(c) The condenser water flow rate generally is estimated as 3.5 gpm per ton. Thus the full load condenser flow rate is $200 \times 3.5 = 700$ gpm.

(d) The chilled water flow rate is:

$$\text{gpm} = \frac{\text{Refrigeration load (tons)} \times 24}{\text{chilled water temp. difference}}$$

$$= \frac{200 \times 24}{8} = 600 \text{ gpm}$$

(e) The heat rejected to the cooling tower is:

$$Q_r = 12{,}000 H_r F_{hr}$$

where

Q_r = heat rejected to cooling tower, Btuh.
H_r = refrigeration load, tons.
F_{hr} = heat rejection factor.

A typical value of the heat rejection factor may be taken as 2.6. Therefore:

$$Q_r = 12{,}000 \times 200 \times 2.6$$
$$= 6{,}240{,}000 \text{ Btuh}$$

Scale (fouling) factors higher than 0.0005 in the absorber-condenser circuit have the same effect as an increase in condenser water temperatures. For a scale (fouling) factor of 0.001, multiply the overall capacity factor by 0.85. For a scale factor of 0.002, multiply the overall capacity factor by 0.65.

Operating conditions not included within the limits shown here may be considered sufficiently unusual to require the direct assistance of manufacturers' representatives. The selection of absorption machines to operate on hot water or other hot fluids should generally be referred directly to the manufacturer.

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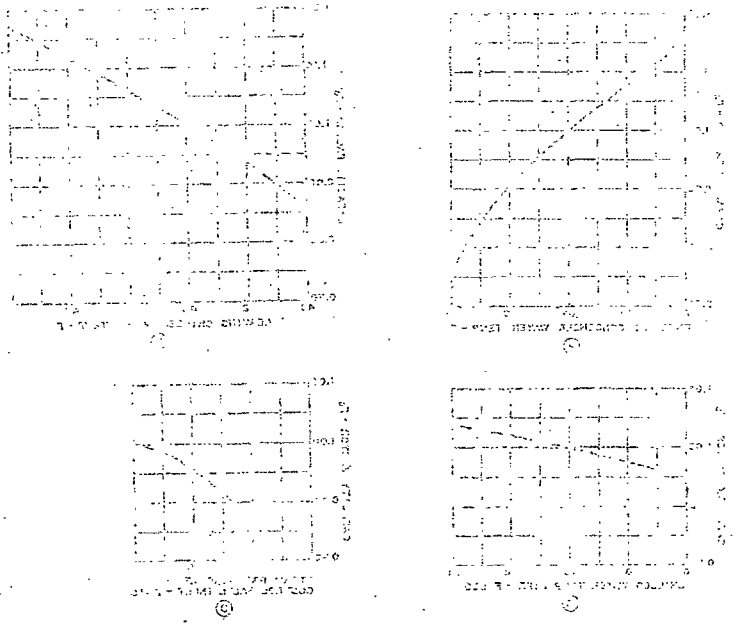
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CHAPTER 41

AIR-CYCLE EQUIPMENT

Air-Cycle Systems: Simple, Bootstrap, Regenerative, and Reduced Ambient Types; Compartment Air Temperature Control, Air Flow Control, Water Separator Anti-Ice Control; Sources of High Pressure Air; Estimating Performance of Fixed-Size Air-Cycle Refrigeration Units; Design of Systems for Other Air Flow Capacity

AIR-CYCLE refrigeration systems are used commonly in the air conditioning of both military and commercial aircraft principally because of the extremely lightweight, compact equipment which is typical of air-cycle systems. Air-cycle air conditioning has not been found to be economical in residential and commercial buildings, because higher power is required to operate an air-cycle system than a conventional vapor-cycle system.

In a refrigeration system using the open air-cycle principle, the refrigerant is air and is used directly to cool the space requiring refrigeration. Unlike the refrigerant of a vapor-cycle system, which continuously changes phase from a liquid to a gas and back to a liquid again, the refrigerant of an air-cycle system remains in the gaseous phase throughout the cycle.

Refrigeration in a simple open air-cycle system is obtained by three basic steps: (1) compression, (2) heat transfer, and (3) expansion accompanied by work extraction. Air is first compressed in a compressor to a pressure higher than the pressure of the space to be cooled. The heat of compression then is removed from the air in a heat exchanger by rejecting it to a suitable heat sink such as air. In the third step air is cooled by extracting work from it as it expands through a turbine. The expansion of air through a simple throttling device, such as an orifice or a valve, does not noticeably lower the air temperature. Therefore work must be extracted from the expanding air. This is accomplished by providing a load on the turbine. The amount of cooling derived from the turbine is a direct function of the amount of work done by the turbine. The load in many cases is a fan which draws cooling air through the heat exchanger located, in most systems, immediately upstream from the turbine. The cold air from the turbine discharge is used directly for refrigeration purposes.

The Lockheed P-80 Shooting Star airplane made use of an early air-cycle system. That system, however, was not truly a simple air-cycle system, because the cooling turbine fan was used merely as a loading device for the expansion turbine, and ram air pressure was used to force cooling air across the heat exchanger. In a true basic air-cycle system the cooling turbine fan induces flow of cooling air across the heat exchanger. A system of this type used for aircraft application was installed in the Douglas XB-43 airplane. Later a true basic air-cycle refrigeration unit was produced for the Lockheed P-80 airplane. The heat exchanger of that unit was a multipass design utilizing a tubular-type heat transfer surface. The cooling turbine contained a rotating assembly consisting of a turbine wheel and a fan fastened to opposite ends of a common shaft. The rotational speed of this assembly was approximately 100,000 rpm. The refrigeration unit weighed 16 lb and supplied cold air to the cockpit at a rate of 7 lb per min.

Since the time of the P-80 airplane, almost all high-speed, high-altitude airplanes have been equipped with air-cycle refrigeration systems. Refrigeration units have been built in various sizes ranging in weight from 6.5 to 200 lb and ranging in air flow capacity between 7 and 150 lb per min.

AIR-CYCLE REFRIGERATION SYSTEMS

The common air-cycle systems which will be discussed in this chapter are: (1) basic (or simple) type, (2) bootstrap type, (3) regenerative, and (4) reduced ambient type. There are also many other air-cycle systems that are variations or combinations of these systems.

The two systems which have had the greatest use are the basic and bootstrap types.

Basic and Basic-Evaporative Types

The air-cycle refrigeration system, shown in Fig. 1, consists of an air-to-air heat exchanger and a cooling turbine. High-pressure, high-temperature air is cooled initially in the heat

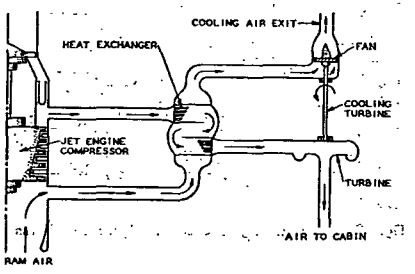


Fig. 1 .... Basic Air-Cycle Refrigeration System

The general responsibility for this chapter is assigned to TC 6.4, Transportation.