

Heat, Mass, and Energy Transfer

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Other Disciplines FE Specifications

Topic: Heat, Mass, and Energy Transfer 9-14 FE exam problems	Exam Problem Numbers
A. Energy, heat, and work	82, 83, 98
B. Thermodynamic laws (e.g., 1 st law, 2 nd law)	82, 93, 98
C. Thermodynamic equilibrium	
D. Thermodynamic properties (e.g., entropy, enthalpy, heat capacity)	92, 98
E. Thermodynamic processes (e.g., isothermal, adiabatic, reversible, irreversible)	83, 92, 93, 94
F. Mixtures of nonreactive gases	

Other Disciplines FE Specifications

Topic: Heat, Mass, and Energy Transfer 9-14 FE exam problems	Exam Problem Numbers
G. Heat transfer (e.g., conduction, convection, and radiation)	95, 100
H. Mass and energy balances	83
I. Property and phase diagrams (e.g., T-s, P-h)	
J. Phase equilibrium and phase change	96
K. Combustion and combustion products (e.g., CO, CO ₂ , NO _x , ash, particulates)	25
L. Psychrometrics (e.g., relative humidity, wet-bulb)	

1. The thermodynamic state of a mixture of saturated liquid and saturated vapor is specified by giving any of the following EXCEPT:

- (A) temperature and quality
- (B) pressure and quality
- (C) specific volume and specific internal energy
- (D) temperature and pressure

Properties for Two-Phase (vapor-liquid) Systems

Quality x (for liquid-vapor systems at saturation) is defined as the mass fraction of the vapor phase:

$$x = m_g / (m_g + m_f), \text{ where}$$

m_g = mass of vapor

m_f = mass of liquid

Specific volume of a two-phase system can be written:

$$v = xv_g + (1 - x)v_f \text{ or } v = v_f + xv_{fg}, \text{ where}$$

v_f = specific volume of saturated liquid

v_g = specific volume of saturated vapor

v_{fg} = specific volume change upon vaporization
 $= v_g - v_f$

x of a saturated liquid = 0
 x of a saturated vapor = 1

2. The change in enthalpy of an ideal gas undergoing a constant volume process is given by

(A) $C_v \Delta T$

(B) $C_p \Delta T$

(C) $R \Delta T$

(D) $P \Delta V$

State Functions (properties)	
Absolute Pressure, P	(lbf/in ² or Pa)
Absolute Temperature, T	(°R or K)
Volume, V	(ft ³ or m ³)
Specific Volume, $v = V/m$	(ft ³ /lbm or m ³ /kg)
Internal Energy, U	(Btu or kJ)
Specific Internal Energy, $u = U/m$	(Btu/lbm or kJ/kg)
Enthalpy, H	(Btu or kJ)
Specific Enthalpy, $h = u + Pv = H/m$	(Btu/lbm or kJ/kg)

For cold air standard, *heat capacities are assumed to be constant at their room temperature values. In that case, the following are true:*

$$\Delta u = c_v \Delta T; \quad \Delta h = c_p \Delta T$$

$$\Delta s = c_p \ln (T_2/T_1) - R \ln (P_2/P_1)$$

$$\Delta s = c_v \ln (T_2/T_1) + R \ln (v_2/v_1)$$

3. An isentropic process is one which is

- (A) only adiabatic
- (B) reversible but not adiabatic
- (C) reversible only
- (D) reversible and adiabatic

Isentropic Process

$$\Delta s = 0; ds = 0$$

A reversible adiabatic process is isentropic.

Turbines, Pumps, Compressors: Often considered adiabatic (no heat transfer). Velocity terms usually can be ignored. There are significant work terms and a single-mass stream.

Reversible means that a process is ideal and therefore has no irreversibilities.

4. Water, initially a saturated vapor at 0.2 MPa, is compressed isentropically to 1 MPa. The temperature at the end of the process is, in °C, most nearly

(A) 180

(B) 300

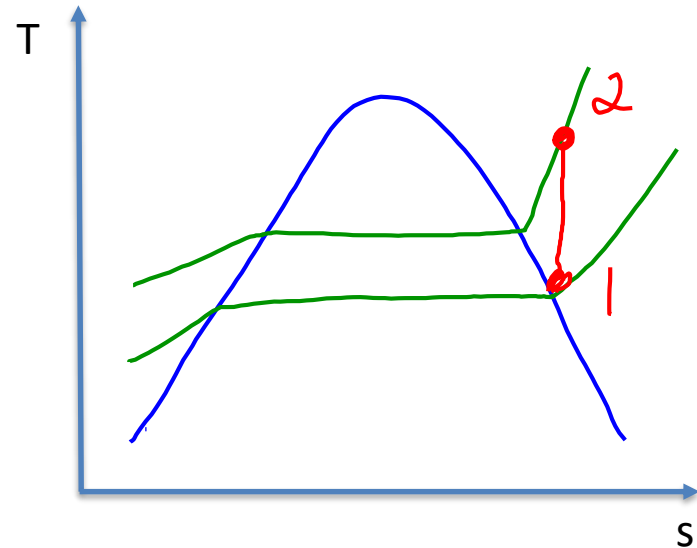
(C) 420

(D) 540

Isentropic Process

$$\Delta s = 0; ds = 0$$

A reversible adiabatic process is isentropic.



4. Water, initially a saturated vapor at 0.2 MPa, is compressed isentropically to 1 MPa. The temperature at the end of the process is, in °C, most nearly

(A) 180

(B) 300

(C) 420

(D) 540

STEAM TABLES												
Saturated Water - Temperature Table												
Temp. °C <i>T</i>	Sat. Press. kPa <i>P_{sat}</i>	Specific Volume m ³ /kg		Internal Energy kJ/kg			Enthalpy kJ/kg			Entropy kJ/(kg·K)		
		Sat. liquid <i>v_f</i>	Sat. vapor <i>v_g</i>	Sat. liquid <i>u_f</i>	Evap. <i>u_{fg}</i>	Sat. vapor <i>u_g</i>	Sat. liquid <i>h_f</i>	Evap. <i>h_{fg}</i>	Sat. vapor <i>h_g</i>	Sat. liquid <i>s_f</i>	Evap. <i>s_g</i>	Sat. vapor <i>s_g</i>
0.01	0.6113	0.001 000	206.14	0.00	2375.3	2375.3	0.01	2501.3	2501.4	0.0000	9.1562	9.1562
5	0.8721	0.001 000	147.12	20.97	2361.3	2382.3	20.98	2489.6	2510.6	0.0761	8.9496	9.0257
10	1.2276	0.001 000	106.38	42.00	2347.2	2389.2	42.01	2477.7	2519.8	0.1510	8.7498	8.9008

At P_1 , $s_g = s_1 \approx 7.1296$ kJ/kgK

$s_1 = s_2$, $P_2 = 1$ MPa

At P_2 , $s_g \approx 6.5857$ kJ/kgK so $s_2 > s_g$.

Therefore, state 2 is a superheated vapor.

Superheated Water Tables								
<i>T</i> Temp. °C	<i>v</i> m ³ /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/(kg·K)				
					<i>p</i> = 0.01 MPa (45.81°C)			
					<i>v</i> m ³ /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/(kg·K)
Sat.	14.674	2437.9	2584.7	8.1502	3.240	2483.9	2645.9	7.5939
50	14.869	2443.9	2592.6	8.1749				
100	17.196	2515.5	2687.5	8.4479	3.418	2511.6	2682.5	7.6947
150	19.512	2587.9	2783.0	8.6882	3.589	2585.6	2780.1	7.9401
200	21.825	2661.3	2879.5	8.9038	4.356	2659.9	2877.7	8.1580
250	24.136	2736.0	2977.3	9.1002	4.820	2735.0	2976.0	8.3556

5. If air is compressed isentropically to twice its original pressure, its absolute temperature increases by a factor of

(A) 2

(B) 1/2

(C) $2^{0.286}$ (D) $2^{3.5}$

Also, for constant entropy processes:

$$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^k; \quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1}, \text{ where } k = c_p/c_v$$

$$\frac{T_2}{T_1} = \left(\frac{2P_1}{P_1}\right)^{\frac{1.4-1}{1.4}} = 2^{0.286}$$

Thermal and Physical Property Tables
(at room temperature)

GASES							
Substance	Mol wt	c_p		c_v		k	R
		kJ/(kg·K)	Btu/(lbm·°R)	kJ/(kg·K)	Btu/(lbm·°R)		kJ/(kg·K)
Gases							
Air	29	1.00	0.240	0.718	0.171	1.40	0.2870

6. The area under the P-v process curve for a closed system represents:

- (A) internal energy change
- (B) enthalpy change
- (C) heat transfer
- (D) work

Reversible boundary work is given by $w_b = \int P dv$.

Special Cases of Closed Systems (with no change in kinetic or potential energy)

Constant System Pressure process (*Charles' Law*):

$$w_b = P\Delta v$$

(ideal gas) $T/v = \text{constant}$

Constant Volume process:

$$w_b = 0$$

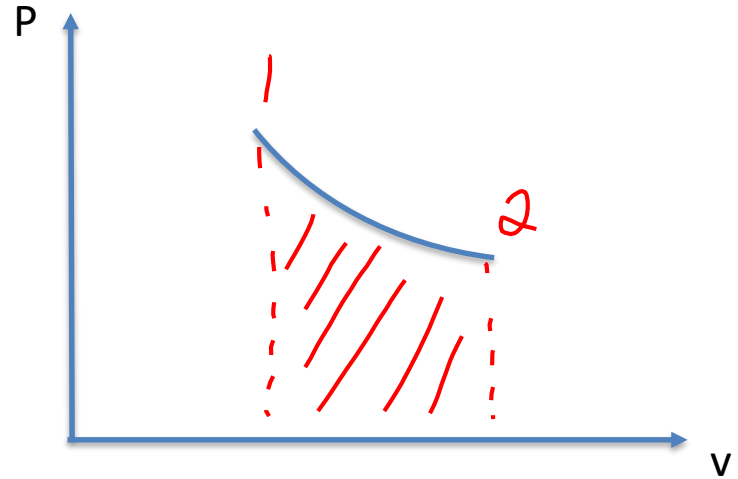
(ideal gas) $T/P = \text{constant}$

Isentropic process (ideal gas):

$$Pv^k = \text{constant}$$

$$w = (P_2v_2 - P_1v_1)/(1 - k)$$

$$= R(T_2 - T_1)/(1 - k)$$



Constant Temperature process (*Boyle's Law*):

(ideal gas) $Pv = \text{constant}$

$$w_b = RT \ln(v_2/v_1) = RT \ln(P_1/P_2)$$

Polytropic process (ideal gas):

$$Pv^n = \text{constant}$$

$$w = (P_2v_2 - P_1v_1)/(1 - n), n \neq 1$$

7. A Carnot engine operates between 35°C and 200°C. If the work output is 1000 kW, the rate of heat rejection, in kW, is most nearly

(A) 670

(B) 1070

(C) 1470

(D) 1870

BASIC CYCLES

Heat engines take in heat Q_H at a high temperature T_H , produce a net amount of work W , and reject heat Q_L at a low temperature T_L . The efficiency η of a heat engine is given by:

$$\eta = W/Q_H = (Q_H - Q_L)/Q_H$$

The most efficient engine possible is the *Carnot Cycle*. Its efficiency is given by:

$$\eta_c = (T_H - T_L)/T_H \text{ where}$$

T_H and T_L = absolute temperatures (Kelvin or Rankine).

$$\eta_{th,Carnot} = 1 - \frac{T_L}{T_H} = 1 - \frac{308K}{473K} = 0.349$$

$$\eta_{th} = \frac{W_{net}}{Q_H} \Rightarrow Q_H = \frac{W_{net}}{\eta_{th}} = 2865 \text{ kW} = Q_{in}$$

$$Q_{net} = W_{net} \text{ for any cycle}$$

$$Q_L = Q_H - W_{net} = 1865 \text{ kW}$$

8. An ideal gas contained in a closed system receives 60 kJ/kg of work and has 60 kJ/kg of heat transfer to surroundings during a process. The gas has constant specific heats: $c_v = 0.6$ kJ/kg·K and $c_p = 1.1$ kJ/kg·K. As a result of the process, the temperature change of the gas, in °C, is most nearly

(A) 0

(B) 100

(C) -100

(D) -55

Closed Thermodynamic System

No mass crosses system boundary

$$Q - W = \Delta U + \Delta KE + \Delta PE$$

where ΔU = change in internal energy ΔKE = change in kinetic energy ΔPE = change in potential energy

For cold air standard, *heat capacities are assumed to be constant at their room temperature values. In that case, the following are true:*

$$\Delta u = c_v \Delta T; \quad \Delta h = c_p \Delta T$$

$$\Delta s = c_p \ln (T_2/T_1) - R \ln (P_2/P_1)$$

$$\Delta s = c_v \ln (T_2/T_1) + R \ln (v_2/v_1)$$

$$q_{net} - w_{net} = \Delta u$$

$$w_{in} - q_{out} = \Delta u = c_v \Delta T$$

$$q_{net} = q_{in} - q_{out}$$

$$w_{net} = w_{out} - w_{in}$$

9. The thermodynamic properties of a compressed liquid at temperature T_o and pressure P_o are nearly equal to the thermodynamic properties of which of the following?

- (A) a saturated liquid at temperature T_o
- (B) a saturated liquid at the critical point
- (C) a saturated liquid at pressure P_o
- (D) a saturated liquid at atmospheric pressure

Methane, CH₄, burns with air according to the reaction equation



10. If the mass flow rate of the methane is 1 kg/s, the mass flow rate of the air supplied in kg/s is most nearly,

- (A) 6 (B) 12 (C) 40 (D) 52

Incomplete Combustion

Some carbon is burned to create carbon monoxide (CO).

Molar Air-Fuel Ratio, $\overline{A/F} = \frac{\text{No. of moles of air}}{\text{No. of moles of fuel}}$

Air-Fuel Ratio, $A/F = \frac{\text{Mass of air}}{\text{Mass of fuel}} = (\overline{A/F}) \left(\frac{M_{\text{air}}}{M_{\text{fuel}}} \right)$

$$AF = \frac{m_a}{m_f} = \frac{6(4.76)(29)}{1(16)} = 51.7$$

Thermal and Physical Property Tables
(at room temperature)

Substance	Mol wt	GASES				k	R
		c _p		c _v			kJ/(kg·K)
		kJ/(kg·K)	Btu/(lbm·R)	kJ/(kg·K)	Btu/(lbm·R)		
Gases							
Air	29	1.00	0.240	0.718	0.171	1.40	0.2870
Argon	40	0.520	0.125	0.312	0.0756	1.67	0.2081
Butane	58	1.72	0.415	1.57	0.381	1.09	0.1430

Methane, CH₄, burns with air according to the reaction equation



11. If the pressure of the products is 100 kPa, the pressure of the water in the product gases, in kPa, is most nearly,

(A) 6.8

(B) 7.3

(C) 25

(D) 100

$$P_v = y_v P_{mix} = \frac{2}{1 + 2 + 4 + 22.56} (100 \text{ kPa}) = 6.77 \text{ kPa}$$

Thermal and Physical Property Tables
(at room temperature)

GASES							
Substance	Mol wt	c _p		c _v		k	R
		kJ/(kg·K)	Btu/(lbm·°R)	kJ/(kg·K)	Btu/(lbm·°R)		kJ/(kg·K)
Gases							
Air	29	1.00	0.240	0.718	0.171	1.40	0.2870

VAPOR-LIQUID EQUILIBRIUM (VLE)

Henry's Law at Constant Temperature

At equilibrium, the partial pressure of a gas is proportional to its concentration in a liquid. Henry's Law is valid for low concentrations; i.e., $x \rightarrow 0$.

$$P_i = P_i^* = h x_i, \text{ where}$$

h = Henry's Law constant

P_i = partial pressure of a gas in contact with a liquid

x_i = mol fraction of the gas in the liquid

y_i = mol fraction of the gas in the vapor

P = total pressure

Raoult's Law for Vapor-Liquid Equilibrium

Valid for concentrations near 1; i.e., $x_i \rightarrow 1$ at low pressure (ideal gas behavior)

$$P_i = x_i P_i^*, \text{ where}$$

P_i = partial pressure of component i

x_i = mol fraction of component i in the liquid

P_i^* = vapor pressure of pure component i at the temperature of the mixture

Methane, CH_4 , burns with air according to the reaction equation



12. If the pressure of the products is sufficient for the pressure of the water in the products to be 20 kPa, the temperature at which the water would begin to condense when the products are cooled at constant pressure is, in $^\circ\text{C}$, most nearly

(A) 45

(B) 60

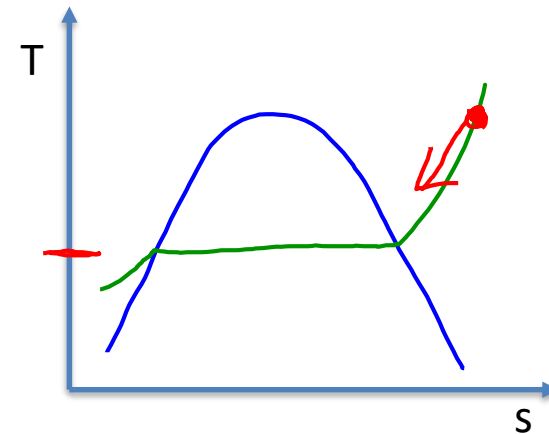
(C) 85

(D) 100

Dew-Point Temperature T_{dp} :

$$T_{dp} = T_{sat} \text{ at } P_g = P_v$$

Wet-bulb temperature T_{wb} is the temperature indicated by a thermometer covered by a wick saturated with liquid water and in contact with moving air.



13. A room contains air at 30°C and a total pressure of 96.0 kPa with a relative humidity of 75 percent. The partial pressure of dry air is

- (A) 82.0 kPa
- (B) 85.8 kPa
- (C) 92.8 kPa
- (D) 90.6 kPa

STEAM TABLES												
Saturated Water - Temperature Table												
Temp. °C <i>T</i>	Sat. Press. kPa <i>P_{sat}</i>	Specific Volume m ³ /kg		Internal Energy kJ/kg			Enthalpy kJ/kg			Entropy kJ/(kg·K)		
		Sat. liquid <i>v_f</i>	Sat. vapor <i>v_g</i>	Sat. liquid <i>u_f</i>	Evap. <i>u_{fg}</i>	Sat. vapor <i>u_g</i>	Sat. liquid <i>h_f</i>	Evap. <i>h_{fg}</i>	Sat. vapor <i>h_g</i>	Sat. liquid <i>s_f</i>	Evap. <i>s_{fg}</i>	Sat. vapor <i>s_g</i>
0.01	0.6113	0.001 000	206.14	0.00	2375.3	2375.3	0.01	2501.3	2501.4	0.0000	9.1562	9.1562
5	0.8721	0.001 000	147.12	20.97	2361.3	2382.3	20.98	2489.6	2510.6	0.0761	8.9496	9.0257
10	1.2276	0.001 000	106.38	42.00	2347.2	2389.2	42.01	2477.7	2519.8	0.1510	8.7498	8.9008

$$P_g \text{ at } T = 4.246 \text{ kPa}$$

$$\Phi = .75 = \frac{P_v}{P_g} \text{ so } P_v = 3.1845 \text{ kPa}$$

$$P_{air} = P - P_v = 96.0 \text{ kPa} - 3.1845 \text{ kPa} = 92.8 \text{ kPa}$$

PSYCHROMETRICS

Properties of an air-water vapor mixture at a fixed pressure are given in graphical form on a psychrometric chart as provided in this section. When the system pressure is 1 atm, an ideal-gas mixture is assumed.

The definitions that follow use subscript *a* for dry air and *v* for water vapor.

P = pressure of the air-water mixture, normally 1 atm

T = dry-bulb temp (air/water mixture temperature)

P_a = partial pressure of dry air

P_v = partial pressure of water vapor

$$P = P_a + P_v$$

Specific Humidity (absolute humidity, humidity ratio) ω :

$$\omega = m_v / m_a \text{ where}$$

m_v = mass of water vapor

m_a = mass of dry air

$$\omega = 0.622 P_v / P_a = 0.622 P_v / (P - P_v)$$

Relative Humidity (rh) ϕ :

$$\phi = P_v / P_g \text{, where}$$

P_g = saturation pressure of water at *T*.

14. An ideal gas mixture whose apparent molar mass is 20 kg/kmol consists of N₂ and three other gases. If the mole fraction of nitrogen is 0.55, its mass fraction is

- (A) 0.23
- (B) 0.39
- (C) 0.55
- (D) 0.77

Mole fraction, $x_i = 0.55$

$$\text{Mass fraction, } y_i = \frac{x_i M_i}{M} = \frac{0.55(28 \text{ kg/kmol})}{(20 \text{ kg/kmol})} = 0.77$$

Thermal and Physical Property Tables
(at room temperature)

GASES							
Substance	Mol wt	c_p		c_v		k	R
		kJ/(kg·K)	Btu/(lbm·°R)	kJ/(kg·K)	Btu/(lbm·°R)		kJ/(kg·K)
Gases							
Air	29	1.00	0.240	0.718	0.171	1.40	0.2870
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Ideal Gas Mixtures

$i = 1, 2, \dots, n$ constituents. Each constituent is an ideal gas.

Mole Fraction:

$$x_i = N_i / N; N = \sum N_i; \sum x_i = 1$$

where N_i = number of moles of component i

N = total moles in the mixture

Mass Fraction: $y_i = m_i / m; m = \sum m_i; \sum y_i = 1$

Molecular Weight: $M = m / N = \sum x_i M_i$

To convert mole fractions x_i to mass fractions y_i :

$$y_i = \frac{x_i M_i}{\sum (x_i M_i)}$$

To convert mass fractions to mole fractions:

$$x_i = \frac{y_i / M_i}{\sum (y_i / M_i)}$$

15. A piston-cylinder device contains an ideal-gas mixture of 3 kmol of He gas and 7 kmol of Ar gas at 50°C and 400 kPa. Now the gas expands at constant pressure until its volume doubles. The amount of heat transfer to the gas mixture is

- (A) 67 MJ
- (B) 4.2 MJ
- (C) 27 MJ
- (D) 10 MJ

Ideal Gas

For an ideal gas, $Pv = RT$ or $PV = mRT$, and $P_1v_1/T_1 = P_2v_2/T_2$, where

Special Cases of Closed Systems (with no change in kinetic or potential energy)

Constant System Pressure process (*Charles' Law*):

$$w_b = P\Delta v$$

(ideal gas) $T/v = \text{constant}$

Thermal and Physical Property Tables
(at room temperature)

GASES							
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$$\left(\frac{PV}{T}\right)_1 = \left(\frac{PV}{T}\right)_2 \text{ so } T_2 = \frac{V_2}{V_1}T_1 = 2T_1 = 646K$$

$$Q_{net} - W_{net} = \Delta U$$

$$Q_{net} = P\Delta V + \Delta U = \Delta H$$

$$Q_{net} = m_{He}c_{p,He}(T_2 - T_1) + m_{Ar}c_{p,Ar}(T_2 - T_1)$$

$$Q_{net} = 3 \text{ kmol} \left(4 \frac{\text{kg}}{\text{kmol}}\right) \left(5.19 \frac{\text{kJ}}{\text{kgK}}\right) (T_2 - T_1) + 7 \text{ kmol} \left(40 \frac{\text{kg}}{\text{kmol}}\right) \left(0.52 \frac{\text{kJ}}{\text{kgK}}\right) (T_2 - T_1)$$

$$Q_{net} = 67000 \text{ kJ}$$

16. Heat is transferred steadily through a 0.2 m thick 8 m x 4 m wall at a rate of 2.4 kW. The inner and outer surface temperatures of the wall are measured to be 15°C and 5°C. The average thermal conductivity of the wall is

(A) 0.002 W/mC

(B) 1.5 W/mC

(C) 0.75 W/mC

(D) 3.0 W/mC

$$Q = \frac{kA}{L} (T_2 - T_1)$$

$$k = \frac{(2.4 \text{ kW})(0.2 \text{ m})}{(8 \text{ m})(4 \text{ m})} \frac{1}{(T_2 - T_1)} = 0.0015 \text{ kW/mC}$$

BASIC HEAT-TRANSFER RATE EQUATIONS**Conduction**

Fourier's Law of Conduction

$$\dot{Q} = -kA \frac{dT}{dx}, \text{ where}$$

 \dot{Q} = rate of heat transfer (W) k = the thermal conductivity [W/(m•K)] A = the surface area perpendicular to direction of heat transfer (m²)

17. A 3 m² hot black surface at 80°C is losing heat to the surrounding air at 25°C by convection with a convection heat transfer coefficient of 12 W/m²C, and by radiation to the surrounding surfaces at 15°C. The total rate of heat loss from the surface is

- (A) 1987 W
- (B) 2239 W
- (C) 2348 W
- (D) 3451 W**

Convection

Newton's Law of Cooling

$$\dot{Q} = hA(T_w - T_\infty), \text{ where}$$

h = the convection heat-transfer coefficient of the fluid
[W/(m²·K)]

A = the convection surface area (m²)

T_w = the wall surface temperature (K)

T_∞ = the bulk fluid temperature (K)

Radiation

The radiation emitted by a body is given by

$$\dot{Q} = \varepsilon\sigma AT^4, \text{ where}$$

ε = the emissivity of the body

σ = the Stefan-Boltzmann constant
= 5.67 × 10⁻⁸ W/(m²·K⁴)

A = the body surface area (m²)

T = the absolute temperature (K)

$$Q = Q_{conv} + Q_{rad}$$

$$Q = hA(T_s - T_{air}) + \varepsilon\sigma A(T_s^4 - T_{surr}^4)$$

$$Q = \left(12 \frac{W}{m^2C}\right) (3 m^2)(80-25) \text{ } ^\circ C + (1) \left(5.67 \times 10^{-8} \frac{W}{m^2K^4}\right) (3 m^2)(353^4 - 288^4) K$$

$$Q = 3451 W$$

18. Which of the following is not an intensive property?

- (A) temperature
- (C) density

- (B) age
- (D) weight

PROPERTIES OF SINGLE-COMPONENT SYSTEMS

Nomenclature

1. Intensive properties are independent of mass.
2. Extensive properties are proportional to mass.
3. Specific properties are lowercase (extensive/mass).

19. A closed system undergoes a reversible process, does work equal to 50 kJ/kg, and has an internal energy decrease of 50 kJ/kg. This is a process in which the

- (A) volume is constant
- (B) pressure is constant
- (C) entropy is constant
- (D) information is insufficient to determine the process

Closed Thermodynamic System

No mass crosses system boundary

$$Q - W = \Delta U + \Delta KE + \Delta PE$$

where ΔU = change in internal energy

ΔKE = change in kinetic energy

ΔPE = change in potential energy

$$Q_{net} - W_{net} = \Delta U$$
$$q_{net} = 50 \text{ kJ/kg} - 50 \text{ kJ/kg} = 0$$

Isentropic Process

$$\Delta s = 0; ds = 0$$

A reversible adiabatic process is isentropic.

20. The thermodynamic state of a system is specified by giving

- (A) any one extensive property
- (B) any two independent extensive properties
- (C) any one intensive property
- (D) any two independent intensive properties

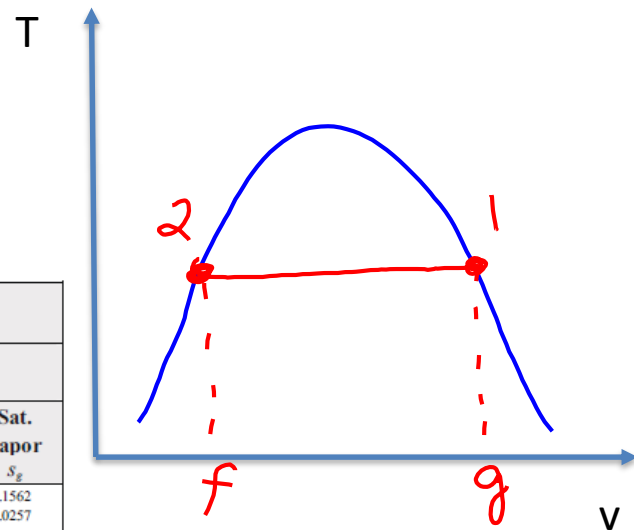
For a single-phase pure component, specification of any two intensive, independent properties is sufficient to fix all the rest.

21. Water is contained in a piston-cylinder device at a temperature of 95°C. The water is cooled at constant pressure from a saturated vapor to a saturated liquid. The heat transfer for this process is, kJ/kg, most nearly

- (A) -2270 (B) -2100 (C) 2100 (D) 2270

$$q_{net} - w_{net} = \Delta u$$

$$q_{net} = P\Delta v + \Delta u = \Delta h = h_{fg}$$



STEAM TABLES
Saturated Water - Temperature Table

Temp. °C <i>T</i>	Sat. Press. kPa <i>P_{sat}</i>	Specific Volume m ³ /kg		Internal Energy kJ/kg			Enthalpy kJ/kg			Entropy kJ/(kg·K)		
		Sat. liquid <i>v_f</i>	Sat. vapor <i>v_g</i>	Sat. liquid <i>u_f</i>	Evap. <i>u_{fg}</i>	Sat. vapor <i>u_g</i>	Sat. liquid <i>h_f</i>	Evap. <i>h_{fg}</i>	Sat. vapor <i>h_g</i>	Sat. liquid <i>s_f</i>	Evap. <i>s_{fg}</i>	Sat. vapor <i>s_g</i>
0.01	0.6113	0.001 000	206.14	0.00	2375.3	2375.3	0.01	2501.3	2501.4	0.0000	9.1562	9.1562
5	0.8721	0.001 000	147.12	20.97	2361.3	2382.3	20.98	2489.6	2510.6	0.0761	8.9496	9.0257
10	1.2276	0.001 000	106.38	42.00	2347.2	2389.2	42.01	2477.7	2519.8	0.1510	8.7498	8.9008

22. The heat added to a vessel containing an ideal gas during an isothermal process is equal to

- (A) internal energy change
- (B) enthalpy change
- (C) work
- (D) entropy change

For cold air standard, *heat capacities are assumed to be constant* at their room temperature values. In that case, the following are true:

$$\Delta u = c_v \Delta T; \quad \Delta h = c_p \Delta T$$

$$\Delta s = c_p \ln (T_2/T_1) - R \ln (P_2/P_1)$$

$$\Delta s = c_v \ln (T_2/T_1) + R \ln (v_2/v_1)$$

$$q_{net} - w_{net} = \Delta u = c_v \Delta T = 0$$

23. The heat added to a vessel containing an ideal gas during a constant volume process is equal to

- (A) internal energy change
- (B) enthalpy change
- (C) work
- (D) entropy change

Constant Volume process:
 $w_b = 0$
(ideal gas) $T/P = \text{constant}$

$$q_{net} - w_{net} = \Delta u$$
$$q_{net} = \Delta u$$

24. In a steady flow process, the work done plus the heat lost by an engine, per kilogram of substance flowing through it, when the kinetic and potential energies of the flow are neglected must equal the drop in _____ of the substance.

(A) temperature

(B) internal energy

(C) enthalpy

(D) pressure

$$E_{in} = E_{out}$$

$$m_{in} = m_{out}$$

$$m_{in}h_{in} = W_{out} + Q_{out} + m_{out}h_{out}$$

Steady-Flow Systems

The system does not change state with time. This assumption is valid for steady operation of turbines, pumps, compressors, throttling valves, nozzles, and heat exchangers, including boilers and condensers.

$$\sum \dot{m}_i (h_i + V_i^2/2 + gZ_i) - \sum \dot{m}_e (h_e + V_e^2/2 + gZ_e) + \dot{Q}_{in} - \dot{W}_{out} = 0$$

and

$$\sum \dot{m}_i = \sum \dot{m}_e$$

where

\dot{m} = mass flowrate (subscripts i and e refer to inlet and exit states of system)

g = acceleration of gravity

Z = elevation

V = velocity

\dot{Q}_{in} = the net rate of heat transfer into the system

\dot{W}_{out} = the net rate of work out of the system