Date:

the 2nd law of thermodynamics can be stated into a number of ways.

KELVIN'S STATEMENT:

"It is impossible to devise a process which may convert heat, extracted from a single reservoir, entirely into work without leaving any change in the working system.

Explanation:

According to kelvin, a sink is necessary for the working of a heat engine. It means that heat engine cannot work with a source only. Thus two bodies at different temperatures are essential for conversion of heat into work. This is the reason that we cannot utilize the heat contents of oceans & atmosphere because we donot have a temp reservoir lower than any one of the two

CLAUSIUS STATEMENT:

"It is impossible to construct a device which operates on a cycle & produce no other effect than the transfer of heat from a cooler body to a hotter body.

HEAT ENGINE:

A device which converts heat energy into mechanical energy is called a heat engine

eg: the earliest heat engine was steam engine

Cause: Heat engine was developed on the fact that when water is boiled in a vessel covered with a lid, the steam inside the tries to push the lid off showing the ability to do work. It become the cause for developing heat engine.

Construction:

A heat engine consist of following parts

1. Hot Reservoir: It is also called source. A body kept at high temperature is called hot reservoir. It is used to supply heat to the engine

2. Cold reservoir: It is also called sink. A body kept at low temperature is called cold reservoir. The remaining heat is rejected to the sink.

3. Working Substance: A working substance is needed which can absorb heat Q_1 from source, convert some of it into work W by its expansion & rejects the rest heat Q_2

to the cold reservoir or sink.

Cyclic heat engine:

A heat engine which operates in a cycle is called a cyclic heat engine.

Working of a heat engine:

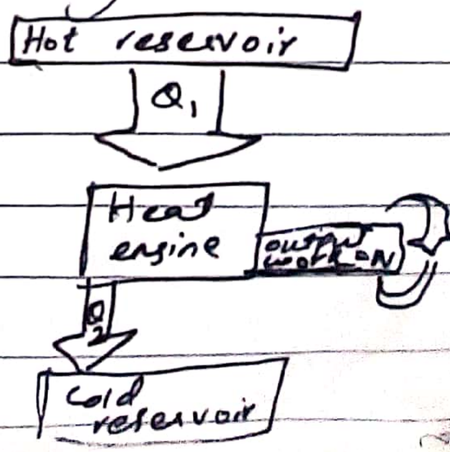
A heat engine absorbs heat Q_1 from the hot reservoir at Temperature T_1. It does work W and expels heat Q_2 to low Temperature reservoir at Temperature T_2. As the working substance under a cyclic process, returns to its initial state, the change in internal energy is zero.

Hence from first law of thermodynamics

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

$$\Delta Q = W$$

$$W = Q_1 - Q_2$$



Important:

Ayshe's

CARNOT ENGINE

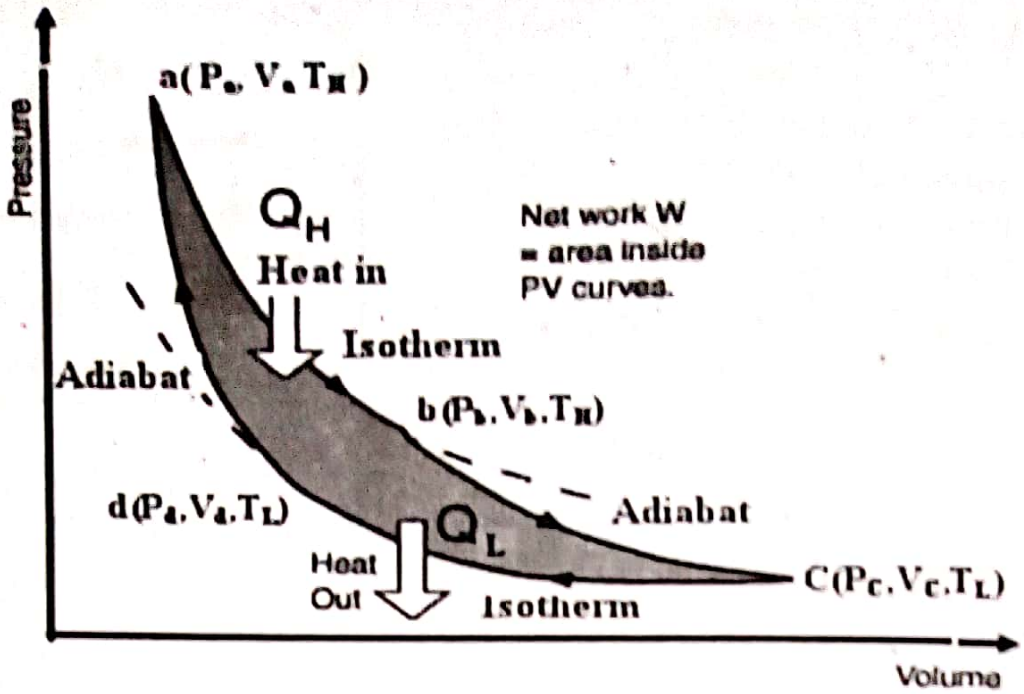
The most efficient heat engine is called Carnot heat engine. It was proposed by Carnot in 1824.

PRINCIPLE

The heat engine extracts heat from HTR and converts this heat partially into work and remaining is discharged into LTR. The work done is maximum during a cycle.

CONSTRUCTION

The Carnot heat engine consists of an ideal gas enclosed in a cylinder provided with movable piston. It has two thermal reservoirs called HTR and LTR.



WORKING

The Carnot heat engine operates in a cycle called Carnot cycle. The Carnot cycle has four steps. The behavior of Carnot cycle during four steps is shown on PV diagram.

1: ISOTHERMAL EXPANSION

Consider an ideal gas is enclosed in a cylinder provided with piston having pressure P_a, volume V_a and temperature T_H. Along path ab gas is expanded isothermally. The pressure and volume becomes P_b and V_b respectively. The temperature T_H is constant. Heat Q_H enters into system from HTR. The change in internal energy is zero. The work done is negative because $V_f > V_i$.

2: ADIABATIC EXPANSION

Along path bc, gas is expanded adiabatically. The pressure decreases from P_b to P_c and volume rises from V_b to V_c. The temperature falls from T_H to T_L. The work done is negative as $V_f > V_i$. The heat transfer is zero.

3: ISOTHERMAL COMPRESSION

Along path cd, gas is compressed isothermally. The pressure increases from P_c to P_d and volume reduces from V_c to V_d. The temperature is constant. The Heat Q_L is discharged into LTR. The work done is +ve as $V_f < V_i$.

4: ADIABATIC COMPRESSION

Along path da, gas is compressed adiabatically. The volume decreases from V_d to V_a and pressure rises from P_d to P_a. The heat transfer is zero. The work done is positive as $V_f < V_i$. The temperature rises from T_L to T_H.

EFFICIENCY OF CARNOT ENGINE

The Carnot cycle of Carnot heat engine consists of four processes

ISOTHERMAL EXPANSION PROCESS

The process along path ab is isothermal expansion in which temperature remains constant. The work done on ideal gas is

$$W = -\int_{V_i}^{V_f} P\,dV$$

$$W = -\int_{V_i}^{V_f} \frac{nRT}{V}\,dV \qquad [\,PV = nRT\,]$$

The temperature remains T_H during path ab and volume changes from V_a to V_b. The work done is W_1 and given as

$$W_1 = -\int_{V_a}^{V_b} \frac{nRT_H}{V}\,dV = -nRT_H \Big| \ln V \Big|_{V_a}^{V_b}$$

$$W_1 = -nRT_H \ln\left(\frac{V_b}{V_a}\right) \qquad \text{--------- (1)}$$

The first law of thermodynamics is

$$dE_{int} = dQ + dW$$

For isothermal expansion change in internal energy is zero because temperature is constant and work done is negative because $V_b > V_a$ and heat Q_H is taken positive because heat enters into system. Under these condition first law becomes

$$0 = Q_H + (-W_1)$$

$$Q_H = W_1 \qquad \text{--------- (2)}$$

Comparing eq(1) and eq(2)

$$Q_H = -nRT_H L_n\left(\frac{V_b}{V_a}\right) = nRT_H L_n\left(\frac{V_b}{V_a}\right)^{-1}$$

$$Q_H = nRT_H L_n\left(\frac{V_a}{V_b}\right) \qquad \text{--------- (3)}$$

ISOTHERMAL COMPRESSION PROCESS

The process along path cd is isothermal compression in which temperature remains T_L and volume changes from V_c to V_d. The work done is W_2 taken as positive because $V_d < V_c$ and given as

$$W_2 = +\int_{V_c}^{V_d} \frac{nRT_L}{V}\,dV = +nRT_L \Big| \ln V \Big|_{V_c}^{V_d}$$

$$W_2 = nRT_L \ln\left(\frac{V_d}{V_c}\right) \qquad \text{--------- (4)}$$

The first law of thermodynamics is

$$dE_{int} = dQ + dW$$

The change in internal energy is zero because temperature is constant and work done is positive because $V_d < V_c$ and heat Q_L is taken negative because heat leaves the system. Under these condition first law becomes

$$0 = (-Q_L) + (W_2)$$

$$Q_L = W_2 \quad \text{--------- (5)}$$

Comparing eq(4) and eq(5)

$$Q_L = n R T_L \, Ln\left(\frac{V_d}{V_c}\right) \quad \text{--------- (6)}$$

Divide eq(3) and eq(6)

$$\frac{Q_H}{Q_L} = -\frac{R T_H \, L_n\left(\frac{V_a}{V_b}\right)}{n R T_L \, Ln\left(\frac{V_d}{V_c}\right)}$$

$$\frac{Q_H}{Q_L} = \frac{T_H \, L_n\left(\frac{V_a}{V_b}\right)}{T_L \, Ln\left(\frac{V_d}{V_c}\right)} \quad \text{--------- (7)}$$

ADIABATIC EXPANSION PROCESS

The process along path bc is adiabatic expansion in which temperature changes from T_H to T_L and volume changes from V_b to V_c. The Boyle's law for adiabatic process is $P V^\gamma$ = Constant

$$P V^\gamma = \text{Constant}$$

$$\frac{n R T}{V} V^\gamma = \text{Constant} \qquad [P V = n R T]$$

$$T V^{\gamma - 1} = \text{Constant}$$

For path bc

$$T_H (V_b)^{\gamma - 1} = T_L (V_c)^{\gamma - 1} \quad \text{---------- (8)}$$

ADIABATIC COMPRESSION PROCESS

The process along path da is adiabatic compression in which temperature changes from T_L to T_H and volume changes from V_d to V_a.

For path da

$$T_L (V_d)^{\gamma - 1} = T_H (V_a)^{\gamma - 1}$$

$$T_H (V_a)^{\gamma - 1} = T_L (V_d)^{\gamma - 1} \quad \text{---------- (9)}$$

Dividing eq (8) and eq (9)

$$\frac{T_H (V_a)^{\gamma - 1}}{T_H (V_b)^{\gamma - 1}} = \frac{T_L (V_d)^{\gamma - 1}}{T_L (V_c)^{\gamma - 1}}$$

$$\frac{V_a}{V_b} = \frac{V_d}{V_c} \quad \text{---------- (10)}$$

Form eq (7) and eq (10)

$$\frac{Q_H}{Q_L} = \frac{T_H}{T_L} \frac{Ln\left(\frac{V_a}{V_b}\right)}{Ln\left(\frac{V_a}{V_b}\right)} = \frac{T_H}{T_L}$$

THERMAL EFFICIENCY

The net amount of work done during a Carnot cycle divided by heat input Q_H called thermal efficiency of Carnot heat engine and denoted by e.

$$e = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

Since $\frac{Q_H}{Q_L} = \frac{T_H}{T_L}$

$$e = 1 - \frac{T_L}{T_H}$$

The efficiency of Carnot heat engine will be 100%, if Q_L is zero. This is not possible because engine becomes perfect which is against Kelvin statement of second law of thermodynamics. The efficiency depends upon temperatures of HTR and LTR.