ESO201A

Lecture#30

(Class Lecture)

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The Second Law of Thermodynamics

Introduction

- The first law of thermodynamics states that during any cycle that a system undergoes, the cyclic integral of heat is equal to the cyclic integral of work. The first law, however, places no restrictions on the direction of flow of heat and work.

- A cycle in which a given amount of heat is transferred from the system and an equal amount of work is done on the system satisfies the first law just as well as a cycle in which the flows of heat and work are reversed.

Introduction
(contd.)

- However, we know from our experience that a proposed cycle that does not violate the first law does not ensure that the cycle will actually occur. It is this kind of experience that led to the formulation of the second law of thermodynamics.

- Thus, a cycle will occur only if both the first and second laws of thermodynamics are satisfied.

Introduction (contd.)

- In its broader significance, the second law acknowledges that processes proceed in a certain direction but not in the opposite direction.

- A hot cup of coffee cools by virtue of heat transfer to the surroundings, but heat will not flow from the cooler surroundings to the hotter coffee.

- Electrical work is transformed to heat but if heat is supplied to a wire an equivalent of electrical energy is not generated.

Such familiar observations as these, and a host of others, are evidence of the validity of the second law of thermodynamics.

Heat Engines

A heat engine is shown in Fig. 1. It consists of a cylinder fitted with appropriate stops and a piston. Let the gas in the cylinder constitute the system. Initially the piston rests on the lower stops, with a weight on the platform. Let the system now undergo a process in which heat is transferred from some high-temperature body to the gas, causing it to expand and raise the piston to the upper stops. At this point the weight is removed. Now let the system be restored to its initial state by transferring heat from the gas to a low-temperature body, thus completing the cycle. Since the weight was raised during the cycle, it is evident that work was done by the gas during the cycle. From the first law we conclude that the net heat transfer was positive and equal to the work done during the cycle.

Heat Engines

(Contd.)

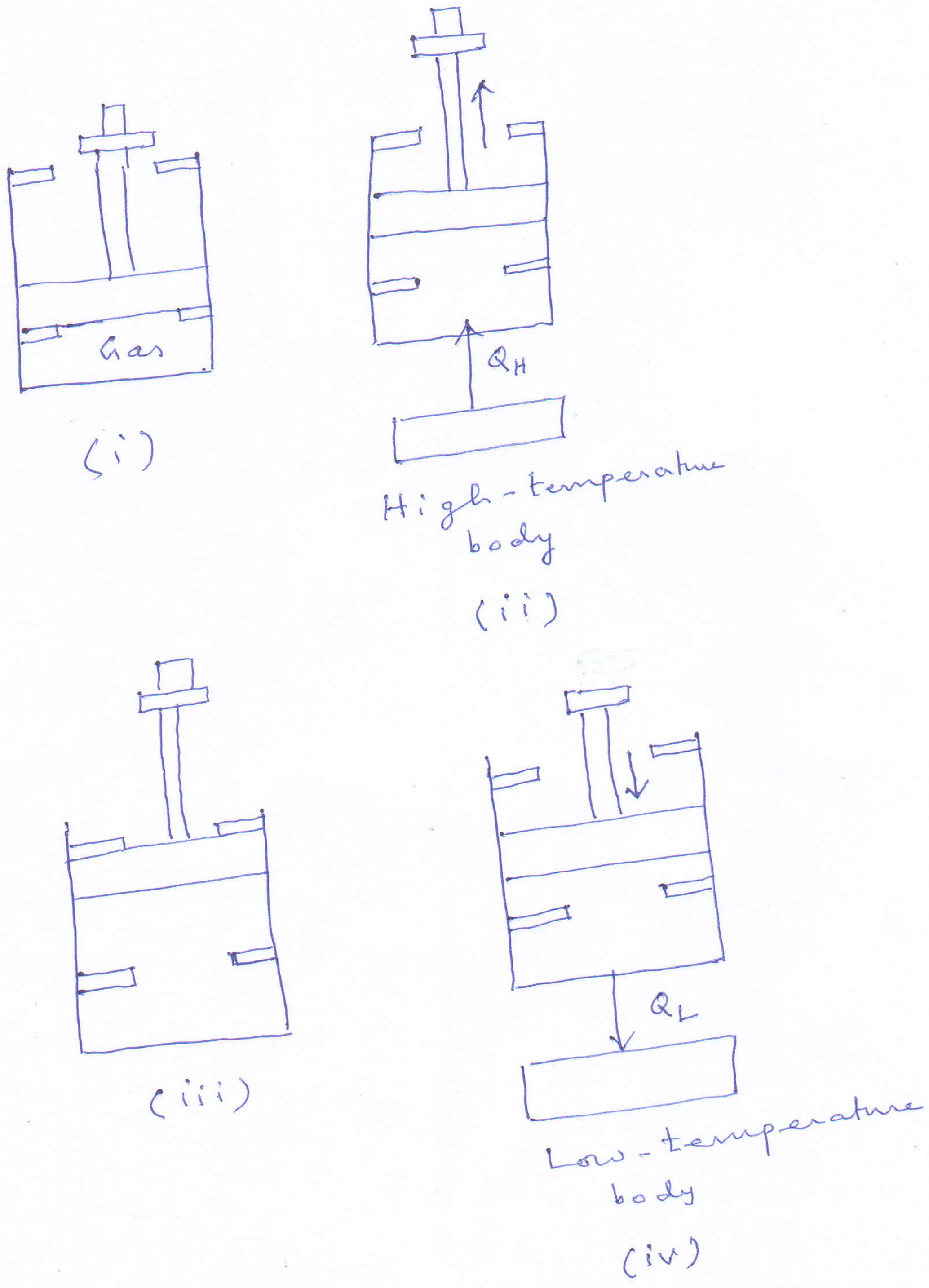

Fig. 1 A simple heat engine

Heat Engines (Contd.)

Such a device as shown in Fig. 1 is called a heat engine, and the substance to which and from which heat is transferred is called the working substance or working fluid.

A heat engine may be defined as a device that operates in a thermodynamic cycle and does a certain amount of net positive work through the transfer of heat from a high-temperature body to a low-temperature body.

Heat Engines (Contd.)

- Often the term heat engine is used in a broader sense to include all devices that produce work, either through heat transfer or through combustion, even though the device does not operate in a thermodynamic cycle. The internal combustion engine and the gas turbine are examples of such devices, and calling them heat engines is an acceptable use of the term.

- However, we are concerned with the more restricted form of heat engine, as just defined, one that operates on a thermodynamic cycle.

- A simple steam power plant is an example of a heat engine in this restricted sense.

Steam Power Plant

Each component in this plant may be analyzed individually as a steady-state, steady-flow process, but as a whole it may be considered a heat engine (Fig. 2) in which water (steam) is the working fluid.

An amount of heat, Q_H, is transferred from a high-temperature body, which may be the products of combustion in a furnace, a reactor, or a secondary fluid that in turn has been heated in a reactor.

In Fig. 2 the turbine is shown schematically as driving the pump. So, the net work delivered is

$W_{turbine} - W_{pump}$.

The quantity of heat Q_L is rejected to a low-temperature body, which is usually the cooling water in a condenser.

Thus, the simple steam power plant is a heat engine in a restricted sense, for it has a working fluid, to which and from which heat is transferred, and which does a certain amount of work as it undergoes a cycle.

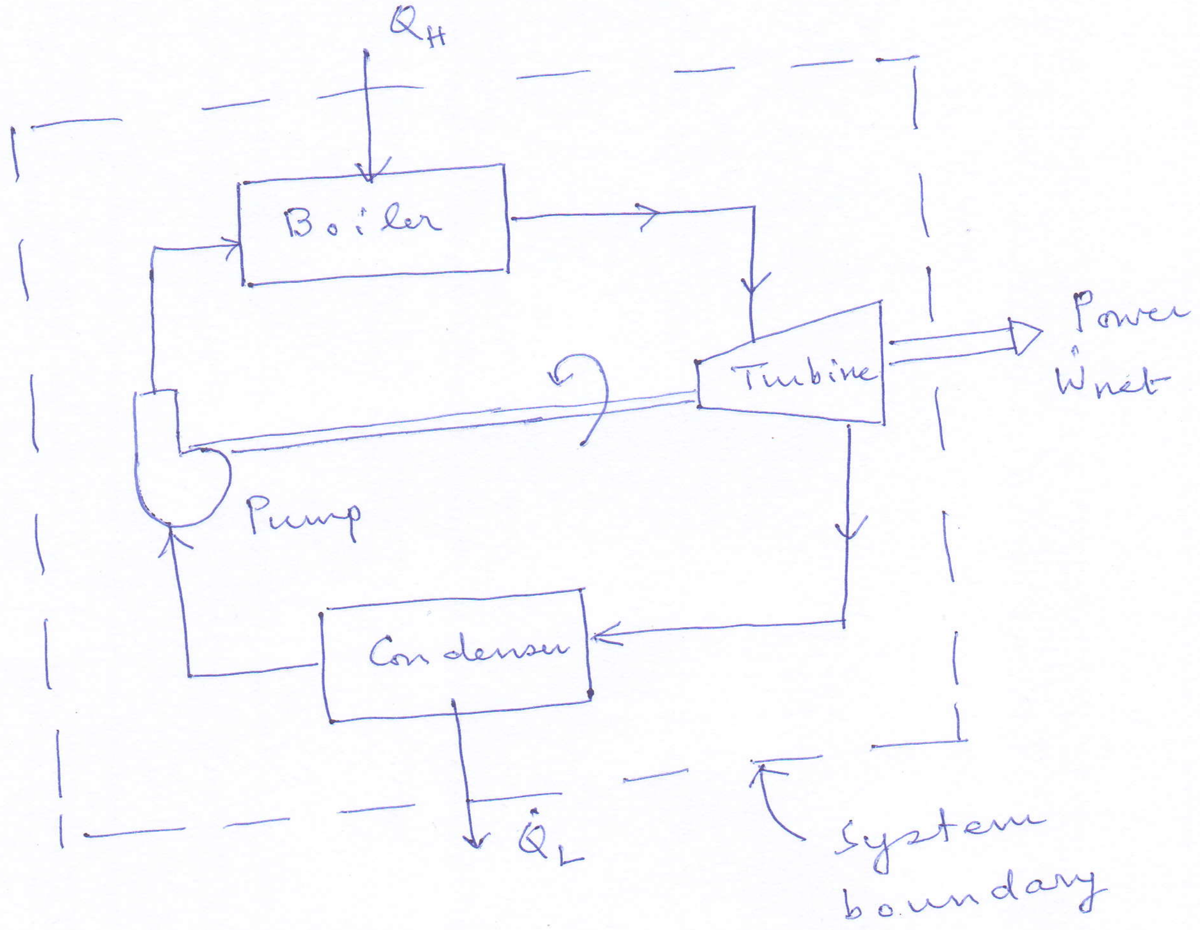

Fig. 2 Schematic diagram of a steam power plant

Thermal Efficiency

At this point, it is appropriate to introduce the concept of thermal efficiency of a heat engine.

Thermal efficiency

$$= \frac{\text{Net work output}}{\text{Total heat input}}$$

$Q_H \rightarrow$ Heat transfer to or from the high temp. body at T_H.

$Q_L \rightarrow$ Heat transfer to or from a low-temp. body at T_L.

We are not using the sign convention for heat here.

$$\text{or } \eta_{th} = \frac{W_{net,\,out}}{Q_H}$$

$$= \frac{Q_H - Q_L}{Q_H}$$

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

Note: Q_H and Q_L are defined as magnitudes and therefore, are positive quantities.

Typical values for the thermal efficiency of real engines are about 35–50% for large power plants, 30 – 35% for gasoline engines, and 30 – 40% for diesel engines.

The Second Law of Thermodynamics:

Kelvin-Planck Statement

On the basis of the discussion so far, we are now ready to present the Kelvin-Planck statement of the second law of thermodynamics.

The Kelvin-Planck Statement:

It is impossible to construct a device that will operate in a cycle and produce no effect other than the raising of a weight and the exchange of heat with a single reservoir.

See Fig. 3.

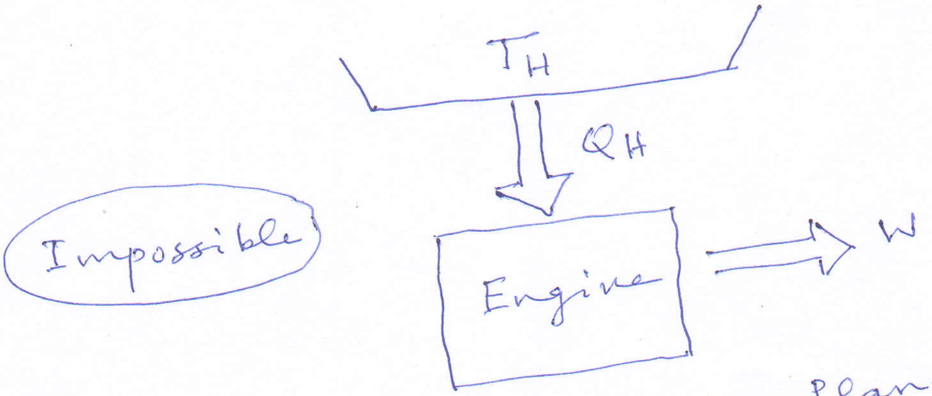

Fig. 3 Kelvin-Planck statement

The statement is in line with our discussion of the heat engine. In effect, it states that it is impossible to construct a heat engine that operates in a cycle, receives a given amount of heat from a high-temperature body, and does an equal amount of work.

The only alternative is that some heat must be transferred from the working fluid at a lower temperature to a lower temperature-body. Thus, work can be done by the transfer of heat only if there are two temperature levels, and heat is transferred from the high temperature body to the heat engine and also from the heat engine to the low-temperature body. This implies that it is impossible to build a heat engine that has a thermal efficiency of 100%.