Estimating the Size and Cost of Steam Vacuum Refrigeration

For process refrigeration requirements between 35 and 80°F, use these charts to estimate the three types of steam vacuum refrigeration

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When process refrigeration requirements call for utmost reliability in the temperature range of 35 to 80° F or higher, steam vacuum refrigeration deserves first consideration.

Many processes require water at temperatures below those available from the cooling water source. In the range of 55 to 80° F or higher, conventional reciprocating. centrifugal and absorption systems encounter a variety of problems of maintenance and reliability, particularly at the higher temperature levels. Steam vacuum refrigeration systems on the contrary exhibit improved performance, with no change in reliability or maintenance.

Seven Key Considerations. Steam vacuum refrigeration should be considered when:

- Steam is the motive fluid and either high or low pressure steam is readily available.
- Variations in cooling water temperature produce lower condensing temperatures during a large portion of the operating period, resulting in steam economy.
- Reliability is of utmost importance.
- Brackish or scaling water is the only condensing medium (in this case barometric condensers offer a large advantage).
- Outdoor installation is contemplated.
- Chilled water temperature is above 55° F.
- Chilled water temperature range is large.

Basic Types. Three types of steam vacuum refrigeration systems are available today. These are:

- Steam Vacuum Refrigeration With a Barometric Condenser (Fig. 1)
- Steam Vacuum Refrigeration With a Surface Condenser (Fig. 2)
- Steam Vacuum Refrigeration With an Evaporative Condenser (Fig. 3)

The steam vacuum refrigeration cycle is best illustrated by the system using a barometric condenser (Fig. 1). In this cycle a vacuum equivalent to the chilled water temperature desired (for example 50° F equal to 9.21 mm. hg. abs.) is maintained in the flash tank (1) by the booster ejector (4). Water is flashed to vapor in the flash tank and is compressed by the booster to a pressure (which is dependent upon the available condensing water temperature) higher than the flash tank pressure (for example, 103° F, 52 mm. hg. abs.) and is discharged into the barometric condenser (5). In the barometric condenser the motive and flash steam are condensed and the noncondensables are removed by the secondary ejector system (7), which compresses the noncondensibles and saturation vapor and discharges them to atmospheric pressure.

Surface-Type Condenser. In the system shown in Fig. 2, the barometric condenser has been replaced by a surface condenser. This system requires that condensate be removed by a condensate pump, which is usually supplied in duplicate. unless the system is at such an elevation that a barometric leg can be installed.

Evaporative Condenser. Fig. 3 shows a system that replaces the barometric condenser with an evaporative surface condenser, essentially combining the surface condenser and the cooling tower in one unit.

Utility requirements for steam vacuum refrigeration systems can be determined by reference to Fig. 4.

As in all refrigeration systems, energy requirements are a function of refrigerant temperature and condensing temperature. As the available condenser medium temperature rises, utility requirements go up. Similarly as the refrigerant temperature drops, utility requirements go up. Conversely a reduction in condensing medium temperature, or increase in refrigerant temperature, results in decreased utility requirements.

Steam vacuum refrigeration systems are particularly responsive to a reduction in this split, more so than other systems. Generally speaking a five degree reduction in condenser temperature results in a reduction in steam consumption of as much as 10 percent. Thus when making a determination of the most economical refrigeration system, the process engineer should take into account the variation in temperature of the condensing medium during the day and over the entire year. The average steam rate, when this is taken into consideration, will be improved considerably over the theoretical design rate, and is a true indication of the steam consumption of these systems.

Since energy requirements and first cost are a function of chilled water temperature, steam vacuum refrigeration systems will be most economical if the highest possible refrigerant temperature is

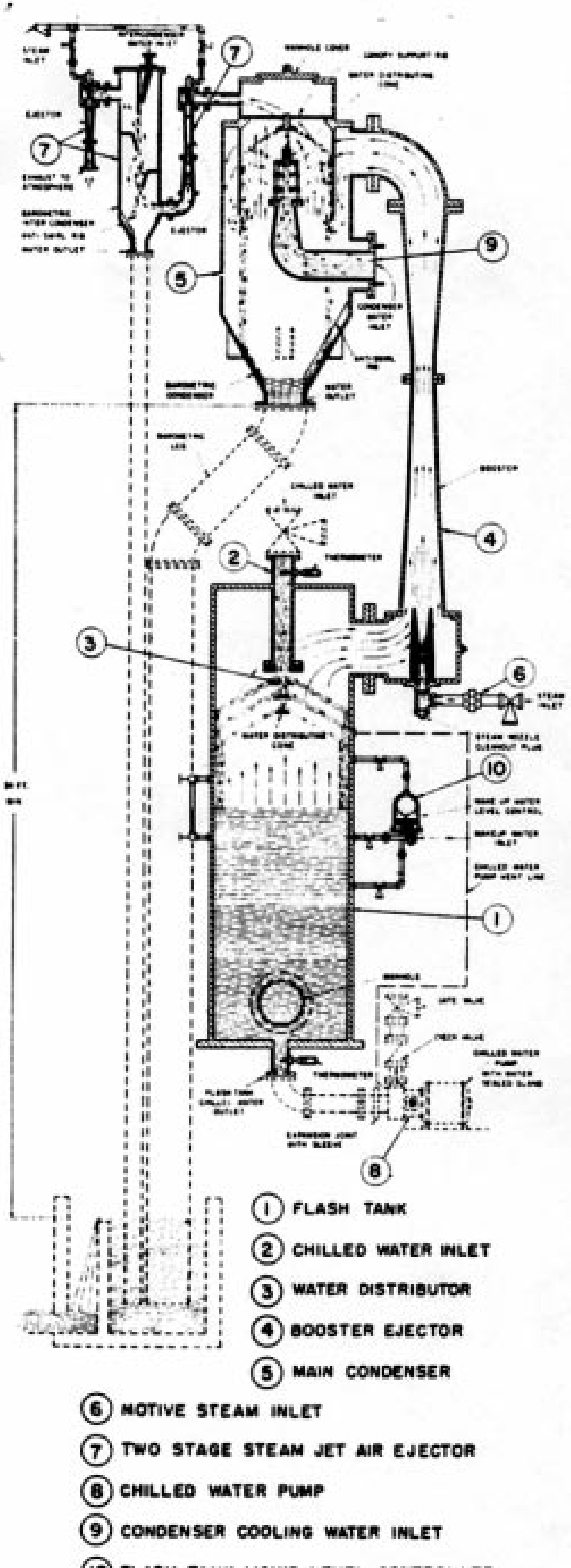


Fig. 1: *Steam vacuum refrigeration system with barometric type condenser*

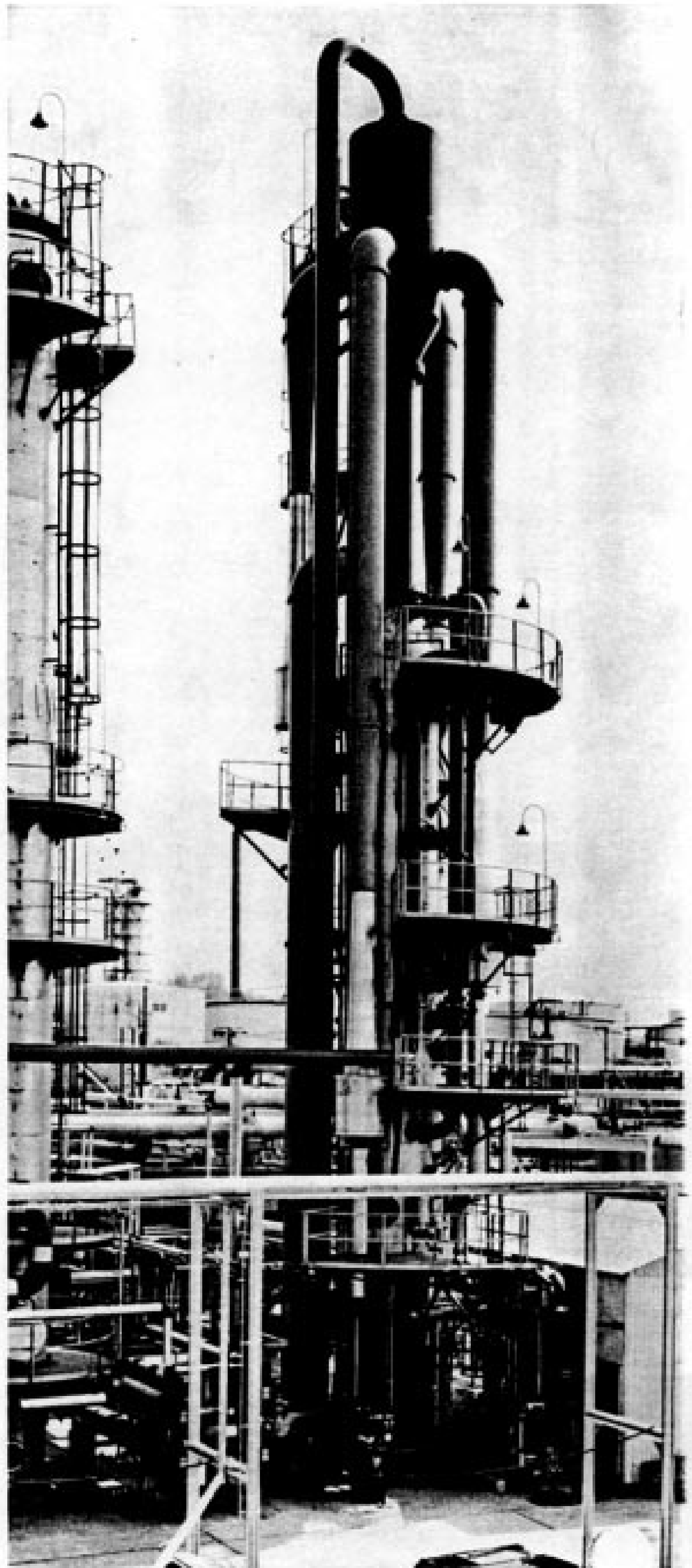
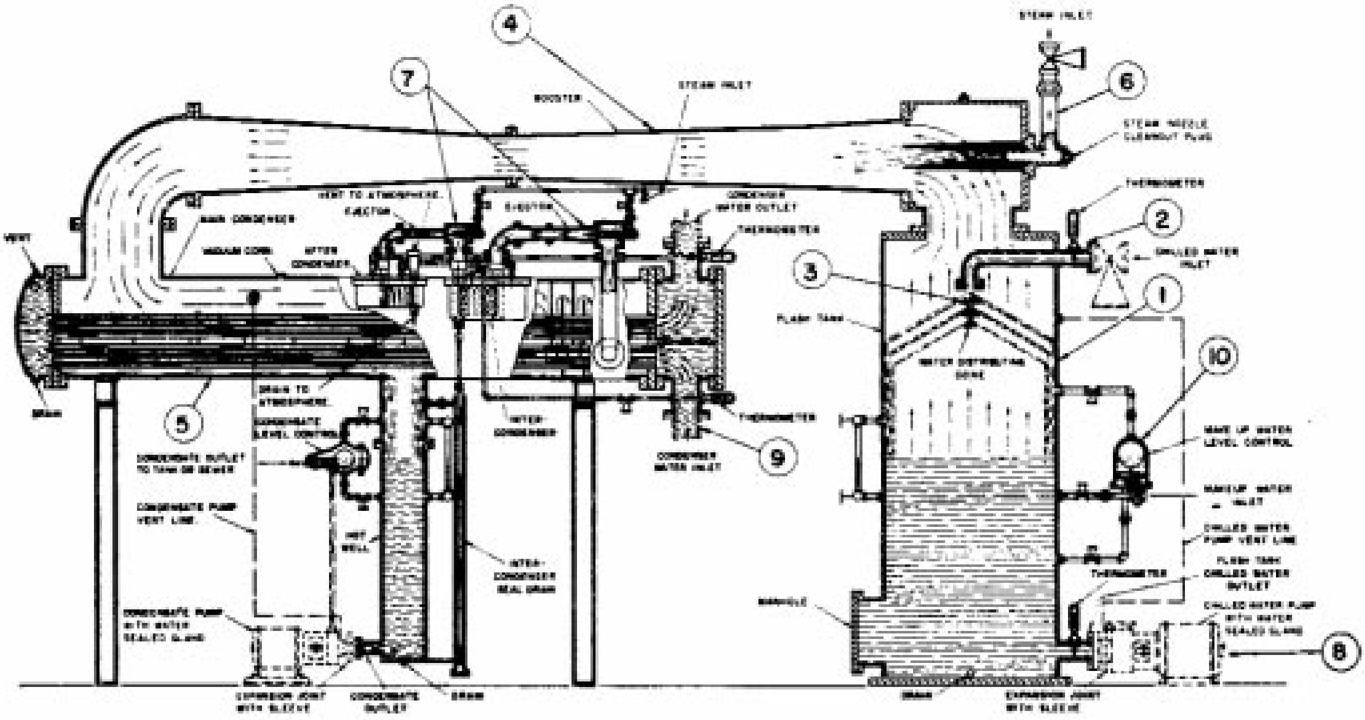


Fig 1a: *A 2,000-ton vacuum refrigeration system with barometric condensers installed in a refinery*



(1) FLASH TANK
(2) CHILLED WATER INLET
(3) WATER DISTRIBUTOR
(4) BOOSTER EJECTOR
(5) MAIN CONDENSER
(6) MOTIVE STEAM INLET
(7) TWO STAGE STEAM JET AIR EJECTOR
(8) CHILLED WATER PUMP
(9) CONDENSER COOLING WATER INLET
(10) FLASH TANK LIQUID LEVEL CONTROLLER

Fig. 2: *Steam vacuum refrigeration system with surface type condenser.*

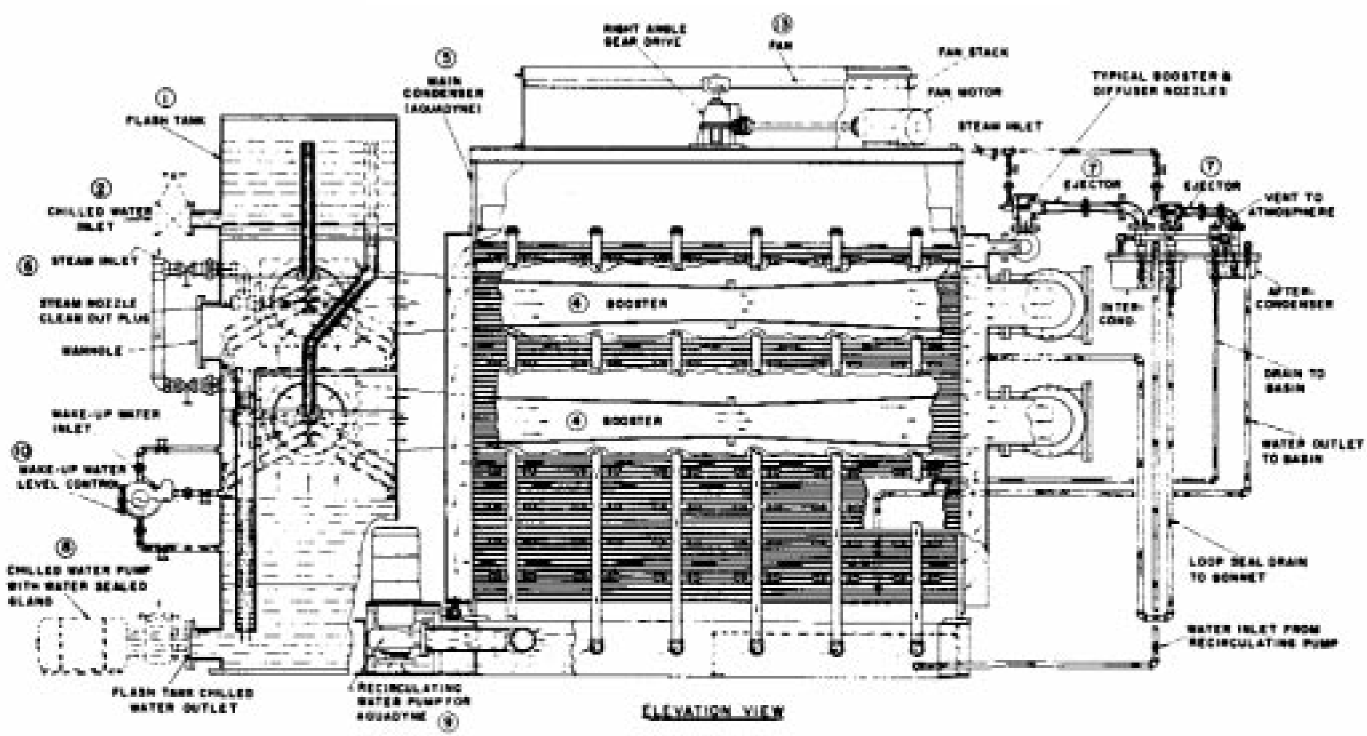


Fig. 3: *Steam vacuum refrigeration system with evaporative type condenser.*

selected. In systems where the refrigerant temperature range is large, say 45 to 65° F, a two stage flash system will result in economies. This can easily be understood by reference to Fig. 4. If half the load is flashed at 55° F, the steam requirement is 16.7 lbs. per hr. ton of refrigeration, and the water requirement is 5.3 gpm per ton of refrigeration for this portion of the load. The other half of the load is flashed at 45° F, requiring a steam a rate of 23.6 lbs. per hr. per ton of refrigeration, and the water requirement is 6.4 gpm per ton of refrigeration. Thus the total steam consumption is lower than if all of the refrigerant were flashed at 45° F.

In actual practice the loads are balanced in proportion to the flashed volume, but the effect of two stage flash is essentially as illustrated above.

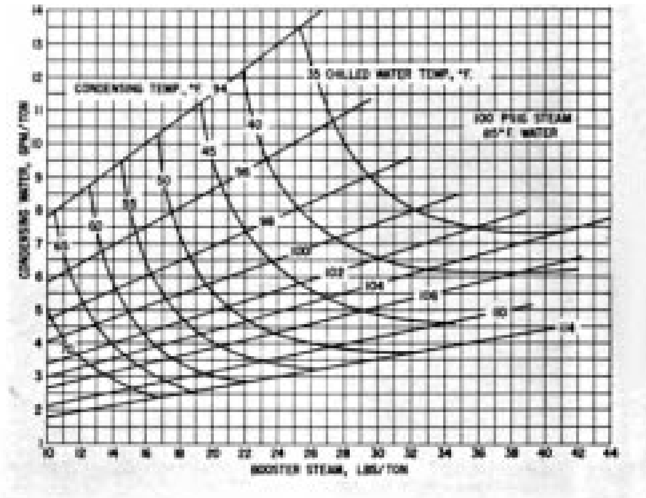


Fig. 4: *Utility requirements for steam vacuum refrigeration systems.*

SELECTING A STEAM VACUUM REFRIGERATION SYSTEM

- Determine desired chilled water temperature (check range)
- Determine maximum available condensing water temperature
- Determine available steam pressure.

Having determined the above, you may make several selections using Fig. 4, depending upon whether you wish to optimize steam consumption or water consumption.

For surface condenser systems, condensing temperatures will be approximately 8° above the leaving water temperatures; whereas in barometric systems, condensing temperatures will be approximately 3° above leaving water temperatures.

Thus utility requirements for surface condenser systems will be somewhat above those for barometric systems.

Cost Data. Fig. 5 gives installed cost data per ton of refrigeration for packaged barometric systems using one, two or three boosters. Fig. 6 gives installed costs for systems using surface condensers. Steam consumption of steam vacuum refrigeration systems using evaporative condensers (Fig. 3) is a function of wet-bulb temperature. Steam consumption for these systems may be determined by the use of Fig. 8.

Cost correction factors for motive steam pressures are given in Fig. 9. Fig. 7 gives cost per ton of refrigeration for systems with evaporative condensers.

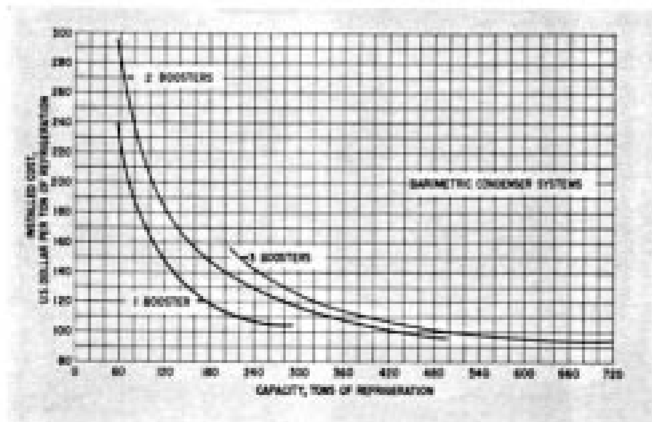


Fig. 5: *Installed cost per ton, barometric systems using one, two or three boosters.*

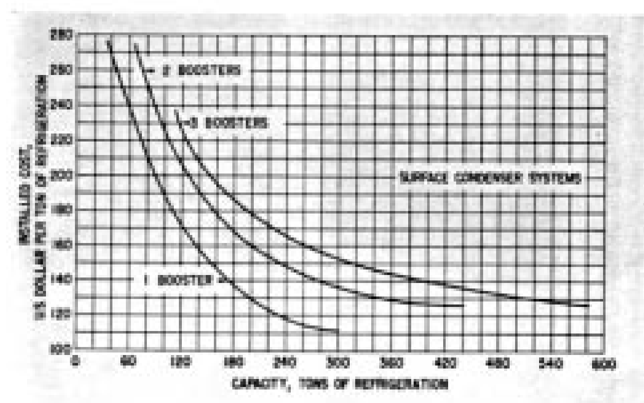


Fig. 6: *Installed cost per ton, surface condenser systems, using one, two or three boosters.*

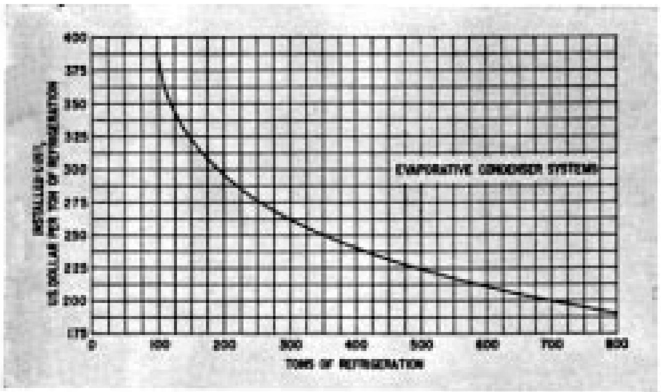


Fig. 7: *Installed cost per ton for systems with evaporative condensers.*

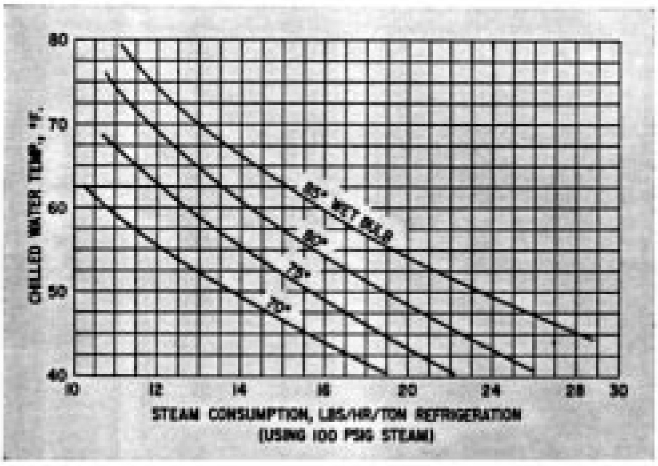


Fig. 8: *Steam Consumption in pounds per hour per ton of refrigeration.*

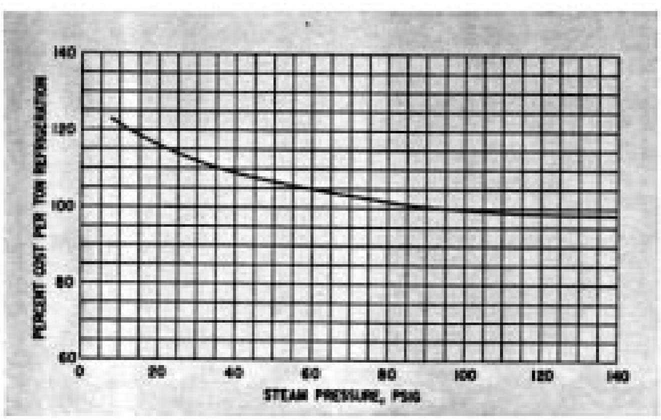
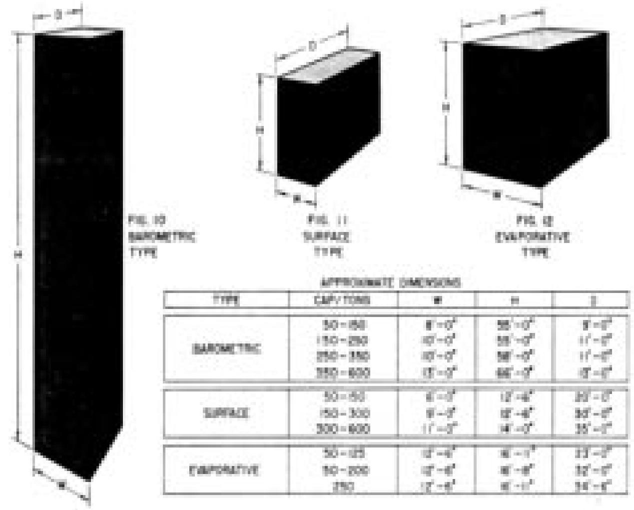


Fig. 9: *Cost correction factors for various steam pressures.*



APPROXIMATE DIMENSIONS

TYPE	CAP/TONS	W	H	D
BAROMETRIC	50-150	8'-0"	55'-0"	9'-0"
	150-250	10'-0"	55'-0"	11'-0"
	250-350	10'-0"	58'-0"	11'-0"
	350-600	13'-0"	66'-0"	13'-0"
SURFACE	50-150	6'-0"	12'-6"	20'-0"
	150-300	9'-0"	12'-6"	30'-0"
	300-600	11'-0"	14'-0"	35'-0"
EVAPORATIVE	50-125	12'-6"	16'-1"	23'-0"
	50-200	12'-6"	16'-6"	32'-0"
	250	12'-6"	16'-11"	34'-6"

Multiple boosters are used for refrigeration systems requiring operation under a variable demand. Capacity control is obtained by cycling boosters in and out of service, either automatically or manually, with variations in load. Generally speaking these boosters are divided in equal increments; however, should circumstances require they may be subdivided in any proportion. Multiple booster systems are particularly advantageous if it is desired to take advantage of part load economy and the effect of reduced condenser water temperature during cool periods of the year.

Multiple Systems. For sizes beyond those shown, multiple systems are generally used; although if the size is only 10 or 15 percent larger than shown, it is quite possible to enlarge the standard designs. Generally it will be more economical and give more flexibility to go to multiple systems. However, single units have been built as large as 2,000 tons of refrigeration.

Space requirements for the three types of systems are given in the block diagrams, Figs. 10, 11 and 12.

Indexing Terms: Barometric—9, Condensers/Process Equipment—9, Cooling—9, Costs—7, Curves—10, Estimating—8, Evaporation—9, Heat Transfer—9, Refrigeration—9, Selection—8, Steam—6, Surfaces—9, Water—6.

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