a tip diameter D between approximately 3.5 and 12 in.

$$(F_T)_{4.5} = (F_T)_D\left(\frac{D}{6.5}\right)$$

or

$$\left(\frac{N}{2750\sqrt{(\Delta T_1)_{4.5}}}\right)_{4.5} = \left(\frac{N}{2750\sqrt{(\Delta T_1)_{4.5}}}\right)_D\left(\frac{D}{6.5}\right)$$

$$(F_{TF})_{4.5} = (F_{TF})_D$$

$$\left(\frac{W_B\sqrt{T_1}}{P_1A}\right)_{4.5} = \left(\frac{W_B\sqrt{T_1}}{P_1A}\right)_D$$

$$\left(\frac{P_2}{P_1}\right)_{4.5} = \left(\frac{P_2}{P_1}\right)_D$$

$$(M)_{4.5} = (M)_D$$

or

$$\left(\frac{N}{1725\sqrt{T_1}}\right)_{4.5} = \left(\frac{N}{1725\sqrt{T_1}}\right)_D\left(\frac{D}{6.5}\right)$$

$$(A)_D = (A)_{4.5}\left(\frac{D}{6.5}\right)^2$$

Heat Exchangers

Figs. 10 and 11 present the performance of a two-pass, combination cross-counterflow, air-to-air, aluminum heat exchanger with a plate-fin type heat transfer surface. The overall core dimensions of this unit are 5.2 in. in the no-flow direction (L_n), 6.2 in. in the bleed air flow direction (L_B), and 7.2 in. in the cooling air flow direction (L_c). The weight of this core proper is approximately 6.7 lb.

Figs. 16 and 18 present the performance of a single-pass, crossflow, air-to-air, aluminum heat exchanger with a flattened and dimpled tubular type heat transfer surface. The overall core dimensions of this unit are 14.5 in. in the no-flow direction (L_n), 22 in. in the bleed air flow direction (L_B), and 12 in. in the cooling air-flow direction (L_c). The weight of the core is approximately 37 lb.

Figs. 17 and 20 present the performance of a two-pass cross-counterflow, air-to-air, aluminum heat exchanger with a flattened and dimpled tubular type heat transfer surface. The overall core dimensions of this unit are 14.6 in. in the no-flow direction (L_n), 13.1 in. in the bleed air flow direction (L_B), and 6.5 in. in the cooling air flow direction (L_c). The weight of the core is approximately 48 lb.

By increasing or decreasing the length of any of the three heat exchangers in the no-flow direction only, the performance of the new heat exchangers can be determined from the given performance by using the following formulas:

$$(W_B)_{new} = (W_B)_{old}\frac{(L_c)_{new}}{(L_c)_{old}}$$

$$(W_C)_{new} = (W_C)_{old}\frac{(L_c)_{new}}{(L_c)_{old}}$$

$$(\sigma\Delta P)_{new} = (\sigma\Delta P)_{old}$$

$$(\text{Core Weight})_{new} = (\text{Core Weight})_{old}\frac{(L_n)_{new}}{(L_n)_{old}}$$

BIBLIOGRAPHY

P. C. Scofield: Air cycle refrigeration (REFRIGERATING ENGINEERING, June 1949, p. 558).

H. J. Wood: Air conditioning military aircraft (*SAE Journal*, February 1947, p. 58).

B. L. Messinger: Refrigeration for air conditioning pressurized transport aircraft (*SAE Journal*, March 1946, p. 93).

R. C. Jordan and G. B. Priester: *Refrigeration and Air Conditioning* (Prentice-Hall, Inc., New York, 1956).

CHAPTER 42

CONDENSERS

WATER-COOLED CONDENSERS: Heat Removed, Overall Heat Transfer, Fouling Factors, Horizontal Closed Shell-and-tube Ammonia Condensers, Vertical Open Shell-and-tube Ammonia Condensers, Other Types, Noncondensable Gases, Liquid Receivers; AIR-COOLED CONDENSERS: Function and Mechanism of Operation Types, Selection and Rating, Control, Installation and Maintenance; EVAPORATIVE CONDENSERS: Coils, Coil Wetting, Air Flow, Heat Transfer Process, Ratings, Accessory Coils, Location, Capacity Modulation; Liquid Receivers

THE condenser in a refrigerating system removes, from the compressed refrigerant gas, the heat of compression and the heat absorbed by the refrigerant in the evaporator. The refrigerant is thereby converted back into the liquid phase at the condenser pressure and is available for re-expansion into the evaporator.

The common forms of condensers may be broadly classified on the basis of the cooling medium as: (1) water-cooled, (2) air-cooled, and (3) evaporative (air and water) cooled.

PART I: WATER-COOLED CONDENSERS

Within this classification the following general types are used: (1) shell-and-tube (vertical), (2) shell-and-tube (horizontal), (3) shell-and-coil (horizontal and vertical), (4) double pipe, and (5) atmospheric.

The selection of a water-cooled condenser is dependent upon the cooling load, the refrigerant used, the source of the cooling water, the condenser location, and the required operating pressures.

Heat Removed

The heat in Btu per minute removed in the condenser for each ton of refrigeration (12,000 Btuh) produced in the evaporator, may be estimated from Fig. 1 for ammonia, Fig. 2 for Refrigerant 12, and Fig. 3 for Refrigerant 22. The theoretical values shown are based on saturated vapor at the compressor inlet and on adiabatic compression.

The quantity of condensing water required for each ton of refrigeration produced in the evaporator may be found from Equation 1.

$$w = \frac{H}{8.33(t_2 - t_1)} \qquad (1)$$

where

w = weight of condensing water, gallons per (minute) (ton).
H = heat to be removed in condenser, Btu per (minute) (ton).
t_1 = temperature of water entering condenser, Fahrenheit.
t_2 = temperature of water leaving condenser, Fahrenheit.
8.33 = pounds of water per gallon.

Table 1 gives the maximum water temperature and hardness of city water supplies for various localities in the United States. These temperatures may be used if specific information is not available regarding the temperature of water entering a condenser using city water.

Example 1: Determine the quantity of condensing water required per ton of refrigeration for an ammonia condenser operating at a condensing temperature of 100 F, a suction temperature of 13 F, an initial condensing water temperature of 85 F, and a final condensing water temperature of 90 F.

Solution: From Fig. 1, H is found to be 247 Btu per (min) (ton). From Equation 1:

$$w = \frac{247}{8.33(90 - 85)} = 5.9 \text{ gpm per ton.}$$

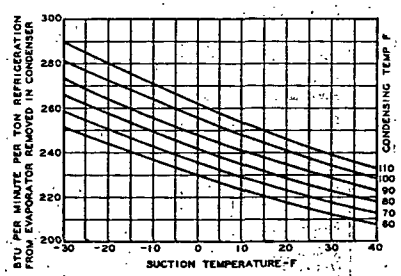
Overall Heat Transfer

The computation of *overall heat transfer* in a condenser may be made from test data of heat transfer coefficients of the water and refrigerant sides, physical measurements of the condenser, and assumed fouling factors, by using Equation 2:

$$U = \frac{1}{\frac{S_B}{h_i} + \frac{S_B}{h_f} + \frac{L}{k} + \frac{1}{h_o}} \qquad (2)$$

where

U = overall heat transfer coefficient, Btu per (hour) (square foot) (Fahrenheit degree), based on the external surface and the mean temperature difference between the external and internal surfaces.
S_B = ratio of external surface to internal surface.
h_i = internal, or water-side, film coefficient, Btu per (hour) (square foot) (Fahrenheit degree).
h_f = fouling allowance on water-side, Btu per (hour) (square foot) (Fahrenheit degree).
h_o = external, or refrigerant-side, coefficient, Btu per (hour) (square foot) (Fahrenheit degree).
L = thickness of tube wall, inches.



[a] *Per ton of refrigerating effect occurring in evaporator.*

Fig. 1 . . . . Heat Removed in Ammonia Condenser[a]

The general responsibility for this chapter is assigned to TC 9.1, Coils, Fan-Coil Units, Air-Cooled Condensers; TC 9.2, Liquid Heat Exchangers; and TC 9.3, Cooling Towers, Evaporative Condensers.