Technical Development Programs (TDP) are modules of technical training on HVAC theory, system design, equipment selection and application topics. They are targeted at engineers and designers who wish to develop their knowledge in this field to effectively design, specify, sell or apply HVAC equipment in commercial applications.

Although TDP topics have been developed as stand-alone modules, there are logical groupings of topics. The modules within each group begin at an introductory level and progress to advanced levels. The breadth of this offering allows for customization into a complete HVAC curriculum – from a complete HVAC design course at an introductory-level or to an advanced-level design course. Advanced-level modules assume prerequisite knowledge and do not review basic concepts.

Water-cooled chillers range in size from small 20-ton capacity models that can fit in an elevator to several thousand-ton models that cool the world’s largest facilities such as airports, shopping centers, skyscrapers, and other facilities. This TDP module will review all sizes of water-cooled chillers, but will contain more information on the larger chillers in the range of 200-ton and upward. Screw and centrifugal compressor water-cooled chillers tend to be the most popular designs for larger commercial applications, while scroll and reciprocating compressor chillers are used on the smaller ones. Air-cooled chillers are covered in a companion module, TDP-622.
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Introduction

This TDP module on water-cooled chillers starts with a history of the first centrifugal chiller and describes the first applications for early water-cooled chillers. After a discussion of the relative merits of water-cooled chillers, the refrigeration cycle for a water-cooled centrifugal chiller is explained using pressure-enthalpy diagrams.

We will examine the major components used in water-cooled chillers such as evaporators, condensers, compressors, and metering devices. The types of chiller starters and their applications are also discussed.

A greater emphasis is placed on the larger screw and centrifugal types of water-cooled chillers in this TDP module. A more detailed discussion of the screw and centrifugal compression process and its characteristics is included. Current refrigerant issues, phase out dates, and applicable codes and standards for water-cooled chillers are also examined.

Finally, computerized selection software for a centrifugal chiller is used to demonstrate the required inputs and the selection process for a typical application.

The First Centrifugal

The art of building centrifugal air compressors was already 75 years old in 1916 when Dr. Willis H. Carrier recognized their potential use in the then infant air-conditioning industry.

By 1922, the Carrier Company had purchased a German-manufactured centrifugal air compressor and modified it for use with dielene refrigerant (C₂H₂Cl₂). After two years of test and development, this first centrifugal refrigeration machine was sold in 1924 to the Onondaga Pottery Company in Syracuse, New York. The machine ran for 26 years, providing air conditioning until 1950. The compressor of that first machine was then retired to the Smithsonian Institute in Washington, D.C. where it remains today on exhibit as one of the major technical developments in the United States.

Dielene

was used in the dry cleaning industry as a cleaning agent.

Figure 1

Early Centrifugal Chiller
Carrier’s second centrifugal machine was installed in 1923 in Cambridge, Massachusetts, at the candy manufacturing plant of the W. F. Schraft and Sons Company. The second one built ended up being installed prior to the first one.

Because of those early efforts in the 1920s, water-cooled chillers have gained widespread acceptance in both large and medium systems. Technology has resulted in the evolution of water-cooled chillers, which are characterized by their excellent reliability, high efficiency, and compact, cost-effective construction.

Water-Cooled versus Air-Cooled Chillers

Two methods are used to condense the refrigerant in chillers. The condensers can be air-cooled or water-cooled. A typical air-cooled chiller uses propeller fans to draw ambient air over a finned coil to condense the refrigerant. It may contain multiple or single compressors. For a complete discussion on air-cooled chillers, refer to TDP-622, Air-Cooled Chillers.

Figure 2
A Carrier chiller is on display at the Smithsonian Institute.

Figure 3
Evolution of Centrifugal Chillers

Figure 4
Air-Cooled and Water-Cooled Chiller Benefits
A typical water-cooled chiller uses recirculating condenser water from a cooling tower to condense the refrigerant. For a complete discussion on cooling towers, refer to TDP-641, Condensers and Cooling Towers.

Cost and efficiency are the important factors when considering air or water-cooled chillers. Chilled-water systems with air-cooled chillers typically have lower installed and maintenance costs than water-cooled because a condenser water system using a cooling tower is not required. A condenser water pump and chemical treatment for the condenser water loop adds to the maintenance required with a water-cooled system. However, water-cooled chillers have higher efficiency and therefore lower operational costs. Air-cooled chillers are chosen when it is impractical to use a cooling tower, such as when little water is available or water is highly corrosive.

The refrigerant condensing temperature in an air-cooled chiller is dependent on the ambient dry-bulb temperature. In a water-cooled chiller, refrigerant condensing temperature is dependent upon the entering condenser water temperature (and flow rate), which is a function of the ambient wet-bulb temperature. Since the wet-bulb temperature is always lower than the dry-bulb temperature, the refrigerant condensing temperature (and pressure) in a water-cooled chiller is often significantly lower than in an air-cooled chiller. This is why water-cooled chillers are more efficient.

In terms of capacity, air-cooled chillers are available in packaged sizes ranging up to approximately 500 tons, while water-cooled chillers are typically available up to 3,000 tons, with limited custom designs available up to 10,000 tons.

Water-cooled chillers typically last longer than air-cooled chillers. Air-cooled chillers may last 20 years while water-cooled chillers may last 23 years or more. This may be attributable to the fact that water-cooled chillers are installed indoors, and most air-cooled chiller configurations spend their lives outdoors in the elements. Also, some of the larger water-cooled chillers are constructed with heavy duty, industrial-grade components.
Basic Refrigeration Cycle for Water-Cooled Chillers

In this TDP, we will explain the refrigeration cycle using components from a centrifugal chiller since that type of chiller is water-cooled. The following temperatures are typical of the standard refrigeration cycle for comfort cooling applications. In the evaporator of a water-cooled chiller, liquid refrigerant at approximately 42º F takes on heat from building return water (whose entering temperature may be represented at 54º F) flowing through the evaporator, and changes to a vapor. The refrigerant vapor is drawn into the compressor and its temperature and pressure are elevated. The compressor provides the work necessary to compress the gas to a temperature and pressure required by the condenser, typically 97º F. The gas is then discharged into the condenser where it condenses on tubes through which water flows, typically at 85º F. This is the entering condenser water from the cooling tower. The condensed droplets of liquid refrigerant then fall to the bottom of the condenser, flow through a pressure reducing device such as a float valve or an orifice, and return to the bottom of the cooler where the process repeats itself.

The cycle can be shown on a pressure-enthalpy (p-h) diagram. Pressure is the force exerted per unit area, while enthalpy is the total heat content expressed in Btu per pound of the substance. When the compressor is close-coupled to the evaporator, there is negligible pressure loss in the suction line, and gas enters the compressor at approximately the saturated conditions that exist in the evaporator, Point 1.

If we follow the steps shown, you can see that from A to 1 is the refrigeration effect. In this step, building heat from the chilled water is absorbed by the refrigerant, and the refrigerant transitions from a liquid to a saturated vapor, at Step 1. From Step 1 to 2 is the compression stage. This stage raises the temperature and pressure of the saturated refrigerant vapor to the saturated condensing temperature, so that heat can be rejected to the condensing fluid. This compression is also called the “lift” of the compressor, which will be discussed later in the TDP.