CH12 – THERMODYNAMICS

1. A geyser heats water flowing at the rate of 3.0 litres per minute from 27 °C to 77 °C. If the geyser operates on a gas burner, what is the rate of consumption of the fuel if its heat of combustion is 4.0×10^4 J/g?

Solution:

Given

Water is flowing at a rate of 3.0 litre/min

The geyser heats the water, raising the temperature from 27^0 C to 77^0 C.

Initial temperature, $T_1 = 27^0$ C

Final temperature, $T_2 = 77^0$ C

Rise in temperature, $T = T_2 – T_1$

= 77 – 27

= 50^0 C

Heat of combustion = 4×10^4 J / g

Specific heat of water, C = 4.2 J / g ^{0}C

Mass of flowing water, m = 3.0 litre / min

= 3000 g / min

Total heat used, Q = mcT

= 3000 x 4.2 x 50

On calculation, we get,

= 6.3×10^5 J / min

Rate of consumption = $6.3 \times 10^5 / (4 \times 10^4)$

We get,

= 15.75 g/min

Therefore, rate of consumption is 15.75 g/min

2. What amount of heat must be supplied to 2.0×10^{-2} kg of nitrogen (at room temperature) to raise its temperature by 45 °C at constant pressure? (Molecular mass of N_2 = 28; R = 8.3 J mol^{-1} K^{-1}.)

Solution:

Given,

Mass of nitrogen = 2×10^{-2} kg

= 20 g

Rise in temperature = ΔT

= 45^0 C

Heat required = Q =?

Q = nCT
We know,
C = 7R / 2 (diatomic molecule)
C = 7 x 8.3 / 2
n (no. of moles) = w / m
where,
w = 20 g
m = 28 u
n = 20 / 28
n = 1/ 1.4 moles
Let the temperature be 45 K
Q = 10 / 14 x 7 / 2 x 8.3 x 45
We get,
Q = 933.75 J

3. Explain why
(a) Two bodies at different temperatures T_1 and T_2 if brought in thermal contact, do not necessarily settle to the mean temperature $(T_1 + T_2)/2$.
(b) The coolant in a chemical or a nuclear plant (i.e., the liquid used to prevent the different parts of a plant from getting too hot) should have high specific heat.
(c) Air pressure in a car tyre increases during driving.
(d) The climate of a harbour town is more temperate than that of a town in a desert at the same latitude.

Solution:
(i). When two bodies having different temperatures, say T_1 and T_2 are brought in thermal contact with each other, there is a flow of heat from the body at the higher temperature to the body at the lower temperature till both the bodies reach an equilibrium position, i.e., both the bodies are having equal temperature. The equilibrium temperature is only equal to the mean temperature when the thermal capacities of both the bodies are equal.
(ii).The coolant used in a chemical or nuclear plant should always have a high specific heat. Higher is the specific heat of the coolant, higher is its capacity to absorb heat and release heat. Therefore, a liquid with a high specific heat value is the best coolant to be used in a nuclear or chemical plant. This would prevent different parts of the plant from getting too hot.

(iii). When the driver is driving a vehicle then due to the motion of air molecules the air temperature inside the tyre increases. And according to the Charles' law, the temperature is directly proportional to pressure. Therefore, when the temperature inside a tyre increases, then there is also an increase of air pressure.

(iv). The relative humidity in a harbour town is more than that of the relative humidity in a desert town. Humidity is a measure of water vapor in the atmosphere and the specific heat of water vapor is very high. Therefore, the climate of a harbour town is more temperate than that of a town in a desert at the same latitude.

4. A cylinder with a movable piston contains 3 moles of hydrogen at standard temperature and pressure. The walls of the cylinder are made of a heat insulator, and the piston is insulated by having a pile of sand on it. By what factor does the pressure of the gas increase if the gas is compressed to half its original volume?

Solution:

The cylinder is completely insulated from its surroundings.
Therefore, no heat is exchanged between the system (cylinder) and its surroundings.
Thus, the process is adiabatic
Initial pressure inside the cylinder = P_1
Final pressure inside the cylinder = P_2
Initial volume inside the cylinder = V_1
Final volume inside the cylinder = V_2
Ratio of specific heat, $\gamma = C_p / C_v = 1.4$
For an adiabatic process, we have:
$P_1V_1^\gamma = P_2V_2^\gamma$
The final volume is compressed to half of its initial volume
Hence,
$V_2 = V_1 / 2$
$P_1V_1^\gamma = P_2(V_1 / 2)^\gamma$
$P_2 / P_1 = V_1^\gamma / (V_1 / 2)^\gamma$
$= 2^{1.4}$
We get,
$= 2.639$
Therefore, the pressure increases by a factor of 2.639

5. In changing the state of a gas adiabatically from an equilibrium state A to another equilibrium state B, an amount of work equal to 22.3 J is done on the system. If the gas is taken from state A to B via a process in which the net heat absorbed by the system is 9.35 cal, how much is the net work done by the system in the latter case? (Take 1 cal = 4.19 J)

Solution:

Given

The work done (W) on the system while the gas changes from state A to state B is 22.3 J

This is an adiabatic process.

Therefore, change in heat is zero.

So,

$\Delta Q = 0$

$\Delta W = -22.3$ (Since the work is done on the system)

From first law of thermodynamics, we have:

$\Delta Q = \Delta U + \Delta W$

Where,

ΔU = Change in the internal energy of the gas

Hence,

$\Delta U = \Delta Q - \Delta W$

$= 0 - (-22.3\ J)$

We get,

$\Delta U = +22.3\ J$

When the gas goes from state A to state B via a process, the net heat absorbed by the system is:

$\Delta Q = 9.35$ cal

$= 9.35 \times 4.19$

On calculation, we get,

$= 39.1765\ J$

Heat absorbed, $\Delta Q = \Delta U + \Delta W$

Thus,

$\Delta W = \Delta Q - \Delta U$

$= 39.1765 - 22.3$

We get,

$= 16.8765\ J$

Hence, 16.88 J of work is done by the system

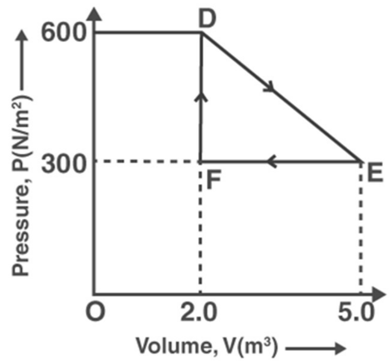
6. Two cylinders A and B of equal capacity are connected to each other via a stopcock. A contains a gas at standard temperature and pressure. B is completely evacuated. The entire system is thermally insulated. The stopcock is suddenly opened. Answer the following:
(a) What is the final pressure of the gas in A and B?
(b) What is the change in internal energy of the gas?
(c) What is the change in the temperature of the gas?
(d) Do the intermediate states of the system (before settling to the final equilibrium state) lie on its P-V-T surface?
Solution:
(a). Now, as soon as the stop cock is opened the gas will start flowing from cylinder P to cylinder Q which is completely evacuated, and thus the volume of the gas will be doubled because both the cylinders have equal capacity. And since the pressure is inversely proportional to volume, hence the pressure will get decreased to half of the original value.
Since the initial pressure of the gas in cylinder P is 1 atm, therefore, the pressure in each of the cylinder will now be 0.5 atm.
(b). Here, in this case, the internal energy of the gas will not change i.e. $\Delta U = 0$. It is because the internal energy can change only when the work is done by the system or on the system. Since in this case, no work is done by the gas or on the gas.
Therefore, the internal energy of the gas will not change.
c) There will be no change in the temperature of the gas. It is because during the expansion of gas there is no work being done by the gas. Therefore, there will be no change in the temperature of the gas in this process.
d). The above case is the clear case of free expansion and free expansion is rapid and it cannot be controlled. The intermediate states do not satisfy the gas equation and since they are in non – equilibrium states, they do not lie on the Pressure-Volume – Temperature surface of the system
7. A steam engine delivers 5.4×10^8 J of work per minute and services 3.6×10^9 J of heat per minute from its boiler. What is the efficiency of the engine? How much heat is wasted per minute?
Solution:
Given
Work done by the steam engine per minute, $W = 5.4 \times 10^8$ J
Heat supplied from the boiler, $H = 3.6 \times 10^9$ J

Efficiency of the engine = Output Energy / Input Energy
Hence,
$\eta = W / H$
$= 5.4 \times 10^8 / (3.6 \times 10^9)$
On simplification, we get,
= 0.15
Therefore, the percentage efficiency of the engine is 15%
Amount of heat wasted = $3.6 \times 10^9 - 5.4 \times 10^8$
We get,
$= 30.6 \times 10^8$
$= 3.06 \times 10^9$ J
Hence, the amount of heat wasted per minute is 3.06×10^9 J

8. An electric heater supplies heat to a system at a rate of 100W. If system performs work at a rate of 75 joules per second. At what rate is the internal energy increasing?

Solution:
According to law of conservation of energy
Total energy = work done + internal energy
$\Delta Q = \Delta W + \Delta U$
Here,
Rate at which heat is supplied $\Delta Q = 100$ W
Rate at which work is done $\Delta W = 75$ Js^{-1}
Rate of change of internal energy is ΔU
$\Delta U = \Delta Q - \Delta W$
$\Delta U = 100 - 75$
We get,
$\Delta U = 25$ J s^{-1}
Hence,
The internal energy of the system is increasing at a rate of 25 W

9. A thermodynamic system is taken from an original state to an intermediate state by the linear process shown in Fig. (12.13)



Its volume is then reduced to the original value from E to F by an isobaric process. Calculate the total work done by the gas from D to E to F

Solution:

Total work done by the gas from D to E to F = Area of ΔDEF
Area of ΔDEF = (1/2) x DE x EF
Where,
DF = Change in pressure
= 600 N/m^2 – 300 N/m^2
We get,
= 300 N/ m^2
FE = Change in volume
= 5.0 m^3 – 2.0 m^3
We get,
= 3.0 m^3
Area of ΔDEF = (1/ 2) x 300 x 3
On further calculation, we get,
= 450 J
Hence, the total work done by the gas from D to E to F is 450 J

10. A refrigerator is to maintain eatables kept inside at 9^0 C. If room temperature is 36^0 C, calculate the coefficient of performance.

Solution:

Temperature inside the refrigerator, T_1 = 9^0 C
= 273 + 9
= 282 K
Room temperature, T_2 = 36^0 C
= 273 + 36
= 309 K
Coefficient of performance = $(T_1) / (T_2 – T_1)$

On substituting, we get,
= 282 / (309 – 282)
We get,
= 10.44
Hence, the coefficient of performance of the given refrigerator is 10.44

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