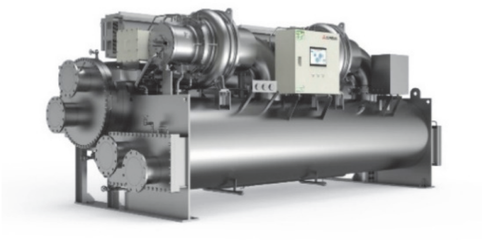
Development of High-Performance Centrifugal Chillers with Global-Warming-Potential of 1, Focusing on Energy-Saving and Miniaturization



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ETI-Z centrifugal chillers(1), which use low-environmental-impact refrigerant HFO-1233zd(E), have been widely used since their launch not only for industrial applications but also for general air conditioning applications such as building air conditioning, and are the most widely employed centrifugal chillers in Japan.

Recent growing environmental awareness following the Paris Agreement requires equipment to have a low environmental impact and be energy-efficient. At the same time, the emergence of the AI industry has led to the expansion of data centers and demand for semiconductors, while the need for air conditioning and refrigeration continues to grow along with industrial development. Against this background, centrifugal chillers of Mitsubishi Heavy Industries Thermal Systems, Ltd., which have been providing air conditioning and refrigeration solutions over the years, are now required to be even more energy-efficient. Therefore, we have developed high-performance models in the ETI-Z series, which have been based on the concept of high performance and miniaturization, with even higher energy efficiency while retaining the miniaturization advantage over competitors in the market, achieving a significant improvement in performance compared to conventional models.

1. Introduction

As a piece of refrigerating and air conditioning equipment which produce cold and hot water through heat exchange, centrifugal chillers have been used in district heating, large-scale buildings, semiconductor manufacturing, and the pharmaceutical and food industries. Mitsubishi Heavy Industries Thermal Systems, Ltd. developed ETI-Z series centrifugal chillers using HFO-1233zd(E) refrigerant, which has zero ozone depletion potential (ODP) and a global warming potential (GWP) equivalent to that of carbon dioxide. ETI-Z centrifugal chillers are not subject to the High Pressure Gas Safety Act and qualified personnel are not required for their management. Due to their ease of handling, high performance, and miniaturized size, ETI-Z centrifugal chillers have been rated as having the top market share in the domestic industry.

In recent years, environmental awareness has increased dramatically, while demand for air conditioning and refrigeration has continued to grow due to industrial development. To meet these demands, we have developed high-performance models (hereinafter referred to as “developed models”) that maintain the miniaturized size of the ETI-Z while achieving energy savings and improving performance by up to 12% compared to conventional models, based on a design database of abundant operating data from ETI-Z centrifugal chillers, which have been delivered to many customers. This report introduces developed models by presenting the technologies employed in their development and comparing them with conventional models.

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2. High performance and miniaturization design optimized for low-GWP refrigerant specifications

Developed models use low-GWP refrigerant HFO-1233zd(E), which is classified as a low-pressure refrigerant and should be used in a negative pressure band. Low-pressure refrigerants do not require qualified personnel to handle them, thus eliminating the difficulty to introduce them, but are characterized by their larger gaseous volume in the temperature range used by centrifugal chillers and necessitate an increase in chiller size, which is a technical problem. For developed models, design data was updated from the data of conventional models to achieve higher performance while maintaining the miniaturized size of the conventional model. The following sections outline the technologies employed for development.

2.1 Performance improvement by optimizing refrigerant flow path

Among several important factors for improving the performance of centrifugal chillers, distributing the refrigerant uniformly in the heat exchanger and reducing the pressure loss in the refrigerant flow path are low-cost methods to realize high performance.

Centrifugal chillers utilize the latent heat of the refrigerant, and therefore they have many areas in which the refrigerant exists in a gas-liquid two-phase state. Since low-pressure refrigerant has a large gas volume, i.e., a small gas density, its gas-liquid two-phase flow causes a large difference in inertia force acting on the gas and liquid phases, resulting in a biased flow. For example, the refrigerant supplied to an evaporator is not uniform, because the liquid phase with large inertia and the gas phase with small inertia are unevenly distributed. To solve this, we reanalyzed the structure and flow conditions of conventional models and compared them with actual operation data to optimize the shape and arrangement of the components that play the role of a cushion to make the inertial force of the liquid phase uniform. As a result, the heat exchange efficiency of the evaporator was improved.

For the refrigerant flow path from the evaporator to the compressor, we also modified the flow path shape to follow the refrigerant flow based on the comparison of analysis and actual data, reducing the pressure loss by about 78% and improving the performance.

2.2 Miniaturization based on operational database

To miniaturize centrifugal chillers, we focused on the evaporator, which is the largest-volume components. The smaller body size and flow paths associated with miniaturization result in higher refrigerant flow velocity in the chiller. If the evaporator is made too small, the refrigerant is sucked into the compressor as droplets, which may damage the compressor. Therefore, we realized droplet suppression at higher flow velocities by carefully examining the criteria for preventing droplets from being sucked into the compressor based on accumulated operational data. Specifically, by creating a space above the evaporator and innovating the arrangement and structure of internal components to make the flow uniform, we could minimize the overall size of the evaporator. The other major components remain unchanged from the conventional model, achieving miniaturization while maintaining reliability.

3. Comparison with conventional models and competitors' models in the market

3.1 Comparison with conventional ETI-Z series models

Developed models achieve high performance while maintaining the miniaturized size of conventional ETI-Z series models (**Table 1**). The coefficient of performance (COP)[*1] under JIS conditions (the chilled water temperatures are 12°C at the inlet and 7°C at the outlet, and the cooling water temperatures are 32°C at the inlet and 37°C at the outlet) was improved by up to 12% compared to conventional models of the ETI-Z series. The highest COP among the developed series is 6.52 (**Figure 1**).

Table 1 Performance comparison with conventional model at maximum capacity

-	Conventional model	Developed model
Model	ETI-Z70	ETI-Z73
Refrigerant	HFO-1233zd(E)	
Refrigeration capacity	700 USRt (2,461 kW)	730 USRt (2,567 kW)
Chilled water temperature	in 12°C => out 7°C	
Chilled water flow rate	422.3 m^3/h	440.4 m^3/h
Cooling water temperature	in 32°C => out 37°C	
Cooling water flow rate	502.3 m^3/h	517.8 m^3/h
Power consumption (per compressor)	222.6 kW	214.2 kW
COP (for 2 compressors)	5.52	5.99
IPLV *2	8.410	8.663
Length x width x height	4.3 m x 2.0 m x 2.1 m	4.9 m x 2.0 m x 2.1 m
Reference: Series capacity range	Single-compressor model:150-350 USRt Two-compressor model: 350-700 USRt	Single-compressor model:150-370 USRt Two-compressor model: 370-730 USRt

Note: Comparison at maximum refrigeration capacity for each

*1: Value obtained by dividing the refrigeration capacity by the power consumption; the higher the COP, the lower the power consumption and the better the performance.

*2: Value obtained by weighting COPs at four points with different loads by the annual frequency of occurrence and summing them. The larger the value, the lower the running cost.

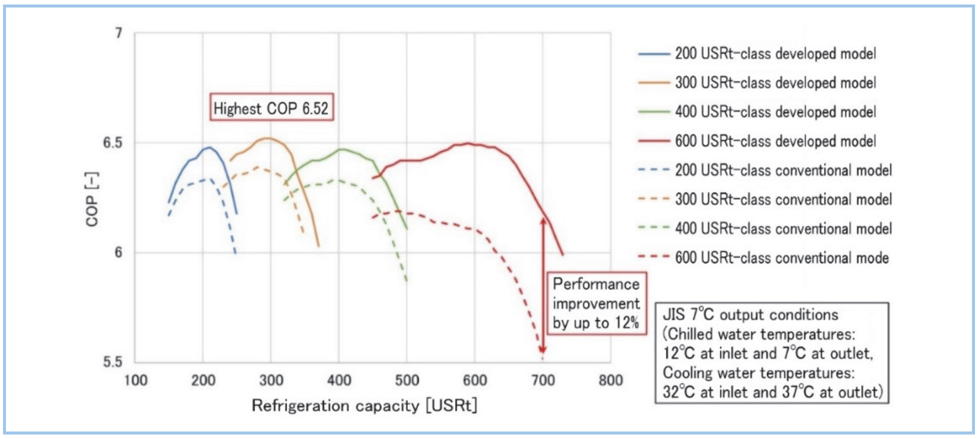

Figure 1 Comparison of rated performance (COP) with conventional models

3.2 Comparison with competitors' models in the market

In general, the performance improvement of centrifugal chillers requires higher compressor efficiency, lower mechanical losses, and a larger heat-transfer area in the heat exchanger, resulting in a larger installation footprint. However, the developed models achieve both high performance and a small footprint by using our technologies described in Chapter 2 (**Figure 2**). Developed models are designed to be miniaturized to up to approximately 60% of competitors' models in the market (**Figure 3**).

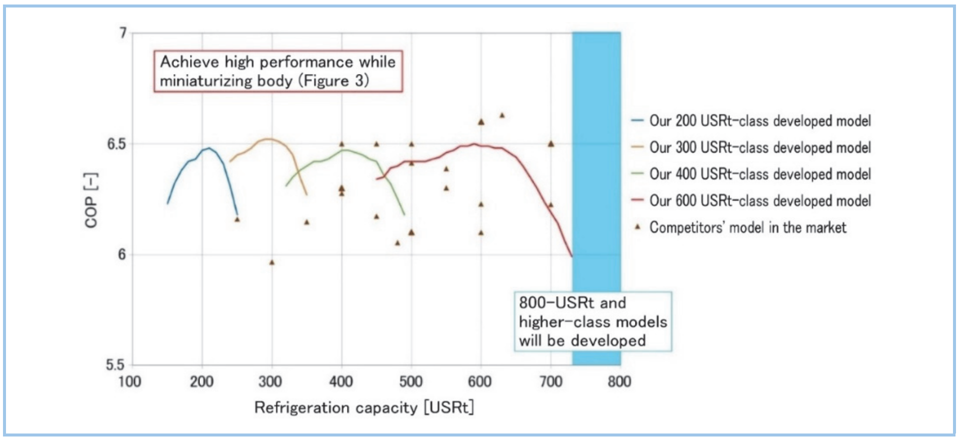

Figure 2 Comparison of rated performance (COP) between competitors in the market using R1233zd(E) and our developed models

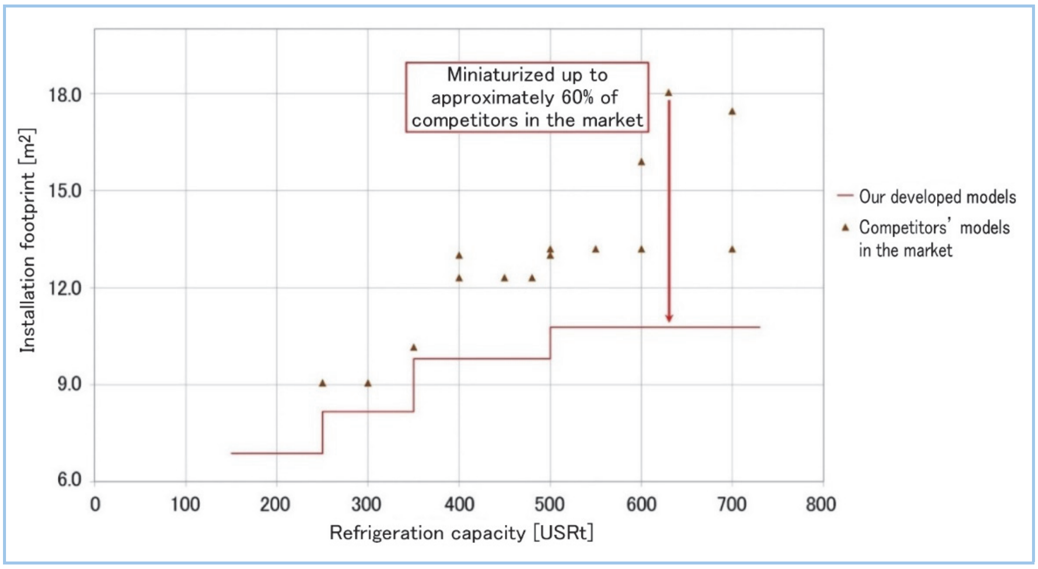

Figure 3 Comparison of installation footprint between competitors using R1233zd(E) and our developed models

4. Conclusion

To address environmental issues that have been attracting attention in recent years, we provide air conditioning and refrigeration solutions focusing more on energy efficiency with developed centrifugal chillers presented in this report. Developed models realized miniaturized installation footprints compared to competitors in the market and the significant performance improvements compared to our conventional models. These centrifugal chillers are suitable for any market, satisfying the maximum demand for air-conditioning and refrigeration in a limited space.

The capacity lineup of developed models is currently 150 to 730 USRt (1 USRt = 3.516 kW), but we will further promote the development of larger-capacity models to meet various market needs in Japan and overseas.

References

(1) K. Ueda et al., "ETI-Z Series" Centrifugal Chiller Applied Low GWP Refrigerant to Contribute to the Prevention of Global Warming, Mitsubishi Heavy Industries Technical Review Vol.52 No.4 (2015)