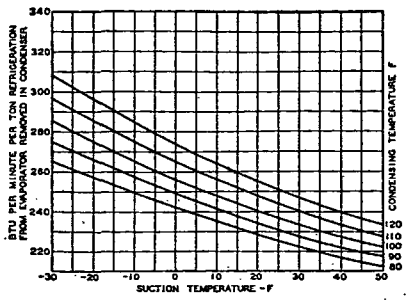


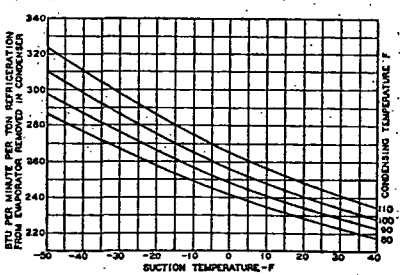
[a] Per ton of refrigerating effect occurring in evaporator.

Fig. 2 .... Heat Removed in Refrigerant 12 Condenser[a]

lished after some period of use, but on steel tubes fouling seems to be progressive and performance after each successive period of use and recleaning is often progressively lower.

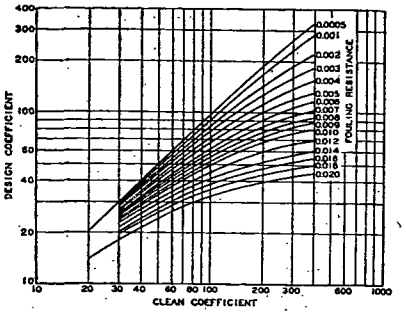
Bimetallic tubes, in which the outer tube is steel and the inner liner is copper, admiralty metal, or other nonferrous alloy, have good cleanability for ammonia condenser applications. Since ammonia condenser ratings should be based upon the fouled and corroded condition of steel tubes, it is possible to obtain the same performance and a more consistent heat transfer rate with less surface by using bimetallic tubes. The cost of bimetallic tubes may be about three times that of ordinary steel tubing, but can often be justified by the use of less surface, longer life, and better performance.

The progressive decrease in capacity of shell-and-tube or shell-and-coil condensers is due to the fouling on the water-side of the tubes. In order that condensers will have sufficient excess tube surface to maintain satisfactory performance in normal operation, with a reasonable period of service between cleanings, it is recommended that standard minimum fouling factors be used. For general rating purposes the values of fouling factors $1/h_f$ are recommended[4] as 0.0005 for nonferrous tubes and 0.001 for steel tubes. For conditions of extreme fouling and poor maintenance, higher fouling factors should be used. The factor is the reciprocal of the heat transfer rate through the layer of the deposit on the surface of the tubing. The effect of fouling resistances in reducing clean



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

Fig. 3 .... Heat Removed in Refrigerant 22 Condenser[a]



Note: Fouling resistance $1/h$ is equivalent to S_E/h_f. In using Fig. 1, if the added fouling resistance is based on external surface, use the fouling resistance curves directly. If the added fouling resistance is based on internal surface, use an equivalent external resistance found by multiplying the internal fouling resistance by the ratio of external to internal surface (S_E).

Fig. 4 .... Effect of Fouling Resistance on Heat Transfer Coefficients

tube coefficients is shown in Fig. 4. Since it is customary to refer all resistances to external surface, Fig. 4 may be used directly for external fouling, but for internal fouling the fouling factor $1/h_f$ must be multiplied by the ratio of the external to internal tube surfaces S_E.

Example 8: Determine the design coefficient U for a shell-and-tube condenser (water in the tubes and refrigerant in the shell) with finned tubes having a ratio of external to internal surface, S_E, of 3.54, if the coefficient for clean tubes is 200 Btu per (hr) (sq ft) (F deg) and the water-side fouling resistance $1/h_f$ is 0.001.

Table 2 .... Fouling Factors for Condenser Water

Types of Water	For Non-ferrous Tubes Water Velocity, fps		For Ferrous Tubes Water Velocity, fps	
	3 or less	Over 3	3 or less	Over 3
Sea Water	0.0005	0.0005	0.001	0.001
Brackish Water	0.002	0.001	0.004	0.002
Cooling Tower and Artificial				
Spray Pond: Treated Make-Up	0.001	0.001	0.002	0.002
Untreated	0.003	0.003	0.006	0.006
City or Well Water (Such as Great Lakes)	0.001	0.001	0.002	0.002
Great Lakes	0.001	0.001	0.002	0.002
River Water:				
Minimum	0.002	0.001	0.004	0.002
Mississippi	0.003	0.002	0.006	0.004
Delaware, Schuykill	0.003	0.002	0.006	0.004
East River and New York Bay	0.003	0.002	0.006	0.004
Chicago Sanitary Canal	0.008	0.006	0.016	0.012
Muddy or Silty	0.003	0.002	0.006	0.004
Hard (Over 15 grains/gal)	0.003	0.003	0.003	0.003
Engine Jacket	0.001	0.001	0.002	0.002
Distilled	0.0005	0.0005	0.001	0.001
Treated Boiler Feedwater	0.001	0.0005	0.002	0.001
Boiler Blowdown	0.002	0.002	0.004	0.004

Notes: Values are expressed as $1/h_f$. Values for nonferrous tubes are from data in the Tubular Exchanger Manufacturers Association Standards, 1952, *for any tubing in which the water to be employed is non-corrosive to the alloy being used.* For the purposes of this recommended standard, ARI has interpreted these data as applying to *nonferrous* tubes. For stainless steel tubes, use values for nonferrous tubes.

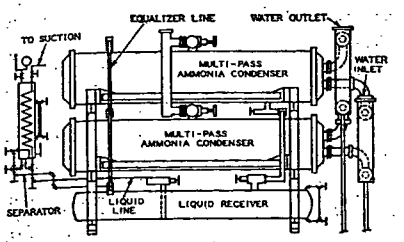


Fig. 5 .... Horizontal Shell-and-tube Ammonia Condenser and Receiver

Solution: The equivalent fouling resistance is determined by multiplying the fouling resistance $1/h_f$ by the ratio of external to internal surface S_E, or $0.001 \times 3.54 = 0.00354$. Enter Fig. 4 at the clean coefficient value of 200 and proceed vertically to the equivalent fouling resistance of 0.00354. Proceeding horizontally the design coefficient U is found to be 117 Btu per (hr) (sq ft) (F deg).

Tubes of halocarbon refrigerant condensers are normally nonferrous, externally finned tubes. Although internal scale forms at a slower rate than with steel tubes, the fouling factor for a given scale thickness is greater for finned tubes because it must be multiplied by a higher surface ratio. Table 2 lists the fouling factors for various types of water.

Horizontal Closed Shell-and-Tube Ammonia Condensers

This type of condenser is used in many industrial applications since it can be located in the compressor room in a compact installation under convenient supervision of the operating engineer. See Fig. 5.

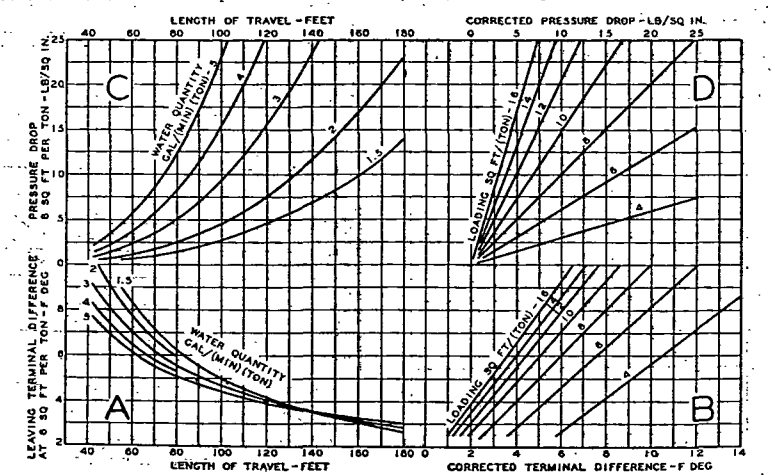
Steel tubes, 1¼ in. OD, having 0.095 in. average wall thickness are common. The number of tubes varies from approximately 50 in a 14-in. shell to 1100 in a 60-in. shell.

Fig. 6 may be used to calculate the performance of horizontal ammonia condensers based on: (1) commercially-clean tubes in a condenser free of noncondensable gases, (2) a temperature rise factor of 30 gal deg per (min) (ton) for the condenser water, and (3) heat rejection of 15,000 Btuh per ton from the ammonia vapor.[4]

The *leaving terminal difference* (Parts A & B of Fig. 6) is the difference between the condensing temperature (temperature corresponding to the pressure of the ammonia) and the leaving temperature of the condenser water. The *length of travel* is the tube length multiplied by the number of passes through the condenser. The *loading* of a condenser is the square feet of external tube surface per ton of refrigeration. The quantity of circulated water is commonly given in gpm per ton of refrigeration.

The condensing temperature (the sum of the entering water temperature, the temperature rise in the condenser, and the leaving terminal difference) is determined by the selection of a water quantity, length of travel, and loading that will give a relatively low condensing temperature, with a reasonable pressure drop. Since the terminal differences given in Fig. 6 are based on a condenser free of noncondensable gases, it is recommended that *an allowance of 1.5 F deg be added to the leaving terminal difference, to allow for noncondensable gases.* In refrigeration systems operating below atmospheric pressure, or where unusually high percentages of noncondensable gases are present, this allowance should be increased.

Parts A and B of Fig. 6 show typical values of leaving terminal difference as a function of length of travel, water quantity, and loading. Part A is based on a loading of 8 sq ft per ton, while Part B provides corrections for other loadings.



[a] For commercially clean 1¼ in. OD steel tubes and condenser free of noncondensable gases.

Fig. 6 .... Performance of Horizontal Closed Shell-and-tube Type Ammonia Condensers[a]