High-Efficiency Centrifugal Chillers "JHT-Y Series" Using Low GWP Refrigerant HFO-1234yf

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ABSTRACT

JHT-Y series of centrifugal chillers have been developed using HFO-1234yf refrigerant, which has a global warming potential (GWP) of less than 1 and an extremely low environmental impact. HFO-1234yf is used as a refrigerant for automotive air-conditioners and can be reliably sourced. It is equipped with a highly efficient and compact compressor that is optimized to HFO-1234yf and can maintain the same cooling capacity range and COP as conventional units. The overall unit has been reduced in height by up to 4% and in mass by up to 11% compared to conventional chillers by downsizing the compressor and optimizing the heat exchanger. If the entire market stock were converted to JHT-Y, the CO2 equivalent of the refrigerant charge would be equivalent to a reduction potential of 5.26 x 103 t from 7.52 x 106 t, which is a 40% reduction in electricity compared to the machine 30 years ago.

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Keywords: Centrifugal chiller, Low-GWP refrigerants, HFO-1234yf

1. INTRODUCTION

Centrifugal chillers are widely used for air conditioning in large-scale facilities such as office buildings, airports, and district heating and cooling systems, as well as in industrial applications including pharmaceutical and food processing plants. In recent years, they have also been increasingly utilized in semiconductor manufacturing plants—driving IT and digital transformation (DX)—and as cooling sources for data centers. However, the conventional refrigerant used in centrifugal chillers, HFC-134a, has a high global warming potential (GWP) of 1430 [1]. In Japan, due to the enforcement of the Act on Rational Use and Appropriate Management of Fluorocarbons, the shipment of centrifugal chillers using HFC refrigerants has been restricted since April 2025. To address this issue, our company has developed centrifugal chillers using low-GWP HFO refrigerants. For capacities below 1000 USRt, the ETI-Z series utilizing HFO-1233zd(E) was launched in 2015. For larger capacities, the GART-ZE series employing HFO-1234ze(E) was introduced in 2017. However, these models had a limited range of cooling capacity compared to conventional HFC-134a-based chillers. HFO-1234yf, with a GWP of less than 1 [2], is not subject to the aforementioned regulation. Its saturated pressure is very similar to that of HFC-134a, and its volumetric flow rate is also comparable, making it possible to operate at equivalent cooling capacities. Based on these advantages, we have newly developed the JHT-Y series, which adopts HFO-1234yf as the refrigerant (Fig. 1).

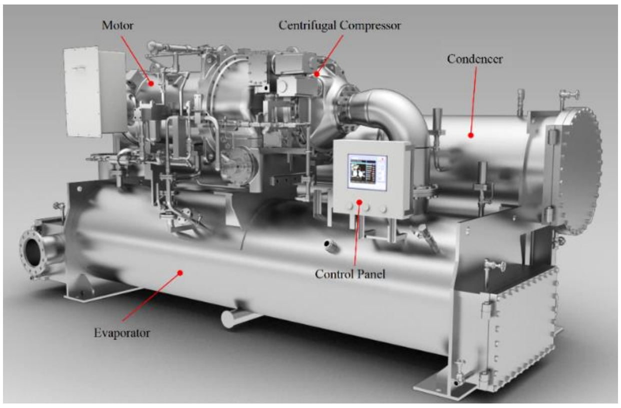


Fig.1 Appearance of JHT-Y series

2. Selection of Refrigerant (HFO-1234yf)

The selection of the refrigerant was evaluated based on four criteria: environmental impact, refrigerant properties, availability, and safety. Table 1 presents a comparison between the conventional refrigerant HFC-134a and HFO refrigerants. The environmental criteria require an ozone depletion potential (ODP) of 0.001 or less, a global warming potential (GWP) of 100 or less, and low toxicity. HFO-1234yf has an ODP of 0, a GWP of less than 1, and is classified as toxicity group A (low toxicity), thus satisfying all environmental requirements and is exempt from the Act on Rational Use and Appropriate Management of Fluorocarbons.

The refrigerant property criteria require that the refrigerant has equal or higher refrigeration cycle efficiency compared to the conventional refrigerant HFC-134a, that the saturation pressure at the expected operating temperatures does not become significantly higher than that of HFC-134a, and that the compressor volumetric flow rate under the same operating conditions as HFC-134a does not increase significantly. The refrigeration cycle efficiency of HFO-1234yf is approximately 96% of that of HFC-134a, indicating a slight energy efficiency challenge. To achieve equivalent performance to conventional machines, high-efficiency compressors and other measures described later are adopted to improve performance. Additionally, the saturation pressure of HFO-1234yf is very close to that of HFC-134a, allowing the equipment design pressure to remain unchanged. The latent heat of vaporization of HFO-1234yf is approximately 82% of that of HFC-134a, and the saturated gas specific volume is about 84%, resulting in a volumetric flow rate approximately 102% of HFC-134a, enabling equivalent refrigeration capacity output with the same equipment size.

The availability criteria require that the refrigerant has applications other than for centrifugal chillers and that sufficient production volume is expected. Since centrifugal chillers use less refrigerant per unit of cooling capacity and have lower production numbers compared to other air conditioning equipment, the total market demand for refrigerant is small. Therefore, refrigerants with stable supply and reasonable pricing, which are widely used in other air conditioning systems or as foam blowing agents, are preferred. HFO-1234yf is widely adopted mainly in automotive air conditioners and vending machines, ensuring stable supply, and thus meets the availability criteria.

The safety criteria require low toxicity and inertness (i.e., no fire hazard under machinery room specifications). HFO-1234yf is classified as A2L (low toxicity, mildly flammable) according to ASHRAE Standard 34 and is categorized as a specified inert gas under the High Pressure Gas Safety Act in Japan. Specified inert gases can be safely used under appropriate measures such as ventilation equipment with regulated capacity interlocked with the chiller, refrigerant leak detection, and alarm systems, similarly to inert gases.

As described above, HFO-1234yf satisfies all selection criteria and exhibits many characteristics close to those of HFC-134a, leading to its adoption.

Table 1 Comparison of COP of low GWP refrigerants

		Conventional refrigerant	Low GWP refrigerants		
		HFC-134a	HFO-1233zd(E)	HFO-1234ze(E)	HFO-1234yf
Ozone depletion potential (ODP)	-	0	0	0	0
Global warming potential (GWP)	-	1430 [1]	1 [2]	< 1 [2]	< 1 [2]
Classification (Refrigeration Safety Regulation under High Pressure Gas Safety Act)	-	Inert gas	- (Low pressure refrigerant)	Specific Inert gas	Specific Inert gas
Classification* (ASHRAE Standard 34)	-	A1	A1	A2L	A2L
Fluorocarbon Emission Control Law	-	Applicable	Not applicable		
Saturation pressure (at 6°C)	kPa(G)	260.7	-39.3	167.3	283.9
Saturation pressure (at 38°C)	kPa(G)	861.8	100.8	624.3	866.4
Evaporation latent heat (at 6°C)	kJ/kg	194.0	200.7	180.3	159.4
Saturated gas specific volume (6°C)	m^3/kg	0.056	0.277	0.069	0.047
Saturated gas specific volume (38°C)	m^3/kg	0.021	0.091	0.026	0.018
Ideal refrigeration cycle COP**	-	7.23	7.47	7.26	7.11
Major applications	-	Refrigerant (for vehicle)	Foaming agent	Aerosol	Refrigerant (for vehicle)

*A1: nonflammability/lower toxicity, A2L: lower flammability/lower toxicity, B1: nonflammability/higher toxicity
**Double-stage compressor/double-stage expansion sub-cooler cycle. Refrigeration cycle efficiency at evaporation temperature of 6°C, condensation temperature of 38°C and adiabatic efficiency of 90%

3. Applied Technologies

3.1. Compressor

(1) Downsizing and Performance Enhancement of the Compressor

The theoretical COP of HFO-1234yf is approximately 98% that of HFC-134a; therefore, to achieve performance equivalent to conventional machines, a more efficient mechanical design is required. Additionally, since the volumetric flow rate per unit cooling capacity is 102% compared to HFC-134a, a compressor capable of handling a larger flow rate is necessary to maintain the same selection range as before. In impeller design, there is a trade-off in which efficiency decreases as the flow rate increases. However, by employing CFD analysis to optimize the aerodynamic shape, the impeller was redesigned to increase the flow rate by approximately 20% while maintaining the adiabatic efficiency of the conventional impeller, achieving a more compact compressor.

Furthermore, accompanying the downsizing of the compressor, components such as bearings, seals, and gears were also optimized to reduce losses and improve overall unit performance. The guide vanes adopted a new blade shape matched to the inflow angle, which expanded the high-efficiency operating range.

From a control perspective, a challenge arises because the gas density of HFO-1234yf is higher than that of HFC-134a, resulting in a larger pressure difference caused by the working fluid acting on the guide vanes, which raised concerns about insufficient driving torque during startup. For the new compressor, a computational control algorithm was implemented to optimize the guide vane opening angle at startup, ensuring reliable startup performance even when using HFO-1234yf.

(2) Optimal Selection of the Compressor

The centrifugal compressors used in centrifugal chillers exhibit their highest efficiency near the design-point flow rate, with efficiency decreasing as the operating point deviates from the design point. In the previous models, five compressor types were used to cover a cooling capacity range of 300 to 2700 USRt. However, in capacity ranges where the optimal compressor type transitions, selection often deviated from the optimal design-point flow rate.

In the newly adopted compressors for the JHT-Y series, aerodynamic components such as blade shapes have been optimized. While limiting the number of compressor models to five, the number of performance variants has been expanded to twelve. This enables high-performance models to be selected across a wider range of cooling capacities.

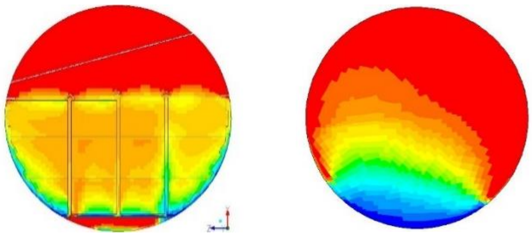
3.2. Evaporator and Condenser

The evaporator and condenser adopt a shell-and-tube type design, and, similar to the compressor, their internal structures were optimized using CFD. Figure 2 shows examples of CFD analysis conducted on the evaporator and condenser during the development of the JHT-Y series centrifugal chillers.

For the evaporator, gaps were provided to allow gas bypass and prevent dry-out in the heat transfer tube bundle. In addition, a baffle was installed near the compressor inlet to prevent liquid refrigerant from being drawn in. For the condenser, to reduce the impact of inundation—where condensed liquid refrigerant in the upper section comes into contact with the lower tube bundle and impairs condensation performance—countermeasures such as optimization of tube arrangement and partitioning between upper and lower tube bundles were implemented.

Although the circulation volume of HFO-1234yf is greater than that of HFC-134a, the flow velocities in each part of the heat exchangers were maintained at levels equivalent to those of HFC-134a.

In conventional models, a single heat exchanger was assigned to each compressor type, which sometimes resulted in an oversized specification depending on the required cooling capacity. By expanding the number of heat exchanger types from 9 to 17 to match the extended lineup of compressor models, it became possible to propose optimally sized heat exchangers according to specific operating conditions.



(a) Evaporator (b) Condenser

Fig. 2 CFD analysis image of heat exchanger (void fraction)

4. Features of the JHT-Y Series

4.1. High Performance and Compact Design

Table 2 presents a comparison with conventional models. The rated COP is 6.4 for the fixed-speed centrifugal chiller in the 2000 USRt class, demonstrating performance equivalent to that of conventional models (GART series) using HFC-134a. The series can operate up to a maximum capacity of 5400 USRt (models with two compressors are used for capacities above 2700 USRt), which is equivalent to the maximum capacity of conventional models and approximately 20% higher than the GART-ZE series employing HFO-1234ze(E). Furthermore, the compressors newly adopted in the JHT-Y series are up to approximately 15% lighter compared to those used in conventional models. Considering the impact on heat transfer performance due to the refrigerant transition from HFC-134a to HFO-1234yf, the heat exchangers were also redesigned. The total number of heat exchanger types was increased from 9 in conventional models to 17, enabling the selection of optimally sized centrifugal chillers according to specific operating conditions. This expansion resulted in a reduction of up to approximately 9% in the combined mass of the condenser and evaporator units. For the entire centrifugal chiller unit, the maximum reductions in height and mass were approximately 4% and 11%, respectively.

Table 2 Comparison of JHT-Y series and conventional chiller

		GART series	JHT-Y series
Refrigerant	-	HFC-134a	HFO-1234yf
Chiller model	-	GART-270	JHT-Y245
Cooling capacity	USRt	1850	
Chill water temperature	℃	12.0 → 7.0	
Cooling water temperature	℃	32.0→ 37.0	
COP	-	6.38	6.38
L×W×H	m	6.2×3.4×3.4	6.2×3.5×3.3
Installation area	m^2	21.08	21.70
Shipping weight	ton	33.0	31.4
Operating weight	ton	43.4	40.8

4.2. Contribution to Global Warming Mitigation

Table 3 shows the CO_2 equivalent reduction potential when all of our HFC-134a centrifugal chillers are replaced with HFO-1234yf models. Since 1999, approximately 5,000 units of our centrifugal chillers have been shipped, of which about 4,400 units use HFC refrigerants. As the current series can replace HFC-134a models, assuming a refrigerant charge of 1200 kg per unit for the 800 USRt class, the CO_2 equivalent of the charged refrigerant is estimated to be reduced from 7.52 × 10^6 t to 5.26 × 10^3 t.

Figure 3 illustrates the estimated relationship of electricity costs per unit when replacing the ART model, launched 30 years ago with HFC-134a, and the AART model, launched 20 years ago, with the JHT-Y60I centrifugal chiller. The power consumption estimates assume continuous operation for 24 hours a day, 365 days a year. Replacement from AART to JHT-Y results in an annual power consumption reduction of 20% and a CO_2 emission reduction of approximately 20 t per year. Replacement from ART to JHT-Y achieves a 40% reduction in electricity costs and an annual CO_2 emission reduction of approximately 60 t.

Table 3 Comparison of JHT-Y series and conventional chiller

		HFC-134a	HFO-1234yf
Global warming potential (GWP)		1430	< 1
Refrigerant charge per unit		1200	1200
Number of shipments	All chillers	5070	5070
	With HFC refrigerant	4385	4385
Amount of HFC refrigerant with centrifugal chillers		5262	5262
CO2 equivalent of the refrigerant charge		t	7.52.E+06

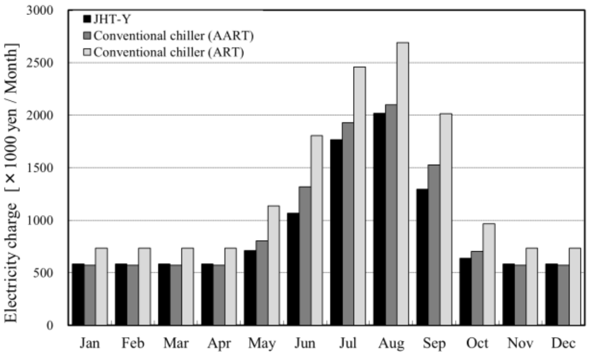


Fig. 3 Comparison of electricity charge (usage charge) with conventional chillers

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