Centrifugal Chiller Model RTSF for Low-temperature Brine

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Abstract
An antifreeze called brine of which the temperature is approximately -20 °C, is used by facilities such as chemical plants to cool process loads. While EBARA has manufactured and sold centrifugal chillers for cooling this brine, needs for a new model have risen in response to demand for higher efficiency. Under these circumstances, EBARA developed and commercialized a centrifugal chiller model RTSF, for low-temperature brine based on the technology of the centrifugal chiller model RTBF, which has been on the market since 2009 and has gaind a great deal of trust from users. EBARA began selling model RTSF in April 2016.

Keywords: Centrifugal chiller, Low-temperature brine, Refrigerant, High pressure gas safety act, High reliability

1. Introduction

A centrifugal chiller for brine is a centrifugal chiller designed to cool an antifreeze called brine to 0 ℃ or below. A centrifugal chiller for general air conditioning applications is a device for cooling chilled water to approximately 5 to 7 ℃, and the main difference between the centrifugal chiller for brine and the centrifugal chiller for general air conditioning applications is the use of brine and the cooling temperature. Brine to be cooled to approximately −5 ℃ is classified as low-temperature brine, and brine cooled to approximately −20 ℃ is classified as extremely-low-temperature brine. The model RTSF explained in this technical literature is a centrifugal chiller for extremely-low-temperature brine.

The centrifugal chiller model RTBF, EBARA's core model at present was released on the market in 2009 and has since earned a great deal of trust from customers. Centrifugal chillers for cooling brine to an extremely low temperature (approximately −20 ℃) are required to offer higher efficiency, and we began selling the model RTSF centrifugal chiller for extremely-low-temperature brine, developed and commercialized based on the technology of the model RTBF model that can also replace conventional models, in April 2016 (**Figure 1**).

Fig. 1 Model RTSF Centrifugal chiller for extremely-low-temperature brine

The model RTSF uses a low-pressure refrigerant HFC245fa. Depending on the refrigerant used, the High Pressure Gas Safety Act may apply, making it necessary to file the necessary forms or inspection/testing before the installation or operation of a centrifugal chiller using that refrigerant. However HFC245fa is exempted from the application of the High Pressure Gas Safety Act. In addition, the same refrigerant is used in the model RTBF and can be stably supplied.

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2. Product Concept

Conventional centrifugal chiller models are used in chemical plants etc. Chillers for industrial applications will have a direct and significant effect on production lines if they break down. For this reason, in the development process of the model RTSF, we investigated the operating status of conventional models and the problems that occurred, and analyzed the potential risks. The obtained results have been reflected on the specifications of the model RTSF, and the structure adopted and refined on the model RTBF centrifugal chiller, the current core model, has been incorporated into the model RTSF. In addition, we aimed to achieve higher efficiency and lower energy consumption than conventional models.

We concentrated our efforts on early commercialization of the model RTSF by using a low-pressure refrigerant HFC245fa and by utilizing the technologies we have developed over many years.

3. Brine

Brine is an antifreeze cooled in a chiller and used for cooling the heat load of a range of plant processes. Sufficiently lower freezing point than the operating temperature, high specific heat, low viscosity, satisfactory heat transfer, non-corrosiveness, low cost and high availability, etc. are characteristics of brine.

The model RTSF is compatible with an ethylene glycol solution, methanol solution, or calcium chloride solution as brine depending on the conditions for use.

4. Refrigerant

The characteristics of refrigerants widely used for centrifugal chillers are shown in **Table 1** for comparison. HFC245fa, a CFC substitute, is exempt from production regulation and can be constantly supplied.

Table 1 Comparison of refrigerant characteristics

Refrigerant	HCFC123	HFC134a	HFC245fa
Molecular formula	$CHCl_2CF_3$	CF_3CH_2F	$CF_3CH_2CHF_2$
Ozone depletion potential (ODP) [1]	0.02-0.06	0	0
Global warming potential (GWP) [2]	79	1 300	858
Condensing pressure MPa (G) [3] (at 38 ℃)	0.0432 Low-pressure refrigerant	0.862 High-pressure refrigerant	0.133 Low-pressure refrigerant
Combustibility	Incombustible	Incombustible	Incombustible

5. Refrigeration Cycle

An overview of the flow of the model RTSF centrifugal chiller and its refrigeration cycle are shown in **Figure 2** and **Figure 3**, respectively. In the flow overview, numbers are assigned to the main points of the refrigerant fluid, and the corresponding points in the refrigeration cycle are marked with the same numbers. In addition, the vertical axis of the refrigeration cycle represents the saturation temperature equivalent to operating pressure. In the explanation below, all references to the pressure head of the compressor are replaced with the temperature head.

In a centrifugal chiller for general air conditioning applications, the refrigerant gas of approximately 5 ℃ evaporated by cooling chilled water in the evaporator is pressurized by the compressor, discharged into the condenser, where heat is removed from the refrigerant, and transformed into a refrigerant liquid of approximately

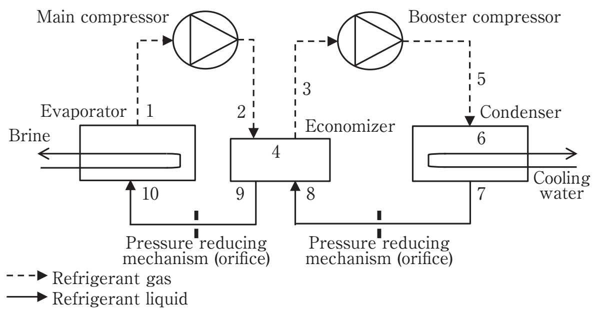

Fig. 2 Model RTSF Flow overview

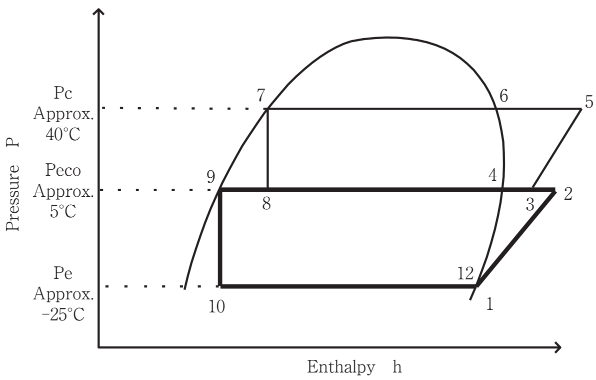

Fig. 3 Model RTSF refrigeration cycle

40 ℃, which returns to the evaporator through the pressure reducing mechanism. These steps form the refrigeration cycle. The temperature head is approximately 35 ℃. In the centrifugal chiller for extremely-low-temperature brine, the refrigerant is evaporated at approximately −25 ℃ because the extremely-low-temperature brine is cooled in the evaporator, and the refrigerant is liquefied at approximately 40 ℃ in the condenser, which is the same temperature as the centrifugal chiller for general air conditioning applications. The temperature head is approximately 65 ℃. The model RTSF centrifugal chiller uses an model RTBF compressor for general air conditioning applications, and this compressor alone cannot boost the temperature head to approximately 65 ℃. For this reason, the temperature head is boosted in the main compressor and further boosted in the booster compressor via the economizer. Both the main and booster compressors are two-stage compressors equipped with two impellers, with an economizer placed between them. This configuration is called a four-stage-compression and one-stage economizer cycle.

The refrigerant liquid supplied from the condenser is expanded in the pressure reducing mechanism, and by feeding only the low-temperature refrigerant liquid to the evaporator, a cycle of increasing the refrigeration effect → reducing the circulated amount of the refrigerant → saving compression power is established, resulting in a higher COP. For the pressure reducing mechanism, an orifice was used because priority was given to reliability over everything else. Examples of the specifications of the model RTSF centrifugal chiller are shown in **Table 2**.

Table 2 Model RTSF specification examples

Chiller model		−	RTSF053B
Refrigeration capability		kW (USRt)	386.8 (110)
Brine	Type	−	35 wt% methanol solution
	Temperature at inlet/outlet	℃	− 20.8→− 23
	Flow rate	L/min	3000
	Path × direction of nozzle	−	4 paths × right side of inlet
Cooling water	Temperature at inlet/outlet	℃	32→37
	Flow rate	L/min	1700
	Path × direction of nozzle	−	2 paths × right side of inlet
Motor	Voltage	V	3300
	Frequency	Hz	50

6. Components

An outline drawing of the model RTSF053 centrifugal chiller is shown in **Figure 4**. The main compressor, booster compressor, evaporator, economizer, and the condenser form the main components of the model RTSF, which also are equipped with a control panel for operating the centrifugal chiller. The sections as follows describe these components.

6.1 Compressors

The compressors have the same configuration as that of compressors for centrifugal chillers used in general air conditioning equipment and consist of a barrel body, inlet guide vane, shaft, speed increasing gear, impeller, haft sealing device and a lubricating device, etc. The main compressor and the booster compressor have the

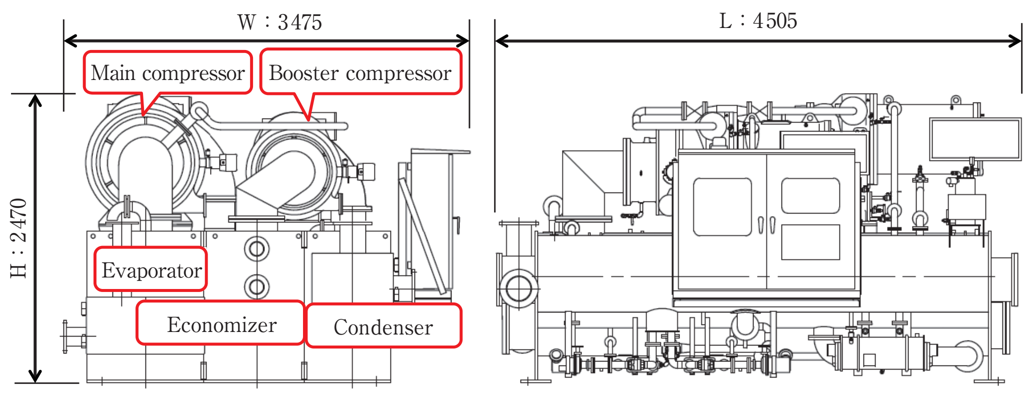

Fig. 4 Model RTSF053 outline drawing

same basic structure. The model RTSF uses the same compressors as the model RTBF, which are superior in efficiency to the compressors of conventional models and have been customized for the model RTSF.

The power voltage of the motors for the compressors supports voltage levels of 400 V, 3000 V, and 6000 V.

6.2 Evaporator

The evaporator adopts a shell-and-tube flooded type heat exchanger. When cooling low-temperature brine, the evaporation pressure is extremely low compared to that of evaporators used in general air conditioning applications. For this reason, in the flooded type heat exchanger, pressure acts for the height from the tube to the liquid level and causes the refrigerant saturation temperature on the tube surface to rise. This state inhibits evaporation of the refrigerant therefore controlling the level of refrigerant is important during operation. As a solution, a manual valve to regulate liquid levels is provided.

A material resistant to brittle fractures at low temperatures is selected for the evaporator, which reaches the lowest temperature among the components of the model RTSF. The materials used for the tube, the tube plate and water chamber, etc. are also selected taking into account temperature and the characteristics of the brine.

6.3 Economizer

The economizer is used to evaporate part of the refrigerant using the intermediate pressure of the evaporator and the condenser and reduce the temperature of the liquid refrigerant. The same material used for economizers in general air conditioning applications can be used for the economizer because it does not reach temperatures as low as the evaporator.

6.4 Condenser

The condenser is a shell-and-tube type and the same as that used in general air conditioning applications. The condenser is compatible not only with cooling tower circulating water but also with seawater, which as a cooling water, is highly corrosive. Materials resistant to seawater can be provided for instruments to be attached to the cooling water system in addition to the materials used for the tube, tube plate, and the water chamber.

Many general-purpose chillers use a sub-cooler to reduce the temperature of the refrigerant before the cooling water is drawn into the condenser. However, sub-coolers are not installed in chillers for chemical plants, which mainly use chillers for brine, because in many cases the scale coefficient of water used as cooling water is higher than that used in general air conditioning applications and scale is likely to accumulate on the inner surface of the tube. An appropriate heat transfer area for the condenser is selected for the refrigeration capability of the model RTSF to enable it to achieve the specified performance without a sub-cooler.

6.5 Control panel

Control panels were designed exclusively for conventional models each time an order for a model was received, and the design of both software and hardware was inefficient. Thus, we carefully investigated the specifications of conventional models, classified the components into standard and optional items, and developed a control panel that does not need to be designed exclusively for each customer and is available for all model RTSF products. This control panel not only provides the functions of control panels for conventional models, but also stores operating data, etc. for improved performance.

Compared with conventional models, earlier presentation and finalization of specifications and a shorter design lead time can be expected from the model RTSF.

7. Temperature Control of Brine

A suction vane control, also used in centrifugal chillers for general air conditioning applications is used for capacity control in the model RTSF. The guide vanes of the main and booster compressors are controlled to keep the temperature constant of the brine at the outlet.

8. Safety Devices and Instruments

Recent chemical plant equipment shows an increasing need for a function that is capable of describing data from safety devices and instruments and storing this data as operation data. The model RTSF was, therefore, configured to have the same safety function as that of conventional models by using a resistance temperature sensor and a pressure sensor. As a result of this configuration, in addition to the control panel, we were also able to standardize safety devices and instruments.

9. Test Results (at time of development)

9.1 Performance at rated points

We confirmed that the model we developed and produced achieved the COP (Coefficient Of Performance) initially intended and offered equivalent brine cooling performance to that of conventional models.

9.2 Other check points

9.2.1 Vibration and noise

We measured and evaluated noise and vibration under four conditions, high and low heads and high and low loads. We measured noise at a distance of 1 m from the periphery of the chiller and vibration of the chiller base plate, each compressor and the piping, etc. in the horizontal, perpendicular and axial directions. The noise level was 87 dB (A) at its highest, and the vibration amplitude was 15 μm or less, proving that the model RTXF produced less noise and vibration than conventional models.

9.2.2 Lubricating oil system

The model RTSF and other centrifugal chillers using a lubricating oil have an ejector for recovering lubricating oil that enters the refrigerant system. We adopted measures, such as optimization of the ejector drive pressure, design of the position of the recovery port, the addition of a recovery system, and attempted continuous operation of the model RTSF under various conditions. We confirmed that the lubricating oil level did not drop from the level at the start of the test and the lubricating oil was recovered as planned.

9.2.3 Operation in special situations

Using facilities in the laboratory, we reproduced situations in which conventional models might be difficult to operate, such as activation with cool brine and activation with a large amount of oil contained in the refrigerant and were able to confirm that it was possible to continuously operate the model RTSF by automatic control.

We also disassembled and inspected the compressors after the chiller was operated over a prolonged period. We performed visual and dimensional inspections, looking at bolt looseness, the shafts, bearings, impellers, speed increasing gears, each of the compressor motors and other parts. We did not find any abnormal flaws or deformation and clearance changes, etc. even after operation under special situations, confirming the integrity of the compressor parts.

10. Specifications

The product line-up for the model RTSF series is shown in **Table 3**. Unlike chillers for general air conditioning applications, the values shown in Table 3 are just for reference. If you desire an in-depth study, please contact us.

11. Conclusion

In this technical literature, we explained the model RTSF centrifugal chiller for extremely-low-temperature brine with emphasis placed on comparison with

Table 3 Model RTSF series product line-up

Model	RTSF053	RTSF083	RTSF085	RTSF135	RTSF053B	RTSF083B	RTSF085B
Refrigeration capability (kW)*1	598	914	985	1512	387	580	598
Brine *2	Ethylene glycol solution, calcium chloride solution, methanol solution						
Temperature of brine at outlet *3	～ −15 ℃				～ −23 ℃		
Refrigeration cycle	Four-stage compression one-stage economizer cycle						
Refrigerant	HFC245fa						
Power voltage	400/3000/6000 V levels						
Starting system	Line/Star-delta/Reactor/Kondorfer						
Installation specifications	Common to indoor installation and outdoor installation						

*1 The values are reference values for selection on the assumption that a 35 wt% methanol solution is used for brine and the temperature of the brine at the outlet is -15 ℃ or -23 ℃.
*2 There are certain conditions, such as of concentration and temperature, etc. the abovementioned types of brine cannot are not suited to.
*3 The reaching temperature at the outlet may depend on the brine conditions, etc.

conventional models and centrifugal chillers for general air conditioning applications. We are determined to meet user needs and contribute to the growth of various industries with centrifugal chillers for extremely-low-temperature brine.

EBARA is currently committed to research and development into the application of a refrigerant with extremely minimized global warming potential (GWP) to centrifugal chillers to reduce global warming.

References

1) Fiscal 2005 Annual report on monitoring results such as ozone layer, p.145.
2) IPCC Fifth Assessment Report.
3) NIST Refprop ver.9.0.