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Study of Scroll Condensing Unit for Green Refrigerant R474B

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ABSTRACT

As a result of the Kigali Amendment to the Montreal Protocol, developed countries have set a target of reducing HFC production and consumption by 85% in GWP terms by 2036. In Japan, the CFC Emission Control Law sets a target environmental impact value of 150 or 750 for condensing units and other categories in the target year of 2029.

In order to promote the use of green refrigerant-compatible equipment, it is important that the refrigerant and equipment meet the S+3E requirements and are easy to handle. R474B was selected as a refrigerant that satisfies these requirements, and a scroll condensing unit compatible with this refrigerant was studied.

Key Word : low GWP refrigerant, R474B, condensing unit, refrigeration, Green refrigerants

1. INTRODUCTION

Condensing units are used for display cases in food retail stores like convenience stores and supermarkets, as well as for walk-in type prefabricated refrigerated storage warehouses constructed by assembling insulated panels (prefabricated panels) for food storage and preservation. In both applications, they operate 24 hours a day, 365 days a year to maintain food freshness, making reducing power consumption and CO_2 emissions critical challenges. Traditionally, refrigerants such as R404A and R448A have been used in condensing units for these low-temperature equipment systems. However, the Global Warming Potential (GWP: using values from the IPCC Fourth Assessment Report; where unavailable, values from the IPCC Sixth Assessment Report are used) of refrigerant R404A is 3922, and refrigerant R448A has a GWP of 1387. From a global warming prevention perspective, switching to refrigerants with lower GWP is required. Furthermore, since these units are often intended for food storage and preservation, requiring time-consuming maintenance poses risks such as food deterioration or spoilage. Therefore, condensing units using refrigerants that are easy to handle during service are essential.

Meanwhile, the market surrounding condensing units has also been changing significantly. The Montreal Protocol, adopted in 1987, functions as an international framework aimed at protecting the ozone layer and has achieved the phase-out of chlorofluorocarbons (CFCs) and halons. Following this, the Kigali Amendment was adopted in 2016, introducing new regulations targeting hydrofluorocarbons (HFCs), which are alternative refrigerants. This strengthened refrigerant regulations from the perspective of global warming countermeasures.

Japan ratified the Kigali Amendment in 2019 and is working to reduce HFCs through domestic legislation. Specifically, amendments to the Ozone Layer Protection Law introduced a quota system for HFC production and import. Based on the Fluorocarbon Emission Control Law, obligations to prevent leaks from refrigeration and air-conditioning equipment and to recover HFCs during disposal have been strengthened. Under the Designated Products System, the weighted average target GWP for condensing units shipped by fiscal year 2029 is mandated to be 150 or less for units with compressor rated outputs of 1.5 kW or less, and 750 or less for units exceeding 1.5 kW rated output. The industry aims to achieve an overall GWP of approximately 10 or less by 2036.

Condensing units have been using refrigerants with a GWP of 1500 or less, such as R448A, since around 2017, but an early transition to green refrigerants is necessary to achieve the ultimate goal of the Kigali Amendment.

To address the above issues, we are considering the green refrigerant R474B, taking into comprehensive consideration the S+3E factors of Safety, Environment performance, Energy efficiency, and Economic feasibility. Green refrigerants refer to refrigerants with a global warming potential (GWP) of 10 or less and an ozone depletion potential (ODP) of 0, which have a low environmental impact.

2. REFRIGERANT SELECTION POLICY

This section outlines our refrigerant selection policy for condensing units.

While the S+3E approach may vary depending on circumstances, safety is a particularly critical consideration among the evaluation factors. Condensing units, which are used in combination with various products such as showcases and unit coolers, have traditionally required the use of non-flammable refrigerants as an essential requirement. However, the Japan Refrigeration and Air Conditioning Industry Association's “Safety Evaluation Project for

Flammable Refrigerants" has established safety standards and guidelines for equipment using A2L refrigerants. Therefore, the lower flammable refrigerants listed in JRA1001 can be safely operated.

Based on this, Table 2.1 shows the considerations for refrigerant selection, Table 2.2 shows the characteristics of each refrigerant, and Table 2.3 shows the pressure and applications for each refrigerant by GWP.

Table 2.1 Considerations for refrigerant selection

Items for consideration	Content
Safety	・Safety Assurance in Case of Leakage.(A1 or A2L) ・Design pressure is equivalent to that of conventional models.
Environment performance	・Ozone Depletion Potential (ODP) = 0 ・Reduction of GWP ・CO_2 emissions reduction (energy efficiency)
Energy efficiency	・Efficiency and energy savings equivalent to or exceeding conventional models
Economic feasibility	・Utilization of existing piping (equivalent design pressure to conventional units) ・Ease of installation and service ・Equipment cost ・Utilization of existing piping (equivalent design pressure to conventional equipment) ・Ease of installation and service , Equipment cost

Table 2.2 Characteristics of each refrigerant

		HFC			HFC+HFO		HFO
		R404A	R410A	R32	R448A	R454C	R474B
Composition (mass%)	R32		50.0%	100.0%	26.0%	21.5%	-
	R125	44.0%	50.0%	-	26.0%	-	-
	R143a	52.0%	-	-	-	-	-
	R134a	4.0%	-	-	21.0%	-	-
	R1234yf	-	-	-	20.0%	78.5%	68.5%
	R1234ze(E)	-	-	-	7.0%	-	-
	R1132(E)	-	-	-	-	-	31.5%
Safety Class		A1	A1	A2L	A1	A2L	A2L
GWP	IPCC AR4	3922	2088	675	1387	148	-
	IPCC AR5	3943	1924	677	1273	146	-
	IPCC AR6	4728	2256	771	1494	166	<1
ET= - 10°C CT= 45°C	P_{cond} (MPa abs)	2.052	2.730	2.795	2.007	1.795	1.737
	P_{evap} (MPa abs)	0.434	0.573	0.583	0.390	0.351	0.345
	Pressure Ratio (-)	4.7	4.8	4.8	5.1	5.1	5.0
	Td theoretical (°C)	77	98	122	87	81	78
	Vs ratio(%)	98%	136%	147%	100%	89%	87%
	COP ratio(%)	97%	96%	97%	100%	101%	101%
	ΔT_{evap}(K)	0.4	0.1	-	4.1	5.2	3.9
ET= - 40°C CT= 40°C	P_{cond} (MPa abs)	1.822	2.422	2.478	1.776	1.591	1.541
	P_{evap} (MPa abs)	0.132	0.175	0.177	0.111	0.101	0.100
	Pressure Ratio (-)	13.8	13.8	14.0	16.0	15.8	15.4
	Td theoretical (°C)	108	146	191	127	116	112
	Vs ratio(%)	107%	147%	157%	100%	90%	89%
	COP ratio(%)	99%	96%	94%	100%	102%	102%
	ΔT_{evap}(K)	0.5	0.0	-	3.9	4.3	3.2

ET: Averaged Evaporation Temp.
CT: Averaged Condensing Temp.
SC: Subcooled degree
P_{cond}: Condensation Pressure
P_{evap}: Evaporating Pressure
Pressure ratio = P_{cond}/P_{ecap}

COP ratio: Theoretical COP ratio to R448A
Vs ratio: Suction volume ratio to R448A
ΔT_{evap}: Evaporation Temp. glide
<Condition>
Suction temp. Ts =18°C,
Subcooled degree SC = 5K
Refrigerant Properties : Refprop ver.10.0

Table 2.3 Refrigerant pressure and GWP classification

Refrigerant type	HCFC	HFC, HFC+HFO				HFO
GWP class	>1500		<1500	<750	<150	<10
[High-Pressure] Air conditioner Condensing unit	-	R410A	-	R32	-	-
[Low-Pressure] Condensing unit	R22	R404A	R448A		R454C	R474B

Table 2.3 classifies refrigerants with a saturated pressure at 65°C of approximately 4.3MPa abs as [High-Pressure] and those with a saturated pressure at 65°C of approximately 3.3MPa abs or less as [Low-Pressure]. Refrigerant R474B belongs to the [Low-Pressure] category, enabling designs that utilize existing piping for refrigerants R22, R404A, and R448A, which were widely used in conventional condensing units.

3. TESTING OF REFRIGERANT R474B

As shown in Table 2.2, the refrigeration capacity per unit of suction gas volume for refrigerant R474B is approximately 10% lower than that for refrigerant R448A. The required refrigeration capacity for the condensing unit can be compensated for by increasing the suction gas flow rate through methods such as increasing the compressor displacement volume or rotational speed. However, increasing the suction gas flow rate may reduce efficiency due to increased pressure loss when flow path constraints exist, necessitating actual measurements.

The results of a test are shown where refrigerant R474B was in a condensing unit for R448A with a compressor rated output of 6.0 kW. Note that SEPR_1JV complies with the Japanese version of SEPR (Seasonal Energy Performance Ratio) specified in JRA 4019:2020.

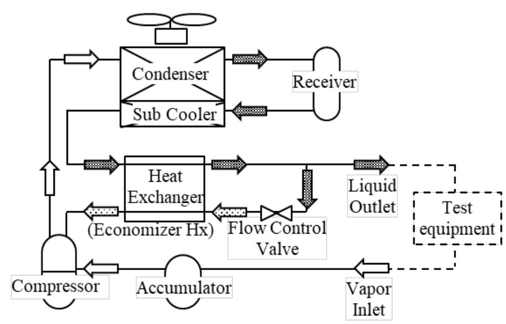

Fig.3.1 Condensing unit cycle

Table 3.1 Test results for refrigerant R474B

Condensing unit		6.0kW
ET		-10°C
Vapor Inlet Temp.		18°C
COP ratio	AT: 32°C	93%
	AT: 20°C	99%
	AT:10°C	96%
SEPR_1JV ratio		97%

ET: Averaged Evaporation Temp. COP ratio: COP ratio to R448A
AT: Ambient Temp. SEPR_1JV ratio: SEPR_1JV ratio to R448A

4. IMPROVEMENT IN EFFICIENCY

In a drop-in test conducted on a condensing unit with a rated output of 6.0 kW, the COP at an ambient temperature of 32°C was 93% for refrigerant R448A. However, since the market expects a COP equivalent to current products, improvement measures are being considered.

By adding a subcooling circuit (Fig.4.1) that reduces pressure loss within the unit and lowers the evaporator inlet temperature, a COP improvement of +4.6% over the drop-in unit has been confirmed in actual testing. Furthermore, calculations indicate that combining measures to reduce accumulator pressure loss (Fig.4.2) and the effect of microchannel heat exchangers (MCHX) (Fig.4.3) could achieve a COP exceeding 100% compared to the current unit. The cumulative results are shown in Fig.4.4.

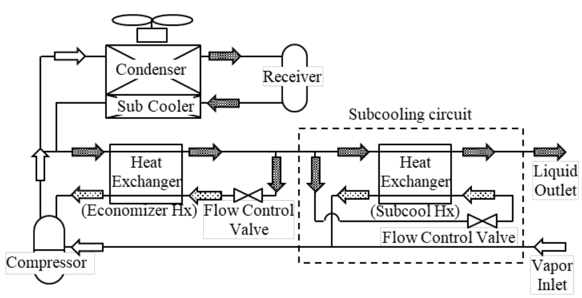

Fig.4.1 Subcooling circuit

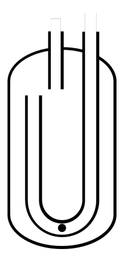

Fig.4.2 Low-pressure loss of the accumulator.

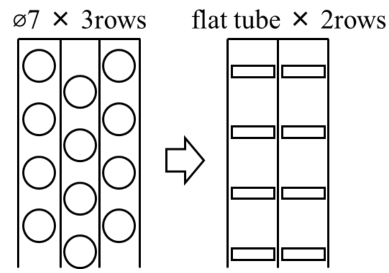

Fig.4.3 MCHX

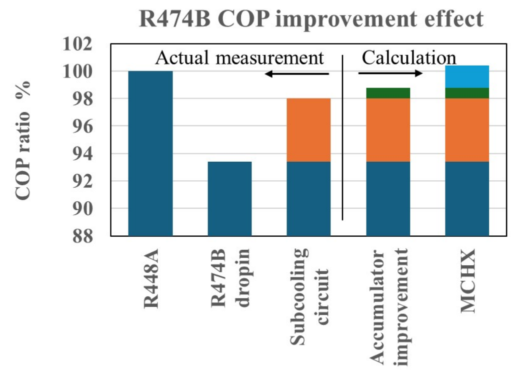

Fig.4.4 COP buildup.

Beyond the considerations in this section, there remains for further optimization, such as adapting the compressor for refrigerant R474B, and we will pursue additional efficiency improvements going forward.

5. REFRIGERANT CHARGE REDUCTION

Refrigerant R474B has a GWP < 1, meaning its environmental impact is low even if leaked from a global warming perspective. However, a lower refrigerant charge within the condensing unit is preferable. While MCHX offers the advantage of enabling high performance, it is also effective in reducing this refrigerant charge.

Fig.5.1 shows the calculated refrigerant reduction effect for the improved MCHX from the previous section, representing the refrigerant ratio in the condensing unit excluding excess refrigerant in the receiver. Compared to current round tube condensers, refrigerant volume can be reduced to 75%.

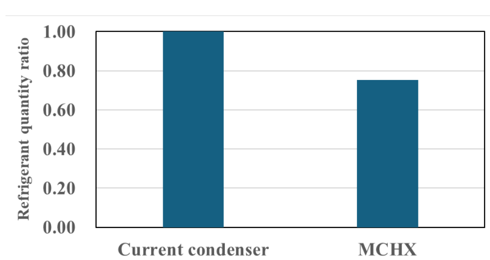

Fig.5.1 Refrigerant quantity in condensing units other than the receiver

6. RISK ASSESSMENT (RA) FOR THE LOWER FLAMMABLE RISK OF REFRIGERANT R474B

Refrigerant R474B is listed as a specified inert gas in the Refrigeration Safety Regulations. However, as it is not currently listed in JRA1001, individual companies must conduct their own risk assessment evaluations. Since the subject this time is a condensing unit, the RA was performed using the same method as the risk assessment report for low-temperature equipment using lower flammable refrigerants. The RA for the condensing unit was conducted at each stage (Installation, Usage, Repair, Disposal) with the probability of a major accident occurring once every 100 years set as the acceptable level. Where the probability was unacceptable, safety measures were implemented to reduce the risk below the acceptable level.

CFD analysis was performed for the RA. The analysis conditions are shown in Fig.6.1. The outdoor unit was modeled as a standard installation with all four sides open, assuming a leak rate of 75 kg/h from the entire heat exchanger. The analysis results are shown in Fig.6.2. The leaked refrigerant showed minimal accumulation on the floor surface, and no flammable zone formed on the floor.

For refrigerants listed under JRA1001, even when not considered ignition sources, R474B is currently under review. For now, all are treated as potential ignition sources, and naked flames are also considered ignition sources as before, with their probability of occurrence calculated accordingly.

Analysis Space

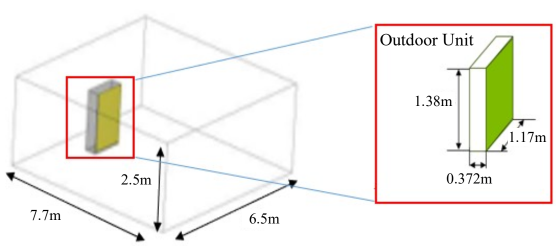

Fig.6.1 Analysis conditions (open on all sides) refrigerant amount 19kg

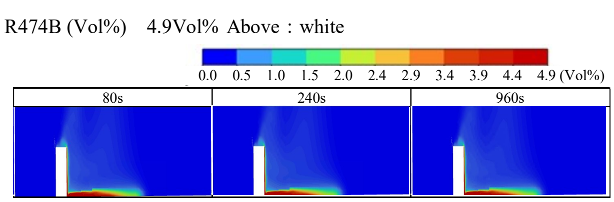

Fig.6.2 Analysis results

Table 6.1 Kind of ignition sources

○: Ignition ×: Does not ignite

Kind		Ignition sources	Ignition sources for refrigerants registered under JRA1001	Ignition source considered in RA
Spark (Occurs in a flammable space)	Electric appliances	Electric appliances (Fire cause)	○	○
		Electrical components inside the device	×	○
	Smoking tools	Match	○	○
		Kerosene lighters	○	○
		Electronic lighter	×	○
	Work tool	Electric tool	×	○
		Refrigerant recovery & reclaim machines	×	○
	Human body	Static electricity (By human body)	×	○

Table 6.2 Ignition probability of each life stage

Stage	Allowable level	Ignition probability
Installation	6.9E-07	2.51E-07
Usage	6.9E-08	4.05E-10
Repair	6.9E-07	1.39E-07
Disposal	6.9E-07	2.39E-07

Table 6.2 shows the ignition probability. Without countermeasures, the installation and disposal stages resulted in ignition probabilities exceeding the allowable value. By implementing safety measures carrying portable leak detectors and educating workers on open flames and combustion equipment the risk was reduced to below the allowable value.

Future tasks include conducting RA for semi-basement installations, confined installations, and installations on each floor. If risks are found unacceptable, it must be confirmed whether existing safety measures can adequately address them.

7. OPERATIONS AT PHYSICAL STORES

At the Seven-Eleven stores within the Osaka-Kansai Expo site, Hitachi condensing units using refrigerant R474B have been adopted. Commercial operation began in April 2025 at two stores, “West Gate” and “Water Plaza,” and they are operating smoothly. (As of September 2025, at the time of writing this paper)

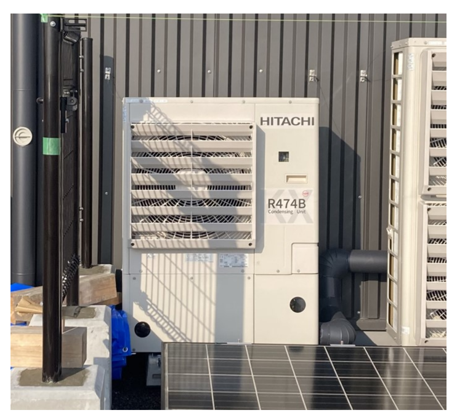

Fig.7.1 Condensing unit runing at the Expo 2025.

8. SUMMARY

From the perspective of preventing global warming, condensing units require early conversion to green refrigerants with low GWP. On the other hand, due to the nature of products intended for food storage and preservation, continuous operation throughout the year is necessary, making improved energy efficiency an important issue.

This study confirmed the safety and Energy efficiency of the environmentally friendly green refrigerant R474B. Since its operating pressure is equivalent to that of conventional refrigerants, existing piping can be easily utilized, making it highly Economic feasibility. This has led to the prospect of practical application of condensing units compatible with R474B refrigerant, realizing S+3E.

Product development is currently underway, aiming for early commercialization and widespread adoption to contribute to global warming countermeasures.

9. ACKNOWLEDGMENTS

This report includes results from a project funded by the New Energy and Industrial Technology Development Organization (NEDO) (JPNP23001). Refrigerant R474B was provided by Daikin Industries, Ltd. We express our deep gratitude to all involved parties.

グリーン冷媒 R474B に対応した スクロールコンデンシングユニットの検討
Study of Scroll Condensing Unit for Green Refrigerant R474B

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In order to promote the use of green refrigerant-compatible equipment, it is important that the refrigerant and equipment meet the S+3E requirements and are easy to handle. R474B was selected as a refrigerant that satisfies these requirements, and a scroll condensing unit compatible with this refrigerant was studied.

Key Word : low GWP refrigerant, R474B, condensing unit, refrigeration, Green refrigerants

1. はじめに

コンデンシングユニットは，コンビニエンスストア，スーパーマーケットなど生活に身近な食品店舗用のショーケースや，食品の保管・保存を目的として断熱パネル(プレハブパネル)を組み立てて構築するウォークインタイプのプレハブ冷凍冷蔵倉庫などに使用されている。どちらの用途においても食品の鮮度を保つため，24 時間 365 日運転しており，消費電力量低減や CO_2 排出量の削減が重要な課題である。これらの低温機器システムの構築には，従来から冷媒 R404A および冷媒 R448A などがコンデンシングユニットに使われているが，冷媒 R404A の地球温暖化係数(GWP, 本文は IPCC 第 4 次評価報告書を使用，IPCC 第 4 次報告書の値がない場合は IPCC 第 6 次評価報告書の値を使用)は 3922, 冷媒 R448A の GWP は 1387 であり, 地球温暖化防止の観点からより低い GWP の冷媒への切り替えが求められている。また，食品の保管・保存を目的としていることが多く，保守・メンテナンスに時間がかかると食品の劣化や腐敗といった危険に直面することになるため，サービス時に取り扱いやすい冷媒を使用したコンデンシングユニットであることが求められる。

一方，コンデンシングユニットを取り巻く市場も大きく変化している。1987 年に採択されたモントリオール議定書は，オゾン層保護を目的とした国際的枠組みとして機能しており，特定フロン(CFC)やハロンなどの段階的廃止を実現してきた。これに続き，2016 年には代替フロンであるハイドロフルオロカーボン(HFC)を新たに規制対象とするキガリ改正が採択され，地球温暖化対策の観点からもフロン規制が強化されるに至った。

日本は 2019 年にキガリ改正を批准し，国内法の整備を通じて HFC 削減に取り組んでいる。具体的には，オゾン層保護法の改正により，HFC の製造・輸入に対する割当制度が導入され，フロン排出抑制法に基づき，冷凍空調機器からの漏えい防止や廃棄時の回収義務が強化された。指定製品制度によりコンデンシングユニットにおいては 2029 年度に出荷台数で加重平均した GWP の値が圧縮機の定格出力 1.5kW 以下で 150 以下，定格出力 1.5kW 超では 750 以下となることを義務付けられ，2036 年には業界全体で GWP10 程度以下をめざすとされている。

コンデンシングユニットは 2017 年頃より冷媒 R448A のような GWP1500 以下の冷媒が採用されているが，キガリ改正の最終目標達成のためにはグリーン冷媒への早期転換を図る必要がある。

当社は上記の課題に対応するため，安全性(Safety)，環境性(Environment performance)，性能(Energy efficiency)，経済性(Economic feasibility)の S+3E を総合的に鑑みてグリーン冷媒 R474B の検討を行う。グリーン冷媒とは GWP が 10 程度以下かつオゾン層破壊係数(ODP)が 0 で環境負荷が少ない冷媒のことを指す。

2. 冷媒選択方針

当社のコンデンシングユニットの冷媒選択方針の考え方を示す。

S+3E の考え方は情勢によって変化するが検討項目の中で特に重要な項目は安全性であり，ショーケースやユニットクーラなど，さまざまな製品と組み合わせて使用されるコンデンシングユニットは従来，不燃性冷媒であることが必須要件であったが日本冷凍空調工業会の「燃焼性を有する冷媒の安全性評価プロジェクト」において A2L 冷媒使用機器の安全基準・ガイドラインが作成されたため，JRA1001 に掲名されている微燃性冷媒については安全に運用できる。

それらを踏まえ Table 2.1 に冷媒選択時の検討事項，Table 2.2 に各冷媒の特性，Table 2.3 に各冷媒の GWP 別の圧力と用途を示す。

Table 2.1 Considerations for refrigerant selection

検討項目	内　　容
安全性 Safety	・漏えい時の安全性確保(A1 or A2L) ・設計圧力が従来機と同程度
環境性 Environment performance	・オゾン層破壊係数(ODP) = 0 ・地球温暖化係数(GWP)の低減 ・CO_2 排出量削減(省エネ性)
性能 Energy efficiency	・従来機同等以上の効率，　省エネ性
経済性 Economic feasibility	・既設配管利用(従来機と同等の設計圧力) ・施工・サービスの容易性 ・機器のコスト

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Safety Class		A1	A1	A2L	A1	A2L	A2L
GWP	IPCC AR4	3922	2088	675	1387	148	-
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	Vs ratio(%)	98%	136%	147%	100%	89%	87%
	COP ratio(%)	97%	96%	97%	100%	101%	101%
	ΔT_{evap}(K)	0.4	0.1	-	4.1	5.2	3.9
ET= - 40°C CT= 40°C	P_{cond} (MPa abs)	1.822	2.422	2.478	1.776	1.591	1.541
	P_{evap} (MPa abs)	0.132	0.175	0.177	0.111	0.101	0.100
	Pressure Ratio (-)	13.8	13.8	14.0	16.0	15.8	15.4
	Td theoretical (°C)	108	146	191	127	116	112
	Vs ratio(%)	107%	147%	157%	100%	90%	89%
	COP ratio(%)	99%	96%	94%	100%	102%	102%
	ΔT_{evap}(K)	0.5	0.0	-	3.9	4.3	3.2

ET: Averaged Evaporation Temp.
CT: Averaged Condensing Temp.
SC: Subcooled degree
P_{cond}: Condensation Pressure
P_{evap}: Evaporating Pressure
Pressure ratio = Pcond/Pecap

COP ratio: Theoretical COP ratio to R448A
Vs ratio: Suction volume ratio to R448A
ΔT_{evap}: Evaporation Temp. glide
<Condition>
Suction temp. Ts =18°C,
Subcooled degree SC = 5K
Refrigerant Properties : Refprop ver.10.0

Table 2.3 Refrigerant pressure and GWP classification

Refrigerant type	HCFC	HFC, HFC+HFO				HFO
GWP class	>1500		<1500	<750	<150	<10
[高圧系] エアコンディショナー コンデンシングユニット	-	R410A	-	R32	-	-
[低圧系] コンデンシングユニット	R22	R404A	R448A		R454C	R474B

Table 2.3 では 65°C の飽和圧力が概ね 4.3MPa abs 程度の冷媒を[高圧系]，3.3MPa abs 程度以下の冷媒を[低圧系]と分類している。冷媒 R474B は[低圧系]に属し，従来のコンデンシングユニットで多く使われた冷媒 R22，冷媒 R404A，冷媒 R448A の既設配管利用可能な設計が実現できる。

3. 冷媒 R474B の試験

Table 2.2 で示すように冷媒 R474B の吸入ガス体積当たりの冷凍能力は冷媒 R448A に対し 1 割程度低下する。コンデンシングユニットに必要な冷凍能力は圧縮機の行程容積増加や回転数の増加などの方法で吸入ガスの流量を増加させれば補うことができる。一方，吸入ガスの流量増加は流路に制約がある場合には圧力損失増加により効率が低下する場合があるため実測を行う。

圧縮機の定格出力 6.0kW の R448A 対応コンデンシングユニットで冷媒 R474B をドロップイン運転した試験の結果を示す。なお，SEPR_1JV は JRA 4019:2020 で規定されている日本版 SEPR(Seasonal Energy Performance Ratio)に準じたものである。

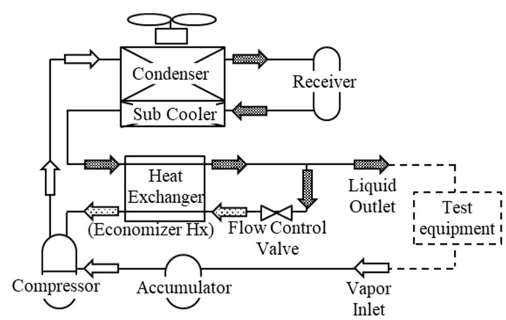

Fig.3.1 Condensing unit cycle

Table 3.1 Test results for refrigerant R474B

Condensing unit		6.0kW
ET		-10°C
Vapor Inlet Temp.		18°C
COP ratio	AT: 32°C	93%
	AT: 20°C	99%
	AT:10°C	96%
SEPR_1JV ratio		97%

ET: Averaged Evaporation Temp.
AT: Ambient Temp.
COP ratio: COP ratio to R448A
SEPR_1JV ratio: SEPR_1JV ratio to R448A

4. 効率の改善

ドロップイン試験を行った圧縮機の定格出力6.0kW のコンデンシングユニットにおいて周囲温度32°CのCOPは冷媒R448A対し93%となった。一方で，市場では現行製品の COP と同等が望ましいため改善の検討を行う。

ユニット内の圧力損失低減と蒸発器入口温度低下効果のある Subcooling circuit (Fig.4.1)を追加し，ドロップインから COP+4.6%を実機確認している。さらに計算にて COP 向上策としてアキュームレータの低圧力損失化(Fig.4.2) ，熱交換器マイクロチャネル(MCHX) (Fig.4.3)の効果積み上げを行い，現行機比 100%以上を達成できる見通しである。積み上げ結果は Fig.4.4 に示す。

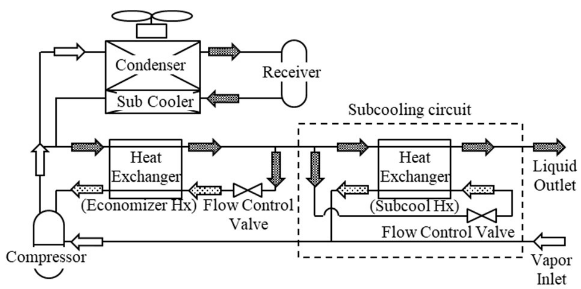

Fig.4.1 Subcooling circuit

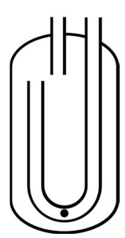

Fig.4.2 Low-pressure loss of the accumulator.

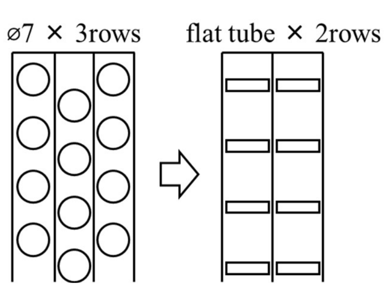

Fig.4.3 MCHX

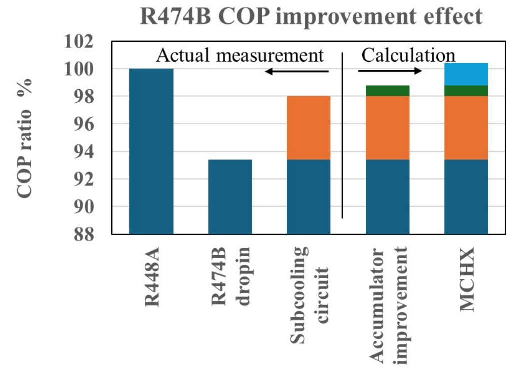

Fig.4.4 COP buildup.

本項での検討以外に圧縮機を冷媒 R474B に最適化するなどの余地が残っており，今後はさらなる効率改善を進める。

5. 冷媒量低減

冷媒 R474B は GWP<1 であることから地球温暖化の観点からは漏えいしても環境負荷が小さい。しかしコンデンシングユニット内の冷媒量は少ない方が望ましい。MCHX は高性能にできる利点もあるが，この冷媒使用量の低減についても効果がある。

Fig.5.1 は前節で性能向上した MCHX での冷媒低減効果の計算値で，レシーバーの余剰冷媒を省いたコンデンシングユニットの冷媒量比率である。現行の丸管凝縮器比で 75%に冷媒量を削減できる。

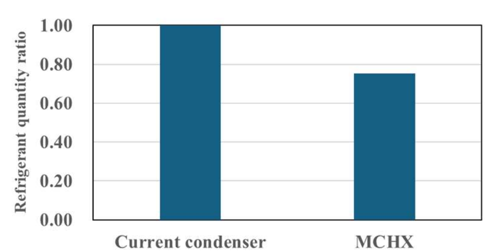

Fig.5.1 Refrigerant quantity in condensing units other than the receiver

6. 冷媒 R474B の微燃性リスクアセスメント(RA)

冷媒 R474B は冷凍保安規則において特定不活性ガスに掲名されているが，現時点では JRA1001 には掲名されていないため個社でリスクアセスメント評価を実施する必要がある。今回の対象はコンデンシングユニットのため，RA は微燃性冷媒を使用した低温機器のリスク評価報告書と同様の方法で行った。コンデンシングユニット の RA は 100 年に一度の重大事故が発生する確率が許容できるレベルとして，据付・使用・修理・廃棄の各ステージで行い，確率が許容できないレベルは安全対策を行うことでリスクを許容値以

下とする。

RA 実施にあたり，CFD 解析を実施した。解析条件を Fig.6.1 に示す。室外機は四面開放の標準設置とし，室外機の熱交換器全体から漏えい速度 75kg/h にて漏えいした場合を想定した。解析結果を Fig.6.2 に示す。漏えい冷媒が床面にほとんど滞留せず，床面に可燃域も生成されない。

Table 6.1 にスパークによる着火源の種類を記載する。JRA1001 掲名の冷媒に対し，R474B の着火源は確認中のものもあり，一旦全て着火源と見なし，かつ，裸火についても従来同様，着火源と見なし存在確率を算出した。

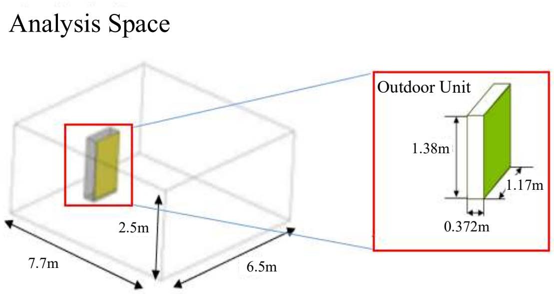

Fig.6.1 Analysis conditions (open on all sides) refrigerant amount 19kg

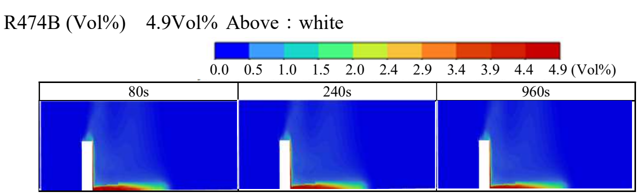

Fig.6.2 Analysis results

Table 6.1 Kind of ignition sources

○:着火 ×:着火せず

分類	種類	着火源	JRA1001 掲名冷媒の着火源	RA で考慮した着火源
スパーク(可燃空間中で発生)	電気部品	電気部品(火災原因)	○	○
		機器内電気部品	×	○
	喫煙器具	マッチ	○	○
		石油ライター	○	○
		電子ライター	×	○
	作業ツール	電動工具	×	○
		冷媒回収機	×	○
	人体	人体からの静電気	×	○

Table 6.2 Ignition probability of each life stage

ステージ	許容値	着火確率	
据付	6.9E-07	未対策	2.52E-06
		対策後	2.51E-07
使用	6.9E-08	未対策	4.05E-10
修理	6.9E-07	未対策	1.39E-07
廃棄	6.9E-07	未対策	4.36E-06
		対策後	2.39E-07

Table 6.2 に着火確率を示す。未対策の場合，据付・廃棄ステージは，着火確率は許容値を上回る結果となる。安全対策として携帯形漏えい検知器の携行や作業者への裸火および燃焼機器に関する教育を実施することで，リスクを許容値以下とすることができた。

今後の課題として，半地下設置，狭小設置，各階設置の RA を実施し，リスクが許容できない場合は従来実施の安全対策で対応できるか含めて確認する。

7. フィールドでの稼働状況

大阪･関西万博会場内のセブン-イレブン店舗において, 冷媒 R474B を使用した日立コンデンシングユニットが採用された。「西ゲート」と「ウォータープラザ」の 2 店舗において 2025 年 4 月から商用運転が行われており，順調に稼働している。(2025 年 9 月論文執筆時点)

Fig.7.1 Condensing unit runing at the Expo 2025.

8. まとめ

コンデンシングユニットは地球温暖化防止の観点から，GWP の低いグリーン冷媒への早期転換が求められている。一方で，食品の保管・保存を目的とする製品の性質上，年間を通して連続的に稼動するため，省エネ性の向上も重要な課題である。

本検討では環境性に優れたグリーン冷媒 R474B について安全性の確認と性能の検討が行われた。動作圧力も従来冷媒と同等で既設配管の利用が容易である点からも経済性に優れ，S+3E を実現する冷媒 R474B 対応のコンデンシングユニット実用化の見通しが立った。

現在は製品の開発を行っており，早期の市販化と普及を目指し地球温暖化対策に貢献する。

9. 謝辞

本報告には，国立研究開発法人新エネルギー・産業技術総合開発機構(NEDO)の助成事業(JPNP23001)の成果が含まれる。また，冷媒R474Bはダイキン工業株式会社より提供いただいた。関係者の皆様に深く感謝の意を表する。