In the reversed Carnot cycle with vapour as refrigerant, the isothermal processes of condensation and evaporation are internally reversible processes, and they are easily achievable in practice although there may be some problem in having only partial evaporation. However, isentropic compression and expansion processes have some limitations which are discussed in Chap. 3. In brief, it is difficult to design an expander to handle a mixture of largely liquid and partly vapour for the process 3-4. Also, because of the internal irreversibilities in the compressor and the expander, the actual COP of the Carnot cycle is very low, though the ideal cycle COP is the maximum. A cycle which is closest to the reversed Carnot vapour cycle is the vapour compression cycle described in Chap. 3.

There are two drawbacks of reversed Carnot cycle with gas as a refrigerant:

(i) Firstly, it is not possible to devise, in practice, isothermal processes of heat absorption and rejection, 4-1 and 2-3 in Fig. 2.15 with gas as the working substance. These are impractical as these will be infinitely slow.

(ii) Secondly, the cycle on *p-v* diagram is very narrow since the volume is changing both during the reversible isothermal and reversible adiabatic processes. Drawn correctly to scale, the Carnot *p-v* diagram is much thinner than the diagram illustrated in Fig. 2.15. As a result, the stroke volume of the cylinder is very large. The cycle, therefore, suffers from poor actual COP as a result of irreversibilities of the compressor and expander.

A gas refrigeration cycle, which is closest to reversed Carnot cycle with gas as a refrigerant, is described in Chap. 11.

2.8 ACTUAL REFRIGERATION SYSTEMS

Although the Carnot cycle is theoretically the most efficient cycle between given temperatures T_k and T_o, it has limitations for practical use. It is, therefore, found useful only as a criterion of perfection of cycle. In an actual cycle, the COPs, $\mathcal{E}_c$ and $\mathcal{E}_h$, will be less than their Carnot values. For the purpose of comparison between the actual and Carnot values, we define the *second law efficiency* or *exergetic efficiency* for cooling and heating, $(\eta_{\text{II}})_c$ and $(\eta_{\text{II}})_h$ as below:

$$(\eta_{\text{II}})_c = \frac{\mathcal{E}_c}{\mathcal{E}_{c,\,\text{Carnot}}}$$

$$(\eta_{\text{II}})_h = \frac{\mathcal{E}_h}{\mathcal{E}_{h,\,\text{Carnot}}}$$

Note that $\mathcal{E}_c$ and $\mathcal{E}_h$ are the first law COPs.

The conventional refrigeration systems work on the *vapour compression cycle* which is closest to the Carnot vapour cycle and has a high COP. *Gas cycle refrigeration* is used in aircraft refrigeration. Among the less conventional ones are the heat-operated refrigerating machines working on the *vapour absorption cycle* and *steam ejector cycle*.

There are also the low temperature refrigeration or cryogenic cycles, e.g., Linde cycle, Claude cycle, etc., used for the liquefaction of gases. Also, we have Philips liquefier which employs a cycle approaching the reversible Stirling cycle.

A recent development is the thermoelectric refrigeration as described in Fig. 1.11. But its COP is so poor that it cannot be exploited commercially. Temperatures approaching absolute zero have been obtained by adiabatic demagnetization, as described in Fig. 1.12, on a limited scale in laboratories.

Revision Exercises

2.1 (a) A refrigerator has working temperatures in the evaporator and condenser coils of –30 and 35°C respectively. What is the maximum possible COP of the refrigerator?

(b) If the actual refrigerator has a refrigerating efficiency of 0.75, calculate the refrigerating effect in kW and TR per kW of power input.

2.2 A reversed Carnot cycle has a COP for cooling of 4. Determine the temperature ratio T_k/T_o.

If the power consumption of the cycle is 7.5 kW, determine the refrigerating capacity of the machine in *TR*.

If the cycle is used as a heat pump with the same ratio of temperatures, determine its COP for heating and the quantity of heat pumped.

2.3 A Carnot refrigerator operates with Refrigerant 134a as a refrigerant condensing at 50°C and evaporating at –15°C.

Find its COP using the Carnot expression as well as the properties of R134a. Also determine the power consumption per ton of refrigeration.

2.4 The overall volume compression ratio of a reversed Carnot cycle working with air as a refrigerant is 10. The temperature limits of the cycle are 40°C and 0°C.

Determine:

(i) the pressure, volume and temperature at each point of the cycle,
(ii) the work done in the cycle,
(iii) the refrigerating effect, and
(iv) the COP of the cycle.

2.5 An air conditioning system is operating in an ambient of 45°C. The room temperature is maintained at 25°C. Determine the power consumption of the system per ton of refrigeration if it is,

(a) air-cooled as in a window-type air conditioner;
(b) water-cooled as in a central air conditioning plant.

The cooling water from cooling tower is available at 30°C. Assume suitable operating temperatures. Actual COP of the system is only 50% of the COP of the reversible cycle.

2.6 Determine the power consumption of a domestic refrigerator if its refrigerating capacity is $\frac{1}{8}$ TR. It is operating in an ambient of 40°C. Temperature in the freezer must be maintained at –15°C. COP of the system is half the Carnot COP. Assume suitable condensing and evaporating temperatures.