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Thermodynamics

الديناميكا الحرارية

اعداد الدكتور
علي شاكر باقر الجابري

Thermodynamics الديناميكا الحرارية

CHAPTER TWO Properties of Pure Substances

Work and heat are energy transfers between a control volume and its surroundings. Work is energy that can be transferred mechanically (or electrically, or chemically) from one system to another and must cross the control surface either as a transient phenomenon or as a steady rate of work, which is power. Work is a function of the process path as well as the beginning state and end state. The displacement work is equal to the area below the process curve drawn in a P–V diagram if we have an equilibrium process. A number of ordinary processes can be expressed as polytropic processes having a particular simple mathematical form for the P–V relation. Work involved by the action of surface tension, single-point forces, or electrical systems should be recognized and treated separately. Any nonequilibrium processes (say, dynamic forces, which are important due to accelerations) should be identified so that only equilibrium force or pressure is used to evaluate the work term.

Heat transfer is energy transferred due to a temperature difference, and the conduction, convection, and radiation modes are discussed.

You should have learned a number of skills and acquired abilities from studying this chapter that will allow you to

- Recognize force and displacement in a system.
- Know power as rate of work (force × velocity, torque × angular velocity)
- Know work is a function of the end states and the path followed in process
- Calculate the work term knowing the P–V or the F–x relationship
- Evaluate the work involved in a polytropic process between two states
- Know work is the area under the process curve in a P–V diagram
- Apply a force balance on a mass and determine work in a process from it
- Distinguish between an equilibrium process and a nonequilibrium process
- Recognize the three modes of heat transfer: conduction, convection and radiation
- Be familiar with Fourier's law of conduction and its use in simple applications
- Know the simple models for convection and radiation heat transfer
- Understand the difference between the rates ($\dot{W}$, $\dot{Q}$) and the amounts (${}_1W_2$, ${}_1Q_2$).

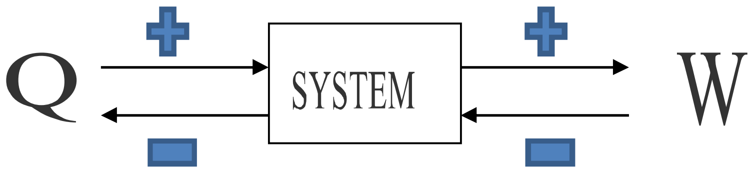
In this chapter we will discuss the two quantities that result from energy transfer across the boundary of a system: work and heat. This will lead into the first law of thermodynamics. Work will be calculated for several common situations. Heat transfer, often simply called “heat,” however, is a quantity that requires substantial analysis for its calculation. Heat transferred by conduction, convection, or radiation to systems or control volumes will either be given or information will be provided that it can be determined in our study of thermodynamics; it will not be calculated from temperature information, as is done in a heat transfer course.

Work, like heat, is an energy interaction between a system and its surroundings. Therefore if the crossing the boundary of a closed system is not heat, it must be work.

Work is also a form of energy has energy units such as kJ. The work done during a process between states 1and 2 is denoted W12 or W. the work per unit mass of a system is denoted w and is defined as

$$w = \frac{W}{m} kJ / kg$$

the work done per unit time is called power and is denoted . The unit of the power is kJ/sec or kW. Work done by a system is positive, and work done on the system is negative, Figure below(3.1)



$$W = \int_{V_1}^{V_2} p\, dV$$

3.2 Work Due to a Moving Boundary

There are a number of work modes that occur in various engineering situations. These include the work needed to stretch a wire, to rotate a shaft, to move against friction, or to cause a current to flow through a resistor. We are primarily concerned with the work required to move a boundary against a pressure force.

Consider the piston-cylinder arrangement shown in Fig. 3.3. There is a seal to contain the gas in the cylinder, the pressure is uniform throughout the cylinder, and there are no gravity, magnetic, or electrical effects. This assures us of a quasiequilibrium process, one in which the gas is assumed to pass through a series of equilibrium states. Now, allow an expansion of the gas to occur by moving the piston upward a small distance *dl.* The total force acting on the piston is the pressure times the area of the piston. This pressure is expressed as *absolute* pressure since pressure is a result of molecular activity; any molecular activity will yield a pressure that will result in work being done when the boundary moves.

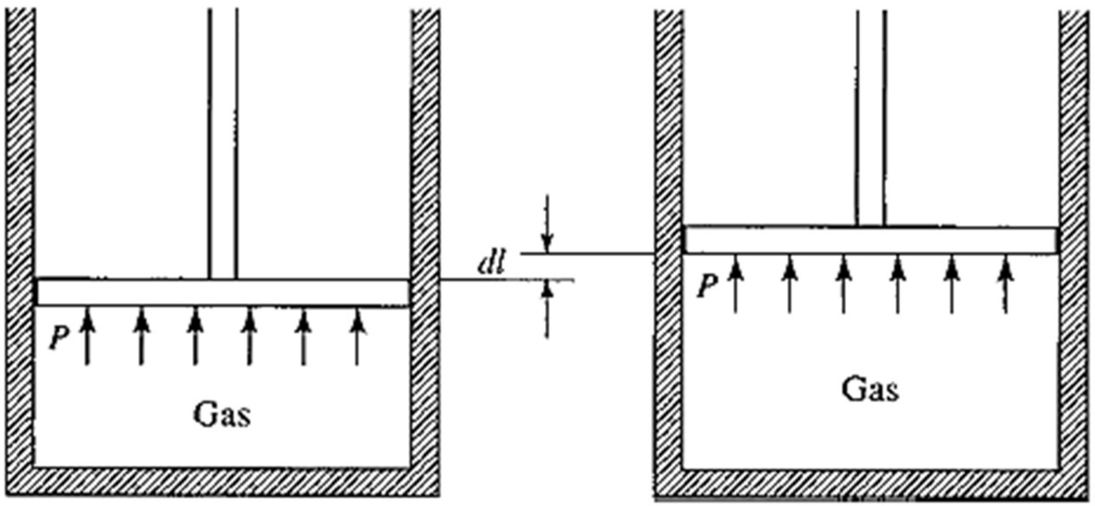


Figure 3.3 Work due to a moving boundary.

The infinitesimal work that the system (the gas) does on the surroundings (the piston) is then the force multiplied by the distance:

$$\delta W = PAdl$$

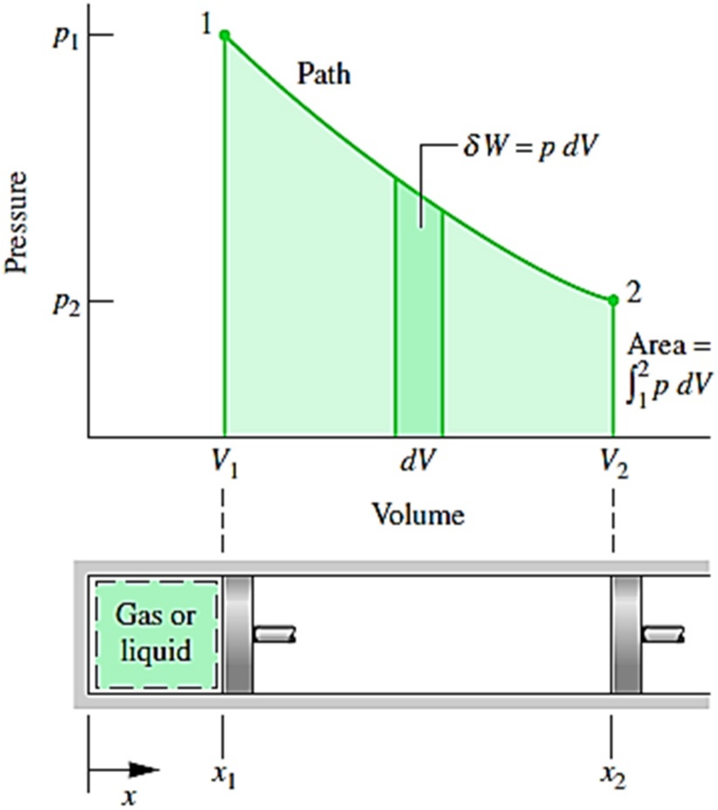
The symbol δ *W* will be discussed shortly. The quantity *Adl* is simply *dV,* the differential volume, allowing Eq. (3.2) to be written in the form

$$\delta W = PdV$$

As the piston moves from some position 1 to another position 2, the above expression can be integrated to give

$$W_{1\text{-}2} = \int_{V_1}^{V_2} PdV$$

where we assume the pressure is known for each position as the piston moves from volume *V*1 to volume *V*2*.* Typical pressure-volume diagrams are shown in Fig. The work *W*1-2 is the area under the *P-V* curve.



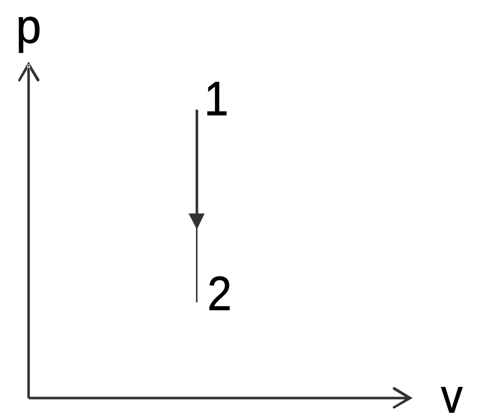
The gas can follow several different paths as it expands from state 1 to state 2. these paths represent a different processes as follows

A- Constant volume process

$$V = Const.$$

$$dV = 0$$

$$W = \int_1^2 PdV = 0$$



Example 3.1

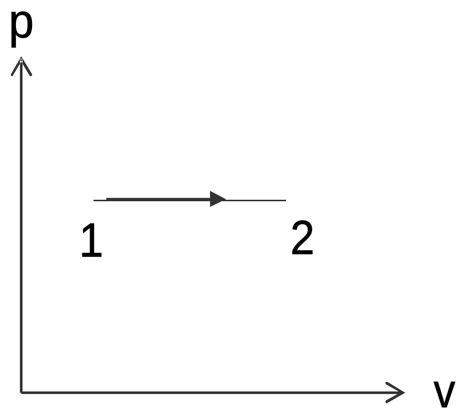
A rigid tank contains air at 500kPa and 150ºC. As a result of the surrounding, the temperature and pressure in side the tank drop to 65ºC and 400kPa, respectively. Determine the work done during this process.

<u>Solution</u>: Given T_1=150ºC and P_1=500 T_2=65ºC and P_2=400kPa

with no change in volume because the tank is rigid.

<u>V=constant and dv=0 and so W=0</u>

B- Constant Pressure Process



$$P = const.$$
$$P = P_1 = P_2$$
$$W = \int_1^2 PdV = P(V_2 - V_1)$$

for process the work of ideal gas is

$$W = P(V_2 - V_1)$$
$$W = MR(T_2 - T_1)$$

and for vapor

$$W = mP(v_2 - v_1)$$

Example 3.2

Five kilograms of saturated vapor water at 1Mpa is contained in a cylinder fitted with a movable piston. This system is now heated at constant pressure until the temperature of the steam is 300°C. Calculate the work done by the steam during the process.

Solution: Given sat vapor water

m=5kg $P_1=P_2=1MPa$

$T_2=300°C$

From the saturated water table

$$v_1 = v_{g_{at\,1MPa}} = 0.19444 m^3/kg$$
$$T_{sat} = 179.91°C$$

The second state is a super-heated vapor because $T_2 > T_{sat}$

$$v_2 = v_{at\ 1MPa\ 300°C} = 0.2579 m^3/kg$$

The process is constant pressure expansion

$$W = mP(v_2 - v_1)$$
$$W = 5kg \times 1000kPa \times (0.2579 m^3/kg - 0.19444 m^3/kg)$$
$$W = 317.3kJ$$

C- Hyperbolic Process

$$PV = Const. = c \quad \rightarrow \quad P = \frac{c}{V}$$

$$W = \int_1^2 pdV = \int_1^2 \frac{c}{V} dV = c\int_1^2 \frac{dV}{V} = c \ln \frac{V_2}{V_1}$$

$$W = P_1V_1 \ln \frac{V_2}{V_1} = P_2V_2 \ln \frac{V_2}{V_1} = P_1V_1 \ln \frac{P_1}{P_2} = P_2V_2 \ln \frac{P_1}{P_2}$$

NOTE: This process are called isothermal process for <u>ideal gas(only)</u>, because for ideal gases when

$$PV = const. \quad so \quad T = const.$$

Example 3.3

One tenth kg of saturated vapor water is at 2MPa is compressed in hyperbolic process to a pressure of 4MPa . Find the final temperature of the water and the work done.

<u>Solution:</u> Given m=0.1kg
P_1=2MPa sat water vapor
P_2=4MPa and the process is PV=constant
At the first state

$$v_1 = v_{g \; at \; 2MPa} = 0.09963 m^3/kg$$

$$P_2v_2 = P_1v_1 \quad OR \quad v_2 = v_1\frac{P_1}{P_2} = 0.09963 m^3/kg \times \frac{2MPa}{4MPa} = 0.04982 m^3/kg$$

The sat. volume at 4MPa $v_g = 0.04978 m^3/kg$

It is found that $v_2 > v_{g \; at \; 4MPa}$ so the state is superheated vapor

To find the temperature by using the superheated water table and interpolation as follows

T °C	v m^3/kg
250.4	0.04978
	0.04982
275.0	0.05457

$$T = 250.4 + \frac{(0.04982 - 0.04978)}{(0.05457 - 0.04978)}(275 - 250.4) = 250.6^\circ C$$

and the work can be calculated by

$$W = mP_1v_1 \ln\frac{P_1}{P_2} = 0.1 \times 2000 \times 0.09963 \ln\frac{2}{4} = -13.812 kJ$$

D- Polytropic Process

During expansion and compression processes of real gases, pressure and volume are often related by $(PV^n = c)$ where n, and c are constants. A process of this kind is called a Polytropic process.

$$W = \int_1^2 PdV$$

$$PV^n = c \rightarrow P = \frac{c}{V^n} = cV^{-n}$$

$$W = \int_1^2 cV^{-n}dV = \left.\frac{cV^{-n+1}}{1-n}\right|_1^2 = \left.\frac{PV^nV^{1-n}}{1-n}\right|_1^2 = \left.\frac{PV}{1-n}\right|_1^2$$

$$W = \frac{P_2V_2 - P_1V_1}{1-n}$$

For change phase substance the Polytropic process

$$W = \frac{m(P_2v_2 - P_1v_1)}{1-n}$$ where v is the specific volume

the ideal gas Polytropic process can be written as

$$W = \frac{P_2V_2 - P_1V_1}{1-n} \quad or \quad \frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n$$

$$W = \frac{mR(T_2 - T_1)}{1-n} \quad\quad \frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{n}}$$

For ideal gas in Polytropic process we can drive the following relation:

$$P_1V_1 = mRT_1 \qquad P_2V_2 = mRT_2$$

$$P_1V_1^n = C \qquad P_2V_2^n = C$$

$$P_1V_1^n = P_2V_2^n$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n = \left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}}$$

$$\frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{n}} = \left(\frac{T_1}{T_2}\right)^{\frac{1}{n-1}}$$

for ideal gas only

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \left(\frac{V_1}{V_2}\right)^{n-1}$$

Example 3.4

Carbon dioxide with mass of 5kg at 100kPa pressure and 300K temperature is compressed polyropically according to the law $PV^{1.32}=C$ until the pressure of 500kPa. Find (a) initial and final volume (b) the final temperature (c) the work done

Solution: Given CO_2 gas

$m = 5kg \quad P_1 = 100kPa \quad T_1 = 300^oC$

$P_2 = 500kPa$

For CO_2 the gas constant R=0.2968kJ/kg.K

$$V_1 = \frac{mRT_1}{P_1} = \frac{5\times0.1889\times300}{100} = 2.8335m^3$$

$$V_2 = V_1\left(\frac{P_1}{P_2}\right)^{\frac{1}{n}} = 2.8335\times\left(\frac{100}{500}\right)^{\frac{1}{1.32}} = 0.8371m^3$$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = 300\times\left(\frac{500}{100}\right)^{\frac{1.32-1}{1.32}} = 443.2K$$

$$W = \frac{mR(T_2-T_1)}{1-n} = \frac{5\times0.1889(443.2-300)}{1-1.32} = 422.5kJ \quad or$$

$$W = \frac{P_2V_2-P_1V_1}{1-n} = \frac{500\times0.8371-100\times2.8335}{1-1.32} = -422.5$$

E- Isothermal Process (Constant Temperature Process)

This process can be discussed separately for ideal gas and vapor

1- Ideal gas

when the temperature is constant $T = constant$ and from the ideal gas equation of state, with no change in the mass $PV = constant$ The process becomes hyperbolic process and

$$W = P_1V_1 \ln\frac{V_2}{V_1} = P_2V_2 \ln\frac{V_2}{V_1} = P_1V_1 \ln\frac{P_1}{P_2} = P_2V_2 \ln\frac{P_1}{P_2}$$

$$PV = mRT$$

$$W = mRT \ln\frac{V_2}{V_1} = mRT \ln\frac{P_1}{P_2}$$

Example 3.5

One kilogram of air at 500°C is expanded isothermally from a pressure of 2MPa to a pressure of 0.5MPa, find the work done by the air.

Solution: Given Air of m=1kg at P_1=2MPa P_2=0.5MPa $T_1=T_2=T$=500°C

It is an ideal gas and isothermal process of expansion

$$W = mRT \ln\frac{P_1}{P_2} =$$

$$W = 1kg \times 0.287 \times (500 + 273.15) \ln\frac{2}{0.5} = 307.61kJ$$

2-Substance with phase change

(i) Saturated region

In saturated region when the temperature is constant the pressure is also constant because the pressure and temperature are dependent properties *P=f(T)*. Therefore the work in this process is the same to that as in constant pressure process

(ii) Superheated region

In this region the temperature and pressure are not dependent properties $(P \neq f(T) \ \ only)$ Therefore the process can be assumed as polytropic process $(PV^n = constant)$

Example 3.6

0.4kg of saturated liquid water at 120°C is vaporized in piston cylinder device isothermally until the volume of liquid becomes one tenth of the total volume. Find the work done by the system.

Solution: Given sat. liquid water m=0.4 kg T=120°C isothermal

$$V_{f2} = \frac{V_2}{10}, \quad V_{g2} = \frac{9V_2}{10}$$

as the water is still in the saturated region the expansion is also constant pressure of $P=P_{sat\ at\ 120^oC}$ =198.53kPa

$$v_f = 0.00106 m^3/kg \quad v_g = 0.8919 m^3/kg \quad v_1 = v_f = 0.00106 m^3/kg$$

$$V_{f2} = m_f v_f = \frac{V_2}{10} = \frac{mv_2}{10} \rightarrow v_2 = 10\frac{m_f}{m} v_f = 10(1-x)v_f$$

$$V_{g2} = m_g v_g = \frac{9V_2}{10} = \frac{9mv_2}{10} \rightarrow v_2 = \frac{10}{9}\frac{m_g}{m} v_g = \frac{10}{9} x v_g$$

$$v_2 = 10(1-x)v_f = \frac{10}{9} x v_g \rightarrow x = \frac{v_f}{\frac{1}{9}v_g + v_f} = \frac{0.00106}{\frac{0.8919}{9} + 0.00106} = 0.0106$$

$$v_2 = v_f + x(v_g - v_f) = 0.00106 + .0106(0.8919 - .00106) = 0.0105 m^3/kg \quad or$$

$$v_2 = \frac{10}{9} x v_g = \frac{10}{9} \times 0.0106 \times 0.8919 = 0.0105 m^3/kg$$

$$W = mP(v_2 - v_1) = 0.4 \times 198.53 \times (0.0105 - 0.00106) = 0.75 kJ$$

3.3 Electrical Work

When N coulombs of electrons moves through potential difference V, the electrical work done is

$W_e = VN(kJ)$ which can also be expressed in the rate form as $\dot{W}_e = VI \ \ [kJ]$

where $\dot{W}_e$ is the electrical power and I is the number of electrons flowing per unit time i.e.(the current)

$$W_e = \int_1^2 VIdt \ \ [kJ]$$

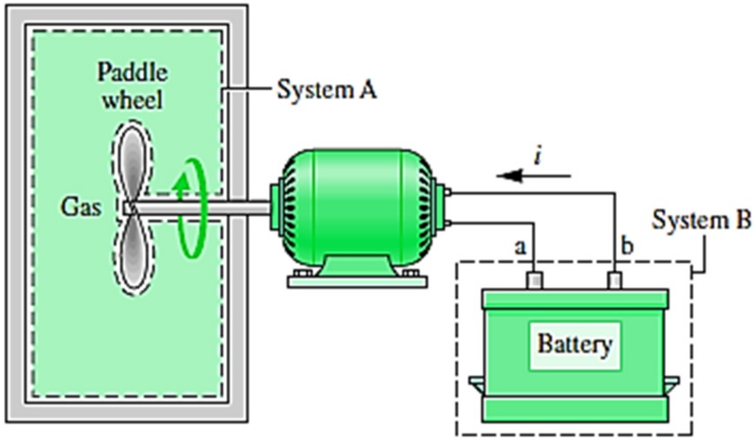
if both V and I remain constant during the time interval Δt, this equation will reduce to

$$W_e = IV\Delta t \ \ [kJ]$$

the electrical work in fan, compressor and heater is negative.

Example 3.7:

Find the electrical work done by heating of voltage 240V and the current passes is 5A operates for 15 minutes.



Solution: V=240 V I=5A and Δt=15 minutes =900sec

$$W_e = VI\Delta t = 240 \times 5 \times 900 = 1102500J = 1102.5kJ$$

3.4 Mechanical Form of Work

In elementary mechanics, the work done by a constant force F on a body which is displaced a distance S in the direction of force

$$W_m = FS \quad [kJ]$$

If the force is not constant, the work done is obtained by adding the differential amounts of work

$$W_m = \int_1^2 F ds \quad [kJ]$$

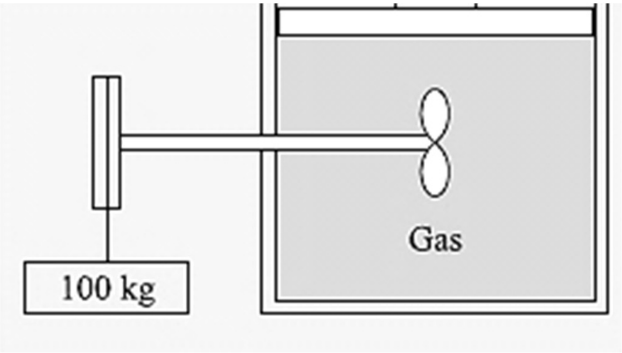
EXAMPLE 3.8

A 100-kg mass drops 3 m, resulting in an increased volume in the cylinder shown of 0.002 m^3. The weight and the piston maintain a constant gage pressure of 100 kPa. Determine the net work done by the gas on the surroundings. Neglect all friction.

Solution

The paddle wheel does work on the system, the gas, due to the 100-kg mass dropping 3 m. That work is negative and is

$$W_m = -F \times d = -(100 \times 9.81) \times 3 = -2940 \text{ N·m (J)}$$



3.5 Shaft Work

Energy transmission with a rotation is very common in engineering practice. Often the torque T applied to the shaft is constant, which means that the force F applied is also constant. For a specified constant torque, the work done during n revolutions is a determined as follows: A force F acting through a moment arm r generates a torque T which is determined from

$$T = Fr \rightarrow F = \frac{T}{r}$$

This force acts through a distance S

$$S = (2pr)n$$

then the shaft work is determined from

$$W_{sh} = FS = \frac{T}{r}(2prn) = 2pnT \quad [kJ]$$

The power transmitted through the shaft is the shaft work done per unit time, which can be expressed as

$$\dot{W}_{sh} = 2p\dot{n}T \quad [kW]$$

where $\dot{n}$ is number of revolution per second.

Example 3.9:

Determine the power transmitted through the shaft of a car when torque applied is 200N.m and the shaft rotates at a rate of 4000r.p.m

Solution: T=200N.m=0.2kN.m $\dot{n}$ =4000rpm=4000/60 rps

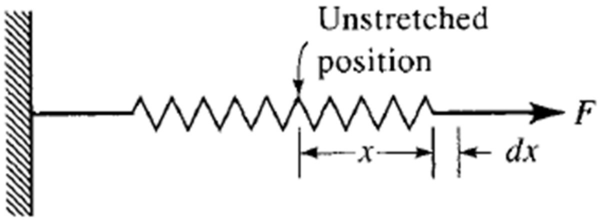
$$\dot{W}_{sh} = 2p\dot{n}T = 2p\frac{40000}{60}0.2 = 83.7kW$$

3.6 Spring Work

It is common knowledge that when a force is applied on a spring, the length of the spring changes. When the length of the spring changes by differential amount dx under the force F.

$$dW_{spring} = Fdx$$

$$and \quad F = Kdx$$



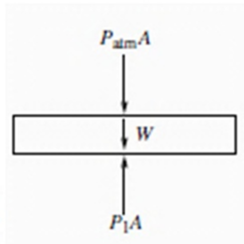
where K= stiffness of spring or spring constant [kN/m]

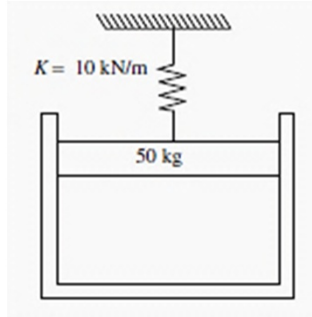
$$W_{spring} = \int_1^2 kxdx = \frac{1}{2}K\left(x_2^2 - x_1^2\right)$$

EXAMPLE 3.10

The air in a 10-cm-diameter cylinder shown is heated until the spring is compressed 50 mm. Find the work done by the air on the frictionless piston. The spring is initially unstretched, as shown.

Solution





The pressure in the cylinder is initially found from a force balance as shown on the free-body diagram:

$$P_1A = P_{atm}A + W$$

$$P_1\pi \times 0.05^2 = 100\ 000 \times \pi \times 0.05^2 + 50 \times 9.81 \qquad \therefore P_1 = 162\ 500 \text{ Pa}$$

To raise the piston a distance of 50 mm, without the spring, the pressure would be constant and the work required would be force times distance:

$$W = PA \times d = 162\ 500 \times (\pi \times 0.05^2) \times 0.05 = 63.81 \text{ J}$$

the work required to compress the spring is calculated to be

$$W = \frac{1}{2}K(x_2^2 - x_1^2) = \frac{1}{2} \times 10\ 000 \times 0.05^2 = 12.5 \text{ J}$$

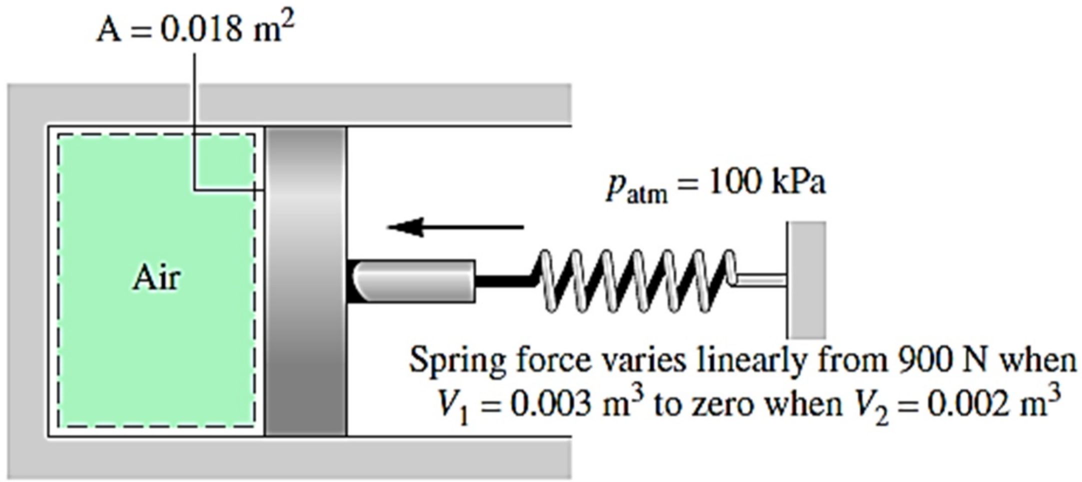
The total work is then found by summing the above two values:

$$W_{total} = 63.81 + 12.5 = 76.31 \text{ J}$$

HOME WORK Warm air is contained in a piston–cylinder assembly oriented horizontally as shown in Figure below. The air cools slowly from an initial volume of 0.003 m^3 to a final volume of 0.002 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 m^2. Friction between the piston and the cylinder wall can be neglected. For the air, determine the initial and final pressures, in kPa, and the work, in kJ.

Answer

150, 100 k, −0.125



3.7 Heat Transfer

Heat is defined as the form of energy that transferred between systems (or system and surroundings) by virtue of a temperature difference.

Heat is energy in transition. It is recognized only as it crosses the boundary of a system.

A process during which there is no heat transfer is called an adiabatic process. The word adiabatic comes from the Greek word adiabatos which means not to be passed.

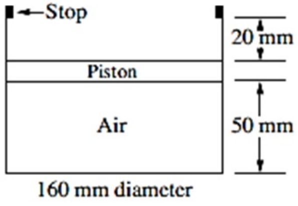
As a form of energy, heat has energy unit kJ (Btu) being most common one. The amount of heat transferred during the process between two states (states 1 and 2) is denoted Q_{12} or just **Q**. heat transfer per unit mass of a system is denoted **q** and is determined from $q = \frac{Q}{m} kJ/kg$. The heat transfer rate is denoted $\dot{Q}$, where the over dot stands for the time derivative, or per unit time. The heat transfer rate $\dot{Q}$ has the unit kJ/sec, which is equivalent to kW. When $\dot{Q}$ varies with time

$$Q = \int_{t_1}^{t_2} \dot{Q} dt \quad \text{(KJ)}$$

Heat transfer to the system is positive and heat transfer from system is negative.

Quiz No. 1

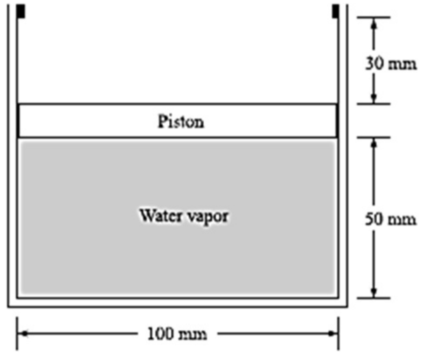
1. Which work mode is a nonequilibrium work mode?
   (A) Compressing a spring
   (B) Transmitting torque with a rotating shaft
   (C) Energizing an electrical resistor
   (D) Compressing gas in a cylinder
2. Ten kilograms of saturated steam at 800 kPa are heated at constant pressure to 400°C. The work required is nearest
   (A) 1150 kJ
   (B) 960 kJ
   (C) 660 kJ
   (D) 115 kJ
3. A stop is located 20 mm above the piston at the position shown. If the mass of the frictionless piston is 64 kg, what work must the air do on the piston so that the pressure in the cylinder increases to 500 kPa?



   (A) 22 J
   (B) 28 J
   (C) 41 J
   (D) 53 J
4. Which of the following statements about work for a quasiequilibrium process is incorrect?
   (A) The differential of work is inexact
   (B) Work is the area under a P-T diagram
   (C) Work is a path function
   (D) Work is always zero for a constant volume process

Questions 5–8

The frictionless piston shown has a mass of 16 kg. Heat is added until the temperature reaches 400°C. The initial quality is 20 percent. Assume $P_{atm} = 100$ kPa.



5. The total mass of the water is nearest
   (A) 0.018 kg
   (B) 0.012 kg
   (C) 0.0014 kg
   (D) 0.0010 kg
6. The quality when the piston hits the stops is nearest
   (A) 32%
   (B) 38%
   (C) 44%
   (D) 49%
7. The final pressure is nearest
   (A) 450 kPa
   (B) 560 kPa
   (C) 610 kPa
   (D) 690 kPa

8. The work done on the piston is nearest
   (A) 21 kJ
   (B) 28 kJ
   (C) 36 kJ
   (D) 42 kJ
9. Air is compressed in a cylinder such that the volume changes from 0.2 to 0.02 m^3. The initial pressure is 200 kPa. If the pressure is constant, the work is nearest
   (A) –36 kJ
   (B) –40 kJ
   (C) –46 kJ
   (D) –52 kJ
10. Estimate the work necessary to compress the air in a cylinder from a pressure of 100 kPa to that of 2000 kPa. The initial volume is 1000 cm^3. An isothermal process is to be assumed.
   (A) 0.51 kJ
   (B) 0.42 kJ
   (C) 0.30 kJ
   (D) 0.26 kJ
11. Estimate the work done by a gas during an unknown equilibrium process. The pressure and volume are measured as follows:

P	200	250	300	350	400	450	500	kPa
V	800	650	550	475	415	365	360	cm^3

   (A) 350 J
   (B) 260 J
   (C) 220 J
   (D) 130 J
12. The force needed to compress a nonlinear spring is given by $F = 10x^2$ N, where x is the distance the spring is compressed, measured in meters. Calculate the work needed to compress the spring from 0.2 to 0.8 m.
   (A) 0.54 J
   (B) 0.72 J
   (C) 0.84 J
   (D) 0.96 J
13. A paddle wheel and an electric heater supply energy to a system. If the torque is 20 N·m, the rotational speed is 400 rpm, the voltage is 20 V, and the amperage is 10 A, the work rate is nearest
   (A) –820 W
   (B) –920 W
   (C) –1040 W
   (D) –2340 W
14. A gasoline engine drives a small generator that is to supply sufficient electrical energy for a motor home. What is the minimum horsepower engine that would be necessary if a maximum of 200 A is anticipated from the 12-V system?
   (A) 2.4 hp
   (B) 2.6 hp
   (C) 3.0 hp
   (D) 3.2 hp

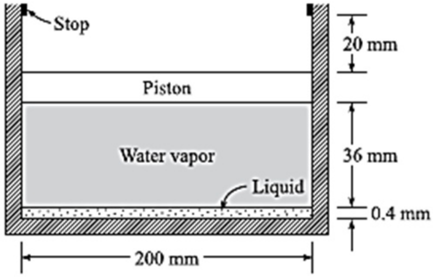
Quiz No. 2

1. Which of the following does not transfer work to or from a system?
   (A) A moving piston
   (B) The expanding membrane of a balloon
   (C) An electrical resistance heater
   (D) A membrane that bursts
2. Ten kilograms of air at 800 kPa are heated at constant pressure from 170 to 400°C. The work required is nearest
   (A) 1150 kJ
   (B) 960 kJ
   (C) 660 kJ
   (D) 115 kJ

3. Ten kilograms of saturated liquid water expands until $T_2 = 200°C$ while the pressure remains constant at 400 kPa. Find $W_{1\text{-}2}$.
   (A) 2130 kJ
   (B) 1960 kJ
   (C) 1660 kJ
   (D) 1115 kJ
4. A mass of 0.025 kg of steam at a quality of 10 percent and a pressure of 200 kPa is heated in a rigid container until the temperature reaches 300°C. The pressure at state 2 is nearest
   (A) 8.6 MPa
   (B) 2.8 MPa
   (C) 1.8 MPa
   (D) 0.4 MPa

Questions 5–8

The frictionless piston shown in equilibrium has a mass of 64 kg. Energy is added until the temperature reaches 220°C. Assume $P_{atm} = 100$ kPa.



5. The initial quality is nearest
   (A) 12.2%
   (B) 8.3%
   (C) 7.8%
   (D) 6.2%
6. The quality when the piston just hits the stops is nearest
   (A) 73%
   (B) 92%
   (C) 96%
   (D) 99%
7. The final quality (or pressure if superheat) is nearest
   (A) 1.48 MPa
   (B) 1.52 MPa
   (C) 1.58 MPa
   (D) 1.62 MPa
8. The work done on the piston is nearest
   (A) 75 J
   (B) 96 J
   (C) 66 J
   (D) 11 J
9. Air is compressed in a cylinder such that the volume changes from 0.2 to 0.02 m^3. The pressure at the beginning of the process is 200 kPa. If the temperature is constant at 50°C, the work is nearest
   (A) –133 kJ
   (B) –126 kJ
   (C) –114 kJ
   (D) –92 kJ
10. Air is expanded in a piston-cylinder arrangement at a constant pressure of 200 kPa from a volume of 0.1 m^3 to a volume of 0.3 m^3. Then the temperature is held constant during an expansion of 0.5 m^3. Determine the total work done by the air.
   (A) 98.6 kJ
   (B) 88.2 kJ
   (C) 70.6 kJ
   (D) 64.2 kJ

11. Air undergoes a three-process cycle. Find the net work done for 2 kg of air if the processes are

$1 \rightarrow 2$: constant-pressure expansion

$2 \rightarrow 3$: constant volume

$3 \rightarrow 1$: constant-temperature compression

The necessary information is $T_1 = 100°C$, $T_2 = 600°C$, and $P_1 = 200$ kPa.

(A) 105 kJ

(B) 96 kJ

(C) 66 kJ

(D) 11.5 kJ

12. A 200-mm-diameter piston is lowered by increasing the pressure from 100 to 800 kPa such that the *P*-*V* relationship is $PV^2 = \text{const.}$
If $V_1 = 0.1\ m^3$, the work done on the system is nearest

(A) −18.3 kJ

(B) −24.2 kJ

(C) −31.6 kJ

(D) −42.9 kJ

13. A 120-V electric resistance heater draws 10 A. It operates for 10 min in a rigid volume. Calculate the work done on the air in the volume.

(A) 720 000 kJ

(B) 720 kJ

(C) 12 000 J

(D) 12 kJ

14. An electrical voltage of 110 V is applied across a resistor providing a current of 12 A through the resistor. The work done during a period of 10 min is nearest

(A) 792 000 kJ

(B) 792 kJ

(C) 792 MJ

(D) 792 mJ