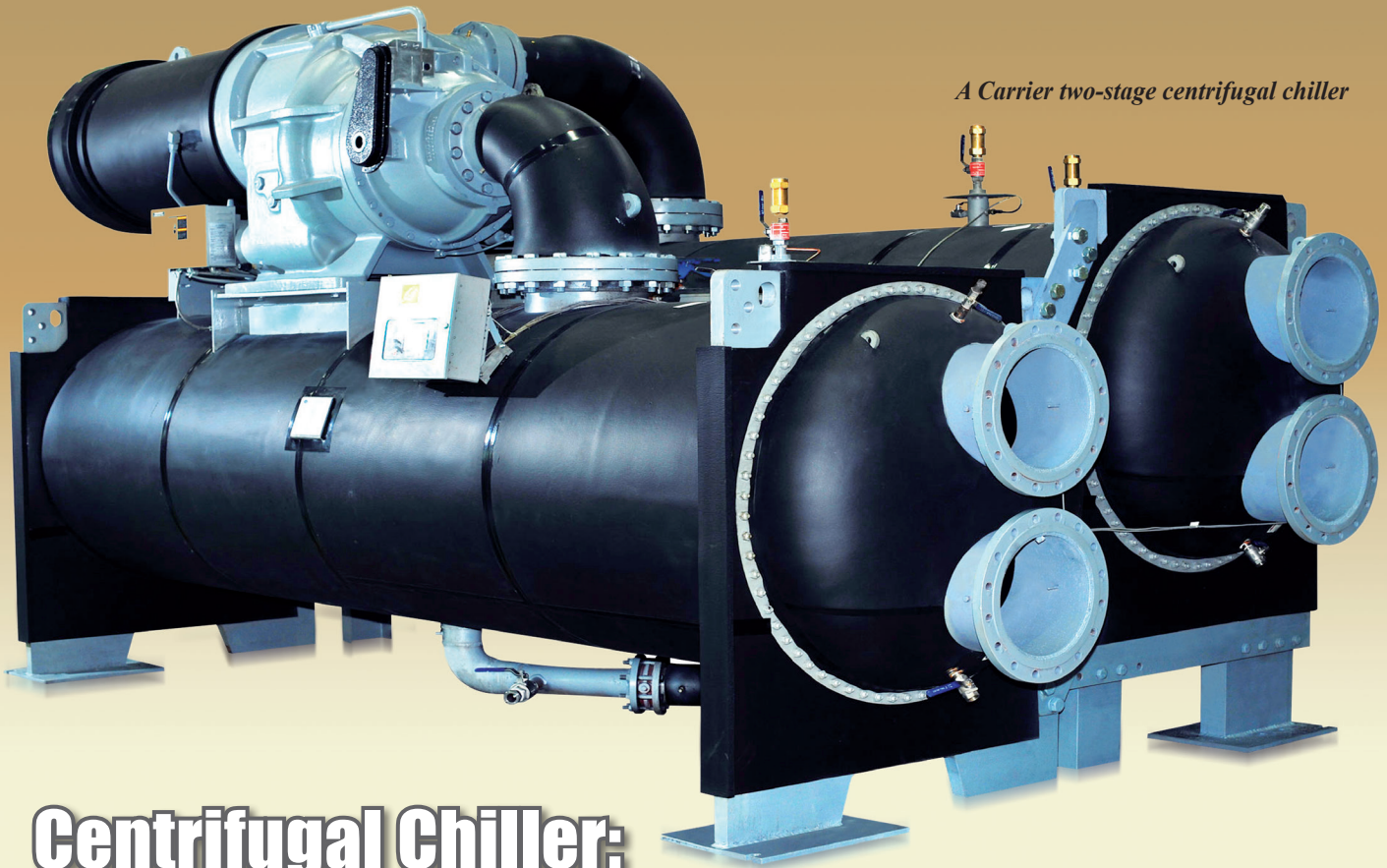


A Carrier two-stage centrifugal chiller



Centrifugal Chiller: Single-stage or Two-stage?

(Reprinted with permission from JARN – November 25, 2013)

Two-stage Centrifugal Chiller Trends

At the 2013 China Refrigeration Expo held in Shanghai in April, U.S.-based Carrier exhibited a centrifugal chiller with a two-stage compressor.

Big U.S. manufacturers, namely Carrier, York, and McQuay, have traditionally offered only single-stage centrifugal chillers. Trane, however, is an exception, as its chillers use a direct drive design and require multi-stage compressors due to the lower impeller revolution.

On the other hand, when Japanese manufacturers switched from low pressure HCFC refrigerant to high pressure R134a (HFC) in the 1990s, all of the manufacturers released two-stage centrifugal chillers. The manufacturers were aiming to increase efficiency by utilizing an economizer effect, a typical system of a two-stage compressor, to compensate for the lower efficiency resulting from the refrigerant switch. Chinese and Korean manufacturers including Midea, Gree, LG, Hanbell and Techno-Century have also focused on new centrifugal chiller development and have aggressively moved to commercialize two-stage centrifugal chillers.

Meanwhile, U.S. manufacturers Carrier, York, and McQuay switched to R134a refrigerant but continued to offer their existing single-stage chiller designs. Against this backdrop, Carrier became



Trane CenTraVac multi-stage centrifugal chillers at a job site in Masdar City, UAE

the first major manufacturer this year adopting U.S.-style gear drive to release a two-stage centrifugal chiller. Carrier reportedly plans to target mainly ice thermal storage and heat pump applications, but the chiller can be used in other applications as well. The release of a two-stage chiller by a U.S. manufacturer is expected to have a major impact in the market.

Two-stage Systems

For centrifugal chillers, a single-stage cycle is basically the same as a standard chiller cycle. As shown in *Figure 1*, the basic

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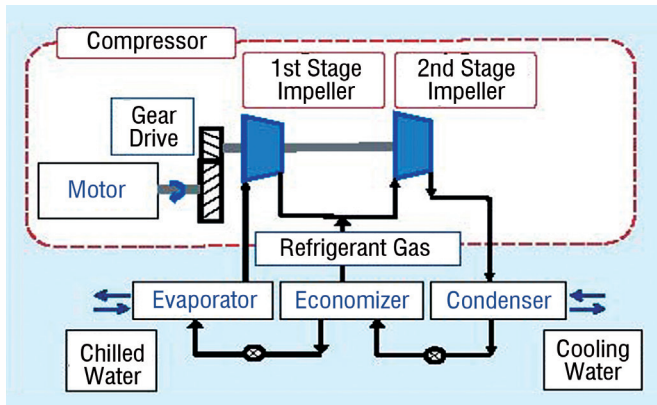


Figure 1: Configuration of a two-stage compression cycle

configuration of a two-stage compression cycle consists of two impellers and an economizer that separates the vapor and liquid in the vapor-liquid mixture expanded in the first stage. The gas compressed by the first-stage impeller is pumped to the second-stage impeller through the gas circuit and mixes with intermediate gas pumped out of the economizer mounted on the refrigerant circuit. This is where the economizer benefit is demonstrated. In short, pumping only liquid to the evaporator increases evaporation capacity, but the power increase is small, resulting in higher cycle efficiency. This cycle efficiency increases as compressor lift pressure ratio becomes higher.

In addition, since compression is done in two stages, the lift of one impeller is lower. A general performance characteristic of centrifugal compressors is higher compression efficiency with lower lift. These features, therefore, improve the efficiency of two-stage systems. Under operating conditions in Asia, two-stage centrifugal chillers can achieve COP higher than 6.2.

Why Have Single-stage Centrifugal Chillers Continued as the Standard in the U.S.?

Climatic conditions in the United States vary rather significantly by region and seasons, but tend to be relatively mild compared with tropical regions. AHRI standard conditions designate an entering condenser water temperature of 85°F (29.4°C) and a leaving chilled water temperature of 44°F (6.7°C), which are lower than Japan Industrial Standards (JIS) conditions and China conditions (32°C and 7°C, respectively).

Therefore lift is also lower, meaning that the economizer benefit is lower compared to Asian region operating conditions. Moreover, with the milder climate in the United States, performance under part-load conditions as typified by Integrated Part Load Value (IPLV) tends to receive more focus than performance under full-load conditions, and variable-frequency drive (VFD) has been widely used. On the other hand, two-stage systems tend to be designed with a focus on high efficiency under full-load conditions.

Such climatic conditions in the U.S. market as well as the benefits of two-stage systems versus product cost and demand versus development cost have worked to keep single-stage centrifugal chillers as the standard. Now, however, considering that close to 80% of world demand for centrifugal chillers is

outside the United States and close to 40% of the centrifugal chillers manufactured in the United States are exported, offering single-stage centrifugal chillers only no longer meets the needs of the global marketplace.

Cost-performance Correlation

Two-stage systems obviously must use two impellers, which increases the size of the casing. On the system side, the addition of the economizer and expansion valves inevitably increases the final product cost.

However, the combination of compressor and heat exchanger determines the performance and cost of centrifugal chillers. If a high efficiency compressor is used, the total product cost may be lower because the heat exchanger can be made smaller and still achieve the same performance as a single-stage system with one large compressor.

This trend becomes remarkable at higher efficiency conditions. As with the economizer benefit, this effect is more pronounced when lift is higher or under high-efficiency conditions.

Even in the United States, there are many opportunities to take advantage of the efficiency benefits of two-stage centrifugal chillers, including in regions with high outdoor temperatures and in ice thermal storage and heat pump applications with high lift conditions. Therefore, two-stage systems can be considered to have potential to grow in the U.S. market.

Two-stage Compressor and System Technologies

The impellers play a key role in determining the two-stage system performance. As the compression conditions and refrigerant flow of two-stage systems are different from single-stage centrifugal chillers, new impeller designs that optimally combine the two impellers for the first and second stages are required.

Also, the flow passage from the suction to the discharge port is longer in two-stage compressors than in single-stage compressors, and the design must optimize this flow for best performance. Manufacturers are adding an intermediate vane and utilizing other technologies to improve this flow passage.

Further, to achieve high performance at part-load conditions in addition to full-load conditions, manufacturers also need to develop a much simpler economizer structure able to stably separate the vapor and liquid as well as the related controls.

Features and Applications of Two-stage Centrifugal Chillers

To summarize, the main features of two-stage centrifugal chillers are:

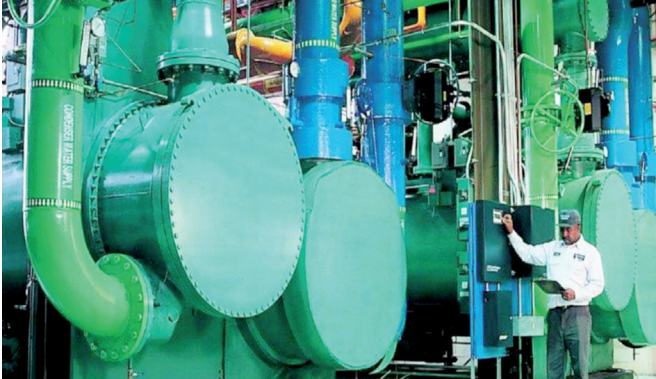
1. High efficiency that is not possible with single-stage chillers, and
2. A wide range of operating lift conditions, and ability to perform efficiently under high lift conditions.

Due to high efficiency, the higher compressor cost can be compensated by the need for lesser tubes and size of the heat exchanger, which can bring down the total chiller system cost. The high efficiency operation, not possible with single-stage centrifugal chillers, also reduces electricity costs and CO₂

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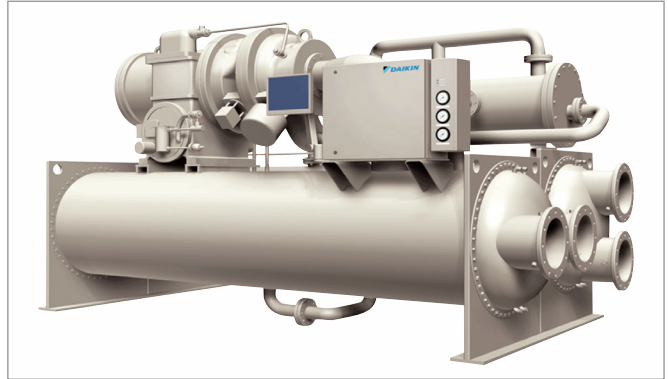
A large installation in the Middle East with York brand chillers from JCI

emissions, which are becoming increasingly important.

Regarding the wide operating envelope, two-stage centrifugal chillers can perform under high lift conditions not possible with single-stage centrifugal chillers, including ice thermal storage applications of high lift conditions with low pressure as well as heat pump applications for high temperature hot water. The wide operating lift conditions are especially relevant in regions such as Asia and the Middle East where outdoor temperatures and cooling water temperature are very high.

Future Trends

High-efficiency equipment will become increasingly important as requirements to save energy and reduce CO₂ emissions become stricter. Air conditioning systems are also becoming more diverse,



Daikin two-stage centrifugal chiller with high efficiency VFD

and needs for optimized performance under a variety of working conditions are increasing.

Amid these trends, the need for two-stage centrifugal chillers is set to grow even more as they can operate in a wider operating envelope and under diverse conditions. As production of two-stage compressors rises, the cost will fall. Two-stage compressors are expected to increasingly become the standard as demand grows in the Asian region.

Meanwhile, VFD centrifugal chillers that can control the centrifugal rotation speed are expected to dominate regions with relatively mild outdoor temperatures where load varies widely, such as markets in mid-latitude regions between the equator and the poles. ❖