**Unit 2: Work & Heat**

**Mechanics definition of work**: Work is done when the point of application of a force moves in the direction of the force. The amount of work is equal to the product of the force and the distance through which the point of application moves in the direction of the force. i.e., work is identified only when a force moves its point of application through an observable distance.

Mathematically, W = 



However, when treating thermodynamics from a macroscopic point of view, it is advantageous to tie in the definition work with the concepts of systems, properties and processes.

**Thermodynamic definition of work**: It is a kind of interaction that would occur at the system boundaries. It can be positive or negative.

Definition of Positive work is said to be done by a system when the ‘sole effect’ external to the system could be reduced to the raising of a weight.

**Comments**: The word ‘sole effect’ indicates that the raising of weight should be the only interaction between the system and surroundings in order to say that there is work interaction between the system and the surroundings. The phrase ‘external to the system’ indicates that the work is a boundary phenomenon. The magnitude of work interaction depends upon the system boundary. This is illustrated with an example.

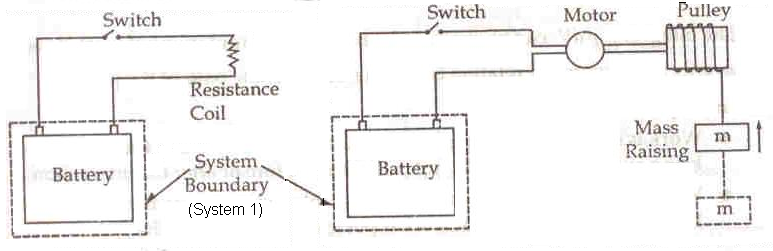


Figure 1: Equivalence of Current Work Interaction between the System and the Surroundings

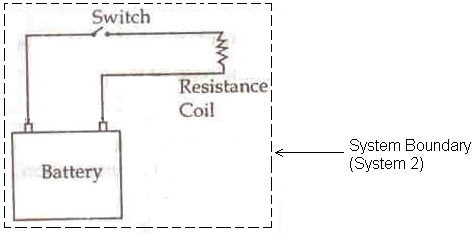


Figure 2: System Comprising of Battery, Switch & Resistance Coil

For the two systems shown in figure, system (1) comprising battery alone has work interaction with the surroundings, whereas for system (2) which includes motor, weights etc along with the battery, the work interaction is zero.

The word ‘could be reduced to’ indicates that it is not necessary that weights should actually be raised in order to say that there is work interaction between the system and the surroundings. It is just sufficient to have an effect which is equivalent to the raising of weight.

Here an electrical storage battery constitutes system 1 whose terminals are connected to an electrical resistance coil through a switch. The circuit external to the battery constitutes the surroundings. When the switch is closed, the current flow through the coil, and the resistance (surroundings) become warmer and the charge of the battery (system) decreases. Obviously there has been interaction between the system and the surroundings. According to mechanics this interaction cannot be classified as work because their has been no action of force through a distance or of torque through an angle. However, as per thermodynamics concepts, the battery (system) does work as the electrical energy crosses the system boundary. Further, the electrical resistance can be replaced by an ideal frictionless motor pulley arrangement which can wind a string and thereby raise suspended weight. The sole effect, external to the system, is raising of a weight. As such interaction of battery with resistance coil is a work.

**Sign Conventions for work**:

Work is said to be positive, if it is done by the system on the surroundings

System

Positive work

Work is said to be negative, if it is done on the system by the surroundings

System

Negative work

Therefore, Wsystem + Wsurroundings = Zero

**The unit of work** is N-m or Joule. The rate at which work is done by, or upon, the system is known as power. The unit of power is J/s or watt.

Work is one of the forms in which a system and its surroundings can interact with each other. There are various types of work transfer which can get involved between them.

**Work done at the moving boundary of a system (Expression for displacement work)**

p

dx

Consider a piston-cylinder arrangement which contains certain working fluid undergoing quasi-static process.

Let p = Pressure exerted by the fluid on the piston

A = Area of c/s of the cylinder

dx = displacement of the piston when the system has undergone an infinitesimal change

of state.

∴ Displacement work: dw = Force x displacement

= p.A x dx

i.e., dw = p.dV

Where dv is the infinitesimal change in volume of the system. If the system undergoes a finite change of state from state (1) to state (2). Then the displacement work is given by



The integration of above equation can be done only if the relationship between P and v during the process is known i.e., if the path of the process is well defined. Hence, work is a path function. As work depends on the path of the process which it follows, there will be different values of work for different process between two given states. Hence the differentials of the path functions are in exact differentials. The symbol δ will be used to designate inexact differentials. The magnitude of the work transfer by the system during the process from state (1) to state (2) containing unit mass of the fluid will be written as,  or W1-2.

The process can be represented by a full line on an appropriate thermodynamic coordinate system (in this case p-V diagram) and the area under the curve gives the work done by the system during the process.

p

V

p1

p2

V2

V1

1

2

A

B

C

p

V

dV

1

2

Quasi-Static Process

Quasi-Static pdV work Work-a path function

Inspection of the pV diagram above shows that just by specifying the end states 1 and 2 does not determine the area (or work); the nature of the curve needs to be known. The curve may be arched upwards or it may sag downwards, and the area under the curve will vary accordingly. For the same initial and final states, the work done by the system in following the paths A, B and C are different. Therefore the work is a path function and not a point function. Accordingly the work transfer across the system boundaries is not classified as a thermodynamic property.

The expression δw = pdV holds good under the following restrictions

1. The system is closed
2. There is no friction within the system
3. The pressure and all other properties are the same on all the boundaries of the system
4. The system is not influenced by motion, gravity, capillarity, electricity and magnetism

**Expression for Displacement work for various Quasi-Static Processes (pdV work)**:

1. **Constant volume process**: **(Isochoric Process)**.

For a constant volume process i.e., V = constant (dV = 0 ) as represented in the p-V diagram below.

p

V

1

2

p1

p2

W1-2 = p.dV but dV = 0

(Wd) 1-2 = 0

∴

1. **Constant pressure process**: **(Isobaric process)**.

For a closed system undergo a constant pressure process from state 1 (volume V1 and pressure p1) to a final state 2 (volume V2). The process is represented in the p-V diagram as shown below.

P

1

2

V1

V2

W1-2

p1 = p2

V

W1-2 = p.dV, where p = constant

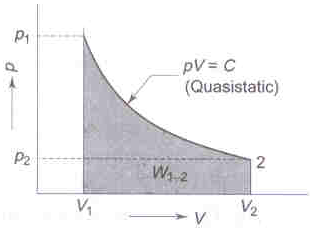
∴ W1-2 = p dV = p (V2 – V1)

(Wd) 1-2 = p (V2 – V1)

∴

1. **Hyperbolic process** i.e., pV = constant:

The hyperbolic expansion process from state 1 to state 2 is represented on a p-V diagram as shown below.



Process in which pV = Constant

W1-2 = p.dV

But pV = constant i.e., pV = p1V1, 

∴W1-2 = p.dV

= p1 V1 [ln V2 – ln V1] where p1 = Initial pressure of the system

V1 = Initial volume of the system

p2 = Final pressure of the system

V2 = Final volume of the system

i.e., (Wd) 1-2 = 

1. **Polytropic process**, i.e., pVn = constant

A polytropic process is represented on a p-V diagram as shown below.

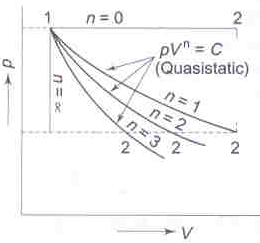


Figure: Process in which pVn = Constant

W1-2 = p.dV

But pVn = constant i.e.,  

∴W1-2 =  

= p1 V1n V-n .dV

= p1 V1n  = 

=  but p1V1n = p2V2n

= 

∴(Wd) 1-2 = 

Where ‘n’ is called the index of expansion or compression

Note: 1. Work is a transient phenomenon i.e., it is present only during a process. Mathematically

speaking, work is a path function.

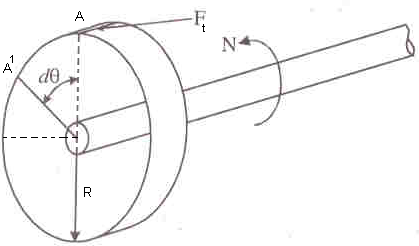
∴ dw = w2 – w1 is wrong

= w1-2 i.e., δw is inexact differentials.

2. For irreversible process δw ≠ P.dv

**Other Types of Work Transfer**

**1. Shaft Work**:



Shaft work

Let Ft = Tangential force on the shaft

R = Radius of the shaft

dθ = Angular displacement of the shaft in an interval of time ‘dt’

∴ Shaft work in time interval ‘dt’, is dWs = Ft. AA1

= Ft. R.dθ

i.e., Ws =T.dθ

∴ Work done / unit time =  T. = T.ω where ω = angular velocity, T = Torque

But ω =  where N = rpm of the shaft

∴Shaft work, Ws = watts

**2. Stirring Work**: Stirring work is nothing but shaft work is done on the system by using a stirrer which is driven by a shaft.

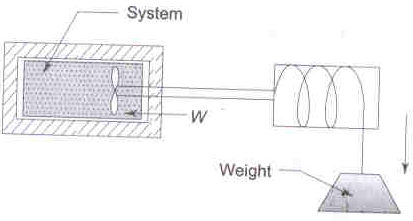


Figure3: Paddle-wheel work

As the weight is lowered, and the paddle wheel turns, there is work transfer into the system which gets stirred. Since the volume of the system remains constant, ∫ pdv = 0. If m is the mass of the weight lowered through a distance dz and T is the torque transmitted by the shaft in rotating through an angle dθ, the differential work transfer to the fluid is given by

δw = mgdz = Tdθ

and the total work transfer is w = mgdz = W1dz = Tdθ where W1 is the weight lowered

**3. Electrical Work**: When a current flows through a resistor, taken as system, there is work transfer into the system. This is because the current can drive a motor, the motor can drive a pulley and the pulley can raise a weight.

I

I

System boundary

The current I, flows is given by,

I =  where C = charge in coulombs

τ = time in seconds

Thus dC is the charge crossing a system boundary during time dτ. If E is the voltage potential, the work is δw = E.dC

= EI dτ

∴ w = EI dτ

∴The electrical work is, w = lim  = EI

δτ 0

This is the rate at which work is transferred.

**4. Work done in stretching a wire**: Consider a wire as the system. If the length of the wire in which there is a tension Ŧ is changed from L to L + dL, the infinitesimal amount of work that is done is equal to, δw = - Ŧ dL

The -ve sign is used because a positive value of dL means an expansion of the wire, for which work must be done on the wire i.e., negative work.

For a finite change of length, w = -Ŧ dL

Within the elastic limits, if E is the modulus of the elasticity, σ is the stress, ε is the strain, and A is the cross sectional area, then

Ŧ = σA = E.ε.A

Therefore δw = - E.ε.AdL

But dε = dL/L or dL = L x dε

∴ δw = - Ŧ dL = - E.ε.A. L dε

i.e., w = -EAL ε d ε

= -

**5. Work done in changing the area of a surface film**: A film on the surface of a liquid has a surface tension which is a property of the liquid and the surroundings. The surface tension acts to make the surface area of the liquid a minimum. It has the unit of force per unit length.

The work done on a homogeneous liquid film in changing its surface area by an infinitesimal amount dA is

δw = - σ dA when σ = surface tension (N/m)

∴ w = - σ dA

**6. Magnetization of a paramagnetic field**: The work done per unit volume on a magnetic material through which the magnetic and magnetization fields are uniform is,

δw = - H.dI

i.e., w = - H.dI

Where H = field strength

I = Component of the magnetization field in the direction of the field.

-ve sign provides that an increase in magnetization (+ve dI) involves -ve work.

Note: It may be noted in the above expressions that the work is equal to the integral of the product of an intensive property and the change in its related extensive property. These expressions are valid only for infinitesimally slow quasi-static process.

**Network Transfer**: The network interaction between the system and the surroundings for any process will be the algebraic sum of all types of work interaction that has taken place between the system and the surroundings.

Therefore if W1-2 represents the net work transfer then,

W1-2 = (Wd)1-2 ± (Ws)1-2 ± (We)1-2 ± (Wmag)1-2 ± ......

+ve sign has to be used when the work transfer takes place from the system to the surroundings and –ve sign to be used when work transfer is from the surroundings to the system.

**Heat**: Heat is a mode of energy transfer that takes place between the system and the surroundings solely due to the temperature difference. Thus, heat is a transient phenomenon. It can be recognized only during a process. It is not a thermodynamic property of the system. Like work, heat is a path function i.e., the magnitude of heat transfer between the system and surroundings depends upon the type of process the system is undergoing.

Heat transfer always takes place from a region of higher temperature to a region of low temperature. The magnitude of the heat transfer into unit mass of the fluid in the system during a process from state (1) to state (2) will be written as  and not as 

 represents the total heat transfer that takes place when the system undergoes a change of state from state 1 to state 2.

-ve

+ve

System

System

**Sign Convention**:

Heat transfer is considered as positive if it takes place from the surroundings to the system and it is considered as negative if it takes place from the system to the surroundings.

During an adiabatic process, Q = 0

**Units**: Since heat is a form of energy transfer it will have the same units as that of energy. In SI units it is expressed in Joules (J) or Kilo Joules (kJ).

**Comparison between work and heat**:

**Similarities**:

* Both are path functions and inexact differentials.
* Both are boundary phenomenon i.e., both are recognized at the boundaries of the system as they cross them.
* Both represent transient phenomenon; these energy interactions occur only when a system undergoes change of state i.e., both are associated with a process, not a state. Unlike properties, work or heat has no meaning at a state.
* A system possesses energy, but not work or heat.
* Concepts of heat and work are associated not with a ‘store’ but with a ‘process’.

**Dissimilarities**:

* Heat is energy interaction due to temperature difference only; work is by reasons other than temperature difference.
* In a stable system, there cannot be work transfer; however there is no restriction for the transfer of heat.
* The sole effect external to the system could be reduced to rise of a weight but in the case of a heat transfer other effects are also observed.
* Heat is a low grade energy whereas work is a high grade energy.

**Problems**:

* 1. Evaluate the work done in the following processes. The systems to be considered are underlined.
     1. An *agent* slowly raises a *body* of mass 2 kg a distance of 3 mts in a gravitational field of standard acceleration.

Solution: By definition, considering agent as the system, it does positive work. The magnitude of work is measured by the product of the weight its lifts and the distance through which it is lifted.

W = +  = 2 x 9.81 x 3 = + 58.86 J

∴Work done by the agent = + 58.86 J

Because, work is done by the agent, work is done on the body to the same amount.

∴ Work done on the body = 58.86 J

or Work done by the body = - 58.86 J

* + 1. A mass of 1 tonne is suspended from a pulley block. An *agent* slowly raises the mass against the standard gravitational acceleration by 2m.

Solution: By definition, considering agent as the system, it does positive work.

∴W = +  =  = 19620 J = 19.62 kJ

∴ Work done by the agent = 19.62 kJ

Because, work is done by the agent, work is done on the mass to the same amount.

∴Work done on the mass = 19.62 kJ

or Work done by the mass = - 19.62 kJ

* + 1. After raising the *mass* as in (b), the mass falls freely through the same vertical distance of 2 m. The drag force of the atmosphere on the body is 50 N.

Actual Surroundings Fictitious Surroundings

1 tonne

Zero mass

50 N

+

1 tonne

50 N

No drag Force

+

Solution: Considering mass as a system (w r t. fictitious surroundings)

W = F x l = 50 x 30 = 1500 J = 1.5 kJ

∴Work done by the mass = 1.5 kJ

Work done by the atmosphere = - 1.5 kJ

Or Work done on the atmosphere = 1.5 kJ

* + 1. A *body* of mass 15 kg falls freely in a vacuum through a vertical distance of 30m. The gravitational acceleration is 6 m/s2.

Solution: Considering body as a system, as it is falling freely there is no interaction with the system boundary and hence work done by the body is zero. (In other words, the work done by the body is zero as it can lift no weight. All that is happening as the body is falling freely is that its PE is decreasing and its KE is increasing accordingly).

* + 1. A *rat* weighing 5.0 N climbs a stair 0.2 m in height.

Solution: Wrat = 0 (since there is no interaction between the system and its surroundings).

* 1. Indicate in the following cases, the heat exchange and work exchange are positive, negative or zero, and why
     1. A *copper block* of 1 kg heated to 1000 C is dipped into water at 150 C. Consider copper as system.

Ans: δW = 0, δQ is negative

* + 1. Heat is added to a *gas* in a rigid container such that pressure and temperature increases. Consider gas as system,

Ans: δW = 0, δQ is positive.

* + 1. *Gas* from a bottle is used to inflate a balloon which is originally flat. Consider gas as system.

Ans: δW is Positive, δQ = 0

* + 1. An insulated *wire* is stretched. Consider wire as a system.

Ans: δW is negative, δQ = 0

* + 1. A mouse climbs 20 steps of a stair case. Consider mouse as the system.

Ans: δQ = δW = 0

* + 1. *Gas* in an insulated cylinder expands as the piston is slowly moved outwards.

Ans: δQ = 0, δW is positive

* + 1. A closed rigid vessel containing steam at a temperature of 2000C is left standing in an atmosphere which is at 200C. Consider steam as the system.

Ans: For a closed rigid vessel, there is no change in volume and accordingly work done is zero. i.e., δW = 0. Since the steam is at a temperature higher than that of the surrounding atmosphere, the heat is rejected to the atmosphere. i.e., heat interaction is negative or δQ is negative.

* + 1. The air in a *tyre* and connecting pump the pump plunger is pushed down, forcing air into the tyre. The tyre, pump walls and connecting tube can be thought of to be non-conducting. Consider air as a system.

Ans: δW is negative and δQ = 0

* + 1. An electric current flows steadily through a *resistor* which is immersed in running water.

Ans: Considering resistor as system, current flows through the resistance i.e., electrical work is done on the system ∴δWe is negative

Due to the flow of current the resistor gets heated up resulting in heat transfer to the surrounding cold water from the resistor.

∴δQ is negative (heat transfer from the system)

* + 1. A *container* with rigid non-conducting walls holds a complete electrical circuit consisting of a heating element and charged storage battery. The temperature and pressure of the air in the container increases.

Ans: No interaction taking place across the boundary. The system boundary does not move as the walls are rigid. ∴δW = 0

The walls are non-conducting ∴ though the temperature inside the system increase, no heat transfer to the surroundings can take place ∴ δQ = 0

* + 1. 0.1 kg of *gas* contained in an insulated cylinder expands moving the piston slowly outwards

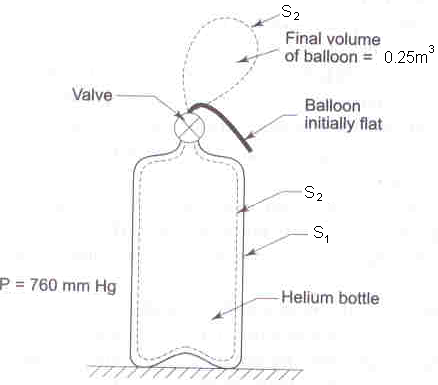
Ans: The cylinder is insulated ∴ No. heat transfer is possible ∴ δQ = 0

The gas expands ∴the system boundary expands ∴ δWd is positive

**Problems:**

* 1. Gas from a bottle of compressed helium is used to inflate a balloon originally folded completely flat, to a volume of 0.25 m3. If the barometer reads 760 mm of mercury, how much work is done by the system comprising the helium initially in the bottle, if the balloon is light and requires no stretching. Sketch the system before and after the process.

Solution:



The firm line S1 shows the boundary of the system before the process, and the dotted line S2 shows the boundary after the process.

Total displacement work is given by

(Wd)1-2 = (Wd)bottle portion of the system + (Wd)Balloon portion of the system

Since there is no displacement of the bottle portion of the system boundary, it follows that (Wd)bottle = 0

= 0 + (Wd)Balloon­

The balloon is expanding against a constant atmosphere pressure of 760 mm of mercury,

i.e., p = wh

= 9810 (13.6) 0.76 = 1.01396 x 105 N/m2 = 101.396 kPa

∴(Wd)balloon = ∫ pdV = p  dV

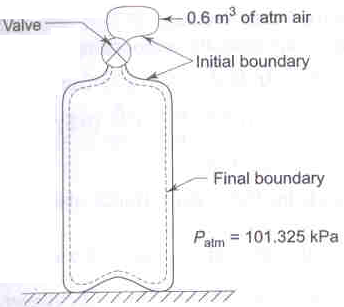
= p (V2 – V1)

= 101.396 (0.25 – 0)

= 25.349 kJ

* 1. Determine the work done by the air which enters an evacuated bottle from the atmosphere when the cork is opened, atmospheric air rushes into it. If the atmospheric pressure is 101.396 kPa and 0.6m3 of air (measured at atmosphere conditions) enters the bottle.

Solution:



No work is done by the part of the boundary in contact with the bottle. Work is done only by the moving part external to the bottle. The pressure over this moving part is uniform at 101.396 kPa

∴ Displacement work done by the system,

Wd = (Wd)bottle + (Wd)atmosphere

= 0 + p.dV

= p (V2 – V1) = 101.396 (0 – 0.6)

= - 60.8 kJ

Negative, because the boundary is contracting. Thus the surroundings do positive work at the boundary and the work done by the air negative

* 1. A spherical balloon has a diameter of 25 cm and contains air at a pressure of 1.5 x 105Pa. The diameter of the balloon increases to 30 cm in a certain process and during this process the pressure is proportional to the diameter. Calculate the work done by the air inside the balloon during this process.

Solution:

D1

D2

State 1 (p1, D1)

State 2 (p2, D2)

D1 = 0.25 m, D2 = 0.3 m,

p α D,

p1 = 1.5 x 105 N/m2

We have W1-2 = p.d V --- (1)

But, volume of sphere = V = 

∴ dV = . 3D2.dD

Also, p α D i.e.,  = constant = K

Equation (1) becomes, W1-2 =   D2. dD

=  D3 = 

= 

=  

W1-2 = 988.13 J

Positive sign indicates that work is done by the system.

* 1. Gas from a bottle of compressed helium is used to inflate an inelastic flexible balloon, originally folded completely flat to a volume of 0.5 m3. If the barometer reads 760 mm of Hg, what is the amount of work done upon the atmosphere by the balloon (50.66 kJ)
  2. When the valve of the evacuated bottle is opened, atmosphere air rushes into it. If the atmosphere pressure is 101.325 KPa, and 1.2 m3 of air (measured at atmosphere conditions) enters the bottle, calculate the work done by the air (-60.8 kJ).
  3. A gas system, confined by a piston and cylinder, undergoes a change of state such that the product of pressure and volume remains constant. If the process begins at a pressure of 3 bar and a volume 0.015m3 and proceeds until the pressure falls to half its initial value, determine the magnitude and direction of the work flow.

Solution:

p

pV = C i.e., hyperbolic process or p1 V1 = p2 V2

Given, p1 = 3 x 105 Pa V1 = 0.015 m3 p2 = 1.5 x 105 m3

V2 = ? W1-2 = ?

We have, p1V1 = p2 V2 ∴ V2 =  =  = 0.03 m3

∴Displacement work, (Wd)1-2 = p.dV = p1V1 ln 

= 3119.16 J = 3.1192 kJ

Positive sign indicates work is done by the system on the surroundings.

* 1. A certain amount of gas is compressed from 1 bar and 0.1m3 to 5 bar and 0.03m3. The process is according to the law pVn = K. Determine the magnitude and direction of work.

Solution: Given: p1 = 1 bar; V1 = 0.1 m3; p2 = 5 bar; V2 = 0.03

We have for a polytropic process,

Displacement work, = (Wd)1-2 = 

To find the compression index n, we have,



i.e., 

Taking log’s on both sides we have





∴(Wd)1-2 =  = - 14706 J = - 14.706 kJ

i.e., work done on the gas = 14.706 kJ

* 1. A gas confined in a cylinder by a piston is at pressure of 3 bar and a volume of 0.015 m3. The final pressure is 1.5 bar. Determine the magnitude and direction of work transfer for the following processes. i) p α V, ii) p α , iii) p α V2 and iv) p α 

Solution: Given: p1 = 3 x 105 Pa; V1 = 0.015 m3; p2 = 1.5 x 105 Pa V2 = ? (Wd) = ?

i) p α V i.e., 

We have, (Wd)1-2 = p.dV

=  V.dV

= 

we have  ∴V2 = p2  = 0.0075 m3

∴ (Wd)1-2 = [0.00752 – 0.015]2 = - 1.688 kJ

-ve sign indicates that work is done on the system

ii) p α  i.e., pV = C

Ans: (Wd)1-2 = 3.1192 kJ

iii) p α V2 i.e.,  ∴V2 = = 0.0106 m3

(Wd)1-2 =  p.dV

=  

= 



=  = -0.9707 kJ

-ve sign indicates that work is done on the system

iv) p α  i.e., pV2 = C = p1V12 = p2V22

∴V2 = = 0.0212 m3

We have (Wd)1-2 = p.dV =   = p1V12  

= 

= 

= 

= 

Substituting the given values, we get (Wd)1-2 = 1.316 kJ

+ve sign indicates that work is done by the system

* 1. A non-flow reversible process occurs for which p = 3V2 + 1/V where p is in N/cm2 and V is in m3. What is the work done when V changes from 0.5 m2 to 1 m3.

Solution: We have (Wd)1-2 = p.dV

= 104 

= 3 V2 dV + dV/V

= 104 

= 104 

= 1.568 x 104J = 15.86 kJ

* 1. A system consists of a cylinder and piston machine. The external normal load applied to the piston is given by F = - 7000 + 15000L Newton’s, where L is the distance in mts from the closed and of the cylinder to the piston. How much work is done when the piston moves from the position L = 1m to L = 1.5 m. Sketch the p-V diagram for this process and show the work done.

Solution: Given: F = - 7000 + 15000 L

We have Work done = (Wd)1-2 = ∫ pdV

= p.A.dL

= Ap.dL

But p = 

∴(Wd)1-2 = A . DL

=  (-7000 + 15000L). dL

= - 7000 (L2 – L1) + 15000/2 (L22 – L12)

= - 7000 (0.5) + 15000/2 (1.25)

= - 3500 + 9375

= 5875 J = 5.875 kJ

Sketching of p-V diagram:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| F | 8000 | 9500 | 11000 | 12500 | 14000 | 15500 |
| L | 1 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 |



* 1. An insulated system contains a mixture of ice and water. A paddle wheel is rotated in the system at 100rpm. Torque applied to the shaft is 3 N-m. In order to effect the transformation of 1 kg of ice to liquid water 300 kJ of heat must be transferred to the system. Determine the length of time the paddle wheel must be rotated in order to achieve 2.5 kg reduction in the quantity of ice.

Solution: Given: T = 3 N-m ; N = 1000 rpm

Paddle work (done on the system), Ws = 

=  = 314 N-m/s = 314 J/s

In order to have a reduction of 2.5 kg of ice into water, the paddle work required is

300 (2.5) = 750 kJ

∴Length of time for which the paddle wheel should be operated, is

 = 2388.5 sec i.e., 39.8 minutes

* 1. A system containing 5 kg of a substance is stirred with a torque of 1 N-m at a speed of 500 rpm for 24 hrs. The system mean while expands from 1.5m3 to 2.0m3 against a constant pressure of 5 bar. Determine the magnitude and direction of net work transfer.

Solution: The system is associated with two interactions with the surroundings i.e., stirring work (surroundings to the system) and displacement work

i.e., W1-2 = Wst(1-2) + (Wd)1-2

Stirring work, Wst = 2π NT / 60

=  = 52.359 n-m/sec

∴Wst = 52.359 x 24 x 60 x 60

= 4523893 J = 4523.893 kJ

This is a negative work, as the work is done on the system by the surroundings

Displacement work, (Wd)1-2 = pdV

= p (V2 – V1)

= 5 x 105 (2 - 1.5)

= 250000 J = 250 kJ

∴Net work transfer W1-2 = - 4523.893 + 250

= - 4273.89 kJ

Negative indicated that net work transfer takes place from the surroundings to the system.

* 1. A mass of 1.5 kg of a substance is compressed in a quasi-static process from 0.1 MPa to 0.7 MPa. The initial pressure density of the substance is 1.16 kg/m3. Determine the magnitude of work done on the substance if i) process is pV = C and pV1-4 = C

Solution: Given: m = 1.5 kg p1 = 0.1 x 106 Pa p2 0.7 x 106 MPa ρ1 = 1.16 kg/m3

Since ρ = 1.16 kg/m3 and m = 1.5 kg, volume V1 = m/ρ = 1.293 m3

Case i) pV = C

i.e., pV = p1V1 = p2V2 or 

We have (Wd)1-2 = p.dV

=

i.e., (Wd)1-2 = p1V1 ln 

= 0.1 x 106 x 1.293 ln 

= - 251595 J = - 251.595 kJ

Negative sign indicates that work is done on the system

Case ii) pV1-4 = C

i.e., p1V11-4 = p2V21-4 = ∴V2 = = 0.322 m3

We have, adiabatic process (Wd)1-2 = 

= 

= - 240381 J = - 240.381 kJ

Negative sign indicates that work is done on the system

* 1. O2 is compressed in a quasi static process according to the relation pV1-2 = C. The initial conditions are 98 KPa and 200 C and the final pressure is 1000 KPa. Assuming an ideal gas behaviour, determine the work required to compress 100 kg of O2. Compare this work with the work of isothermal compression, i.e., pV = C.

Solution: p1 =98 x 103 Pa, T1 = 2930 K, p2 = 1000 x 103Pa, m = 100 kg

We have for polytropic process,

(Wd)1-2 = 



But gas constant, = 0.2598 kJ

Also for polytropic process we have

∴T2 = 293 = 431.520K

∴ (Wd)1-2 = 

= -17938.34 kJ

Negative sign indicates that work is done on the system

Case ii) for isothermal process, we have

(Wd)1-2 = p1V1 ln 

Considering oxygen to be a perfect gas, we have pV = mRT

∴(Wd)1-2 =  since, pV = C = p1V1 = p2V2 i.e., V2/V1 = p1/p2

= -17626.94 kJ

Negative sign indicates that work is done on the system

* 1. The following data refer to a12 Cylinder, single-acting, two-stroke marine Diesel engine:

Cylinder diameter-0.8m

Stroke of piston-1.2m

Area of indicator diagram-5.5E10-4 m2

Length of diagram-0.06m

Spring value-147 MPa per m

Find the net rate of work transfer from the gas to the piston in kW.

Solution: Mean effective pressure, Pm, is given by

\*spring constant



=1.35 MPa

One engine cycle is completed in two strokes of the piston or one revolution of the crank shaft.

∴Work done in one minute= Pm LAN



=122 MJ

Since the engine is single-acting, and it has 12 cylinders, each contributing an equal power, the rate of work transfer from the gas to the piston is given by

W=122\*12 MJ/min

=24.4 MJ/s

=24.4 MW = 24,400 kW

* 1. A gas system has mass m, occupies a volume V at a pressure of p and temperature T. These properties are related by the equation  where a, b and R are constants. Obtain an expression for the displacement work done by this gas system during a constant temperature process where the gas expands from 1 m3 to 10 m3 at a temperature of 293 K. Assume a = 15.7 x 104 Nm4, b = 1.07 x 10-2 and R = 0.278kJ/kg-K.

Solution: For a given gas, 

Solving for p we get, 

∴Displacement work = (Wd)1-2 = ∫pdv

On substituting the values we get, (Wd)1-2 = 1744.8 x 103J = 1744.8 kJ