Herrick Laboratories PURDUE UNIVERSITY

2016 Purdue Conferences
Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

Thermodynamic Properties of Low-GWP Refrigerants for Centrifugal Chiller

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PURDUE UNIVERSITY

C H P B Center for High Performance Buildings at Purdue

Contents

- Introduction
- Experimental and Result
  - Vapor-liquid coexistence curve in the critical region
  - Vapor Pressure and PVT properties
  - Saturated liquid density
- Discussion

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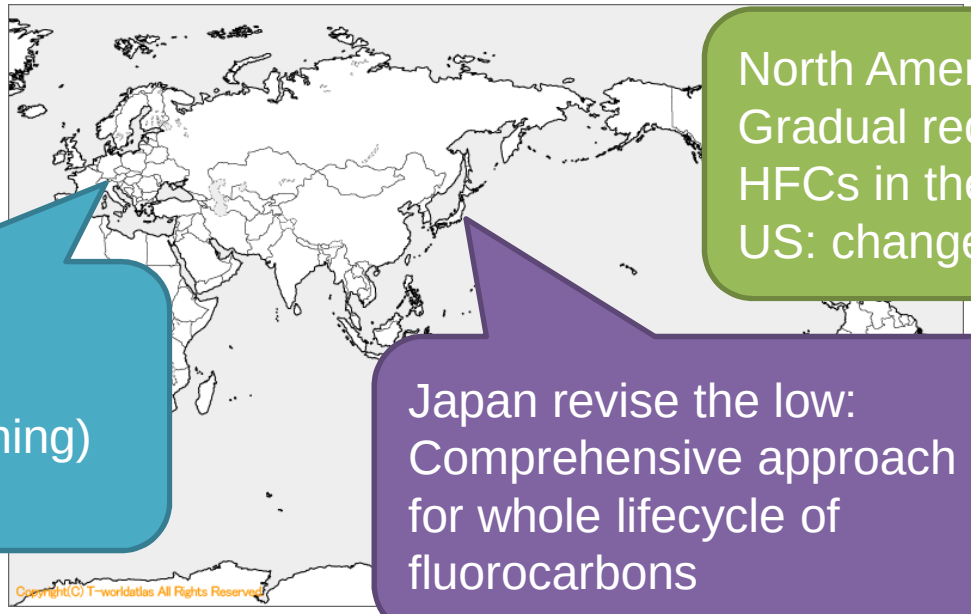
Introduction

- Environment issue

Next Generation!

CFCs, HCFCs → Protect Ozone Layer → HFCs → Prevent Global Warming → HFOs, HCFOs

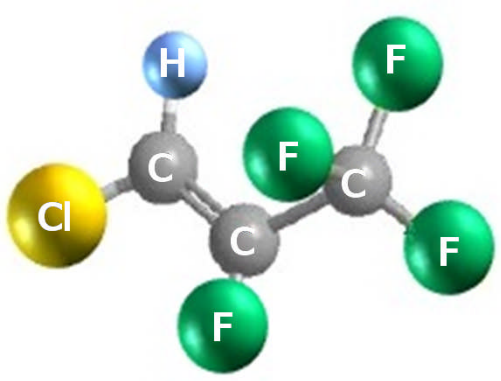


North America Proposal:
Gradual reduction of
HFCs in the Montreal Protocol
US: change SNAP list

Europe:
MAC Directives
(Mobile-air conditioning)
F-gas Regulation

Japan revise the low:
Comprehensive approach
for whole lifecycle of
fluorocarbons

Originally developed gas:HCFO-1224yd(Z)



HCFO-1224yd(Z)

Manufacturer: Asahi Glass Co., Ltd

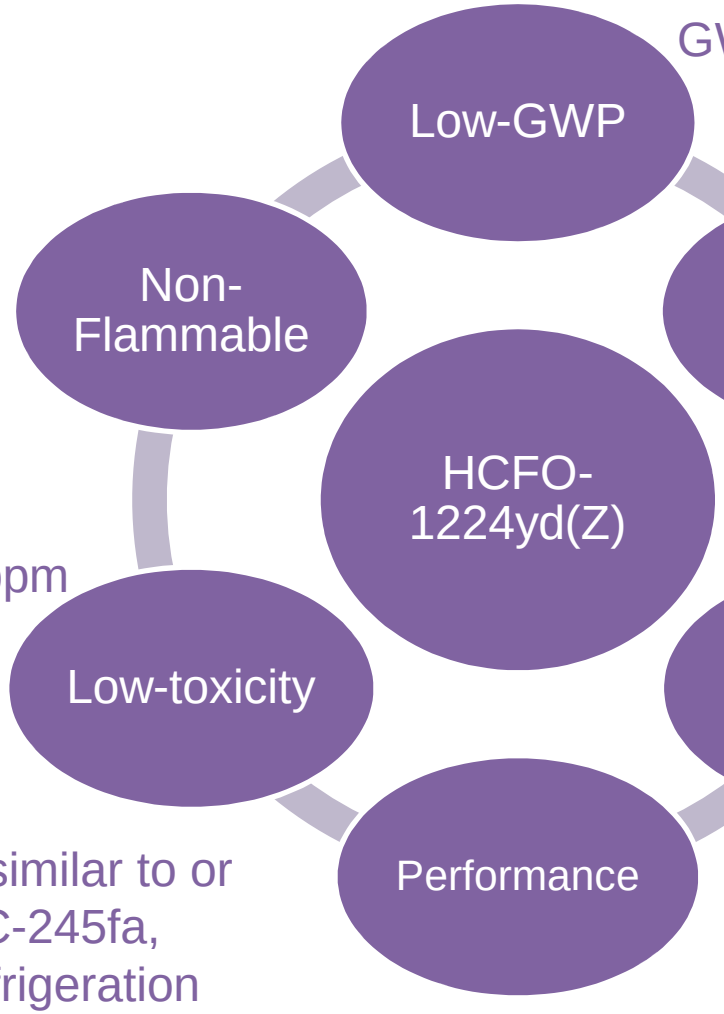
Purity: 98.4% (Z/E isomer =91/9)

Water content: less than 5ppm

Normal boiling point	[^{o}C]	15
Flammable range	[vol%]	None
Atmosphere Lifetime	[year]	21days*
GWP(ITH=100)	[CO_2=1]	1*
Ames test		Negative
LC_{50}	[ppm]	>200,000

***** Measured by Advanced Industrial Science and Technology

Character of HCFO-1224yd(Z)



GWP under 1

Zero-ODP(0.00012)

Same thermal stability as HFCs, more stable than other HFOs

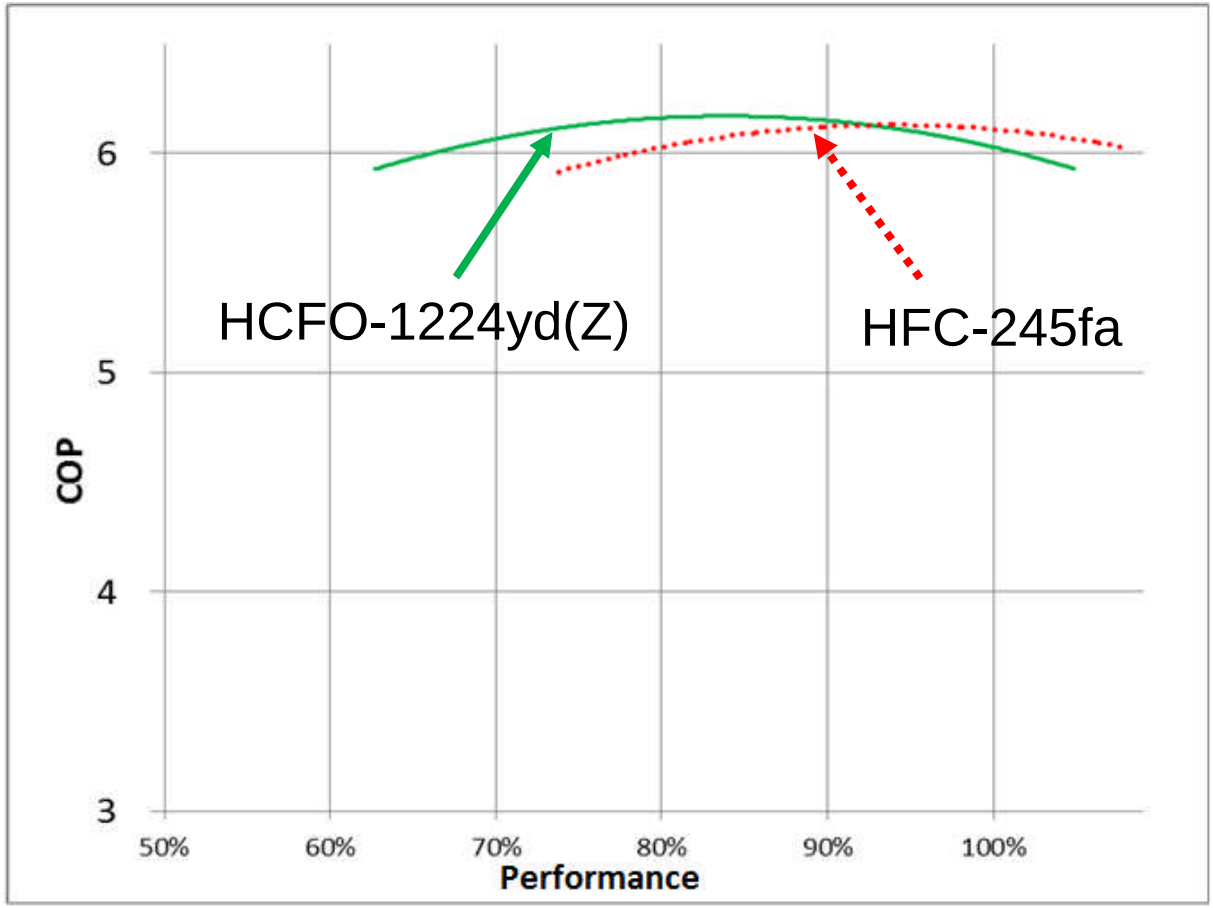
Good compatibility with most oils, metals, plastics and elastomers

Properties are similar to or better than HFC-245fa, especially in refrigeration performance

LC_{50} >200,000ppm
AEL=500ppm
(as AGC)

Chiller Performance of HCFO-1224yd(Z)

Actual machine performance



Condition：JIS B8621-2011(Centrifugal Chiller); chilled water inlet/outlet 12/7°C; cooling water inlet/outlet 32/37°C

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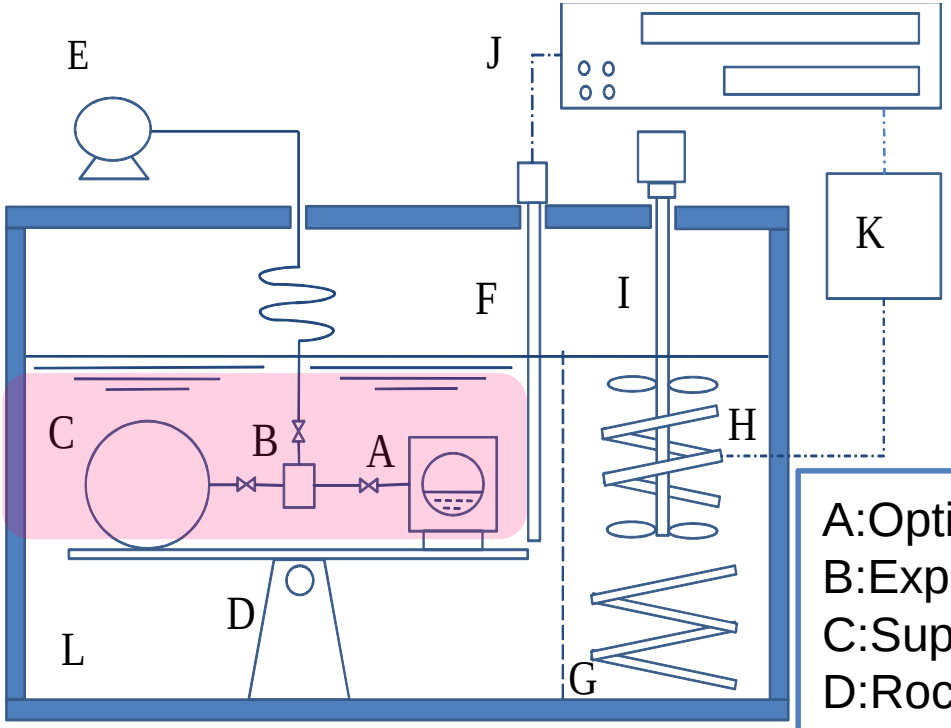
Vapor-liquid coexistence curve in the critical region

- Experimental apparatus



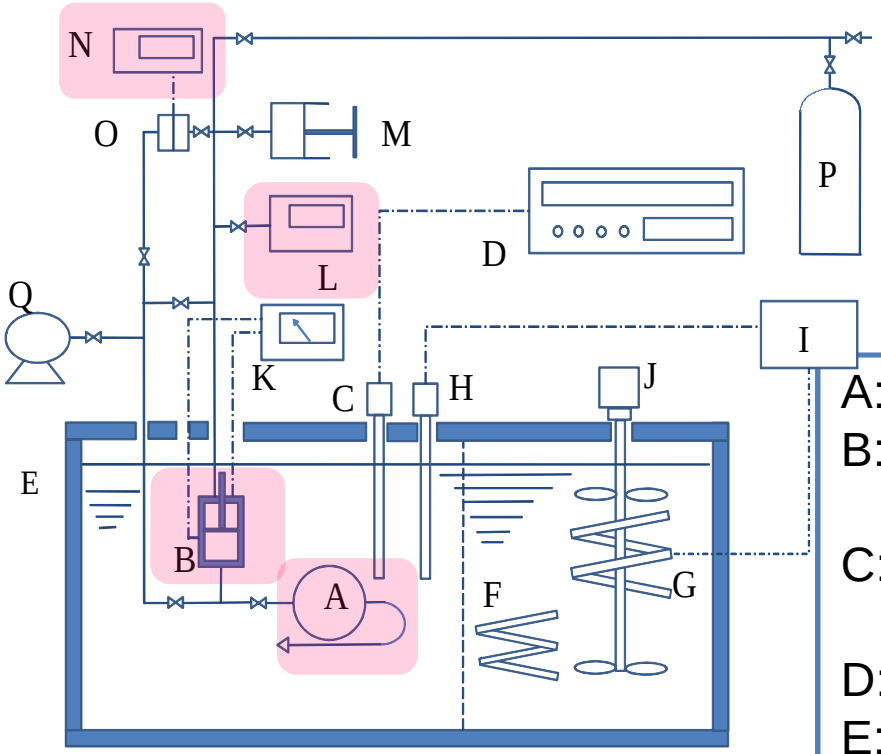
Uncertainties

Temp.	± 20 mK
Density	± 3 kg/m^3

A:Optical cell
B:Expansion vessel
C:Supplying vessel
D:Rocking frame
E:Vacuum pump
F:Platinum resistance thermometer
G:Main-heater
H:Sub-heater
I:Stirrer
J:Thermometer bridge
K:PID controller
L:Thermostated bath

Vapor Pressure and PVT properties

- Experimental apparatus



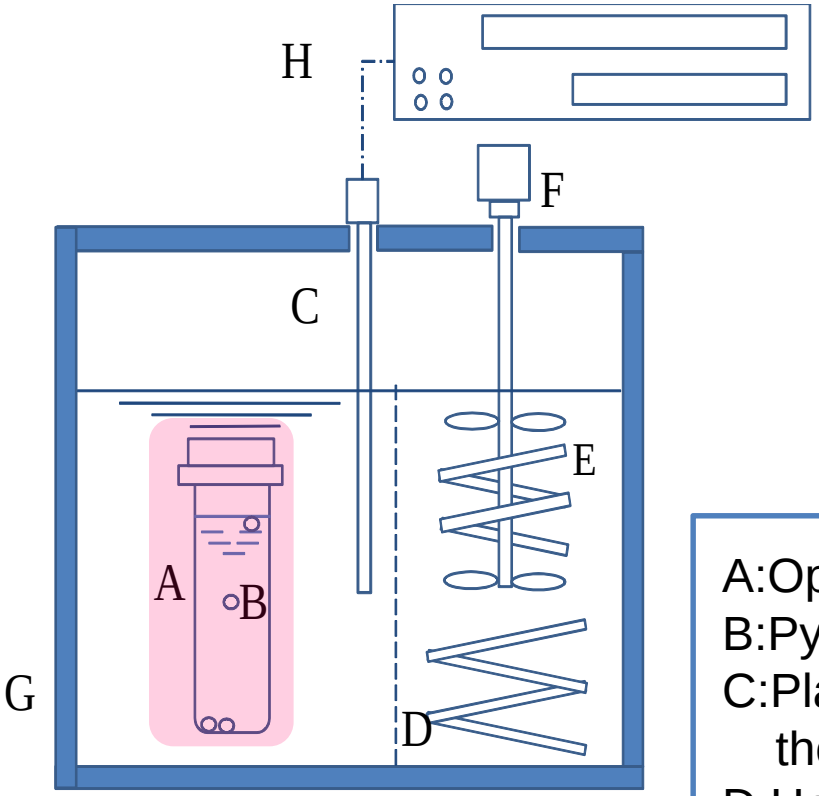
Uncertainties

Temp.	± 10 mK
Pressure	± 3 kPa
Density	± 0.2 %

A:Vessel
B:Differential pressure detector
C:Platinum resistance thermometer
D:Thermometer bridge
E:Thermostated bath
F:Main-heater
G:Sub-heater
H:Platinum resistance thermometer
I:PID controller
J:Stirrer
K:Tester
L:Digital pressure gauge
M:Pressure controller
N:Digital pressure gauge
O: Differential pressure detector
P:N2 bottle
Q:Vacuum pump

Saturated liquid density

- Experimental apparatus



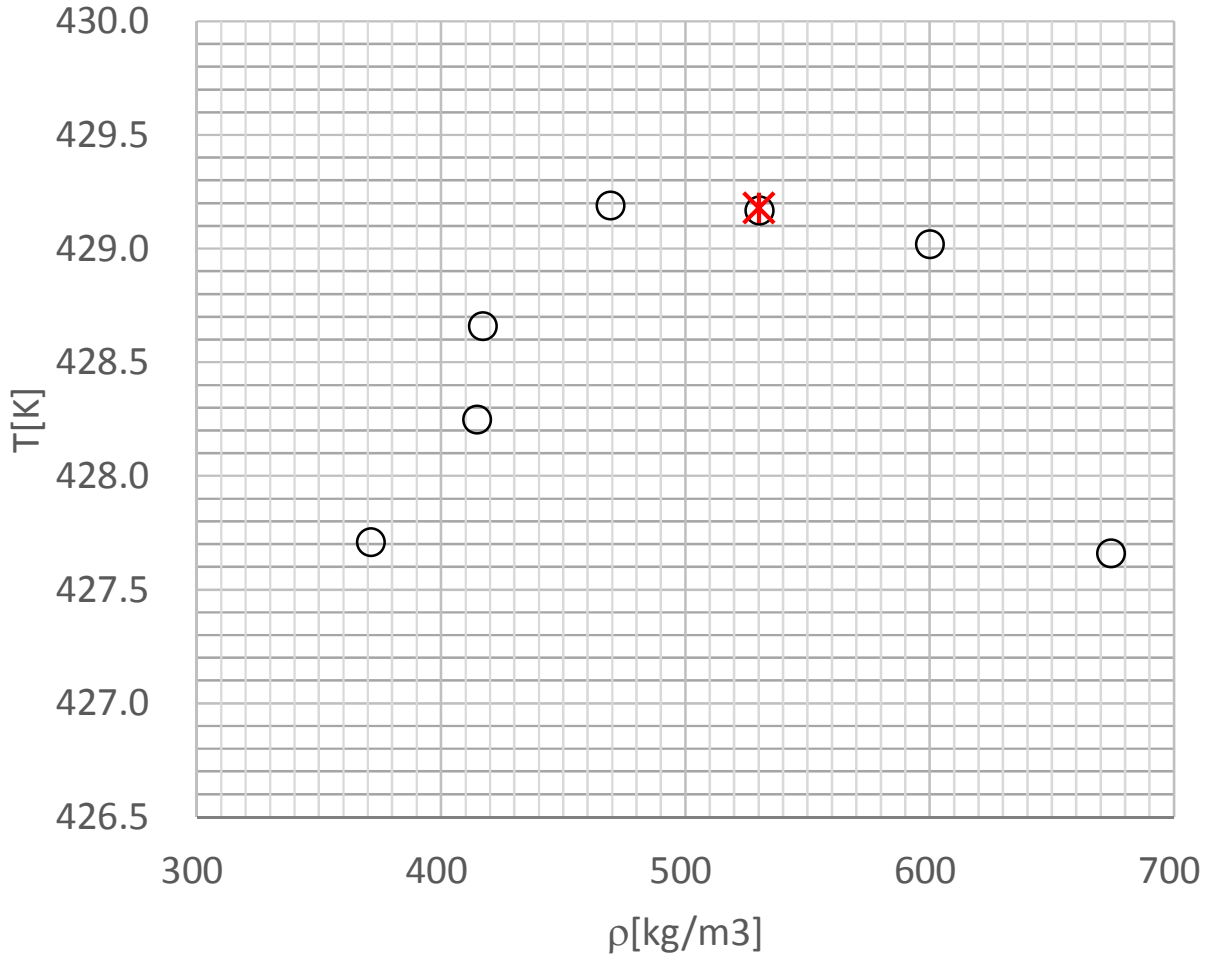
Uncertainties

Density of float at room temp.	± 1 kg/m^3
Temp.	± 20 mK
Density	±3 kg/m^3

A:Optical cell
B:Pyrex glass floats
C:Platinum resistance thermometer
D:Heater
E:Cooler
F:Stirrer
G:Thermostated bath
H:Thermometer bridge

Vapor-liquid coexistence curve in the critical region

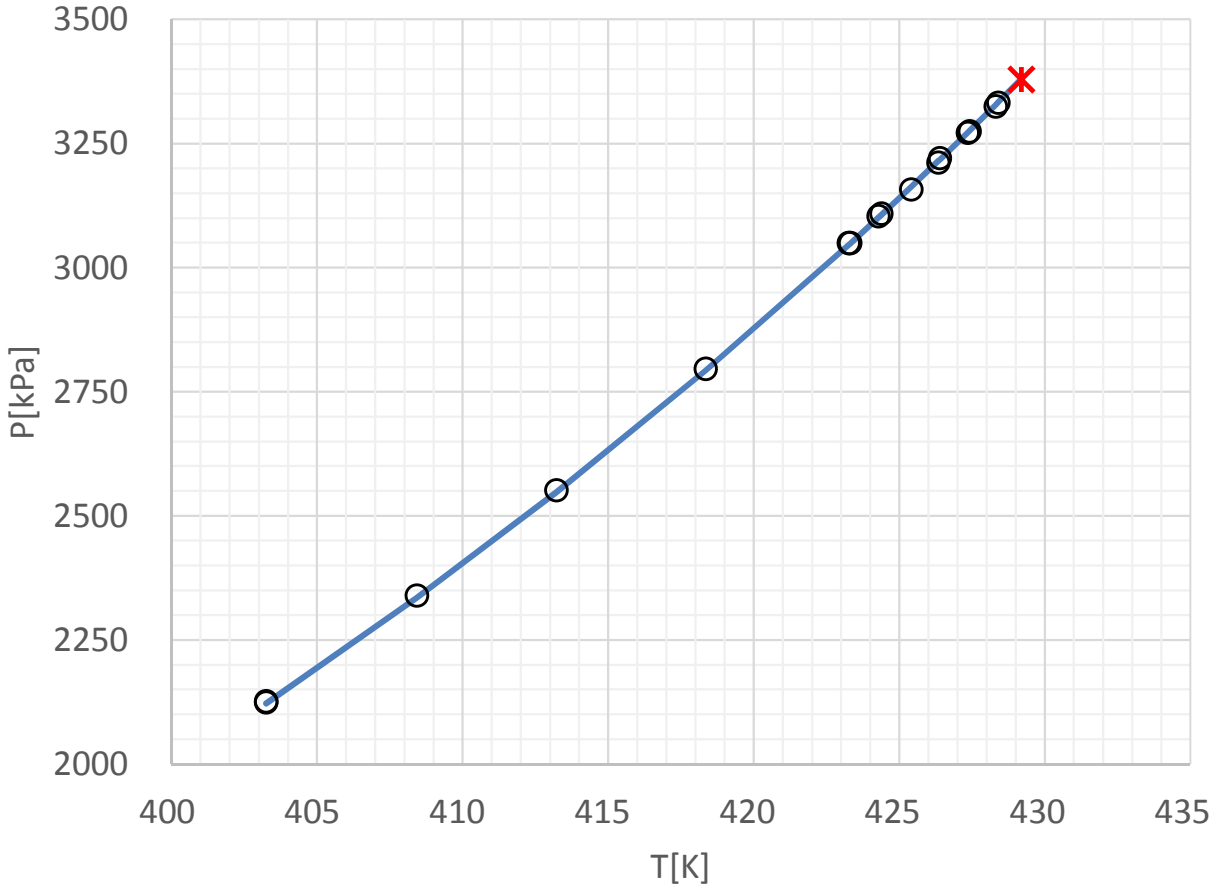
- Results



T[K]	ρ[kg/m3]
427.71	371.20
428.25	414.70
428.66	417.01
429.19	469.29
429.17	530.18
429.02	600.00
427.66	674.13

Vapor Pressure and PVT properties

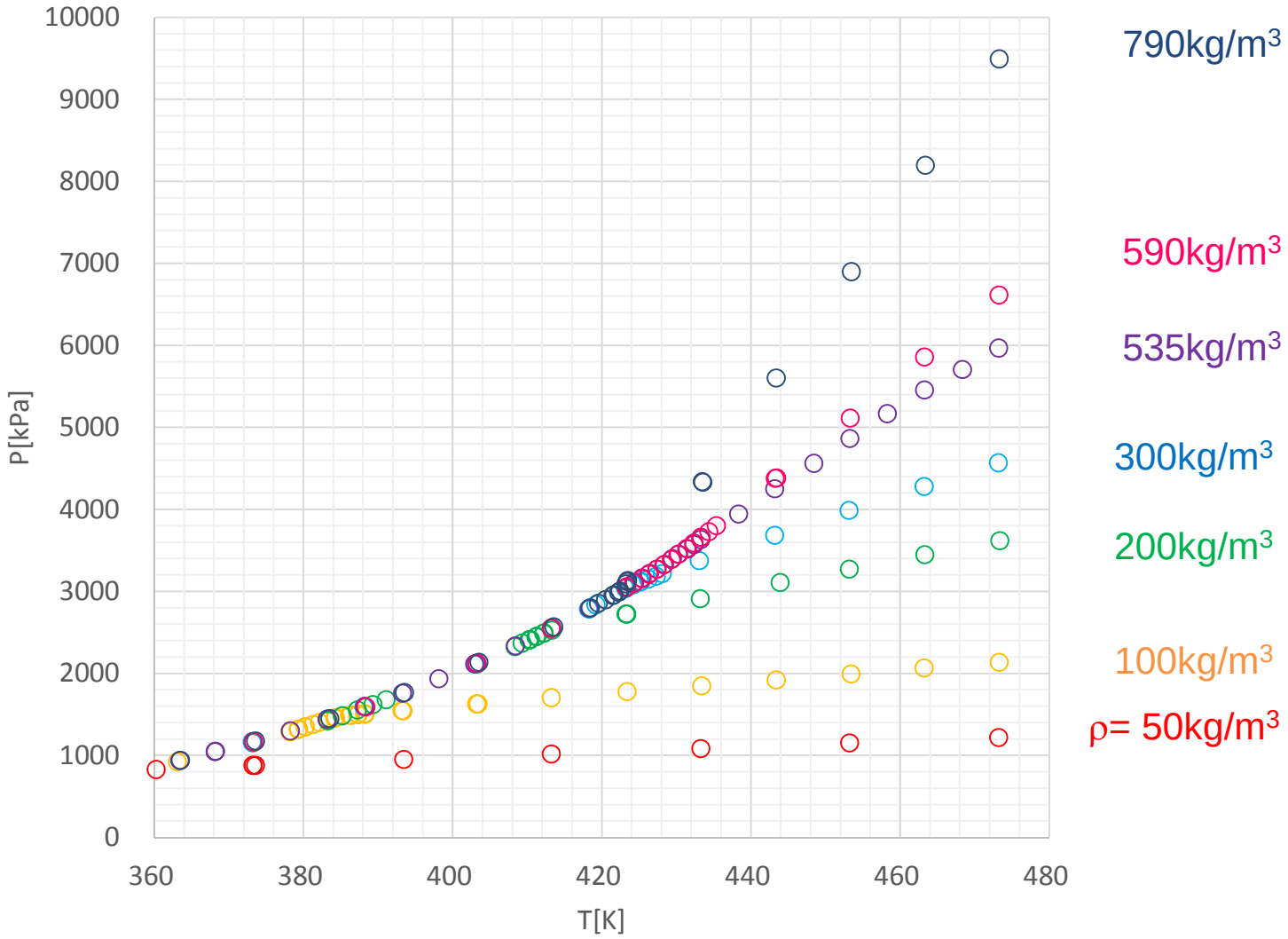
- Results



T[K]	P[kPa]
403.25	2124.3
403.25	2126.3
408.42	2339.0
413.22	2551.7
418.35	2795.8
423.26	3049.4
423.31	3049.2
424.29	3103.8
424.38	3109.0
425.40	3157.5
426.34	3211.4
426.39	3220.4
427.35	3271.6
427.42	3274.8
428.31	3324.8
428.41	3332.6

Vapor Pressure and PVT properties

- Results



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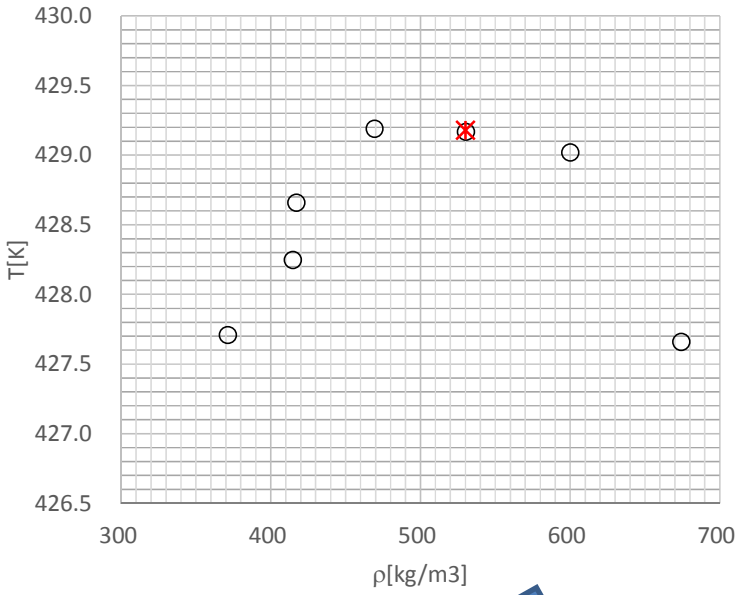
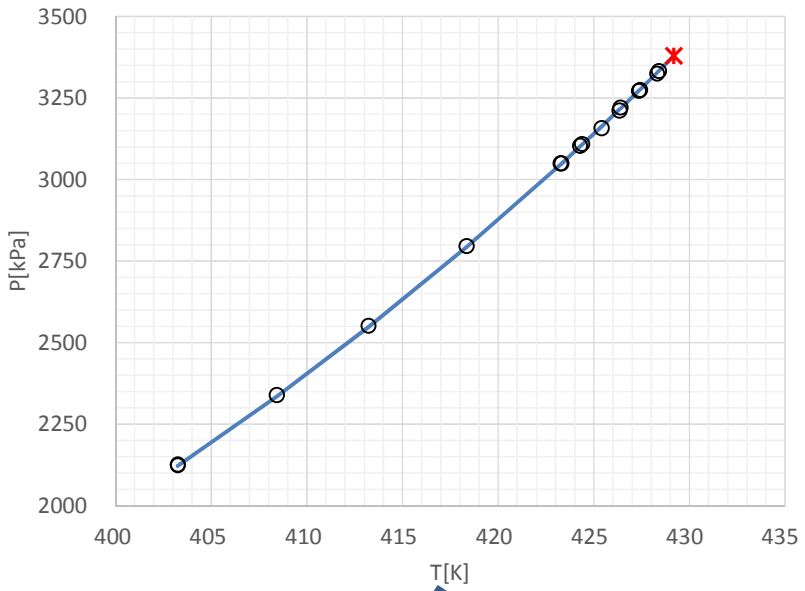
Critical parameter

Critical point measurement



Vapor pressure measurement



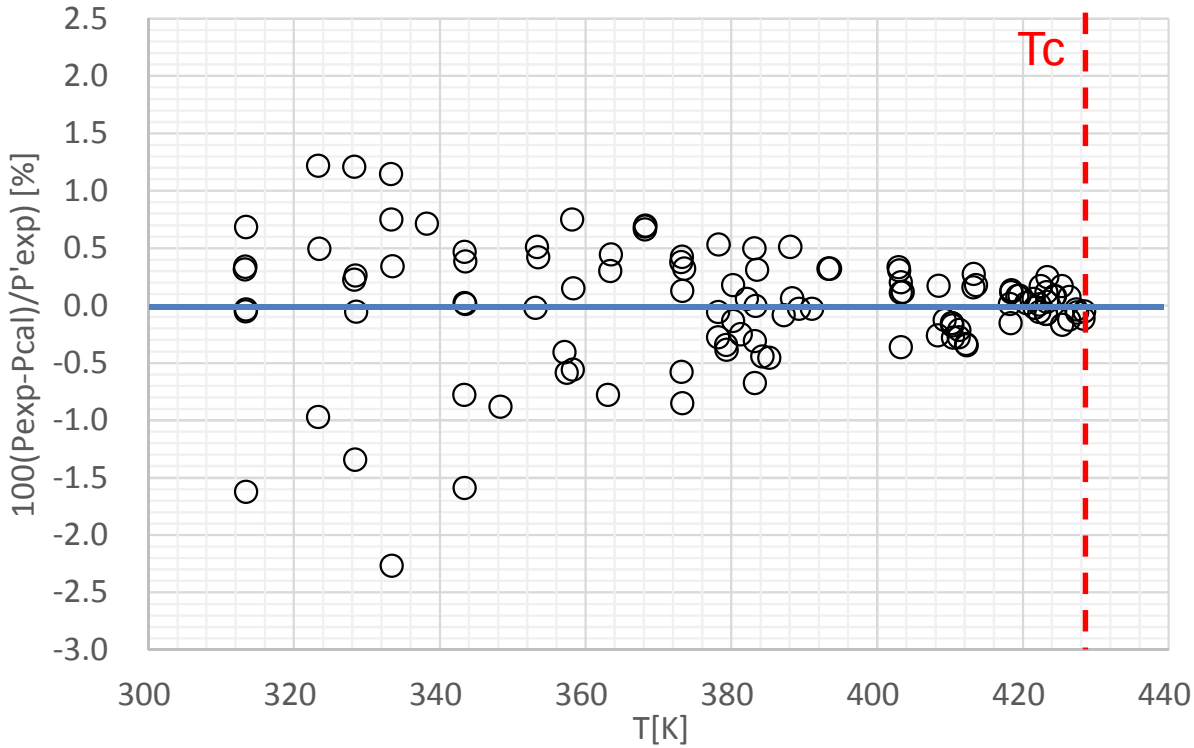
Critical temperature	429.18 ±0.05 K
Critical density	530 ±5 kg/m^3
Critical Pressure	3.380 ±0.005 MPa

Vapor pressure correlation

$$\ln P_{vpr}(MPa) = (A_0\tau + A_1\tau^{1.5} + A_2\tau^{2.5} + A_3\tau^{5}/Tr(K)) \quad \ldots Eq.(1)$$

$$\tau = 1-(T(K)/Tc)$$

A_0 A_1 A_2 A_3	-7.6720 1.9095 -2.6381 -5.5113
RMS Dev.(%) /Number of data points	0.51 / 116
T_C P_C ρ_C	429.18 K 3.380 MPa 530 kg/m^3

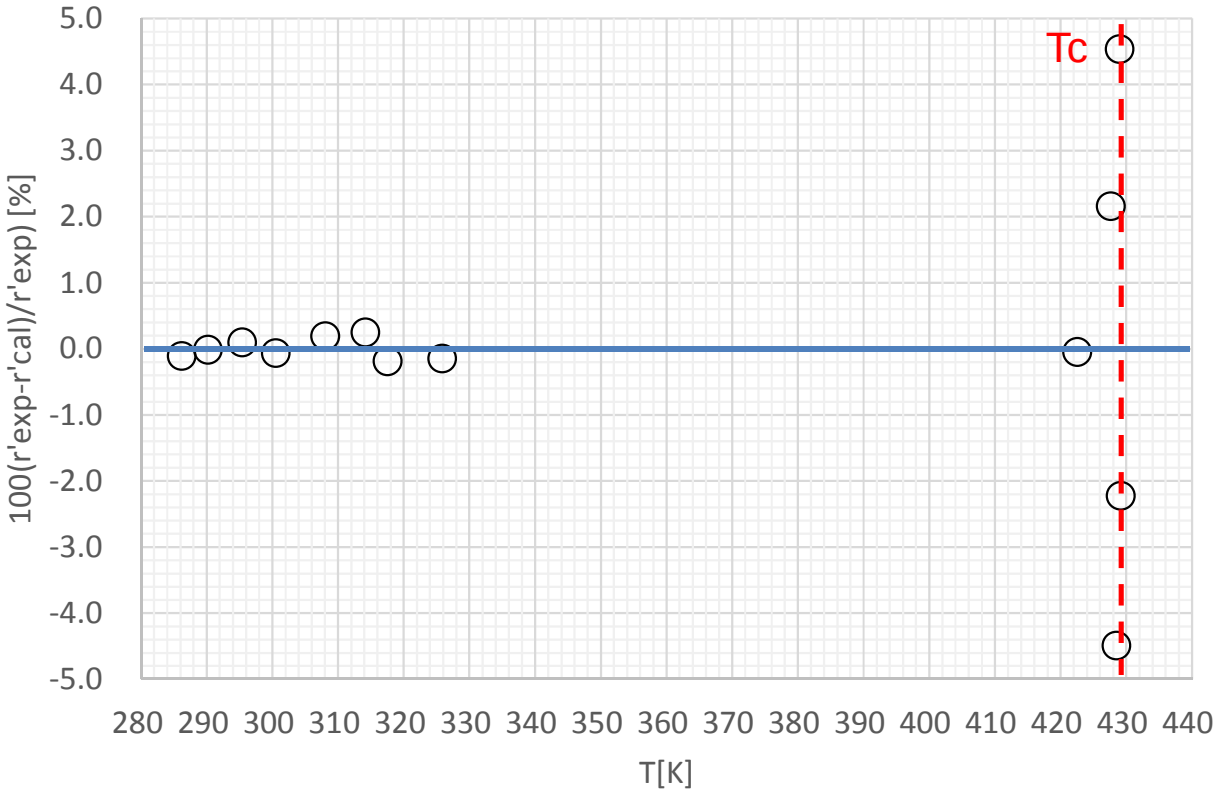


Saturated liquid density Correlation

$$\rho'(kg/m^3)/\rho_c = 1+B_0\tau^{1/3}+B_1\tau^{2/3}+B_2\tau+B_3\tau^{4/3} \quad ...Eq.(2)$$

$$\tau = 1-(T(K)/Tc)$$

B_0 B_1 B_2 B_3	0.51475 9.6947 -18.564 12.138
RMS Dev.(%) /Number of data points	1.97 / 13
T_C P_C ρ_C	429.18 K 3.380MPa 530 kg/m^3



Summary

Newly determine the thermodynamic properties and critical parameters for HCFO-1224yd(Z)

Critical temperature	419.18 ±0.05 K
Critical density	530 ±5 kg/m^3
Critical Pressure	3.38 ±0.005 MPa

Develop the correlations of vapor pressure and saturated liquid density based on the present data

Next Action →→→
Measure High purity of HCFO-1224yd(Z)
Make EOS of HCFO-1224yd(Z)

Acknowledgement

- This study was implemented by NEDO Project

  “Development of high-efficiency non-CFC and HCFC air-conditioning equipment technology”

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  - National Institute of Advanced Industrial Science and Technology (AIST)

Thank you all for your attention