Development of Air to Water Heat Pump for Europe using R290 refrigerant

Teruo NISHIDA*, Yukio MATSUSAKA*, Hirokazu FUJINO, Koju YAMADA*, Takashi ONO*,
Hayato Nuno**, Takuya Nakao**
*DAIKIN INDUSTRIES, LTD., , Osaka Umeda Twin Towers South, 1-13-1, Umeda, Kita-ku, Osaka, Japan
**DAIKIN EUROPE N.V. , Technologiepark-Zwijnaarde 116, 9052 Gent, Belgium

Propane is seen as a expecting next-generation refrigerant because of its low GWP value and relatively good refrigeration performance. On the other hand, since it is a higher flammable refrigerant, careful and sufficient consideration is required when handling it. By adopting microchannel heat exchanger, we have achieved a reduction the inner volume of the air heat exchanger approximately 62%, the refrigerant charge amount has been reduced by 17% as conventional fin-and-tube heat exchangers.

Key Word: R290, Propane, Heat Pump, Space Heating, Microchannel Heat Exchanger

1. Introduction

As the issue of global warming intensifies in modern society, initiatives targeting carbon neutrality are being promoted worldwide. In Europe, which is considered an environmentally advanced region, the shift in heating from the combustion of fossil fuels to heat pumps is accelerating, and there is also a movement towards regulating global warming potential (GWP) values.

A quick look back at refrigerant history reveals that natural refrigerants, such as R290 (propane), R744 (CO_2), and R717 (ammonia), were used as early refrigerants prior to the 1930s. However, safety concerns, including flammability, refrigerant performance, and toxicity, led to a decline in their use in favor of fluorocarbon refrigerants, such as HCFCs, which are more chemically and thermally stable. Later, concerns for ozone layer depletion and global warming prompted a shift from HCFC to HFC refrigerants. Recognizing global warming as a major issue, attention has reverted back to natural refrigerants. Among these, R290 (propane) is considered the most expecting as a next-generation refrigerant because of its low GWP and relatively good refrigerant performance among natural refrigerants. [1]

In light of this, we launched “Altherma 4 H” (Fig. 1), a heat pump type space and water heater using R290 (propane), in Europe in March 2025. Because R290 (propose) is a higher flammable refrigerant, maintaining its safe use is extremely important. Accordingly, risk assessments were conducted at each life stage, and safety measures were implemented based on the results. While safety measures are necessary in the event of refrigerant leakage, decreasing the amount of refrigerant charged into the product is even more important in mitigating risk.

This paper describes the development of air to water heat pump for Europe using R290 refrigerant, and mainly introduces efforts to reduce the amount of refrigerant used.

Fig. 1 Configuration of Air to Water Heat Pump（Altherma 4 H）

2. Characteristics of the R290 refrigerant

Table 1 compares the higher flammable refrigerant R290 with the lower flammable refrigerant R32, which is currently mainstream. Because the ignition energy of R290 is about 1/100 of that of R32, an ignition risk exists even from an static electricity spark, a common occurrence in winter. [1]

Table 1 Comparison of flammability between R290 and R32

Refrigerant	ISO 817 Class	Ignition Energy (mJ)	Combustion Energy (MJ/kg)	Burning rate (cm/s)
R290	A3	0.23	46	46
R32	A2L	29	8.5	6.7

Similarly, when comparing refrigerant characteristics, R290 has a lower gas density than R32, as shown in Fig. 2. This raises the issue of needing greater compressor piston volume. Also, because R290 is a refrigerant operating under lower pressure than R32, it is necessary to design the air heat exchanger, which acts as an evaporator, to minimize pressure drop, especially during heating operation.

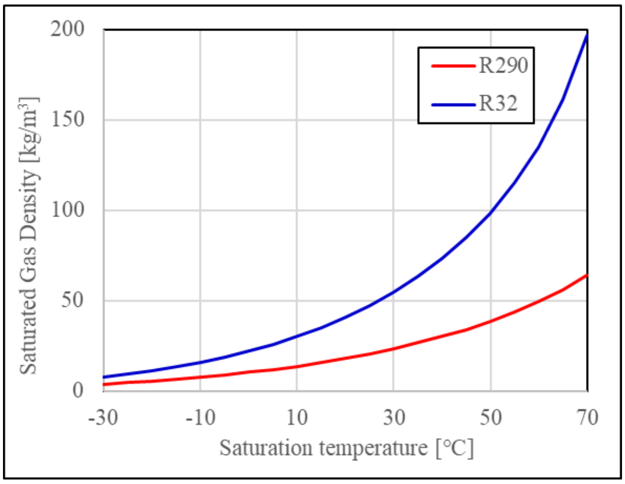

Fig.2 Saturated gas density of R32 and R290

However, R290 has the advantage of being able to achieve a high condensation temperature at a lower pressure than R32, it has the advantage of being able to easily produce hot water at high temperatures. Fig. 3 shows a comparison of the maximum outlet water temperature during the heating operation according to ambient temperature for products using R290 and R32. In R32 model, our flagship model has a design pressure increased to 5.6MPa, achieving an outlet water temperature of 70°C when the outside air temperature is -15°C. On the other hand, The R290 model achieves an outlet temperature of 75°C when the ambient temperature is -15°C, despite its design pressure of 3.2 MPa.

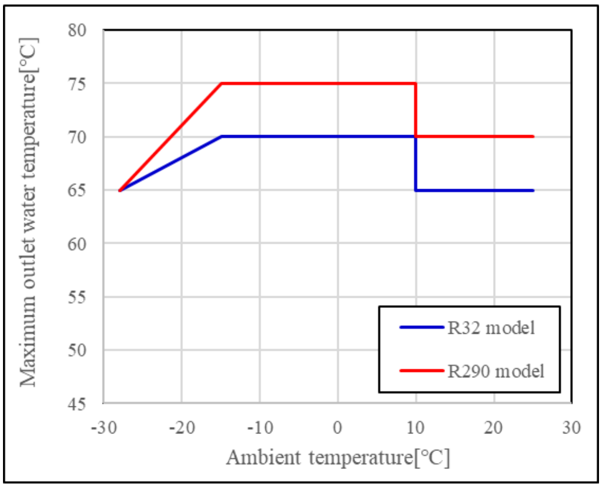

Fig. 3 Operating range in heating operation

3. Technology and Features of Developed Product

3.1 Reduction of refrigerant amount technology (Microchannel Heat Exchanger)

Fig. 4 shows a comparison of a microchannel heat exchanger installed to the product and a conventional fin-and-tube heat exchanger. The microchannel heat exchanger uses flat multi-hole tubes designed with numerous small-diameter flow paths measuring less than 1 mm in diameter. [2],[3] The flat tubes reduce airflow resistance caused by the heat transfer tubes to enable high tube density. This substantially increases the surface area on the refrigerant side compared to conventional heat exchangers and improves heat exchange efficiency. Furthermore, the small-diameter flow paths reduce inner volume, making it possible to reduce the amount of refrigerant used.

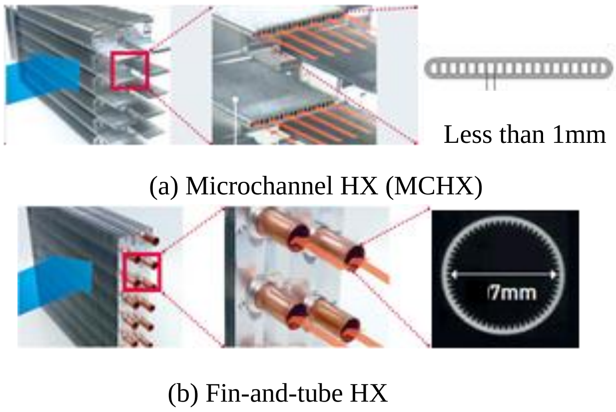

Fig. 4 Comparisons of heat exchanger structures

[Distribution Technology for Thin, Multi-Hole Tubes]

In order to maximize the refrigerant-saving benefits of microchannel heat exchangers, it is important to design more thinner flat multi-hole tubes. However, the small refrigerant flow path increases refrigerant pressure loss, which can lead to performance degradation. For this reason, a refrigerant distribution technology was needed to optimize the refrigerant flow rate distributed per flat tube. [4]

While refrigerant distribution using headers is a commonly used technology, distributing refrigerant to a large number of flat, multi-hole tubes using vertically arranged headers can easily cause uneven distribution of liquid refrigerant due to the effects of gravity. To achieve even distribution across a wide range of operating modes is particularly difficult in inverter-controlled products. Fig.5 shows a header structure that solves these issues. Consisting of multiple stacked plates, the intermediate plate shown on the right side of the figure forms a space for circulating the refrigerant sprayed upward from the nozzle at the bottom. By optimizing the size of this space, well mixed gas and liquid refrigerant circulate from rated to minimum operating conditions, achieving good distribution to each multi-hole pipe without being affected by gravity.

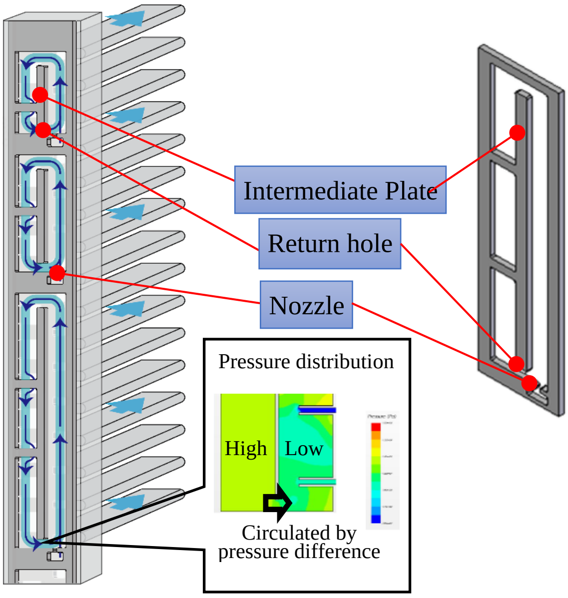

Fig. 5 Header structure

[Challenges Related to Heat Pump Installation]

As shown in Fig. 6, the microchannel heat exchangers that we have been using in our company until now have a structure in which perforated tubes are inserted into the fin notches. The flat tubes are exposed on the upstream side, whereas the continuous fin parts are located on the downstream side. This allows drainage water generated during the heating operation to be drained through the continuous fin part. However, because the flat tubes become cold and are exposed on the upstream side, early stage frost formation had been an issue during operation under low ambient air temperatures.

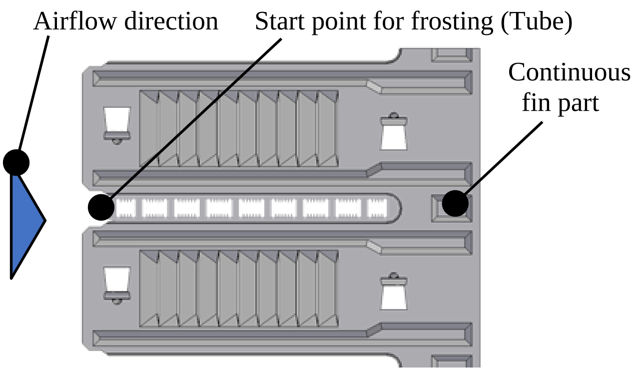

Fig.6 Conventional Microchannel heat exchanger

Fig. 7 shows the structure of the microchannel heat exchanger installed to this product. Inserting fins from both sides of a single flat tube resulted in continuous fin parts on both the upstream and downstream sides. Covering the flat tubes, which have the lowest temperature during the evaporative operation, with the fins makes it possible to position the fin edge as the starting point for frost formation. Fig. 8 shows the analysis results of the fin surface temperature distribution. The surface temperature of the fin edge is optimized by providing a continuous fin part on the upstream side and facilitates a delay in frost formation by more than 120% compared to conventional microchannel heat exchangers.

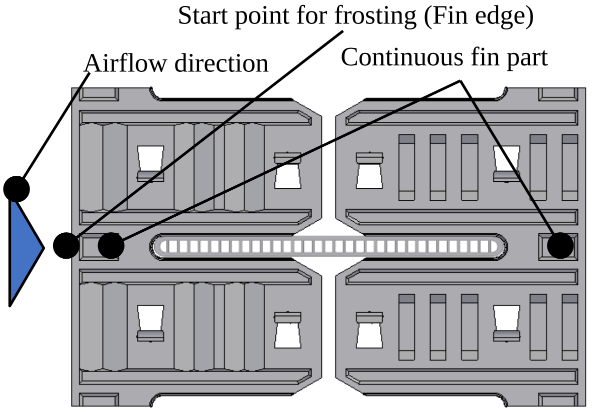

Fig.7 Developed microchannel heat exchanger

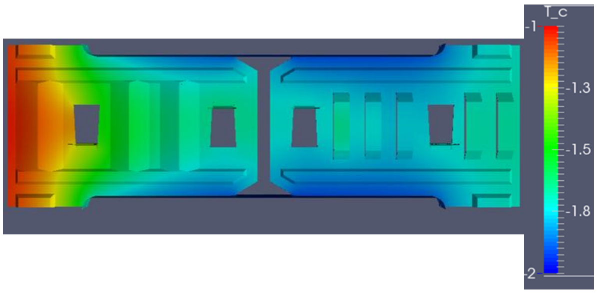

Fig. 8 Temperature distribution for developed fin

Even at low ambient temperatures, heating and hot water supply products must prevent performance degradation due to frost formation and the interruption of heating operation due to defrosting. For this reason, the fin shape and fin pitch were further optimized to achieve low-temperature operating performance equivalent to that of conventional fin-and-tube heat exchangers.

By adopting these technologies, we have achieved a reduction the inner volume of the air heat exchanger approximately 62%, while maintaining the same heating capacity as conventional fin-and-tube heat exchangers. Furthermore, the refrigerant charge amount has been reduced by 17% in the case of the 14kW class Altherma 4 H.

3.2 Safety Measures

Some of the safety measures installed in the newly developed Altherma 4 H are shown in Fig. 9. This product uses a water piping system that connects the indoor and outdoor units. Unless the water heat exchanger is damaged, refrigerant is prevented from reaching indoors. However, there is concern that a serious accident could occur if the water heat exchanger were to be damaged and refrigerant were to leak indoors through the water piping. For this reason, a gas separator has been installed at the outlet of the water heat exchanger. In the event of damage to the water heat exchanger, refrigerant that flows into the water circuit is separated without being circulated and is discharged from the outdoor unit, preventing refrigerant from leaking indoors.

In addition, even in the event of a refrigerant leak from the outdoor unit, the electrical components box housing the control board, which could become an ignition source, has an airtight structure to prevent refrigerant from reaching the ignition source.

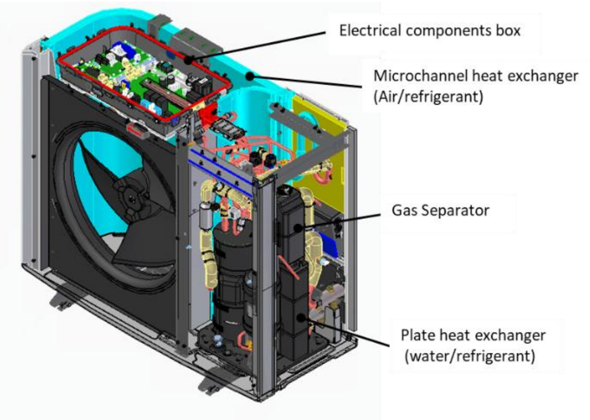

Fig.9 Outdoor unit safety measures

4. Conclusion

We developed the "Altherma 4 H," air to water heat pump for Europe using R290 refrigerant, and obtained the following results.

- Measures were implemented to to ensure the safe use of R290.
- A microchannel heat exchanger was adopted to reduce the amount of refrigerant required, achieving a 62% reduction in the inner volume of the air heat exchanger and the refrigerant charge amount has been reduced by 17% compared to the past.
- By taking advantage of the characteristics of R290, which has a higher condensation temperature at lower pressure than R32, we achieved an outlet temperature of 75°C when the ambient temperature is -15°C.

In the future, we will continue to work on technological development that will contribute to the promotion of a heat pump type heating and hot water supply products.

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R290 冷媒を採用した
欧州向けヒートポンプ式暖房給湯機の開発

Development of Air to Water Heat Pump for Europe using R290 refrigerant

西田 照男・松坂 幸雄・藤野 宏和・山田 甲樹・小野 貴司　ダイキン工業株式会社
布 隼人・中尾 拓哉　ダイキンヨーロッパ社

Teruo NISHIDA*, Yukio MATSUSAKA*, Hirokazu FUJINO, Koju YAMADA*, Takashi ONO*,
Hayato Nuno**, Takuya Nakao**
*DAIKIN INDUSTRIES, LTD., , Osaka Umeda Twin Towers South, 1-13-1, Umeda, Kita-ku, Osaka, Japan
**DAIKIN EUROPE N.V. , Technologiepark-Zwijnaarde 116, 9052 Gent, Belgium

Propane is seen as a promising next-generation refrigerant because of its low GWP value and relatively good refrigeration performance. On the other hand, since it is a higher flammable refrigerant, careful and sufficient consideration is required when handling it. By adopting microchannel heat exchanger, we have achieved a reduction the inner volume of the air heat exchanger approximately 62%, the refrigerant charge amount has been reduced by 17% as conventional fin-and-tube heat exchangers.

Key Word: R290, Propane, Heat Pump, Space Heating, Microchannel Heat Exchanger

１．はじめに

地球の温暖化が進行する現代社会において、カーボンニュートラルを目指す取り組みがグローバルで推進されている。環境先進地域とされる欧州では、化石燃料を使用する燃焼暖房のヒートポンプ化が加速するとともに、地球温暖化係数(GWP)が高い冷媒を規制する方向にある。

ここで、冷媒の歴史を振り返ると、1930 年代以前は R290（プロパン）、R744（CO2）、R717（アンモニア）などの自然冷媒が初期の冷媒として使用されていた。これら自然冷媒は可燃性、冷媒性能、あるいは毒性といった安全性の課題から使用が減少し、化学的、熱的に安定な HCFC 冷媒などフロン系冷媒が普及してきた。その後オゾン層破壊や地球温暖化の課題から HCFC 冷媒から HFC 冷媒への転換を経て、地球温暖化への影響が大きな課題と認識されるようになり、自然冷媒へ回帰する動きとなっている。その中でも R290（プロパン）は GWP が低く冷媒性能も自然冷媒の中では比較的良好であるため次世代冷媒として有望視されている。[1]

そこで、当社では R290（プロパン）を用いたヒートポンプ式暖房給湯機「Altherma 4 H」(Fig.1) を 2025 年 3 月に欧州で発売した。強燃性の冷媒である R290（プロパン）を採用するうえでは安全性の確保が重要であり、当社では各ライフステージでのリスクアセスメントを実施しその結果から、安全対策を実施した。冷媒が漏洩した際の安全対策も重要だが、根本的なリスク低減のために製品への冷媒充填量を削減することがより重要である。

本稿では R290 冷媒を採用した欧州向けヒートポンプ式暖房給湯機の開発について述べ、主に冷媒量削減の取り組みについて紹介する。

Fig.1　Configuration of Air to Water Heat Pump（Altherma 4 H）

２．R290 冷媒の特徴

Table.1 は、強燃性冷媒である R290 と現在主流となっている微燃性冷媒の代表である R32 を比較したものである．R290 の着火エネルギーは R32 と比べて 1/100 程度と小さいため、冬場に経験する静電気スパーク程度でも着火するリスクがある。[1]

Table.1 Comparison of flammability between R290 and R32

Refrigerant	ISO 817 Class	Ignition Energy (mJ)	Combustion Energy (MJ/kg)	Burning rate (cm/s)
R290	A3	0.23	46	46
R32	A2L	29	8.5	6.7

また冷媒としての特徴を比較すると、Fig.2 に示すように R290 は、R32 と比べてガス密度が小さいため、圧縮機ピストン容積が大型化するという課題がある。また、R290 は R32 と比べて動作圧力が低い冷媒であるため、特に暖房運転時に蒸発器となる空気熱交換器には圧力損失を抑える設計が必要となる。

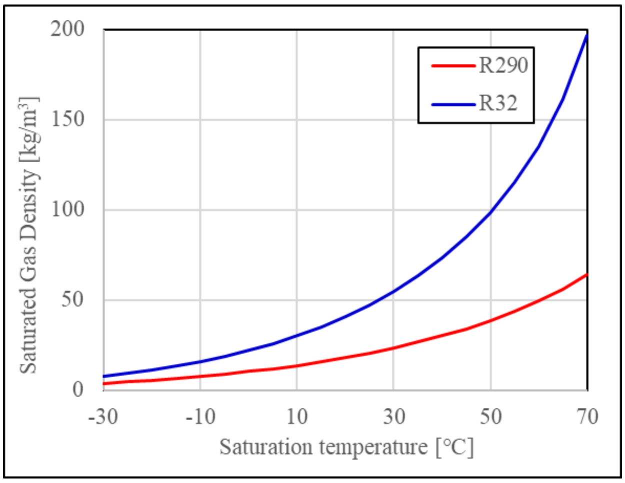

Fig.2 Saturated gas density of R32 and R290

一方、R290 は R32 と比べて低い圧力で高い凝縮温度が得られるため、高温出湯が容易となるメリットがある。Fig.3 に R290 と R32 を用いた製品における外気温度に対する暖房運転時の最高出湯温度の比較を示した。R32 を用いた製品では、設計圧力を 5.6MPa まで高めたフラグシップモデルにて外気 - 15℃で出湯温度 70℃を実現したが、R290 の場合は設計圧力 3.2MPa で外気 - 15℃で 75℃を実現した。

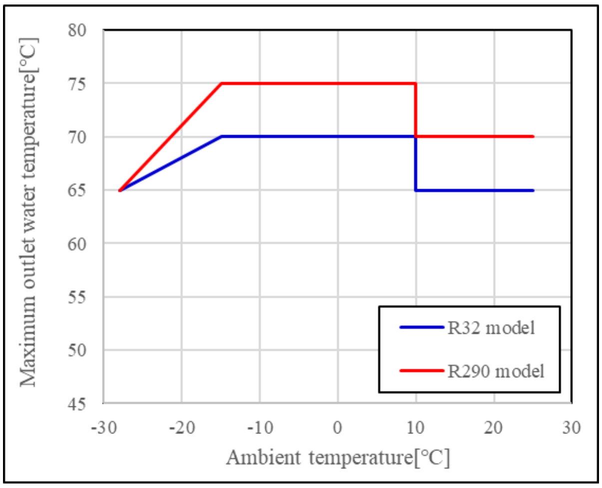

Fig.3　Operating range in heating operation

３．開発機の技術と特徴

３．１．省冷媒技術（マイクロチャネル熱交換器）

Fig.4 に本機に搭載したマイクロチャネル熱交換器と従来のフィン＆チューブ熱交換器の比較を示す。マイクロチャネル熱交換器には、1 ミリ以下の細径流路を多数配した扁平多穴管を採用した。[2],[3] 扁平管は、伝熱管に起因する通風抵抗を抑えられるため、管の高集積化が可能となり、従来型の熱交換器よりも冷媒側の表面積を飛躍的に拡大でき、熱交換効率の向上が図れる。さらに、細径流路により内容積を低減し、冷媒の使用量を削減することが可能となる。

(a) Microchannel HX (MCHX)

(b) Fin-and-tube HX

Fig. 4 Comparisons of heat exchanger structures

【薄型多穴管を実現する冷媒分流技術】

省冷媒効果を高めるには、扁平管を薄く設計することが重要である。ただし、流路の細径化は、冷媒の圧力損失の増大による性能低下を招くため、扁平管 1 本あたりに分配する冷媒流量を適正化する冷媒分配技術が必要となる。[4]

ヘッダによる冷媒分配は広く使われている技術であるが、垂直方向に配置したヘッダで多数の扁平多穴管に分配するには重力の影響により液冷媒の偏りが生じ易い。特にインバータで能力可変する製品では広い運転モードで良好な分配を実現することが難しい。Fig.5 にこれらの課題を解決したヘッダ構造を示す。積層された複数のプレートで構成されており、図中の右側に示す中間プレートが、下部のノズルから吹き上げた冷媒を循環させる空間を形成している。この空間形状を最適化し、定格から最小運転の範囲で気液冷媒を循環させることで均一に混合し、重力影響を排して良好な冷媒分配を実現した。

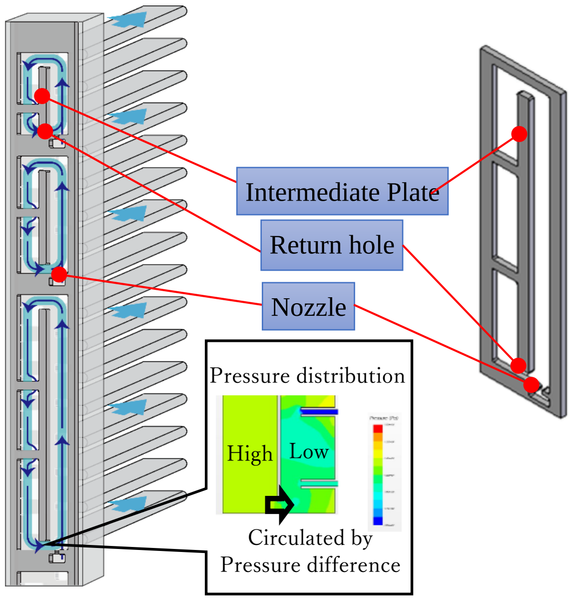

Fig.5 Header structure

【ヒートポンプ機への搭載の課題】

Fig.6 に示すように、これまで当社が採用したマイクロチャネル熱交換器は、フィン切欠部に多穴管を挿入する構造を採用している。風上側は扁平管が露出しているが、風下側にフィン連通部を配置する構造により、暖房運転時に発生するドレン水をフィン連通部から排水している。しかしながら、風上側に低温となる扁平管が露出しているため、低外気運転時に早期に着霜することが課題であった。

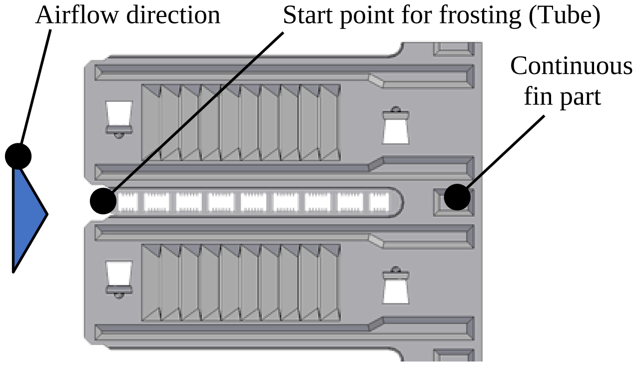

Fig.6 Conventional Microchannel heat exchanger

Fig.7 に本機に搭載したマイクロチャネル熱交換器の構造を示す。1 本の扁平管の両側より、フィンを挿入することで風上側と風下側それぞれにフィン連通部を配置した。蒸発運転時に最も温度が低い扁平管をフィンで覆うことで、着霜起点をフィン端面とすることが可能となる。Fig.8 にフィン表面温度分布の解析結果を示す。風上側にフィン連通部を設けることでフィン端面温度を適正化し従来マイクロチャネル熱交換器と比較して 1.2 倍以上の着霜遅延が可能となった。

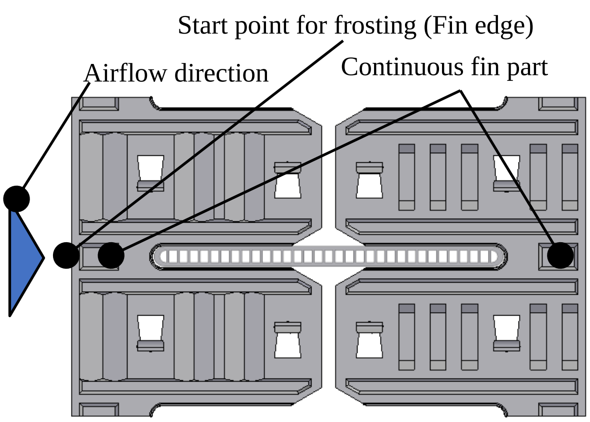

Fig.7 Developed Microchannel heat exchanger

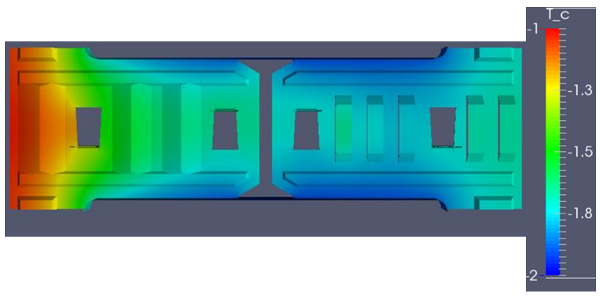

Fig.8 Temperature distribution for developed fin

暖房給湯機は低外気温度でも着霜による性能低下、およびデフロストによる暖房運転の停止を抑える必要がある。そのため、さらにフィン形状、およびフィンピッチの最適化を行い、従来のフィン＆チューブ熱交換器と同等の低温運転性能を実現した。

これらの技術を採用し、従来のフィン＆チューブ熱交換器と同等の暖房能力を確保しつつ、空気熱交換器の内容積約 62%削減、冷媒充填量としては、Altherma 4 H の 14kW クラスの場合、約 17%削減を達成した。

３．２．安全対策

Fig.9 に開発した Altherma 4 H に搭載した安全対策の一部を示す。本機は室内機と室外機の間を水配管で接続するシステムのため、水熱交換器が破損しなければ屋内に冷媒が到達することはない。しかし、万が一水熱交換器が破損して水配管を通して屋内に冷媒が漏洩した場合、重大な事故が懸念される。そのため、水熱交換器の出口に気液分離器を搭載した。水熱交換器が破損した際に水回路に流入した冷媒を循環させることなく分離し室外機から排出することで、屋内への冷媒漏洩を防止する。

また、室外機から冷媒が漏洩した場合でも事故を発生させないため、着火源になりえる制御基板を格納する電装品箱を漏洩した冷媒が着火源に接触することを避ける構造とした。

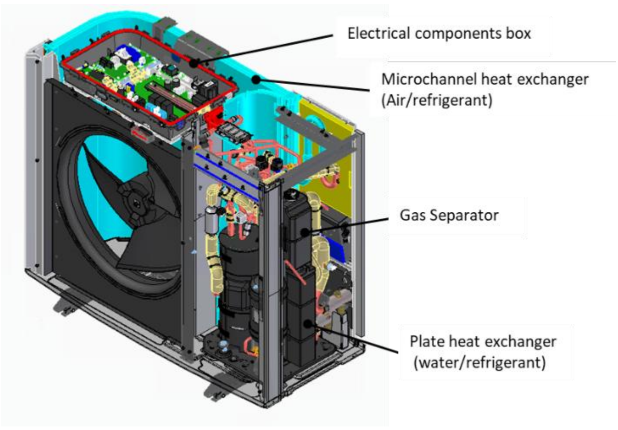

Fig.9 Outdoor unit safety measures

４. まとめ

R290 冷媒を採用した欧州向けヒートポンプ式暖房給湯機「Altherma 4 H」を開発し、以下の結果を得た。

・R290 を採用するうえで安全性を確保するための対策を実施。

・安全性確保のため、冷媒充填量を削減について、マイクロチャネル熱交換器を採用し、従来に比して、空気熱交換器の内容積▲約 62%、冷媒充填量▲約 17%を達成。

・R32 と比較して低い圧力で高い凝縮温度となる R290 の特徴を利用し、外気－15℃で 75℃の高温出湯を実現。

今後は、さらにヒートポンプ式暖房給湯機の普及推進に貢献するための技術開発に取り組んでいく。

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