

Thermodynamics and Refrigeration Cycles

Second law

$$\begin{aligned} \dot{q}_{12} &= \dot{m}(x_2 - x_1) - \frac{\dot{Q}_{12}}{T_0} \\ &= 345(0.0750 - 0.0761) - (-207/549.67) \\ &= 0 \text{ Btu/h} \cdot ^\circ\text{R} \end{aligned}$$

Expansion Device:
Energy balance

$$\dot{q}_{23} = \dot{m}(h_3 - h_2) = 0$$

Second law

$$\dot{q}_{23} = \dot{m}(x_3 - x_2) = 345(0.0880 - 0.0750) = 1.725 \text{ Btu/h} \cdot ^\circ\text{R}$$

These results are summarized in Table 4. For the Carnot cycle,

$$\text{COP}_{\text{Carnot}} = \frac{T_0}{T_0 - T_2} = \frac{479.67}{70} = 6.852$$

The Carnot power requirement for the 2-ton load is

$$\dot{W}_{\text{Carnot}} = \frac{\dot{Q}_{\text{cooling}}}{\text{COP}_{\text{Carnot}}} = \frac{24,000}{6.852} = 3502 \text{ Btu/h}$$

The actual power requirement for the compressor is

$$\begin{aligned} \dot{W}_{\text{comp}} &= \dot{W}_{\text{Carnot}} + \dot{I}_{\text{total}} T_0 \\ &= 3502 + 7.543 \times 549.67 = 7648 \text{ Btu/h} \end{aligned}$$

This result is within computational error of the measured power input to the compressor of 7633 Btu/h.

The analysis in Example 5 can be applied to any actual vapor compression refrigeration system. The only required information for second-law analysis is the refrigerant thermodynamic state points and mass flow rates and the temperatures in which the system is exchanging heat. In this example, the extra compressor power required to overcome the irreversibility in each component is determined. The component with the largest loss is the compressor. This loss is due to motor inefficiency, friction losses, and irreversibilities caused by pressure drops, mixing, and heat transfer between the compressor and the surroundings. Unrestrained expansion in the expansion device is the next largest (also a large loss), but could be reduced by using an expander rather than a throttling process. An expander may be economical on large machines.

All heat transfer irreversibilities on both the refrigerant side and the air side of the condenser and evaporator are included in the analysis. Refrigerant pressure drop is also included. Air-side pressure drop irreversibilities of the two heat exchangers are not included, but these are equal to the fan power requirements because all the fan power is dissipated as heat.

An overall second-law analysis, such as in Example 5, shows the designer components with the most losses, and helps determine which components should be replaced or redesigned to improve

Table 4 Energy Transfers and Irreversibility Rates for Refrigeration System in Example 5

Component	\dot{Q} , Btu/h	\dot{W} , Btu/h	\dot{I} , Btu/h \cdot $^\circ$ R	$\dot{I}/\dot{I}_{\text{total}}$, %
Evaporator	24,000	0	1.405	19
Suction line	586	0	0.279	4
Compressor	-494	7633	2.417	32
Discharge line	-1360	0	0.441	6
Condenser	-36,153	0	1.278	17
Liquid line	-207	0	0	0
Expansion device	0	0	1.725	23
Totals	-7648	7633	7.543	

performance. However, it does not identify the nature of the losses; this requires a more detailed second-law analysis of the actual processes in terms of fluid flow and heat transfer (Liang and Kuehn 1991). A detailed analysis shows that most irreversibilities associated with heat exchangers are due to heat transfer, whereas air-side pressure drop causes a very small loss and refrigerant pressure drop causes a negligible loss. This finding indicates that promoting refrigerant heat transfer at the expense of increasing the pressure drop often improves performance. Using a thermoeconomic technique is required to determine the cost/benefits associated with reducing component irreversibilities.

3. ABSORPTION REFRIGERATION CYCLES

An absorption cycle is a heat-activated thermal cycle. It exchanges only thermal energy with its surroundings; no appreciable mechanical energy is exchanged. Furthermore, no appreciable conversion of heat to work or work to heat occurs in the cycle.

Absorption cycles are used in applications where one or more of the exchanges of heat with the surroundings is the useful product (e.g., refrigeration, air conditioning, and heat pumping). The two great advantages of this type of cycle in comparison to other cycles with similar product are

- No large, rotating mechanical equipment is required
- Any source of heat can be used, including low-temperature sources (e.g., waste heat, solar heat)

3.1 IDEAL THERMAL CYCLE

All absorption cycles include at least three thermal energy exchanges with their surroundings (i.e., energy exchange at three different temperatures). The highest- and lowest-temperature heat flows are in one direction, and the mid-temperature one (or two) is in the opposite direction. In the forward cycle, the extreme (hottest and coldest) heat flows are into the cycle. This cycle is also called the heat amplifier, heat pump, conventional cycle, or Type I cycle. When extreme-temperature heat flows are out of the cycle, it is called a reverse cycle, heat transformer, temperature amplifier, temperature booster, or Type II cycle. Figure 16 illustrates both types of thermal cycles.

This fundamental constraint of heat flow into or out of the cycle at three or more different temperatures establishes the first limitation on cycle performance. By the first law of thermodynamics (at steady state),

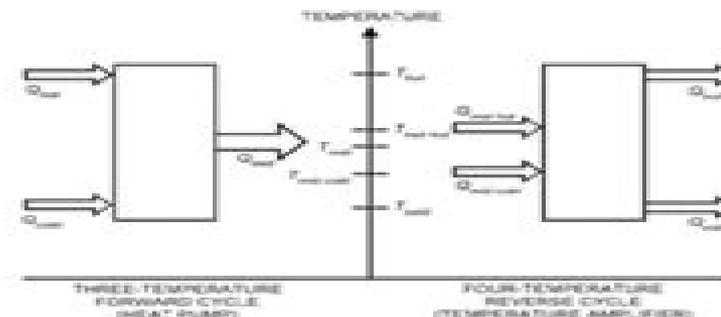


Fig. 16 Thermal Cycles

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90.1 User's Manual American Society of Heating, Refrigerating and Air-Conditioning Engineers,2004 This User s Manual provides detailed instruction for the design of commercial and high rise residential buildings to ensure their compliance with ANSI ASHRAE IESNA Standard 90 1 2004 In addition this Manual encourages the user to apply the principles of effective energy conserving design when designing buildings and building systems offers information on the intent and application of Standard 90 1 illuminates the Standard through the use of abundant sample calculations and examples streamlines the process of showing compliance provides Standard forms to demonstrate compliance provides useful reference material to assist designers in efficiently completing a successful and complying design This Manual also instructs the user in the application of several tools used for compliance with Standard 90 1 the EnvStd computer program used in conjunction with the Building Envelope Trade Off

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