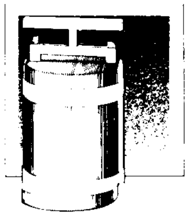


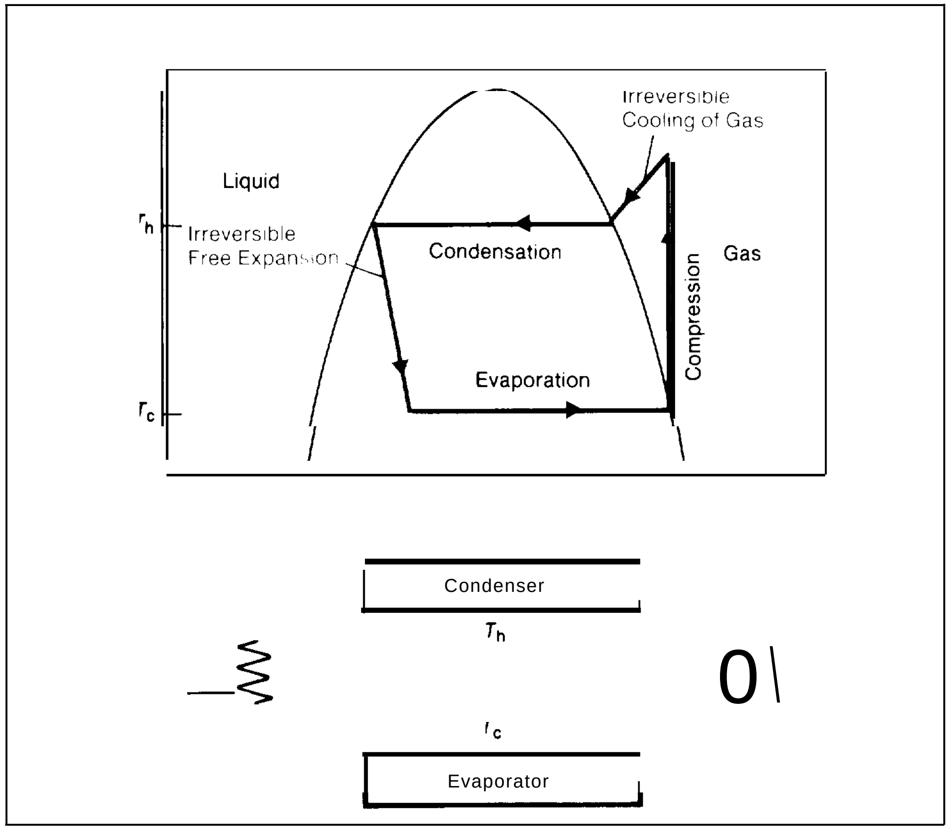
The Fridge

The basis for the household refrigerator is the Rankine cycle, which, as shown in the figure, duplicates a portion of the Carnot cycle in that it has one adiabatic step and two isothermal steps. A key feature of this cycle is a phase change in the working fluid. and the two isothermal steps correspond to condensation of the fluid at T_h and evaporation at T_c. Also, the engine operates with continuous flow rather than by reciprocating: the working fluid cycles through its various thermodynamic states by being forced around a closed loop.

This cycle has intrinsic irreversibilities associated with the free expansion of the liquid and the cooling of the gas to the temperature at which condensation occurs. Thus one expects the Rankine cycle to have less than ideal Carnot efficiency-even *before* accounting for such losses as those due to temperature differences at the heat exchangers. Nevertheless. Rankine engines remain the design of choice in many applications because they are simple and powerful. Many refrigerators will run thirty years with little or no maintenance, and overall cost is low.

The Rankine cycle can also be used in an air-to-air heat pump. Table 1 illustrates the effects of various irreversibilities on the coefficient of performance for such a pump—one designed to keep a house at 20°C when outside air is 5°C so that, ideally, $T_h - T_c$ is 15°C and the Carnot coefficient of performance is 19.5. The largest drop in the the estimated coefficient of performance occurs when ideal heat exchangers are replaced by practical heat exchangers—ones both small enough to get through the door of a house and cheap enough to cost less than the house. A small, cheap heat exchanger can only transfer large amounts of heat if a large temperature difference occurs across it. The net effect in our example is that the temperature difference. $T_h - T_c$ of the working fluid increases from 15°C to 50°C, causing the coefficient of performance for the Carnot cycle to drop from 19.5 to 6.4.

The C.O.P. drops to 5.1 when one takes into account the intrinsic irreversibilities of the Rankine cycle. Further decreases occur because of losses in the compressor (due to friction and the imperfect conversion of electrical power to shaft power) and miscellaneous losses (such as power to run the fans, the thermostat, and the controls). The final C. OP. for a practical, operating Rankine heat pump is 3.0, more than a factor of 6 lower than the C.O.P. for an ideal engine. ■



The Rankine cycle, used in the household refrigerator, is based on a liquid-gas phase change. The cycle is shown here superimposed on the phase diagram for the working fluid; a schematic of the heat pump is also shown. The Rankine cycle resembles the Carnot cycle in that there are two isothermal steps and, on the compression side, an adiabatic step. The two parts of the cycle (shown in red) that differ from the Carnot cycle—the cooling of the gas at constant pressure to the condensation temperature T_h and the free expansion of the liquid—are intrinsically irreversible. A

Table 1

Losses in the coefficient of performance (C. O. P.) due to irreversibilities for an air-to-air heat pump (adapted from *Hear Pumps by* R. D. Heap, 1983).

Cycle	Irreversibilities	T_c(°C)	T_h(°C)	C.O.P.
Carnot	none	5	20	19.5
Carnot	real heat exchangers	–5	45	6.4
Rankine	real heat exchangers. intrinsic irreversibilities	–5	45	5.1
Rankine	real heat exchangers. intrinsic irreversibilities, compressor losses	–5	45	4.0
Rankine	real heat exchangers. intrinsic irreversibilities, compressor losses, miscellaneous	–5	45	3.0