

"ETI-Z, GART-ZE/ZEI" Centrifugal Chillers using Low-GWP Refrigerants for Full Capacity Range



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In October 2016, the “Kigali Amendment” to the Montreal Protocol was adopted. It states that it is obligatory to phase down the production and consumption of hydrofluorocarbons (HFCs), which has set an important global trend in refrigerants. In developed countries, the target is an 85% reduction by 2036 from the respective reference years (2011-2013). As further enforcement of tougher regulations for HFC reduction can be expected, there is an urgent need to start using low global warming potential (GWP) refrigerants. From the viewpoint of product life cycle, it will become increasingly unlikely for centrifugal chillers using HFC refrigerants to be introduced. Under such circumstances, Mitsubishi Heavy Industries Thermal Systems, Ltd. launched the ETI-Z series in September 2015 using HFO-1233zd(E) with a GWP of 1, and the GART-ZE/ZEI series in April 2017 using HFO-1234ze(E) with a GWP of <1. Thus, low GWP refrigerants are used in all our centrifugal chiller models with cooling capacities ranging from 150 refrigeration tons (RT) to 5000 RT.

1. Introduction

The 28th Meeting of the Parties to the Montreal Protocol (MOP28) was held in October 2016, and the Kigali Amendment to the Protocol was adopted to prescribe the obligatory gradual reduction of HFC production and consumption, etc., thus clearly setting the course towards terminating the use of HFCs. In the fields of heating, ventilation and air conditioning (HVAC) and refrigeration, although measures to mitigate global warming such as the F-gas Regulation in Europe and the Fluorocarbon Emission Control Law in Japan have been enacted, even more effort will be required.

Centrifugal chillers are used as the cold source in district heating and cooling systems, HVAC systems in buildings and plants, and process cooling systems in chemical and food factories. With the use of centrifugal compressors, centrifugal chillers produce chilled water with cooling capacities ranging from 150 RT to 5000 RT. Their global warming impact factors include indirect CO₂ emissions due to electricity consumption during operation, and direct greenhouse gas emissions to the atmosphere in unexpected incidents such as refrigerant leakage. We have always taken on the challenge to reduce CO₂ emissions from chillers, by dedicating itself toward the realization of optimal control and improved efficiency of compressors and heat exchangers for reduced power consumption during operation, as well as enhancing maintenance services such as regular leak inspections to minimize the release of refrigerant to the air. However, it has been a concern that the impact of only a very small leak of HFC refrigerant would be significant because of its high GWP.

In response to the market’s fundamental need to terminate the use of substances that can contribute to global warming, we have used low GWP refrigerants in all centrifugal chiller series models throughout the capacity range, which is a first among our domestic competitors. None of the models of these series are subject to the Fluorocarbon Emission Control Law. This report introduces the features and specifications of these centrifugal chiller series using low GWP refrigerants.

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2. Selection of low GWP refrigerants

The following issues were considered when selecting suitable low GWP refrigerants for centrifugal chillers.

(1) Environmental soundness

The refrigerant to be selected should not be destructive to the ozone layer and should have a GWP of 150 or lower.

(2) Physical properties

It is important to have a refrigeration cycle efficiency as good as that of HFC-134a and not to require extremely high design pressure in any chiller components. Refrigerant physical properties determine energy consumption, CO₂ emissions, and working pressure ranges. High working pressure increases the wall thickness of chiller components to produce sufficient strength, consequently increasing the cost as well.

(3) Availability

There should be applications other than centrifugal chiller refrigerants, to ensure a certain level of production. When compared with multi-split building air conditioners, centrifugal chillers require a smaller amount of refrigerant per unit of cooling capacity and are manufactured in smaller quantities. The amount of refrigerant used is smaller than other types of air conditioning systems (such as multi-split building air conditioners, and automobile air conditioners). Therefore, from the viewpoint of constant availability and prices, it is important that the refrigerant is also used as a foaming agent or in other air conditioning systems as well.

(4) Safety

The refrigerant to be selected should be able to be handled as non-flammable and have low toxicity as per the High Pressure Gas Safety Act of Japan.

Table 1 Refrigerant comparison

	Conventional refrigerant			New refrigerant (low GWP)		
	HFC-245fa	HFC-134a	HFC-32	HFO-1234yf	HFO-1234ze(E)	HFO-1233zd(E)
Global warming potential (GWP) ^{*1}	858	1300	677	<1	<1	1
Ozone depletion potential (ODP)	0	0	0	0	0	0
Classification (High Pressure Gas Safety Act, Refrigeration Safety Regulation)	NA ^{*2}	Inert gas	Inert gas ^{*3}	Inert gas ^{*3}	Inert gas ^{*3}	— ^{*2}
Atmospheric lifetime	7.7 years	13.4 years	5.2 years	10.5 days	16.4 days	26 days
Long-term exposure toxicity [ppm] (allowable concentration)	300	1000	1000	500	800	800
Boiling point [°C] (at atmospheric pressure)	15.1	-26.1	-51.7	-29.4	-19.0	18.3
Saturation pressure (at 6°C) [kPaG] ^{*4}	-32.1	260.7	879.8	23.9	167.3	-39.1
Saturation pressure (at 38°C) [kPaG] ^{*4}	133.1	861.9	2258	866.4	624.3	100.8
Specific volume of saturated gas [m ³ /kg] ^{*4} (at 6°C)	0.241	0.056	0.037	0.047	0.069	0.277
Specific volume of saturated gas [m ³ /kg] ^{*4} (at 38°C)	0.075	0.021	0.014	0.018	0.026	0.091
Theoretical COP ^{*5}	6.86	6.58	6.38	6.31	6.56	6.93
Availability	Medium	High	High	Low	Low	Low
Overall rating ^{*6}	△	△	○	○	◎	◎

*1 Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report

*2 The High Pressure Safety Act is not applicable to R-245fa and R-1233zd(E), when used for chillers under the specified conditions.

*3 Designated inert gas

It is necessary to install a mechanical ventilation system (interlocking mechanism between the chiller and the ventilator) with a prescribed ventilation capacity, as well as a refrigerant leak detection and alarm system.

*4 NIST Reference Fluid Thermodynamic and Transport Properties Database (REFPROP) Version 9.1

*5 Two-stage compression/two-stage expansion sub-cooler cycle. Refrigeration cycle efficiency at evaporation temperature of 6°C, condensation temperature of 38°C, and adiabatic efficiency of 90%.

*6 ◎: Low GWP and high theoretical COP, ○: Low GWP, but theoretical COP not as good as HFO-1234ze(E) or HFO-1233zd(E), △: High GWP

In selecting low GWP refrigerants for centrifugal chillers, we have examined those listed in **Table 1**. HFO-1234yf and HFO-1234ze(E) exhibit physical properties that are relatively similar to those of HFC-134a, and are classified as designated inert gases according to the High Pressure Gas Safety Act. On the other hand, the physical properties of HFO-1233zd(E) are close to HFC-245fa rather than HCF-134a. When used in air conditioning systems, it yields only a refrigerant pressure

of less than 0.2 MPaG, and therefore the above Act is not applicable. Because the GWPs of these substances are all below 1, none of them are bound by the Fluorocarbon Emission Control Law. Based on the detailed examination regarding (1) to (4) and other considerations such as risk assessment results, we decided to use HFO-1233zd(E) for chillers with small capacities and HFO-1234ze(E) for chillers with large capacities, respectively.

3. Series line-up

Our centrifugal chillers with low GWP refrigerants are commercially available in the ETI-Z series (small capacity range) and the GART-ZE/ZEI series (large capacity range). The combined capacity of refrigeration in these series ranges from 150 RT to 5000 RT. **Figure 1** shows the capacity range of each series, together with that of the earlier series using the conventional HFC-134a refrigerant.

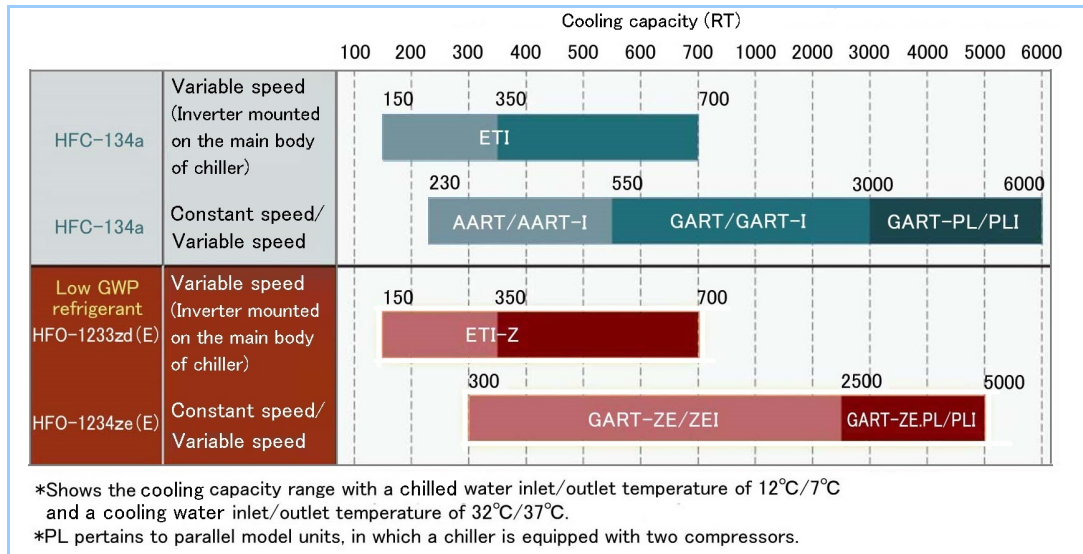


Figure 1 Product line-up of our centrifugal chillers

(1) ETI-Z series

Using HFO-1233zd(E) with a GWP of 1, this series covers the capacity range of 150 RT to 350 RT by single model units with a single compressor, and can also achieve a maximum of 700 RT using parallel model units with two compressors. The series is equipped with the 400 V class inverter as standard. The exterior view is shown in **Figure 2**.

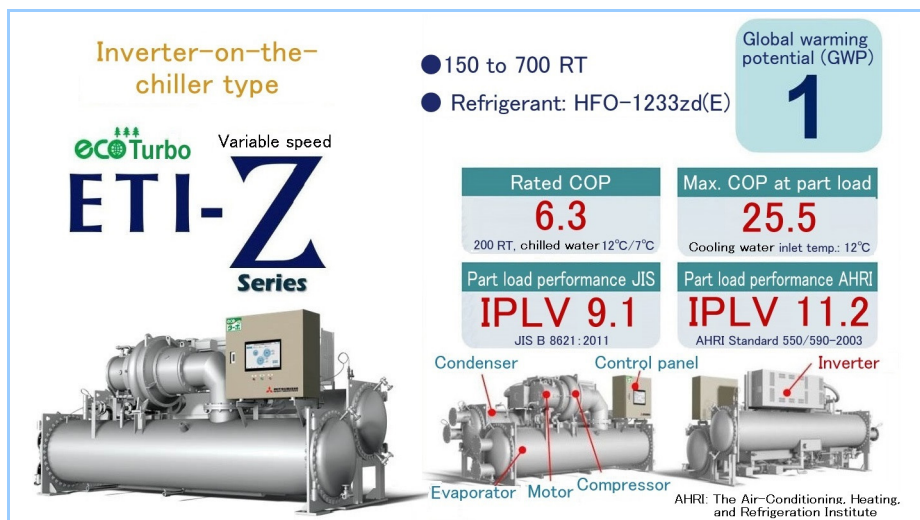


Figure 2 Exterior view of the ETI-Z series

(2) GART-ZE/ZEI series

The refrigerant in this series is HFO-1234ze(E) with a GWP of less than 1. This series can offer a capacity range of 300 RT to 2500 RT using single model units with a single compressor, and a maximum of 5000 RT using parallel model units with two compressors.

With constant speed models (GART-ZE) as standard, the series also includes variable speed models (GART-ZEI). The exterior view is shown in **Figure 3**.



Figure 3 The exterior view of GART-ZE/ZEI series

4. Applied technologies

The specific volume of gaseous HFO-1233zd(E) in the ETI-Z series is about 5 times as large as that of HFC-134a. In the case of HFO-1234ze(E) in the GART-ZE/ZEI series, the factor becomes nearly 1.3. Therefore, it is normally necessary to increase the volume of components such as the compressor, evaporator, condenser, and gas pipes through which gaseous refrigerant passes. If this were the case, however, it would be impossible to replace the earlier models, making them useless as alternative new models. To enable the new models to be widely accepted, we have employed the following component designs to realize efficiency and compactness equivalent to or surpassing existing models.

(1) Improved performance and compactness of the compressor

[i] Aerodynamic design

To deal with an increased specific volume of gaseous refrigerant, we have adopted an aerodynamic design that can withstand a larger gas flow than the existing compressors. However, because of the tendency for the increased design gas flow to impair the adiabatic efficiency, the blade shape of the impeller and the shape of the inlet guide vanes have been optimized using computational fluid dynamics (CFD) analysis. As a result, we have successfully increased the gas flow by 60% while improving the adiabatic efficiency by 3% with the same impeller radius as the existing compressors. The volume of the compressor has thus been reduced.

[ii] Direct coupling of compressor and motor (ETI-Z series only)

When the cooling capacity remains the same but the refrigerant has a higher specific volume, the impeller radius needs to be increased. An increased peripheral velocity of the impeller decreases the number of impeller rotations. For these reasons, we coupled the impeller directly with the motor. Consequently, the motor has been downsized and provides an increased rotational speed. Direct coupling of the compressor and the motor with no increasing gears in between has enabled the downsizing and improved performance of the compressor. The decreased number of bearings in the compressor has reduced the loss and improved the reliability.

(2) Improved performance and compactness of the heat exchanger

For the heat exchanger, the shell and tube type is used. Since the specific volume of refrigerant is larger and the pressure difference between the condenser and the evaporator is smaller than the existing chillers, we have designed the heat exchanger to minimize the pressure loss owing to the flow of refrigerant. Of particular focus are the prevention of drying, which makes it difficult for heat to be exchanged in heat exchanger tubes (owing to the locally

enlarged volume of gaseous refrigerant in the evaporator), the prevention of refrigerant liquid droplets being carried with gaseous refrigerant into the compressor because of the large flow rate of gaseous refrigerant bursting from the outlet above the tube bundle, and the prevention of a large pressure loss

In the ETI-Z series, because some components such as the evaporator operate under working pressure conditions below atmospheric pressure, irregularities such as insufficient air-tightness can cause air (non-condensable gas) to enter the centrifugal chillers. Therefore, we have identified where such gases can collect and accordingly have installed tubes to extract them effectively when needed.

(3) Small control panel with improved performance

The control panel contains the microcontroller board with a CPU with an increased processing speed, thus enabling the control with higher accuracy. Moreover, the operability of the touchscreen and the visibility of the control panel have been improved, along with an increase in the size of the liquid crystal display compared with the previous models (Figure 4). The functionality has also been improved. In the case of irregular shutdowns due to chiller malfunctions, the procedure to be taken is shown on the screen as an operational support guide. It also gives automatic notifications such as regular maintenance schedules.

In the large-capacity GART-ZE/ZEI series, the touchscreen display is placed separately from the electric device cabinet, thus providing even better operability.

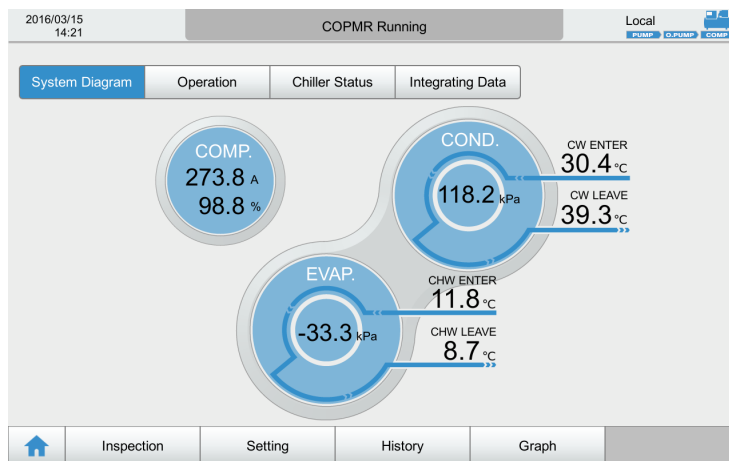


Figure 4 Control panel screen (ETI-Z series)

5. Comparison with earlier models

As examples, the ETI-Z series using HFO-1233zd(E) are compared with the previous models of the ETI series using HFC-134a (Figure 2). These two refrigerants have considerably different physical properties from each other.

Table 2 Rated specifications and performance comparison

	ETI series	ETI-Z series
Chiller model	ETI-20	ETI-Z20
Refrigerant	HFC-134a	HFO-1233zd(E)
Cooling capacity	200 RT (703 kW)	
Chilled water temperature	12.0°C → 7.0°C	
Chilled water flow rate	120.7 m ³ /h	
Cooling water temperature	32.0°C → 37.0°C	
Cooling water flow rate	141.5 m ³ /h	139.6 m ³ /h
Power consumption	115.0 kW	111.3 kW
COP	6.1	6.3
L×W×H	3.7m×1.5m×1.8m	3.8m×1.6m×1.8m
Space for installation	5.55 m ²	5.80 m ²
Shipping weight	3.9 ton	4.3 ton

(1) Performance

While the ETI series (ETI-20) has a COP of 6.1, the COP of the ETI-Z series (ETI-Z20) is 6.3 (an increase of about 3%). The rated performance has thus improved.

(2) Installation space

In addition to the downsizing of the compressor and heat exchanger (as described in Section 4), a compact design has also been achieved by arranging the auxiliary devices and small containers beneath the condenser. Compared with the ETI series, the specific volume of gaseous refrigerant in the ETI-Z series is increased by nearly a factor of 5, but the required space for installation is increased by only about 5%. On the other hand, the GART-ZE/ZEI series successfully retains the compactness of the GART series. In both the ETI-Z and GART-ZE/ZEI series, a reduction of approximately 35% in installation space has been realized compared with our old models released 15 or more years ago, which are ready for to be replaced.

6. Maintenance and management

It is essential to carry out daily maintenance and management for the safe and effective operation of centrifugal chillers. The following are the characteristics of the ETI-Z series (using HFO-1233zd(E)) and the GART-ZE/ZEI series (using HFO-1234ze(E)).

(1) ETI-Z series

As HFO-1233zd(E) has a low design pressure (saturation pressure of less than 0.2 MPaG when used for air conditioning) and is not subject to the High Pressure Gas Safety Act, there is no need for users to be trained for safety and emergency procedures, to conduct regular voluntary examinations and legally required inspections, or appoint someone as a safety superintendent for centrifugal chiller operation. Even if there are no such requirements, it is necessary to properly manage maintenance for the realization of the safe operation and stable performance of chillers (e.g., water quality control for chilled water and cooling water, and electrical parts replacement). We will proactively support users by providing regular inspections and listing the examination items.

(2) GART-ZE/ZEI series

Since HFO-1234ze(E) is subject to the High Pressure Gas Safety Act, this series should be managed as with the earlier models with HFC-134a. According to the above Act, HFO-1234ze(E) is classified as a designated inert gas, which necessitates the installation of a mechanical ventilation system (interlocking mechanism between the chiller and the ventilator) with a prescribed ventilation capacity, as well as a refrigerant leak detection and alarm system.

7. Conclusion

HFO-1233zd(E) and HFO-1234ze(E) have a very low GWP of 1 or less (the GWP of CO₂ is 1). By applying these refrigerants to the new centrifugal chillers, all our centrifugal chiller models are now available with low GWP refrigerants. At present, there is no heat source or heatsink equipment with the use of a low GWP refrigerant in multi-split building air conditioners, which operate in a large-scale unit air-conditioning system. In the centralized air conditioning system, our centrifugal chillers with these refrigerants are the only products available among our domestic competitors. We will promote these new refrigerants to be widely recognized and continue to provide chillers that can satisfy our customers.

References

1. Naoya Miyoshi, Centrifugal Chiller Using HFO-1233zd(E), JRAIA The International Symposium on New Refrigerants and Environmental Technology 2016