		0.007503	
Water at 6 kPa	h_f	h_{fg}	s_f	s_{fg}	ν_f	ν_g
	151.53	2416.62	0.4441	7.9987	0.0010064	24.611

What will be the thermal efficiency ?

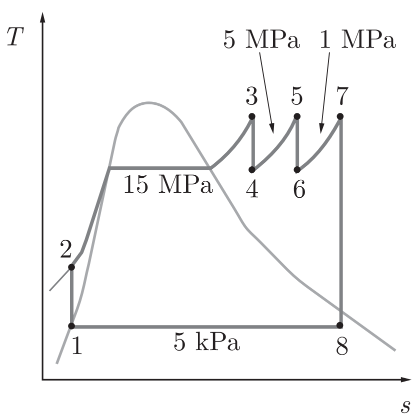
(A) 45.7%

(B) 39.8 %

(C) 49.75%

(D) 41.8%

TD 8.8 A steam power plant operates on an ideal Rankine cycle with two stages of reheat and has a net power output of 120 MW. The cycle on a T-s diagram is as shown in figure. The maximum pressure in the cycle is 15 MPa, and the minimum pressure is 5 kPa. The specific volume of the liquid leaving the condenser is to be 0.001005 m^3/kg. The enthalpies at the various states and quality factor are



$h_1 = h_f = 137.75$ kJ/kg

$h_4 = 3007.4$ kJ/kg

$h_6 = 2971.3$ kJ/kg

$h_{fg} = 2423$ kJ/kg

$h_3 = 3310.8$ kJ/kg

$h_5 = 3434.7$ kJ/kg

$h_7 = 3479.1$ kJ/kg

$x_8 = 0.9204$

The mass flow rate of the steam will be

(A) 96.6 kg/s

(B) 48.3 kg/s

(C) 64.4 kg/s

(D) 80.5 kg/s

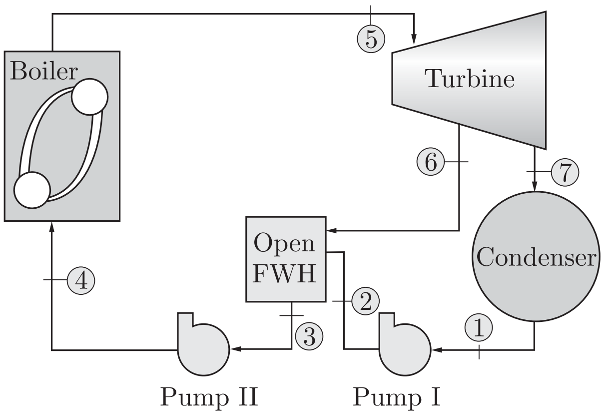
TD 8.9 A smaller power-plant produces 25 kg/s steam at 3 MPa ($h = 3682.34$ kJ/kg) in the boiler. It cools the condenser with ocean water coming in at 12°C and returned at 15°C so the condenser exit is at 9.6 kPa, 45°C ($h = 188.42$ kJ/kg). If the enthalpy of the steam leaving the turbine is 2374.4 kJ/kg and the specific volume of the fluid leaving the condenser is 0.001010 m^3/kg, what will be the net power output and the required mass flow rate of ocean water ($c_p = 4.18$ kJ/kg-K) ?

(A) 54.6 MW, 4358 kg/s
(B) 32.6 MW, 2905 kg/s
(C) 54.6 MW, 2905 kg/s
(D) 32.6 MW, 4358 kg/s

Common Data For Linked Answer Q. 10 and 11

In figure shown, a steam power plant operates on a regenerative Rankine cycle and has a net power output of 150 MW. Steam enters the turbine at 10 MPa ($h = 3375.1$ kJ/kg) and the condenser at 10 kPa ($h_s = 2654.1$ kJ/kg). The isentropic efficiency of the turbine is 80 % and that of the pumps is 95 % percent. Steam is extracted from the turbine at 0.5 MPa ($h_s = 2089.7$ kJ/kg) to heat the feed-water in an open feed-water heater. Water leaves the feed-water heater as a saturated liquid. The thermodynamic states of water are given in the table.

State of water	h, (kJ/kg)		s, (kJ/kg-K)		ν, (m^3/kg)	
	h_f	h_{fg}	s_f	s_{fg}	ν_f	ν_g
10 kPa	191.81	2392.8	0.6492	7.5010	0.001010	14.674
500 kPa	640.21	2108.5	1.8606	4.9606	0.001093	0.3749



TD 8.10 What will be the fraction of steam extracted from the turbine ?

(A) 0.1718
(B) 0.1178
(C) 0.8822
(D) 0.8282

TD 8.11 What will be the mass flow rate of steam through the boiler ?

(A) 103.8 kg/s
(B) 55.9 kg/s
(C) 159.7 kg/s
(D) 183.6 kg/s

TD 8.12 Refrigerant 134a is used as a working fluid in a solar power plant operating on a Rankine cycle. In the cycle, saturated vapor at 60°C ($h = 275.99$ kJ/kg) enters the turbine and the condenser operates at a pressure of 6 bar ($h = 255.54$ kJ/kg). Condensate leaves the condenser with $h = 79.48$ kJ/kg and enters the collector with $h = 80.37$ kJ/kg. The rate of energy input to the collectors from solar radiation is $0.4\,\text{kW/m}^2$ of collector surface area. What will be the minimum possible solar collector surface area in m^2 per kW of power developed by the plant ?

(A) 25 (B) 65

(C) 45 (D) 55

Common Data For Linked Answer Q. 13 and 14

In an ideal Rankine cycle, steam enters the turbine at 30 MPa, 550°C and exits at a pressure of 5 kPa. Then it enters in the condenser and exits as saturated water. Next, a pump feeds back the water to the boiler. The thermodynamic states of water and steam are given in the table.

State	h (kJ/kg)		s (kJ/kg-K)		ν (m^3/kg)	
Steam at 30 MPa, 550°C	3275.4		6.0342		0.010168	
Water at 5 kPa	h_f	h_{fg}	s_f	s_{fg}	ν_f	ν_g
	137.79	2423.7	0.4763	7.9187	0.001005	28.193

TD 8.13 What will be the steam quality at the turbine exit ?

(A) 0.4763 (B) 0.70187

(C) 0.1378 (D) 0.1005

TD 8.14 What will be the thermal efficiency of the cycle ?

(A) 0.63 (B) 0.39

(C) 0.45 (D) 0.56

TD 8.15 The power plant operates on a simple ideal Rankine cycle with turbine inlet conditions of 5 MPa and 450°C and a condenser pressure of 25 kPa. Assume that 75 % percent of this energy is transferred to the steam in the boiler and that the electric generator has an efficiency of 96 %. The thermodynamic states of water and steam are given in the table.

State	h_g (kJ/kg)		s_g (kJ/kg-K)		ν_g (m^3/kg)	
Steam at 5 MPa, 450°C	3317.2		6.8210		0.06330	
Water at 25 kPa	h_f	h_{fg}	s_f	s_{fg}	ν_f	ν_g
	271.96	2345.5	0.8932	6.9370	0.001020	6.204

What will be the overall plant efficiency ?

(A) 63.7% (B) 45.2%

(C) 34.6% (D) 24.5 %

TD 8.16 Consider a simple ideal Rankine cycle. If the condenser pressure is lowered while keeping turbine inlet state the same.

(A) the turbine work output will decrease.

(B) the amount of heat rejected will decrease

(C) the cycle efficiency will decrease

(D) the moisture content at turbine exit will decrease

Common Data For Q. 17 and 18

In a vapor power plant, superheated steam leaves the steam generator at 8 MPa, 480°C ($h = 3348.4$ kJ/kg). The pressure and temperature at the turbine inlet is reduced to 7.6 MPa, 440°C ($h = 3252.3$ kJ/kg) due to heat transfer and frictional effects in the line connecting the steam generator and the turbine. The pressure at the exit of the turbine is 10 kPa ($h_s = 2075.0$ kJ/kg) and the turbine operates adiabatically. Liquid ($\nu = 0.0010063\ \text{m}^3/\text{kg}$) leaves the condenser at 8 kPa, 36°C ($h = 150.86$ kJ/kg). The pressure is increased to 8.6 MPa across the pump. The turbine and pump isentropic efficiencies are 88%. The mass flow rate of steam is 79.53 kg/s.

TD 8.17 What will be the thermal efficiency of the plant ?

(A) 43.5% (B) 46.7%

(C) 32.2 % (D) 49.9%

TD 8.18 What will be the rate of heat transfer from the line connecting the steam generator and the turbine ?

(A) -1910.7 kW (B) -7643 kW

(C) -3821.5 kW (D) -5732.3 kW

TD 8.19 Consider a simple ideal Rankine cycle with fixed boiler and condenser pressures. If the cycle is modified with reheating,

(A) the turbine work output will decrease.

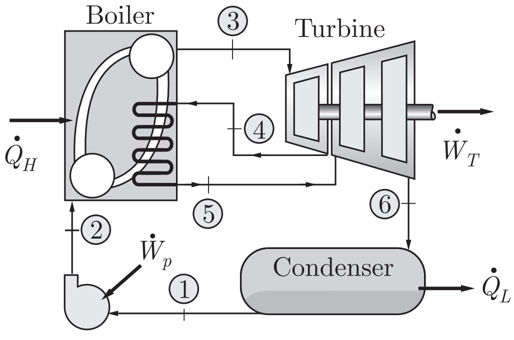
(B) the amount of heat rejected will decrease

(C) the pump work input will decrease

(D) the moisture content at turbine exit will decrease

Common Data For Q. 20 and 21

Consider a steam power plant using a reheat cycle as shown in figure. Steam leaves the boiler and enters the turbine at 3 MPa, 600°C ($h_3 = 3682.34$ kJ/kg). After expansion in the high pressure turbine ($h_4 = 3093.26$ kJ/kg), the steam is reheated to 400°C ($h_5 = 3271.83$ kJ/kg) and then expanded in a low pressure turbine ($h_6 = 2465.1$ kJ/kg). The power plant produces 25 kg/s steam in the boiler. It cools the condenser with ocean water so the condenser exit is at 45°C, 9.6 kPa ($h_1 = 188.42$ kJ/kg).The specific volume of liquid handled by the pump is $\nu_1 = 0.00101\ \text{m}^3/\text{kg}$.



TD 8.20 The net power output is

(A) 34820 kW (B) 8705 kW

(C) 26115 kW (D) 17410 kW

TD 8.21 The total heat transfer in the boiler is

(A) 32108 kW (B) 77976 kW

(C) 55042 kW (D) 91737 kW

TD 8.22 Consider a simple ideal Rankine cycle with fixed boiler and condenser pressures. If the cycle is modified with regeneration that involves one open feed-water heater

(A) the turbine work output will decrease.

(B) the amount of heat rejected will increase

(C) the cycle thermal efficiency will decrease

(D) the quality of steam at turbine exit will decrease

Common Data For Q. 23 and 24

In a regenerative vapor power cycle with one open feed water heater, steam enters the first turbine stage at 12 MPa, 520°C. This steam expands to 1 MPa and some of this steam is extracted and diverted to the open feed water heater operating at 1 MPa. Rest of the steam expands through the second turbine stage to the condenser pressure of 6 kPa. Saturated liquid exits the open feed water heater at 1 MPa. Assume isentropic processes in the turbines and pumps. The thermodynamic properties of steam and water are given in table.

State	h_g (kJ/kg)		s_g (kJ/kg-K)		ν_g (m^3/kg)	
Steam at 12 MPa, 520°C	3401.8		6.5555		0.02503	
Saturated liquid at 6 kPa	h_f	h_{fg}	s_f	s_{fg}	ν_f	ν_g
	151.53	2416.62	0.4441	7.9987	0.0010064	24.611
1 MPa	762.81	2015.3	2.1386	4.4478	0.0011273	0.1944

TD 8.23 What will be the thermal efficiency of the cycle ?

(A) 71.4% (B) 46.1%

(C) 76% (D) 80.6%

TD 8.24 What will be the mass flow rate into the first turbine stage, in kg/h, for a net power out of 330 MW ?

(A) 9.80×10^5 kg/h (B) 272.4 kg/h

(C) 9.80×10^2 kg/h (D) 272.4×10^3 kg/h

TD 8.25 A steam power plant operates on a simple ideal Rankine cycle has a net power output of 45 MW. Steam enters the turbine at 7 MPa, 500°C. This steam is cooled in the condenser at 10 kPa by running cooling water ($c_p = 4.18$ kJ/kg-°C) through the tubes of the condenser at a rate of 2000 kg/s. Assume an isentropic efficiency of 87% for both the turbine and the pump. The thermodynamic properties of water and steam are given in the table.

State	h_g (kJ/kg)		s_g (kJ/kg-K)		ν_g (m^3/kg)	
Steam at 7 MPa, 500°C	3411.4		6.8000		0.04814	
Water at 10 kPa	h_f	h_{fg}	s_f	s_{fg}	ν_f	ν_g
	191.81	2392.8	0.6492	7.5010	0.001010	14.674

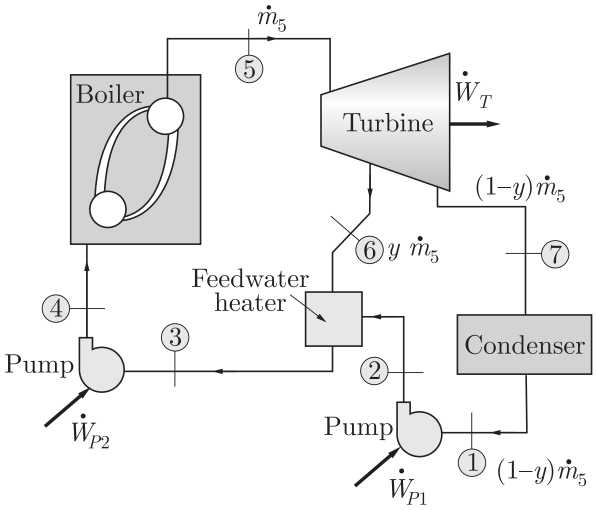
What will be the temperature rise of the cooling water ?

(A) $10.5\,^\circ C$ (B) $21.3\,^\circ C$

(C) $15.6\,^\circ C$ (D) $17.9\,^\circ C$

Common Data For Linked Answer Q. 26 and 27

Consider an ideal regenerative cycle is shown in figure. Steam enters the turbine at $3.0\,MPa$, $400^\circ C$ ($h_5 = 3230.82\,kJ/kg$) and exhausts to the condenser at $10\,kPa$ ($h_7 = 2192.55\,kJ/kg$). Steam is extracted from the turbine at $0.8\,MPa$ ($h_6 = 3682.34\,kJ/kg$) for an open feed-water heater. The feed-water leaves the heater as saturated liquid ($h_3 = 721.1\,kJ/kg$ and $\nu_3 = 0.001115\,m^3/kg$). The specific volume and enthaply of the water leaving the condenser are $\nu_1 = 0.00101\,m^3/kg$ and $h_1 = 191.81\,kJ/kg$, respectively.



TD 8.26 What will be the total pump work per kilogram of steam ?

(A) $2.32\,kJ$ (B) $3.09\,kJ$

(C) $3.86\,kJ$ (D) $4.63\,kJ$

TD 8.27 What will be the thermal efficiency of the cycle ?

(A) 0.483 (B) 0.835

(C) 0.538 (D) 0.358

TD 8.28 In a steam power plant, operates on an ideal reheat Rankine cycle, steam enters the high-pressure turbine at $8\,MPa$, $500^\circ C$ and leaves at $3\,MPa$ ($h = 3105.1\,kJ/kg$). Steam is then reheated at constant pressure to $500^\circ C$ before it expands to $20\,kPa$ in the low-pressure turbine. Consider the data given in table.

State	h_g (kJ/kg)		s_g (kJ/kg-K)		ν_g (m^3/kg)	
Steam at $3\,MPa$, $500^\circ C$	3457.2		7.2359		0.11619	
Steam at $8\,MPa$, $500^\circ C$	3399.5		6.7266		0.04175	
Water at $20\,kPa$	h_f	h_{fg}	s_f	s_{fg}	ν_f	ν_g
	251.42	2357.5	0.8320	7.0752	0.001017	7.6481

What will be the turbine work output, in kJ/kg and the thermal efficiency of the cycle ?

(A) 3492, 38.9% (B) 1358.3, 39.5%

(C) 1366.4, 38.9 % (D) 3492, 39.5%

TD 8.29 A steam power plant operates on an ideal reheat Rankine cycle between the pressure limits of 15 MPa and 10 kPa. Steam enters in high pressure turbine with $h = 3310.8$ kJ/kg and then enters in reheater with $h = 2817.2$ kJ/kg. This reheated steam is now enters in low pressure turbine with $h = 3466.61$ kJ/kg. The properties of the condensed water are $h_f = 191.81$ kJ/kg, $\nu_f = 0.00101\ \text{m}^3/\text{kg}$ and $h_{fg} = 2392.1$ kJ/kg. If mass flow rate of steam through the cycle is 12 kg/s, the total rate of heat input in the boiler will be

(A) 39729 kJ/s (B) 33806 kJ/s

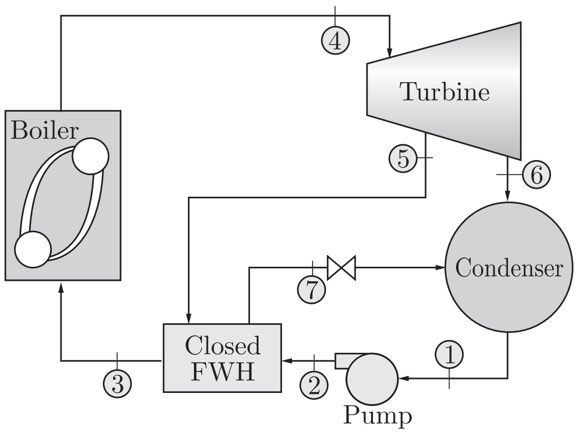
(C) 41599 kJ/s (D) 45039 kJ/s

TD 8.30 Water at 20 kg/s is heated by a closed feed-water heater in a regenerative steam power cycle. The water enters in heater at 100°C, 20 MPa ($h = 434.6$ kJ/kg) and leaves at 250°C, 20 MPa ($h = 1086.75$ kJ/kg). The extraction steam from the turbine enters the heater at 4 MPa, 275°C ($h = 2886.2$ kJ/kg) and leaves as saturated liquid ($h = 1087.31$ kJ/kg). What will be the required mass flow rate of the extraction steam ?

(A) 7.257 kg/s (B) 9.797 kg/s

(C) 4.72 kg/s (D) 13.425 kg/s

TD 8.31 Given figure shows a steam power plant that operates on the ideal regenerative Rankine cycle with a closed feed-water heater. Steam enters in the turbine at 3 MPa, 350°C and the condenser operates at 20 kPa. Steam is extracted at 600 kPa to serve the closed feed-water heater and this steam discharges into the condenser after being throttled to condenser pressure. What will be the thermal efficiency of the cycle ?



$h_1 = 251.42$ kJ/kg
$\nu_1 = 0.001017\ \text{m}^3/\text{kg}$
$h_3 = 671.79$ kJ/kg
$h_4 = 3116.1$ kJ/kg
$h_5 = 2750$ kJ/kg
$h_6 = 2221.7$ kJ/kg
$h_7 = 670.38$ kJ/kg

(A) 46.5% (B) 32.1%

(C) 52.9% (D) 56.2%

TD 8.32 In a regenerative Rankine cycle, cold feed-water enters in a open feed-water heater at 200 kPa, 70°C ($h = 293.07$ kJ/kg) with a rate of 10 kg/s. Bleed steam is available from the turbine at 200 kPa and 160°C ($h = 2789.7$ kJ/kg). At what rate must bleed steam be supplied to the open feed-water heater so the feed-water leaves ($h = 504.71$ kJ/kg) this unit as saturated liquid ?

(A) 1.065 kg/s (B) 0.926 kg/s

(C) 1.345 kg/s (D) 1.528 kg/s

TD 8.33 Consider a simple ideal Rankine cycle that use water as the working fluid and operates between the pressure limits of 3 MPa in the boiler ($h = 3115.5$ kJ/kg) and 30 kPa in the condenser ($h_f = 289.27$ kJ/kg, $h_{fg} = 2335.3$ kJ/kg and

$v = 0.001022\,\text{m}^3/\text{kg}$). If the quality at the exit of the turbine cannot be less than 85 percent, what will be the maximum thermal efficiency of this cycle ?

(A) 40.1% (B) 49.0%

(C) 46.03% (D) 29.7%

TD 8.34 In a closed feed-water heater, water enters in heater at $4\,\text{MPa}$, 200°C ($h = 852.26\,\text{kJ/kg}$) with a rate of $6\,\text{kg/s}$ and leaves the heater at $4\,\text{MPa}$,245°C ($h = 1061.5\,\text{kJ/kg}$). Bleed steam enters this unit at $3\,\text{MPa}$ with a quality of 90 percent and leaves as a saturated liquid with $h_f = 1008.3\,\text{kJ/kg}$ and $h_{fg} = 2623.7\,\text{kJ/kg}$. What will be the rate at which bleed steam is required ?

(A) 1.049 kg/s (B) 0.777 kg/s

(C) 1.204 kg/s (D) 1.437 kg/s

TD 8.35 In a cogeneration plant, steam enters the turbine at $7\,\text{MPa}$, 500°C ($h = 3411.4\,\text{kJ/kg}$). One fourth of the steam is extracted from the turbine at $600\,\text{kPa}$ pressure ($h = 2774.6\,\text{kJ/kg}$) for process heating. The remaining steam continues to expand to $10\,\text{kPa}$ ($h = 2153.6\,\text{kJ/kg}$). The condensed steam from condenser ($h = 191.81\,\text{kJ/kg}$ and $\nu = 0.00101\,\text{m}^3/\text{kg}$) is then mixed with the extracted steam, after the process heating ($h = 670.38\,\text{kJ/kg}$) at constant pressure and the mixture ($\nu = 0.001026\,\text{m}^3/\text{kg}$) is pumped to the boiler pressure of 7 MPa . The mass flow rate of steam through the boiler is $30\,\text{kg/s}$. Disregarding any pressure drops and heat losses in the piping and assuming the turbine and the pump to be isentropic, the utilization factor of the plant will be

(A) 60.3% (B) 52.4 %

(C) 70.7% (D) 81.2%

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TD 9

REFRIGERATION AND AIR CONDITIONING

TD 9.1 In an ideal vapor-compression refrigeration cycle, the refrigerant enters the evaporator at 120 kPa with a quality of 30 percent and leaves the compressor at 60°C. The thermodynamic properties of the refrigerant are given in table. If the compressor consumes 450 W of power, the condenser pressure and the COP of the refrigerator, respectively, are

State	Enthalpy (kJ/kg)		
Superheated refrigerant at 600 kPa, 60°C	299.98		
Superheated refrigerant at 700 kPa, 60°C	298.42		
	h_f	h_{fg}	h_g
Saturated refrigerant at 120 kPa	22.49	214.48	236.97
Saturated refrigerant at 650 kPa	85.26	178.51	263.77
Saturated refrigerant at 700 kPa	88.82	176.21	265.03

(A) 504 kPa, 4.13
(B) 672 kPa, 2.43
(C) 397 kPa, 2.86
(D) 806 kPa, 3.25

TD 9.2 In a heat pump operating on the ideal vapor-compression refrigeration cycle, the condenser operates at 1200 kPa and the evaporator at 280 kPa. The compressor consumes 20 kW. Considering the properties of the working fluid as given in table, what will be the system's COP and the rate of heat supplied to the evaporator ?

Saturated refrigerant at	Enthalpy (kJ/kg)			Entropy (kJ/kg-K)		
	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
280 kPa	50.18	199.54	249.72	0.19829	0.73381	0.93210
1200 kPa	117.77	156.10	273.87	0.42441	0.48863	0.91303

(A) 6.43, 104.58 kW
(B) 4.30, 69.72 kW
(C) 3.75, 61.01 kW
(D) 5.36, 87.15 kW

TD 9.3 Which one of the following is the correct expression of COP for an air standard refrigeration cycle, as function of the compression ratio, r_p ?

(A) $\dfrac{1}{(r_p)^{\frac{k}{(k-1)}} - 1}$
(B) $\dfrac{1}{(r_p)^{\frac{(k-1)}{k}} + 1}$
(C) $\dfrac{1}{(r_p)^{\frac{k}{(k-1)}} + 1}$
(D) $\dfrac{1}{(r_p)^{\frac{(k-1)}{k}} - 1}$

Common Data For Q. 5 and 6

In a Carnot vapor refrigeration cycle refrigerant R-134a is used as the working fluid. The refrigerant enters the condenser as saturated vapor at 28°C and leaves as saturated liquid. The evaporator operates at a temperature of -10°C. The thermodynamic properties of R-134 is given in table.

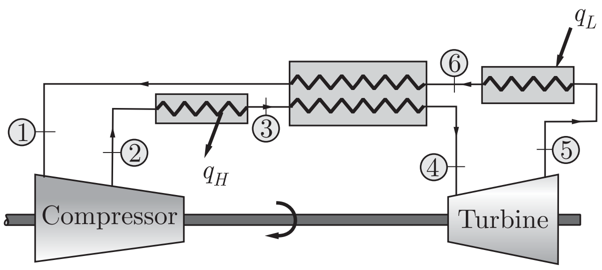
Temperature (°C)	Pressure (kPa)	Enthalpy (kJ/kg)		Entropy (kJ/kg-K)	
		h_f	h_g	s_f	s_g
-10	200.74	38.55	244.51	0.15504	0.93766
28	727.31	90.69	265.68	0.33846	0.91948

TD 9.4 What will be the work input to the compressor and the work developed by the turbine in kJ/kg of refrigerant flow, respectively ?

(A) 25.98, 3.86 (B) 19.50, 2.90

(C) 38.56, 5.79 (D) 32.46, 4.63

TD 9.5 In the figure shown, a heat exchanger is incorporated into an ideal air-standard refrigeration cycle. Both the compression and the expansion are reversible adiabatic processes in this ideal case. What will be the coefficient of performance for the cycle ?



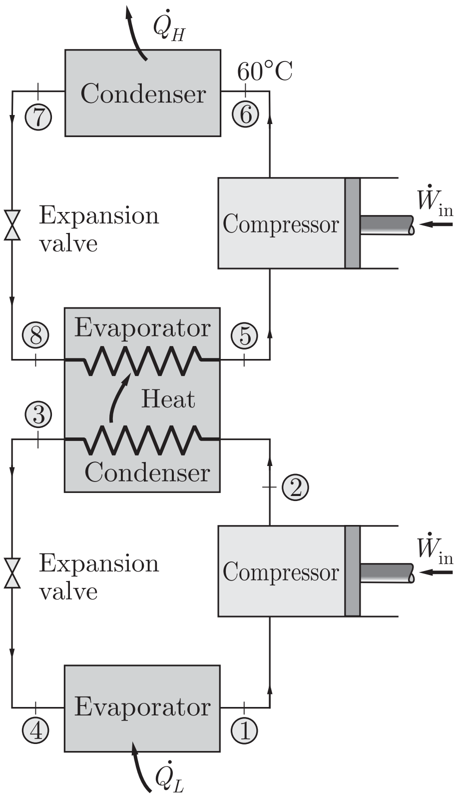
$T_1 = T_3 = 15°C$
$T_4 = T_6 = -50°C$
$p_1 = 100$ kPa
$p_2 = 1.4$ MPa
$k = 1.4$

(A) 0.574 (B) 0.688

(C) 0.774 (D) 0.487

Common Data For Q. 8 and 9

A two-stage cascade refrigeration system operating between the pressure limits of 1.2 MPa and 200 kPa is shown in figure. Heat rejection from the lower cycle to the upper cycle takes place in an adiabatic counterflow heat exchanger. In both cycles, the refrigerant is a saturated liquid at the condenser exit and a saturated vapor at the compressor inlet. The isentropic efficiency of the compressor is 80 percent and the mass flow rate of the refrigerant through the lower cycle is 0.15 kg/s.



$h_1 = 244.46$ kJ/kg

$h_{2s} = 263.30$ kJ/kg

$h_3 = 73.33$ kJ/kg

$h_5 = 255.55$ kJ/kg

$h_{6s} = 278.33$ kJ/kg

$h_7 = 117.77$ kJ/kg

TD 9.6 What will be the mass flow rate of the refrigerant through the upper cycle ?

(A) 0.212 kg/s (B) 0.160 kg/s

(C) 0.347 kg/s (D) 0.276 kg/s

TD 9.7 What will be the COP of this refrigerator ?

(A) 5.12 (B) 3.54

(C) 2.68 (D) 4.18

Common Data For Q. 10 and 11

A commercial refrigerator is used to keep the refrigerated space at -30°C by rejecting its waste heat to cooling water. This cooling water enters the condenser at 18°C ($h_w = 75.47$ kJ/kg) with a rate of 0.25 kg/s and leaves at 26°C ($h_w = 108.94$ kJ/kg). The refrigerant enters the condenser at 1.2 MPa, 65°C ($h = 295.16$ kJ/kg) and leaves at 42°C ($h = 111.23$ kJ/kg). The inlet state of the compressor is 60 kPa, -34°C ($h = 230.03$ kJ/kg) and the compressor is estimated to gain a net heat of 450 W from the surroundings.

TD 9.8 The refrigeration load will be

(A) 9.13 kW (B) 5.85 kW

(C) 4.39 kW (D) 7.31 kW

TD 9.9 What will be the COP of the refrigerator and the theoretical maximum refrigeration load for the same power input to the compressor ?

(A) 4.20, 21.31 kW (B) 3.14, 17.17 kW

(C) 4.89, 26.73 kW (D) 2.33, 12.72 kW

TD 9.10 Ammonia enters in the compressor of a vapor-compression heat pump system at 2.5 bar, -5°C ($h = 1447.10$ kJ/kg) with a volumetric flow rate of 0.6 m^3/min and a specific volume of $0.50180 \text{ m}^3/\text{kg}$. Compression is adiabatic to 14 bar, 140°C ($h = 1752.52 \text{ kJ/kg}$) and saturated liquid exits the condenser at 14 bar ($h = 352.97 \text{ kJ/kg}$). The coefficient of performance of the system will be

(A) 3.43 (B) 4.58

(C) 6.87 (D) 5.50

TD 9.11 Consider 100 m^3 of air-water vapor mixture at 100 kPa, 15°C and 40% relative humidity. If saturation pressure at 15°C is 1.705 kPa, the mass of water vapor and the humidity ratio respectively, are

(Take $R_{vapor} = 0.461 \text{ kJ/kg-K}$, $R_{air} = 0.287 \text{ kJ/kg-K}$)

(A) 0.772 kg, 0.0064 (B) 0.514 kg, 0.0043

(C) 0.385 kg, 0.0032 (D) 0.616 kg, 0.0051

Common Data For Linked Answer Q. 15 and 16

In an ideal gas refrigeration cycle, air enters the compressor at 12°C, 50 kPa and enters the turbine at 47°C, 250 kPa. The mass flow rate of air through the cycle is 0.08 kg/s. Assume variable specific heats for air and consider ideal gas properties of air as given in table.

Temp. (K)	Enthalpy (kJ/kg)	Relative pressure p_r	Temp. (K)	Enthalpy (kJ/kg)	Relative pressure p_r
200	199.97	0.3363	320	320.29	1.7375
210	209.97	0.3987	450	451.80	5.775
285	285.14	1.1584	460	462.02	6.245

TD 9.12 What will be the rate of refrigeration ?

(A) 5.20 kW (B) 8.34 kW

(C) 6.67 kW (D) 11.12 kW

TD 9.13 What will be the net power input and the coefficient of performance ?

(A) 3.35 (B) 2.32

(C) 2.75 (D) 1.72

TD 9.14 Air enters the compressor of an ideal Brayton refrigeration cycle at 100 kPa, 270 K . The temperature at the turbine inlet is 310 K. Considering the air properties given in table, if the compressor pressure ratio is 3, the coefficient of performance will be

Temperature T (K)	Enthalpy h (kJ/kg)	Relative pressure p_r	Temperature T (K)	Enthalpy h (kJ/kg)	Relative pressure p_r
227	226.25	0.5182	310	310.24	1.5546
270	270.11	0.9590	367	370.10	2.877

(A) 2.74 (B) 3.42

(C) 5.75 (D) 4.11

TD 9.15 Consider a gas refrigeration cycle with a pressure ratio of 3 which uses helium as the working fluid. At the compressor inlet the temperature of helium is -10°C and at the turbine inlet is 50°C. The isentropic efficiencies for both the turbine and the compressor are of 80 percent. For a refrigeration rate of 18 kW, the coefficient of performance and the mass flow rate of the helium, respectively, are

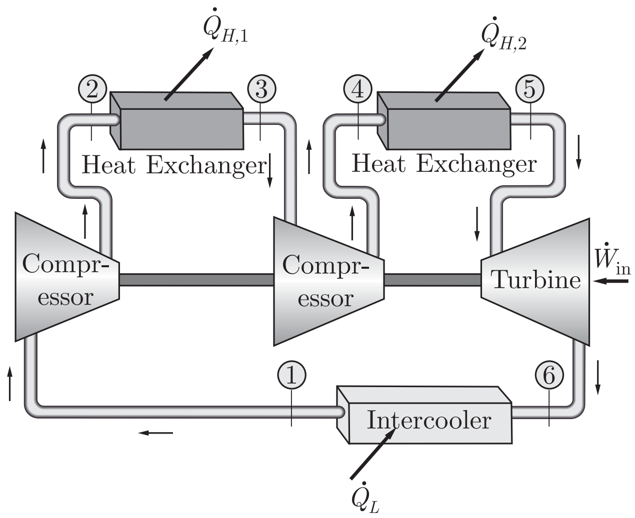
(Take $c_p = 5.1926$ kJ/kg-K and $k = 1.667$)

(A) 0.356, 0.109 kg/s (B) 0.436, 0.141 kg/s

(C) 0.540, 0.251 kg/s (D) 0.250, 0.196 kg/s

TD 9.16 An ideal gas refrigeration system with two stages of compression with intercooling is shown in figure. Air entering the first compressor at 90 kPa and -18°C. Each compression stage has a pressure ratio of 4 and the two intercoolers can cool the air to 10°C. The isentropic efficiencies of each compressor and turbine are 85% and 95%, respectively. This system serves a 75000 kJ/h cooling load. Assuming constant specific heats at room temperature, what will be the coefficient of performance of this system and the rate of air circulation through this system ?

(Use: $c_{p,air} = 1.005$ kJ/kg-K and $k = 1.4$)



(A) 0.415, 0.271 kg/s (B) 0.742, 0.174 kg/s

(C) 0.890, 0.435 kg/s (D) 0.593, 0.140 kg/s

TD 9.17 Saturated moist air (relative humidity 100%) at 100 kPa, 10°C goes through a heat exchanger with a flow rate of 1 kg/s and comes out at 25°C. The saturation pressures at inlet and outlet are 1.2276 kPa and 3.169 kPa, respectively. Also the enthalpies at inlet and outlet are 2519.74 kJ/kg and 2547.17 kJ/kg, respectively. What will be the exit relative humidity and how much power will be needed ?

(A) 54.2%, 21.25 kW (B) 46.4%, 18.21 kW

(C) 38.7%, 15.18 kW (D) 29.1%, 11.38 kW

TD 9.18 Nine canes of water is cooled from 25°C to 3°C in 12 hours by a thermoelectric refrigerator. The refrigerator is powered by a 12 Volts car battery that draws 3 amp. of current when running and the refrigerator resembles a small ice chest. If each the cane has a volume of 0.350 L, the average COP of this refrigerator will be

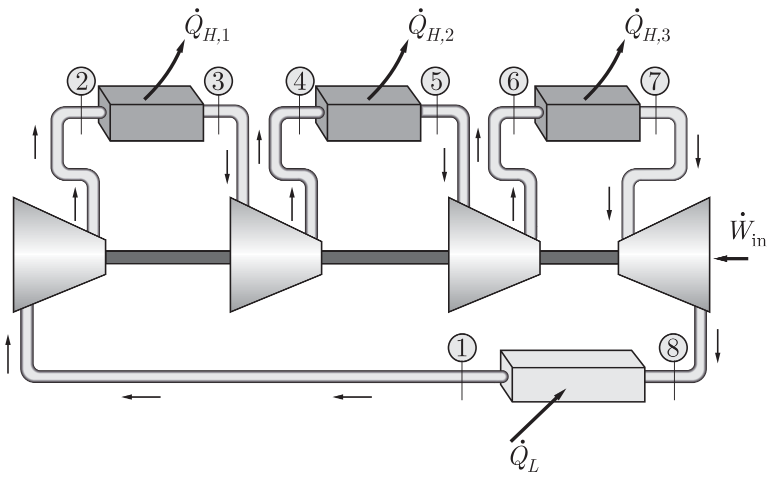
(Take: $\rho = 1$ kg/L and $c_p = 4.18$ kJ/kg-$^\circ$C)

(A) 0.186 (B) 0.465

(C) 0.353 (D) 0.223

TD 9.19 The figure shows an ideal gas refrigeration system with three stages of compression with intercooling. Air enters the first compressor at 80 kPa, -20°C and each compressor in this system has a pressure ratio of 5. The air temperature at the outlet of all intercoolers is 15°C. Using constant specific heats at room temperature, what will be the COP of this system ?

(Take: $c_p = 1.005\,\text{kJ/kg-K}$ and $k = 1.4$)



(A) 0.801
(B) 0.504
(C) 0.673
(D) 0.586

TD 9.20 Air is extracted from the compressor at 2 bar, 380 K. The extracted air enters a heat exchanger where it is cooled at constant pressure to 320 K through heat transfer with the ambient. It then expands adiabatically to 0.95 bar through a turbine and is discharged into the cabin for cooling. The turbine has an isentropic efficiency of 75% and the mass flow rate of the air is 1.0 kg/s. Using the data give in table, the power developed by the turbine and the rate of heat transfer from the air to the ambient, respectively, are

Temperature, T (K)	Enthalpy, h (kJ/kg)	Relative pressure, p_r
258	258.67	0.82531
320	320.29	1.7375
380	380.77	3.176

(A) 32.34 kW, 42.34 kW
(B) 69.3 kW, 90.72 kW
(C) 87.8 kW, 114.9 kW
(D) 46.2 kW, 60.48 kW

TD 9.21 Moist air is passed through a cooling section where it is cooled and dehumidified. How will be the specific humidity and the relative humidity of air change during this process ?

(A) Specific humidity will decrease but relative humidity will increase.
(B) Specific humidity will increase but relative humidity will decrease.
(C) Both specific humidity and relative humidity will decrease.
(D) Both specific humidity and relative humidity will increase.

TD 9.22 How will the humidity ratio and the relative humidity of the air contained in a well-sealed room change as it is heated ?

(A) Humidity ratio will increase but relative humidity will remain constant.
(B) Humidity ratio will remain constant but relative humidity will increase.
(C) Humidity ratio will remain constant but relative humidity will decrease.
(D) Humidity ratio will decrease but relative humidity will remain constant.

TD 9.23 In a combined air cooler and dehumidification unit, outside ambient air enters with 90% relative humidity, 2538.1 kJ/kg of enthaply and 5.628 kPa of saturation pressure. This moist air is first cooled to a low temperature to condense the proper amount of water where the enthalpy is 7.28 kJ/kg. The moist air is then heated and leaves the unit with 30% relative humidity, 2565.3 kJ/kg of enthalpy and 2.339 kPa of saturation pressure at volume flow rate of 0.01 m^3/s. Assume all the liquid leaves at same low temperature. What will be the mass of liquid per kilogram of dry air and the overall heat transfer rate, respectively ?

(A) 0.0835 kg, 3.04 kW (B) 0.0354 kg, 1.27 kW

(C) 0.0288 kg, 1.05 kW (D) 0.0622 kg, 1.78 kW

TD 9.24 How will the specific humidity and the relative humidity of the air contained in a well-sealed room change as it is cooled ?

(A) Humidity ratio will decrease but relative humidity will remain constant.

(B) Humidity ratio will remain constant but relative humidity will decrease.

(C) Humidity ratio will remain constant but relative humidity will increase.

(D) Humidity ratio will increase but relative humidity will remain constant.

TD 9.25 The air has a dry-bulb temperature of 22°C and a wet-bulb temperature of 16°C. The enthalpy of the air at dry-bulb temperature is $h_g = 2541.1$ kJ/kg and at the wet bulb temperature are $h_f = 67.17$ kJ/kg and $h_{fg} = 2463$ kJ/kg. Also the saturation pressure of water at dry-bulb and wet-bulb temperatures are 2.6452 kPa and 1.819 kPa, respectively. Assuming the air pressure of 100 kPa , what will be the specific humidity of kilogram water per kg of dry air and the relative humidity ?

(A) 0.00903, 54.1% (B) 0.01354, 80.1%

(C) 0.01129, 67.6% (D) 0.00506, 30.3%

Common Data For Q. 29 and 30

Air at 35°C, 1 atm and 50% relative humidity enters a dehumidifier operating at steady state. Saturated moist air and condensate stream exit the dehumidifier unit in separate streams, each at 15°C. Neglect the kinetic and potential energy effects and consider the data given in table.

Temperature (°C)	Pressure (bar)	Enthalpy (kJ/kg)	
		h_f	h_g
15	0.01705	62.99	2528.9
35	0.05628	146.68	2565.3

TD 9.26 The amount of water condensed, in kg per kg of dry air, will be

(A) 0.00712 (B) 0.01068

(C) 0.00398 (D) 0.01424

TD 9.27 The heat transfer from the moist air, in kJ per kg of dry air, will be

(A) 57.46 (B) 45.95

(C) 38.31 (D) 28.73

TD 9.28 On the psychrometric chart, a cooling and dehumidification process appears as a line that is

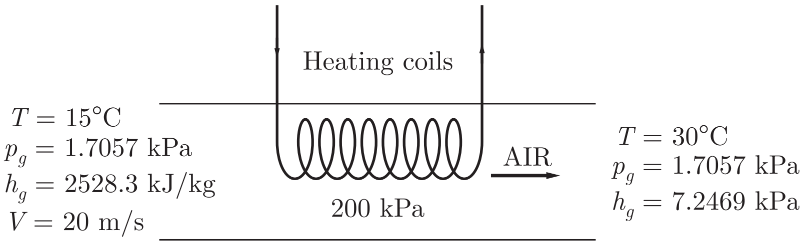
(A) horizontal to the left
(B) vertical downward
(C) diagonal upwards to the right (NE direction)
(D) diagonal downwards to the left (SW direction)

TD 9.29 In an air duct, a flow of moist air at $45^\circ C$ with a flow rate of $0.2\,kg/s$ dry air is mixed with a flow of moist air at $25^\circ C$ and $0.3\,kg/s$ of dry air. The absolute humidities at $45^\circ C$ and $25^\circ C$ are 0.056 and 0.018, respectively. Also the enthalpies at the given temperature are $79\,kJ/kg$ dry air and $90.5\,kJ/kg$ dry air, respectively. If there is no significant heat transfer in the duct and after the mixing there is heat transfer to a final enthalpy of $94\,kJ/kg$ dry air, what will be the enthalpy before mixing and the heat transfer in this process ?

(A) $107.6\,kJ/kg$, $5.20\,kW$
(B) $64.4\,kJ/kg$, $3.04\,kW$
(C) $48.2\,kJ/kg$, $2.26\,kW$
(D) $85.9\,kJ/kg$, $4.05\,kW$

Common Data For Q. 33 and 34

In the given figure, saturated humid air (relative humidity 100%) at $200\,kPa$ and $15^\circ C$ is heated to $30^\circ C$ as it flows through a $4\,cm$ diameter pipe with a velocity of $20\,m/s$. Other useful informations are as shown. Disregard pressure losses.



TD 9.30 What will be the relative humidity at the pipe outlet ?

(A) 31.8%
(B) 40.2%
(C) 54.3%
(D) 48.5%

TD 9.31 What will be the rate of heat transfer to the air ?

(A) 1147 W
(B) 918 W
(C) 592 W
(D) 708 W

Common Data For Q. 35 and 36

Consider a cylinder-piston assembly loaded with a linear spring. It contains saturated moist air at $120\,kPa$, $0.1\,m^3$ volume and also $0.01\,kg$ of liquid water, all at ambient temperature $20^\circ C$. The pressure value for the water vapor corresponding to this stage is $p_v = 2.339\,kPa$. This cylinder is attached by a valve to a line flowing dry air at $800\,kPa$, $80^\circ C$. The valve is opened, and air flows into the cylinder until the pressure reaches $200\,kPa$, at which point the temperature is $40^\circ C$ and pressure for dry air is $p_g = 7.384\,kPa$. The piston area is $0.2\,m^2$ and the spring constant is $20\,kN/m$.

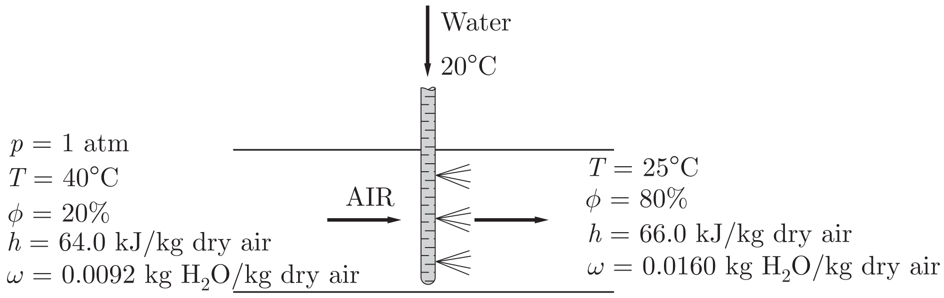
(Take $R_{vapor} = 0.461\,kJ/kg\text{-}K$, $R_{air} = 0.287\,kJ/kg\text{-}K$)

TD 9.32 What will be the relative humidity at the final state ?

(A) 0.705 (B) 0.882
(C) 0.352 (D) 0.529

TD 9.33 The mass of air entering the cylinder and the work done during the process, respectively, are
(A) 0.42 kg, 25.6 kJ (B) 0.53 kg, 32 kJ
(C) 1.05 kg, 64 kJ (D) 0.70 kg, 40.5 kJ

TD 9.34 The outdoor air at 1 atm, 40°C and 20 percent relative humidity is cooled by evaporating water at 20°C into this air as shown in figure. This produces air at 25°C and 80 percent relative humidity. If the enthalpy of water at 20°C is $h = 83.92$ kJ/kg, how much water is required and how much cooling has been produced ?

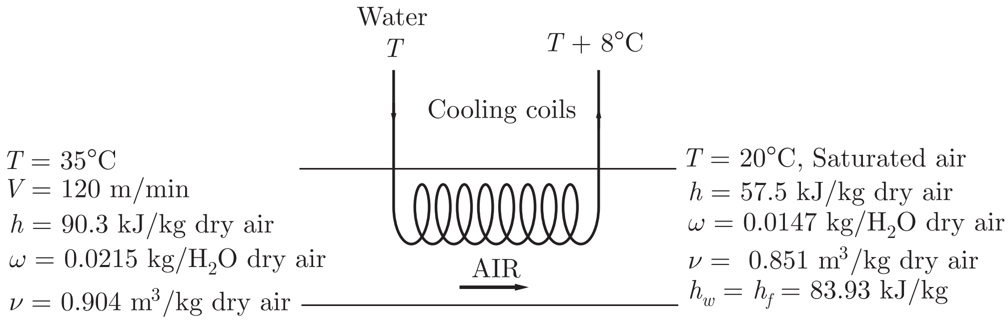


(A) 0.0053 kg/kg dry air, 1.55 kJ/kg dry air
(B) 0.0085 kg/kg dry air, 1.28 kJ/kg dry air
(C) 0.0068 kg/kg dry air, 1.43 kJ/kg dry air
(D) 0.0106 kg/kg dry air, 1.11 kJ/kg dry air

TD 9.35 Consider a tank which contains 21 kg of dry air and 0.3 kg of water vapor at 30°C and 100 kPa total pressure. If the saturation pressure of water at 30°C is 4.2469 kPa, the relative humidity and the volume of the tank will be
(A) 44.7%, 15.9 m^3 (B) 66.2%, 23.4 m^3
(C) 52.9%, 18.7 m^3 (D) 58.2%, 20.6 m^3

Common Data For Linked Answer Q. 40 and 41

Air at 1 atm and 35°C, enters a 30 cm diameter cooling section with a rate of 120 m/ min as shown in figure. The air is cooled by passing it over a cooling coil through which cold water flows. The water experiences a temperature rise of 8°C and the air leaves the cooling section saturated at 20°C.



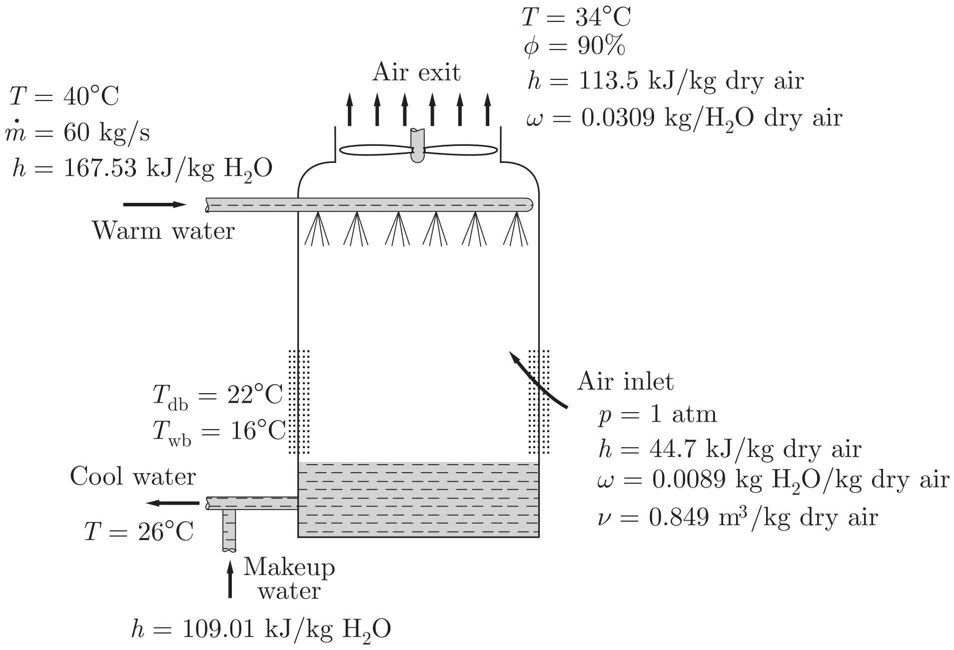
TD 9.36 The rate of heat transfer will be

(A) 235.5 kJ/min (B) 368.8 kJ/min
(C) 302.3 kJ/min (D) 438.4 kJ/min

TD 9.37 What will be the mass flow rate of the water and the exit velocity of the airstream ?

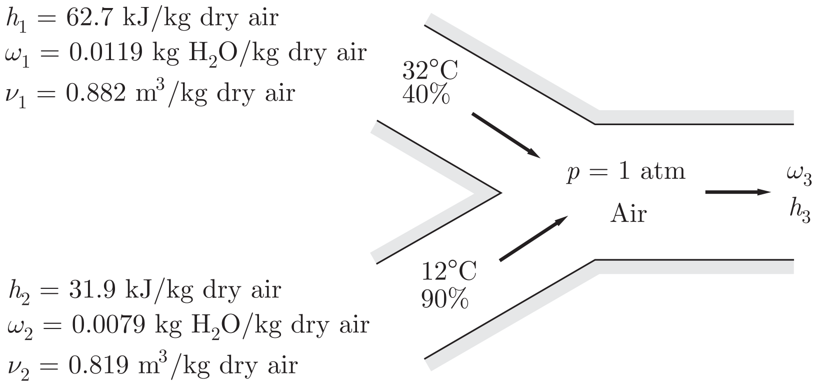
(A) 6.33 kg/min, 79.1 m/min (B) 11.3 kg/min, 141 m/min
(C) 13.1 kg/min, 150.2 m/min (D) 9.04 kg/min, 113 m/min

TD 9.38 A wet cooling tower shown in figure, is to cool 60 kg/s of water from 40°C to 26°C. Atmospheric air enters the tower at 1 atm with dry and wet-bulb temperatures of 22°C and 16°C, respectively. If the air leaves at 34°C with a relative humidity of 90 percent, the volume flow rate of air into the cooling tower and the mass flow rate of the required makeup water will be



(A) 33.6 m^3/s, 0.87 kg/s (B) 53.8 m^3/s, 1.40 kg/s
(C) 65.1 m^3/s, 1.68 kg/s (D) 44.9 m^3/s, 1.16 kg/s

TD 9.39 In the figure shown, the two airstreams are mixed steadily and adiabatically. The first stream enters at 32°C and 40 percent relative humidity at a rate of 20 m^3/min, while the second stream enters at 12°C and 90 percent relative humidity at a rate of 25 m^3/min. If the mixing process occurs at a pressure of 1 atm, the specific humidity and the enthalpy of the mixture are



(A) 0.0144 kg, 68 kJ/kg (B) 0.0096 kg, 45 kJ/kg

(C) 0.0052 kg, 54 kJ/kg (D) 0.0068 kg, 32 kJ/kg

TD 9.40 The dry-bulb, wet-bulb and dew-point temperatures identical at

(A) 50% relative humidity (B) 0% relative humidity

(C) 100% relative humidity (D) Never be identical

TD 9.41 A room contains air at 20°C and 98 kPa at a relative humidity of 85 percent. If the saturation pressure at 20°C is 2.3392 kPa and $h = 2537.4$ kJ/kg, what will be the partial pressure of dry air and the enthalpy per unit mass of dry air ?

(A) 96.01 kPa, 52.83 kJ/kg (B) 124.8 kPa, 68.68 kJ/kg

(C) 76.81 kPa, 42.26 kJ/kg (D) 53.76 kPa, 32.58 kJ/kg

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