CRIEPI
Central Research Institute of Electric Power Industry

ICR 2019
THE 25th IIR INTERNATIONAL CONGRESS OF REFRIGERATION
August 24-30 | Montréal, Québec, Canada

Application of R1224yd(Z) as R245fa Alternative for High Temperature Heat Pump

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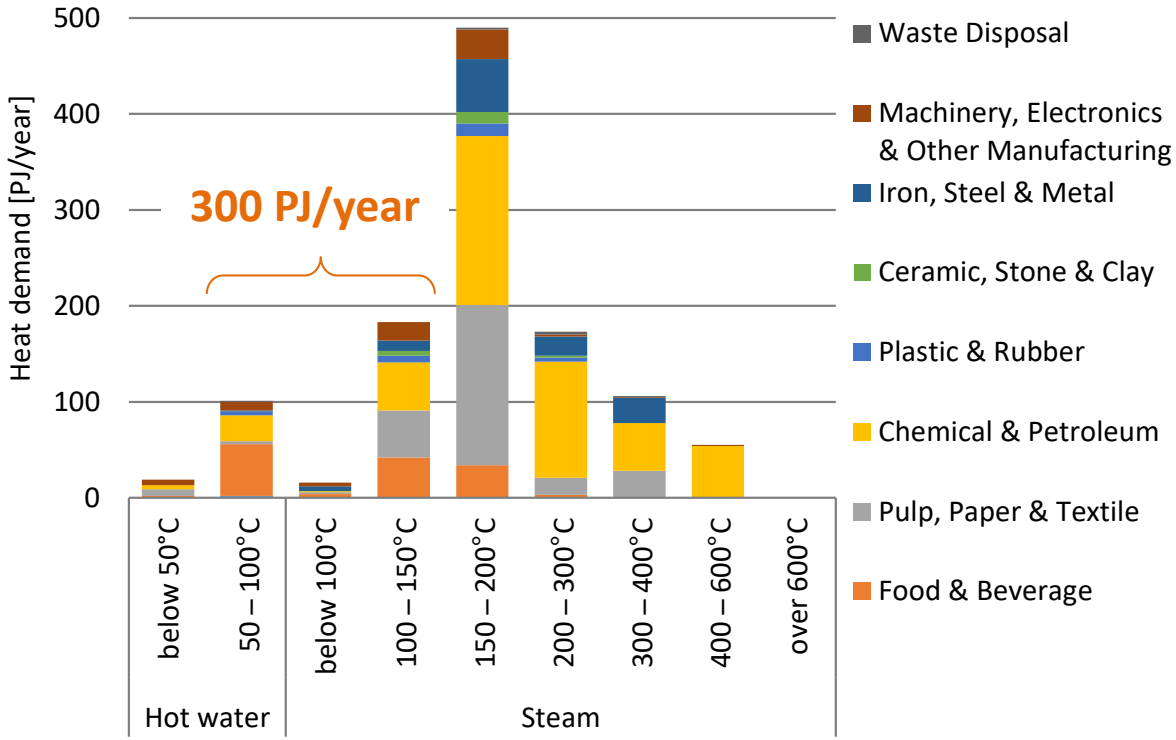
Background

- For significant CO_2 emissions reduction
  - Lower carbonization of power generation
  - Electrification
  - Higher efficient electricity usage
- High temperature heat pump (HTHP)
  - One of the key technologies for expanding electrification of heat usage with relatively high energy efficiency
- Low GWP refrigerant
  - R245fa (GWP = 858) used for HTHPs around 120°C → Necessary for lower GWP
  - R245fa alternative:
    R1234ze(Z), R1233zd(E), **R1224yd(Z)**, ...



Source: MRI, Survey report on heat demand and supply equipment, commissioned by enecho, 2018.

Outline

- Objective
  - Assessing the suitability of R1224yd(Z) as R245fa alternative for high temperature HP
- Contents
  - Performance evaluation of R1224yd(Z) compared to R245fa by drop-in test
  - Compatibility with refrigeration oil, O-ring and motor insulation material

Characteristics of R1224yd(Z)

Basic Properties

- Similar thermodynamic properties with R245fa
- Low-toxicity and non-flammability
- Almost zero ODP
- Very low GWP (< 1)

	R1224yd(Z)	R245fa
Normal Boiling Point [°C]	14.62	15.05
Critical Temperature [°C]	155.54	153.86
Critical Pressure [MPa]	3.34	3.65
OEL [ppm]	1,000	300
Flammability Range [%]	None	None
ASHRAE Safety Classification	**A1**	B1
ODP	0.00023*	0
GWP (IPCC AR5)	**0.88***	858

* K. Tokuhashi et al., Journal of Physical Chemistry A 122, 2018.

R1224yd(Z) is safe and environmental-friendly.

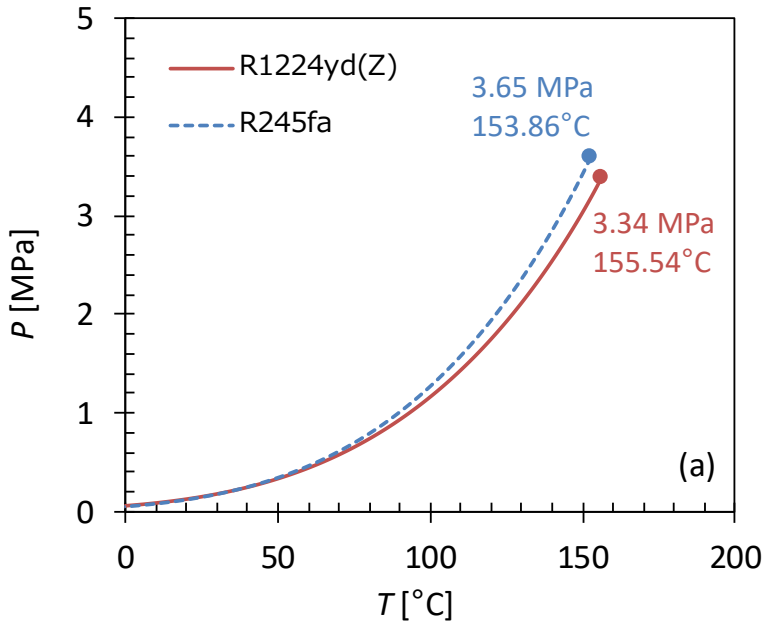
Benefit for Heat Pump Users

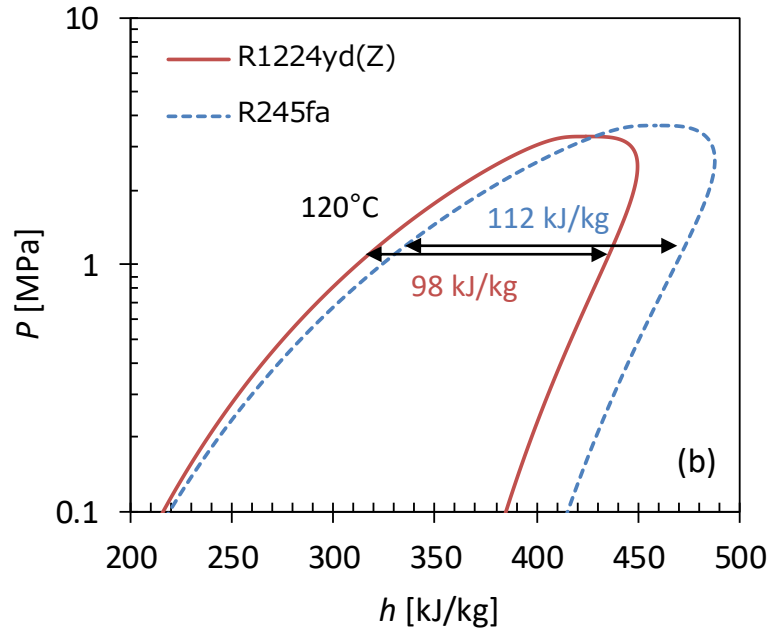
- Easy handling of R1224yd(Z)
  - Environmental-friendly (**very low GWP**) → Not subject to **Revised F-gas Act**
  - Relatively safe (**A1**) → Getting preferential treatment in **High Pressure Gas Act**

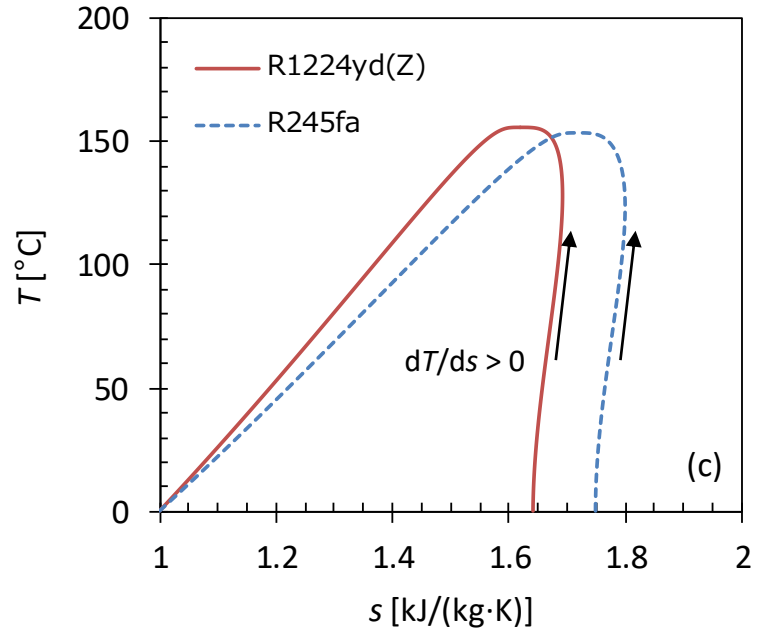
	Revised F-gas Act (Act on Rational Use and Proper Management of Fluorocarbons)	**High Pressure Gas Act**
	For environmental protection	For safety
R245fa	● Need to manage it properly in order not to leak it ● Need to count leaked weight (= recharged weight) ● Need to report leakage amount to the government in the case of large amount ● …	● Need to get permission from the government before operation ● Need to maintain it for safety ● Need to perform periodic inspections ● …
R1224yd(Z)	● **Not subject to Act**	● Getting preferential treatment, which depends on 'legal refrigerating capacity' (ex. Applying to SGH120: **Not subject to Act**)

Thermodynamic Property Diagrams

- Saturated vapor pressure
  - Very close to R245fa at low temperature but somewhat lower at high temperature
- Latent heat
  - Somewhat smaller than R245fa (13% smaller at 120°C)
- Saturated vapor line
  - Slightly positive slope (dT/ds > 0) like R245fa except near the criticl point



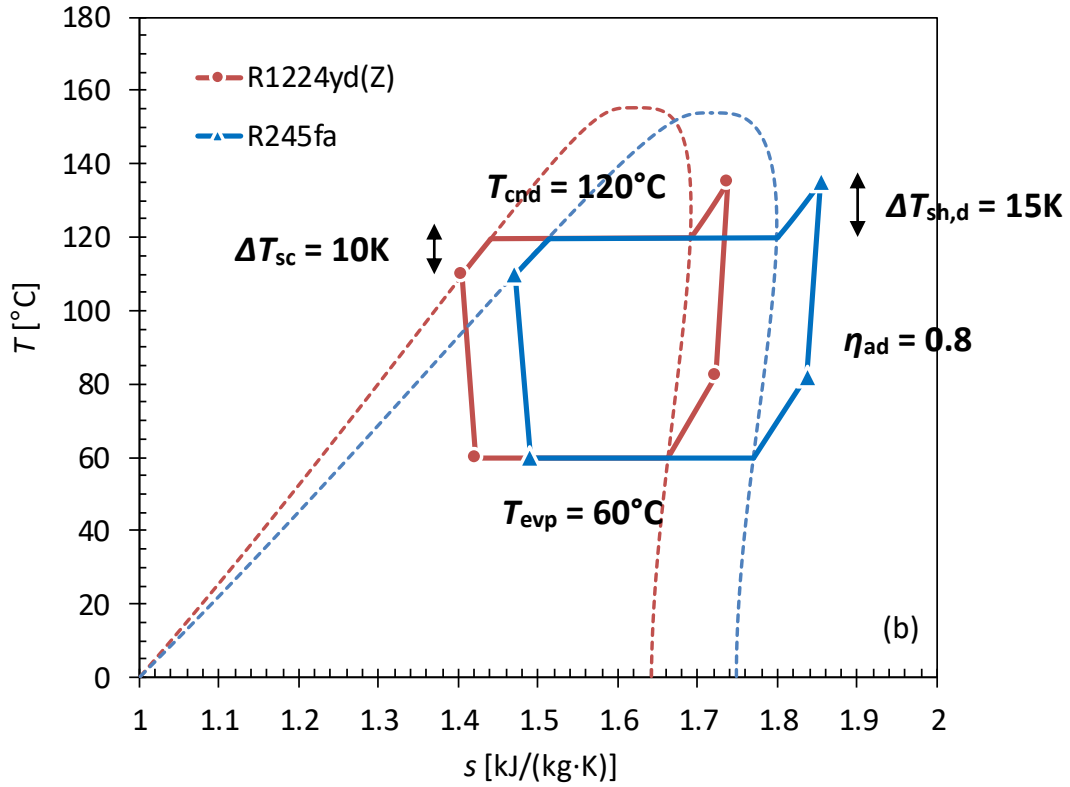


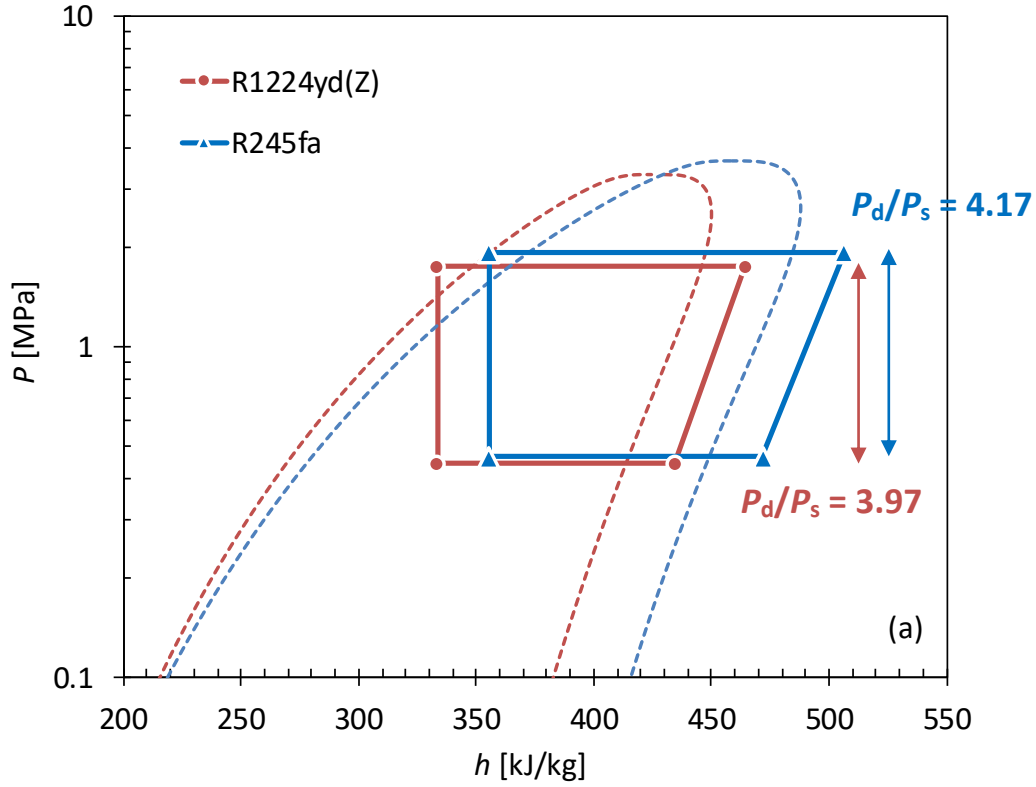


Predicted Thermodynamic Performance

- R1224yd(Z) relative to R245fa
  - P_d/P_s 0.95
  - *COP* 1.00
  - *VHC* 0.92

Prediction: Similar COP but 8% smaller heating capacity



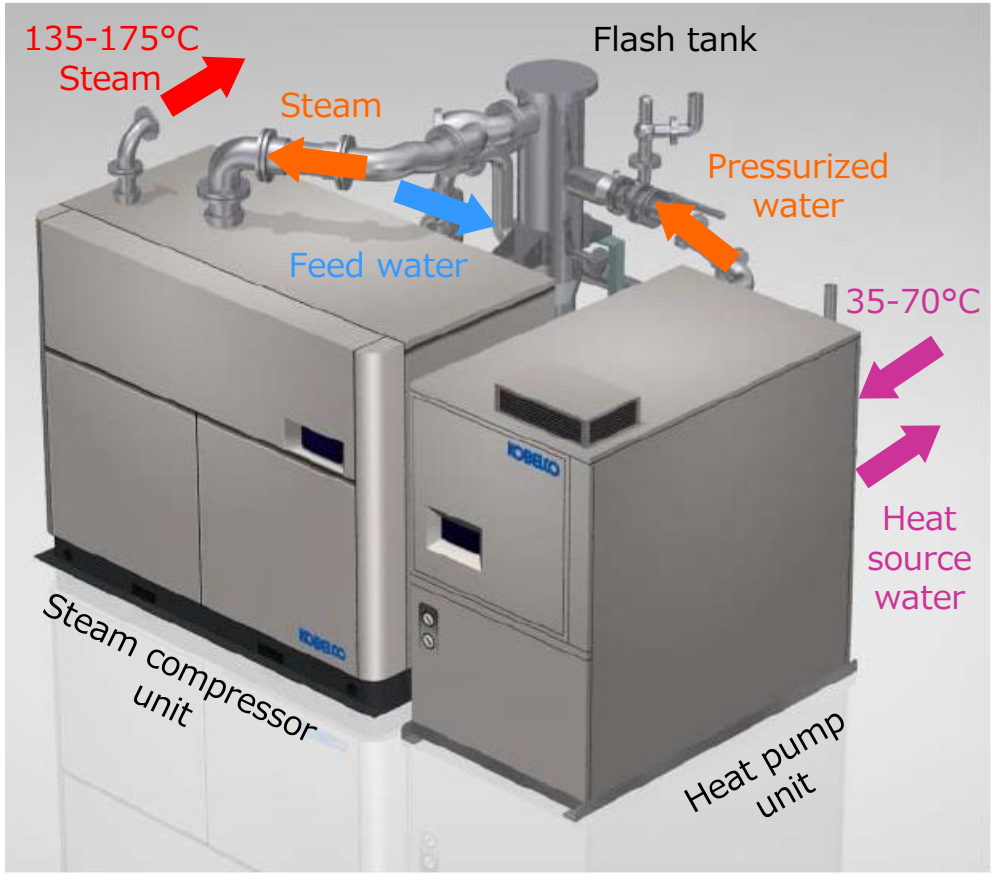


Performance Evaluation

Test Machine

- SGH165
  - Developed by KOBELCO and Japanese electric utilities, and commercialized in 2011
  - Able to supply saturated steam, as recovering the warm effluent in a plant
  - Composed of 3 units

- HEM-HR115
  - Heat pump unit of SGH165
  - Heat source 70°C ---> Heat sink 115°C
  - Mixture of R245fa and R134a



SGH165

R245fa+R134a COP = 2.5
Heating Capacity = 660 kW (0.9 ton/h)
Steam = 165°C, Heat source = 70°C

The test was performed with each pure refrigerant of R245fa and R1224yd(Z).

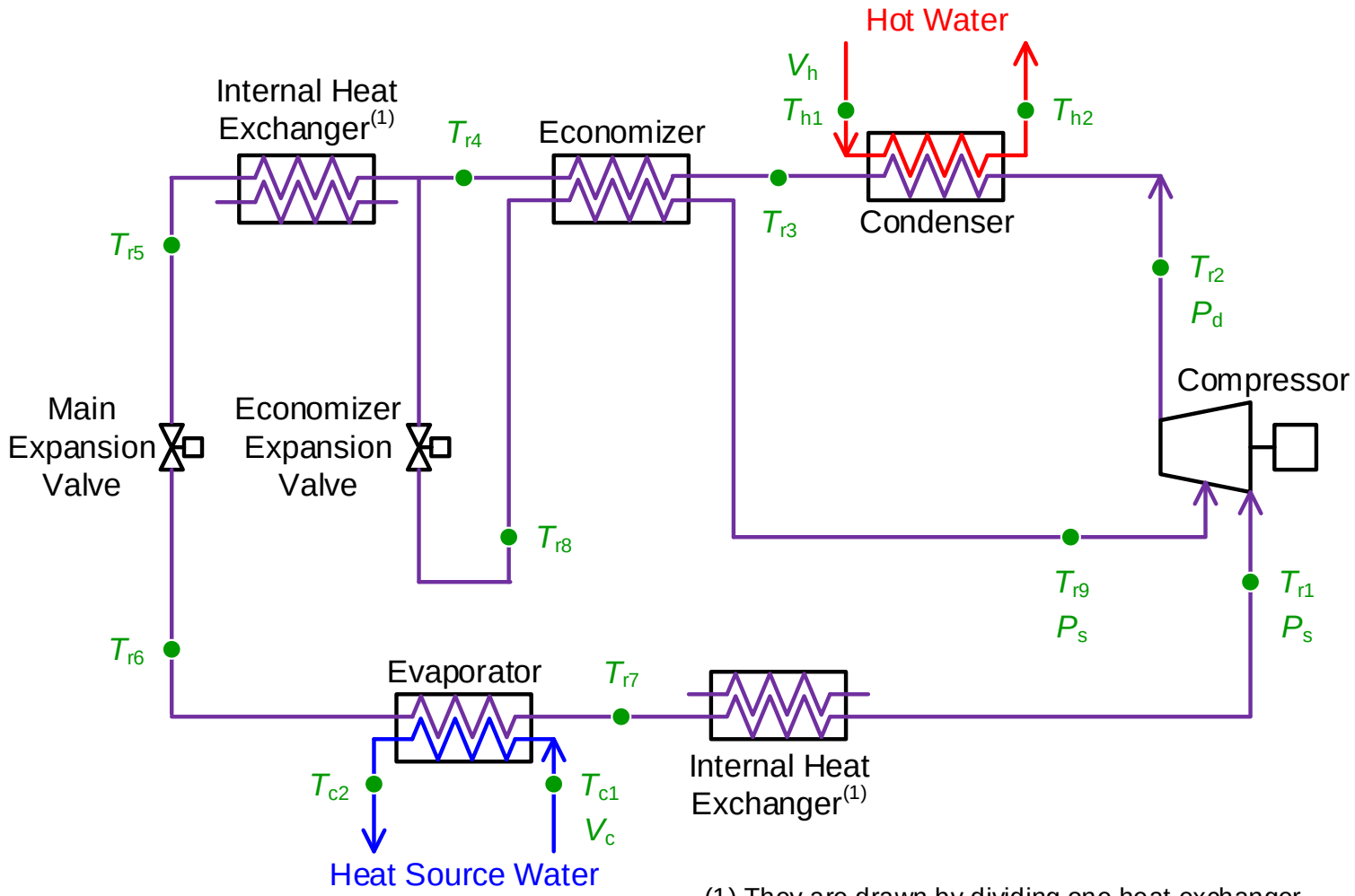
T. Kaida et al., 9th International Conference on Compressors and their Systems, 2015. https://iopscience.iop.org/article/10.1088/1757-899X/90/1/012076

Schematic Diagram and Measure Points

- Measure points
  - Each of the inlet-outlet water temperatures and flow rates
  - Power consumption
  - Each of refrigerant pressures and temperatures as reference

$$Q_h = \rho_{h1} V_h (T_{h2} - T_{h1})$$

$$COP_h = \frac{Q_h}{W}$$



(1) They are drawn by dividing one heat exchanger.

Test Method

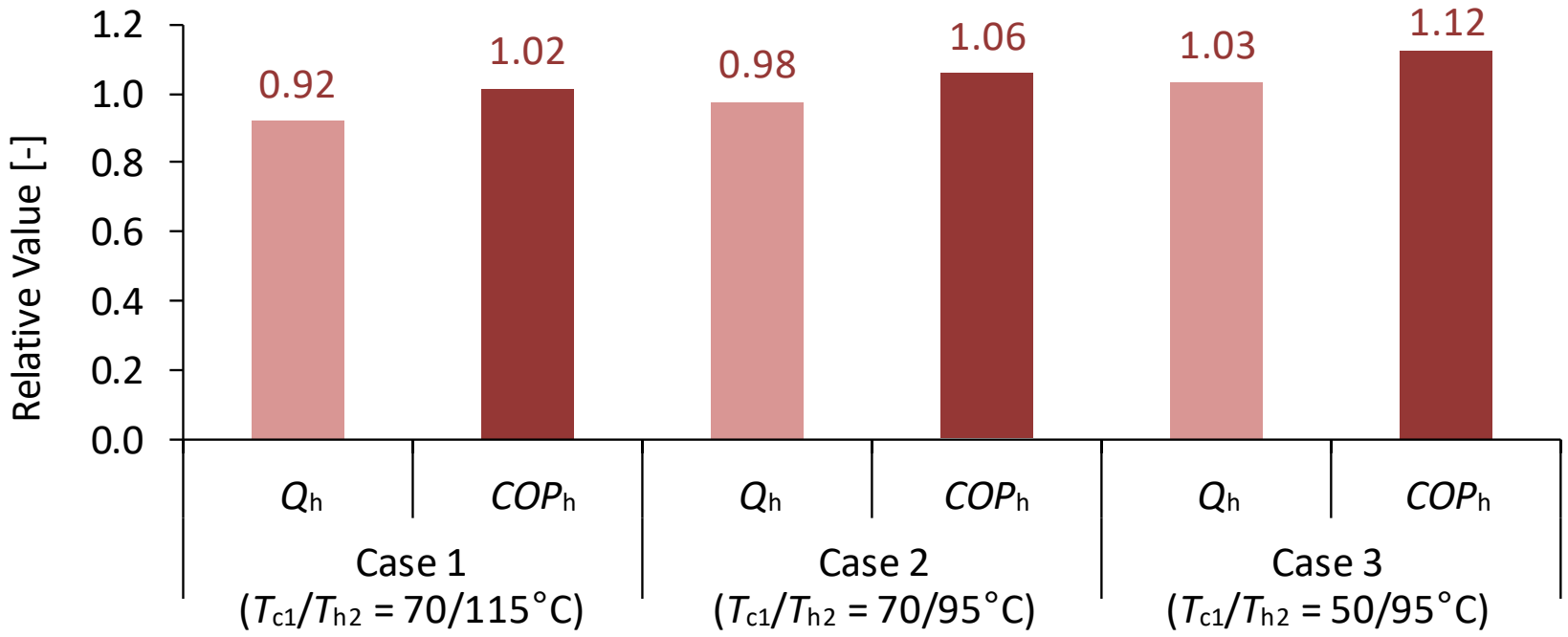
- Test procedure
  - Compressor rotational speed fixed at 100% (= 3,600 rpm)
  - Controlling discharge superheat by adjusting main expansion valve
  - Comparison of R1224yd(Z) and R245fa under the same discharge superheat

- Test conditions
  - 3 cases
  - Temperature differences fixed at 5 K ($\Delta T_c = T_{c1} - T_{c2} = 5$ K, $\Delta T_h = T_{h2} - T_{h1} = 5$ K)

	T_{c1} [°C]	T_{h2} [°C]	$\Delta T_{sh,d}$ [K]	Economizer
Case 1	70	115	15	Open
Case 2	70	95	25	Closed
Case 3	50	95	27	Closed

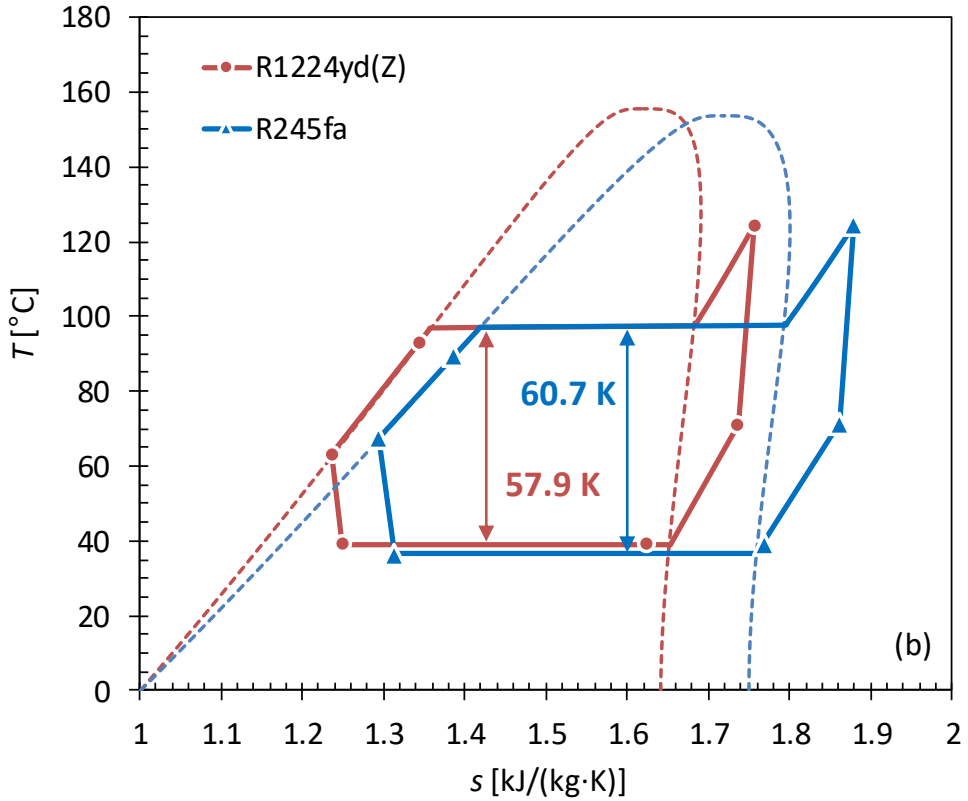
Test Results

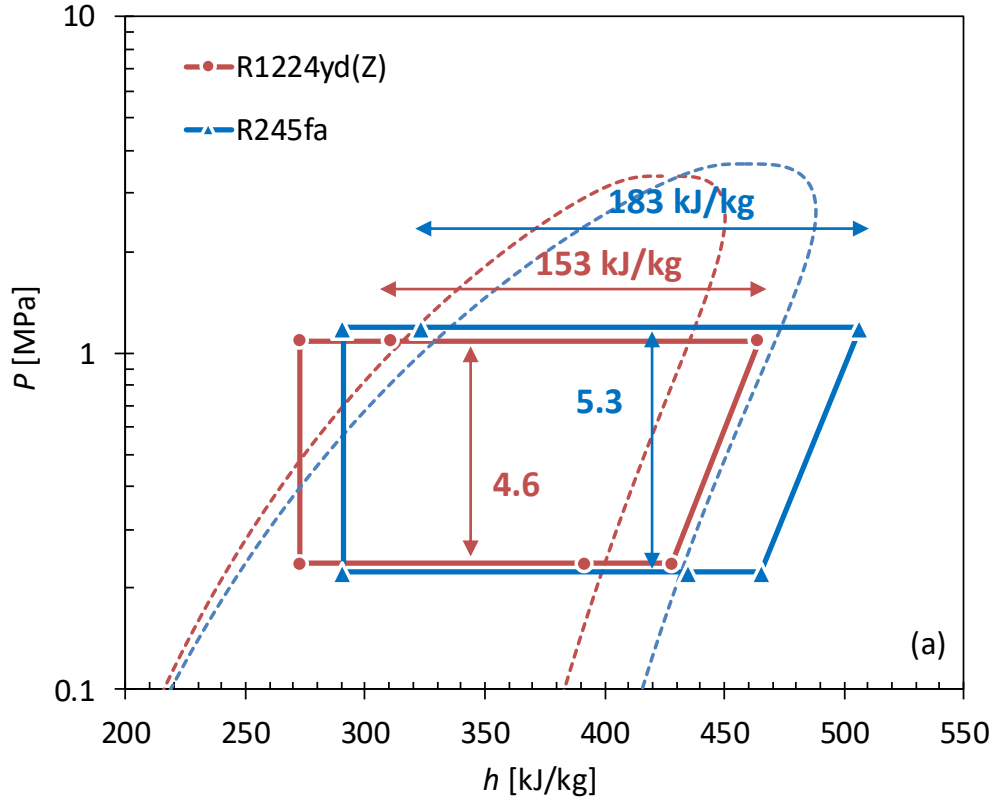
- COP
  - 2-12% higher than R245fa (= better than prediction)
- Heating capacity
  - Case 1: 8% lower than R245fa (= similar to prediction)
  - Case 3: 3% higher than R245fa (= better than prediction)



Comparison of Diagrams in Actual Performance (Case 3)

- Temperature lift (= $T_{cnd} - T_{evp}$) decreases from 60.7 K to 57.9 K (improving *COP*)
- Pressure ratio (= P_d/P_s) decreases from 5.3 to 4.6 (improving *COP*)
- Heating effect (= $h_{r2} - h_{r3}$) decreases from 183 kJ/kg to 153 kJ/kg (as predicted)
- Mass flow rate increases from 1.26 kg/s to 1.55 kg/s (improving *Q*)

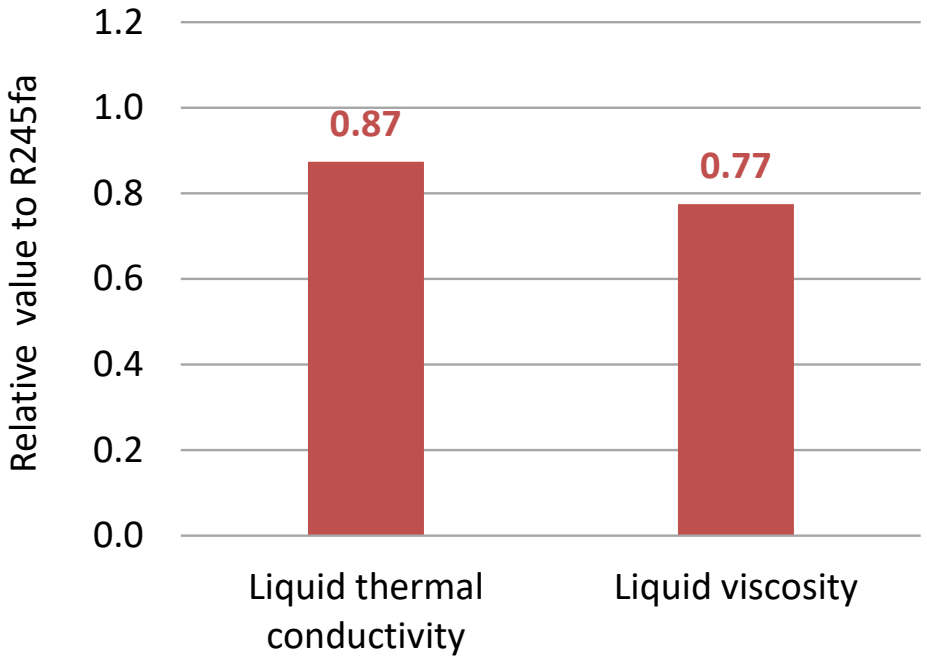




Reasons for Improving Performance

Improvement of heat transfer performance

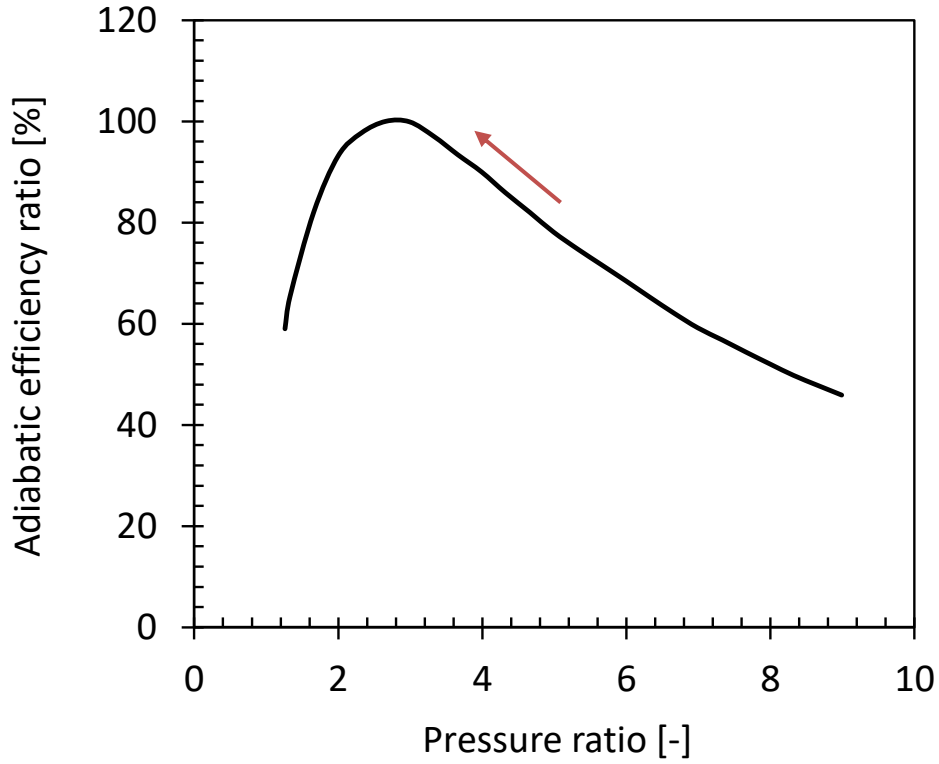
- Increase of refrigerant mass flow rate
- Decrease of viscosity



* Properties of saturated liquid at 70°C, calculated by REFPROP Ver.10

Improvement of compression performance

- Increase of adiabatic efficiency by decreasing pressure ratio



Source: K. Iizuka, High efficiency stem supply systems using by heat pump cycle, JSRAE Journal 89, 2014.

Chemical Stability & Compatibility

Chemical Stability with PAG Oil in Metals

- Sealed tube testing
  - Refrigerant: 60 g, Oil: 60 g, Coexistent metal plate: SS, Cu, Al (25×30×2mm)
  - Temperature: 150°C, Duration: 14 days

		R1224yd(Z)	R245fa
Refrigerant	Purity change [%]	99.8 → 99.5 (Isomerization)	99.9 → 99.9
	Acidity [ppm]	< 0.2	< 0.2
	F [ppm]	< 0.2	< 0.2
	Cl [ppm]	< 0.2	< 0.2
Oil	Acid number [mgKOH/g]	0.05	0.03
	Color of oil (ASTM)	L0.5	L0.5
Metal	SS weight change [mg]	< 0.01	< 0.01
	Cu weight change [mg]	< 0.01	< 0.01
	Al weight change [mg]	< 0.01	< 0.01

There is no significant differences between R1224yd(Z) and R245fa.

Compatibility with O-ring

- Sealed tube testing
  - Refrigerant: 80 g, Coexistent material: HNBR, EPDM
  - Temperature: 150°C, Duration: 7 days

		R1224yd(Z)		R245fa	
Refrigerant	Purity change [%]	99.8 → 99.5 (Isomerization)	99.8 → 99.5 (Isomerization)	99.9 → 99.9	99.9 → 99.9
	Acidity [ppm]	< 0.2	< 0.2	< 0.2	< 0.2
	F [ppm]	< 0.2	<0.2	< 0.2	<0.2
	Cl [ppm]	< 0.2	< 0.2	< 0.2	< 0.2
O-ring	Type	HNBR	EPDM	HNBR	EPDM
	Volume change [%]	9.6	3.6	14.4	2.5
	Weight change [%]	13.7	7.2	16.9	2.8

There is no significant differences between R1224yd(Z) and R245fa.

Compatibility with Motor Insulation Material

- Sealed tube testing
  - Refrigerant: 80 g, Coexistent material: motor insulation
  - Temperature: 150°C, Duration: 7 days

		R1224yd(Z)	R245fa
Refrigerant	Purity change [%]	99.8 → 99.7 (Isomerization)	99.9 → 99.9
	Acidity [ppm]	< 0.2	< 0.2
	F [ppm]	< 0.2	< 0.2
	Cl [ppm]	< 0.2	< 0.2
Motor insulation	Weight change [mg]	0.54	0.63

There is no significant differences between R1224yd(Z) and R245fa.

Conclusions

Conclusions

- R1224yd(Z)
  - **Lower toxicity** and **very lower GWP** compared to R245fa
- Energy performance
  - Thermodynamic prediction: **similar COP** but **8% lower heating capacity** compared to R245fa
  - Actual performance: **better than prediction**
    (because of improvements of heat transfer and compression performances)
- Chemical stability and compatibility
  - PAG oil, O-ring, motor insulation material
  - **No significant differences** between R1224yd(Z) and R245fa
- Overall
  - **R1224yd(Z) can be used as R245fa alternative for high temperature heat pump.**

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Thank you for your attention.

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