the state at the exit of the valve is a vapor-liquid mixture (state ~~4).~~ state 2 This cold stream passes through a heat exchanger in which the vapor-liquid mixture evaporates by drawing heat from the warm stream that is to be cooled. The refrigerant exits the evaporator as saturated vapor (stream 3). To return to throttling, the vapor must be compressed. The state at the exit of the compressor is superheated vapor (state ~~2).~~ state 4 To regenerate the compressed liquid, the vapor is condensed in a heat exchanger (condenser), which completes the cycle. In terms of energy exchanges, the cycle absorbs heat in the evaporator, consumes work in the compressor, and rejects heat in the condenser. The net effect is to "pump" heat from the low temperature of the evaporator to the higher temperature in the condenser through the input of work. This cycle is essentially the reverse of the Rankine power plant. The throttling valve may be replaced by an expander; this would accomplish the expansion while also producing some work, which could be used towards the compression. Most units utilize a throttling valve instead because it is much simpler to operate and maintain, but also because the amount of work that can be extracted from the expansion of a liquid is rather small.

Refrigeration cycles are often represented on the PH chart, which may also be used to perform a graphical solution of the energy balances. Figure 6-13 shows the path of the vapor compression cycle on this chart. Ignoring pressure drops in pipes and heat exchangers, the cycle operates between two pressures, a high pressure that is achieved by the compressor, and a lower pressure that is accomplished by throttling. On the PH chart throttling is represented by a vertical line at constant enthalpy. Heat transfer in the evaporator and in the condenser takes place at constant pressure. For a reversible compressor, the path would follow a line of constant entropy; for a real compressor with an efficiency less than 100%, the compressed vapor emerges hotter and to the right of the isentropic path. The temperature of the evaporator is controlled by the throttling pressure. The lower this pressure, the colder the temperature. It is generally desirable, however, to maintain the pressure in the evaporator near or above atmospheric in order to avoid the expense of vacuum equipment.

Thermodynamic Analysis of Refrigeration

The energy balance on the refrigeration cycle is

$$Q_E + Q_C + W_C = 0, \tag{6.66}$$

where Q_E is the amount of heat removed from the evaporator ($Q_E > 0$), Q_C is the amount of heat rejected in the condenser ($Q_C < 0$), and W_C is the work for compression ($W_C > 0$). The entropy balance is obtained by noting that the refrigerant operates as a cycle and thus does not contribute to the generation of entropy.