no. 2337

Condensation and Evaporation of R744/R32/R1234ze(E) flow in Horizontal microfin Tubes

Chieko KONDOU (Kyushu Univ.)
Fumiya MISHIMA (Kyushu Univ.)
JinFan LIU (Kyushu Univ.)
Shigeru KOYAMA (Kyushu Univ.)

KYUSHU UNIVERSITY

Background and objectives

1

R32/R1234ze(E)
To maintain COP, R32 addition is needed up to 50$_{mass}$% (GWP~350).

Further improvement….
R744 addition was attempted.
- to decrease GWP
- to increase volumetric capacity

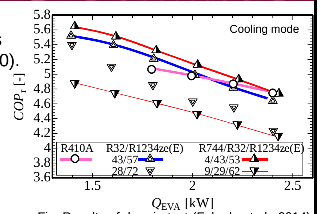


Fig. Results of drop-in-test (Fukuda et al., 2014)

[Difficulty in use of non-azeotropic mixtures]
- Exergy loss in HEX can be minimized by utilizing temp. glide
- Volatility difference causes severe decrease in HTC

Quantifying HTC of R32/1234ze(E) and R744/32/1234ze(E)

(30/70$_{mass}$%)GWP~207 (9/29/62$_{mass}$%)GWP~200
(40/60$_{mass}$%)GWP~274 (4/43/53$_{mass}$%)GWP~293

Physical properties of test refrigerants

2

Calculated with REFPROP 9.1 (Lemmon et al., 2013)
Mixing parameters optimized by Akasaka (2013) for R32/R1234ze(E)

GWP~200

at $(T_{bub}+T_{dew})/2$= 10 °C

Refrigerant composition	R32/1234ze(E) (30/70 mass%)	R32/1234ze(E) (40/60 mass%)	R744/32/1234ze(E) (9/29/62 mass%)	R744/32/1234ze(E) (4/43/53 mass%)
GWP_{100}*a	207	274	200	293
Psat [MPa]	0.62	0.70	0.87	0.84
ΔT_glide [K]	11.7	10.2	21.6	13.7
Δh_VL [kJ kg^{-1}]	220	230	238	241
ρ [kg m^{-3}]	1168 / 24.9	1146 / 26.3	1161 / 32.0	1134 / 29.8
μ [mPa s]	194 / 12.5	180 / 12.6	191 / 13.1	175 / 12.8
λ [mW m^{-1} K^{-1}]	101.4 / 13.0	107.4 / 13.0	108.4 / 14.2	112.2 / 13.4

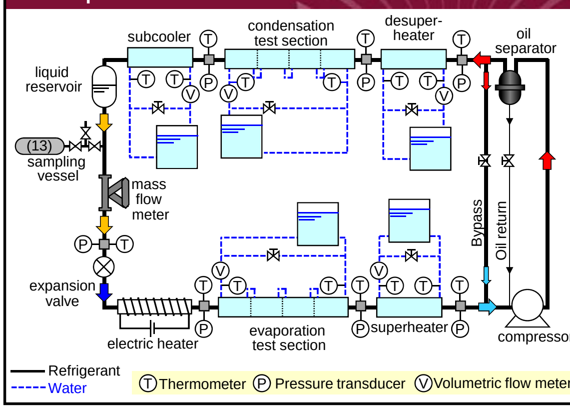
(liquid/vapor)

GWP~300

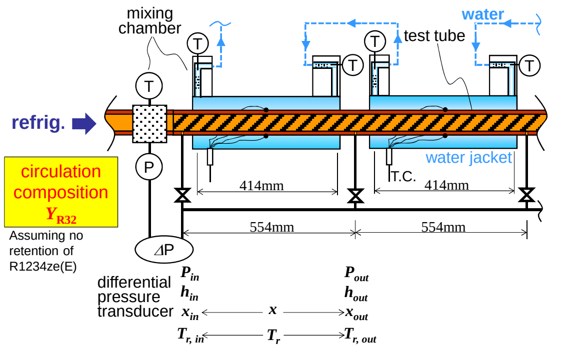
- By addition of R744, degree of the temperature glide increases
- Latent heat and vapor density increase slightly

Test loop

3



Test section



Test microfin tube

Outer diameter	D_o	6.0	mm
Fin root diameter	d_{max}	5.5	mm
Equivalent inner diameter	d_{eq}	5.3	mm
Fin height	h_{fin}	0.255	mm
Helix angle	β	20	deg.
Number of fins	N_{fin}	48	-
Surface enlargement	η_A	2.24	-

Heat flux and HTC based on "**enlarged surface area**"

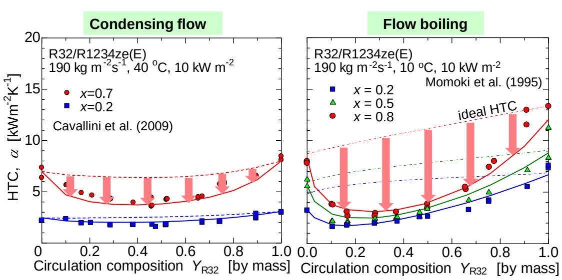
$$q = \frac{Q_{H2O}}{(d_{eq}\pi\eta_A \Delta Z)} \qquad \alpha = \frac{q}{(T_r - T_{wi})}$$

Heat loss: 2.7% of Q_{H2O} at q =10 kW m^{-2}

Uncertainty: U_YR744 = U_YR32 = 1 $_{mass}$%

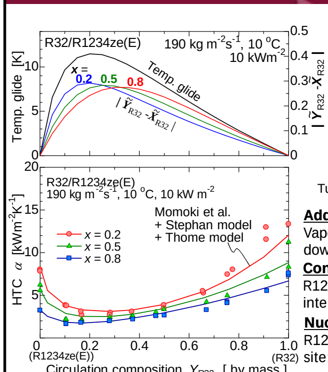
U_T_{wi} = 0.05 K

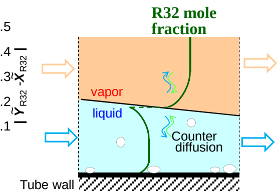
Binary mixture R32/1234ze(E)



- ✓ "Mass transfer resistance" (Jung and Radermacher, 1993)
- ✓ Decrease in HTC caused by the volatility difference.
- ✓ Severer in flow boiling HTC.

Mass transfer resistance in flow boiling of R32/1234ze(E)





Additional sensible heat

Vapor flow must be heated up to local T_{sat} downstream. (Stephan, 1992)

Convective evaporation suppression

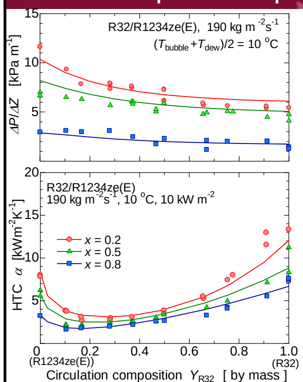
R1234ze(E) concentrates on vapor-liquid interface.

Nuclear boiling suppression

R1234ze(E) concentrates at nuclear boiling site: decrease in effective superheat.

(Thome, 1983)

What about the pressure drop?

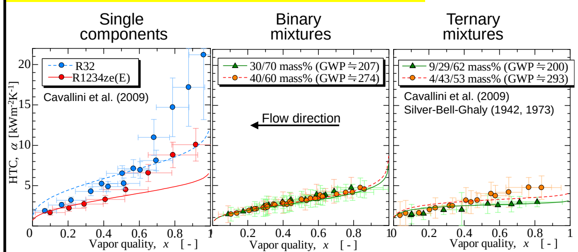


- ✓ Pressure gradient gradually decreases as Y_{R32} increases. (with increasing ρ_V and decreasing μ_L)
- ✓ Variation in DP is predicable with consideration of property change.

Mass transfer resistance does not affect pressure gradient

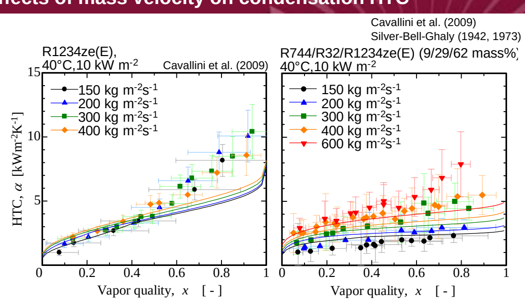
Condensation HTC of the binary and ternary

at (T_{dew}+T_{bub})= 40 °C, 200 kg m^{-2}s^{-1}, 10 kWm^{-2}



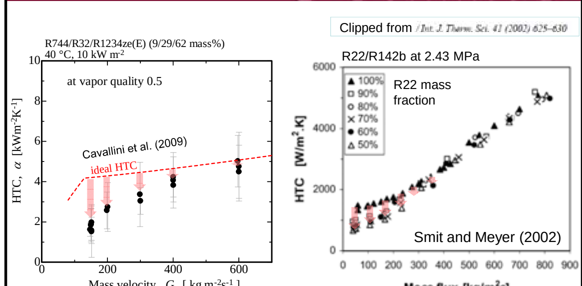
- ✓ HTCs of the binary and ternary mixtures are markedly low.
- ✓ HTC of the ternary mixture with GWP200 is slightly lower that of the others. (large ΔT_glide, ρ_V)

Effects of mass velocity on condensation HTC



- ✓ Change in HTC of R1234ze(E) alone is only slight; while HTC of the ternary increases with increasing mass velocity.

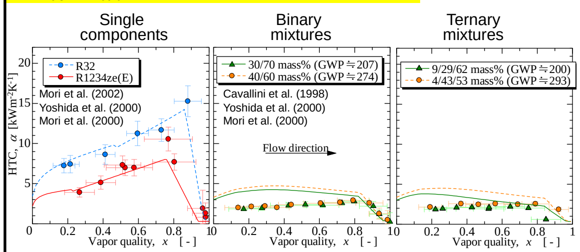
Mitigation of mass transfer resistance



- ✓ With increasing mass velocity, the condensation HTC recovers. (recovering point depends on magnitude of volatility difference)
- ✓ For condensation, there is the way to cancel the mass transfer resistance.

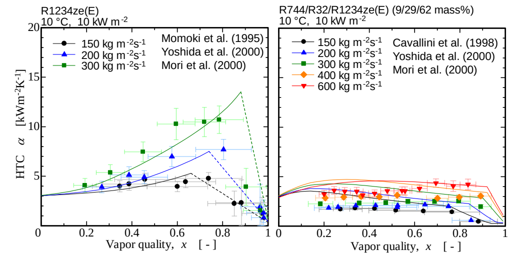
Evaporation HTC of the binary and ternary

at (T_{dew}+T_{bub})=10 °C, 200 kg m^{-2}s^{-1}, 10 kWm^{-2}



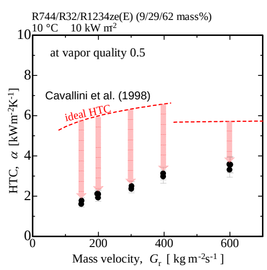
- ✓ HTC of the binary and the ternary is comparable and markedly lower than that of single components.
- ✓ HTC is decreased in *nucleate boiling dominant region* and *forced convection dominant region* both by the volatility difference.

Effects of mass velocity on evaporation HTC



- ✓ HTC increases with increasing mass velocity for the single component and the ternary mixture both.
- ✓ The rate of increase for the ternary is smaller than that for R1234ze(E).

No recovering point in flow boiling HTC…



- ✓ Even though HTC increases with increasing mass velocity, recovering point did not appear in the tested range.
- ✓ Canceling mass transfer resistance would be very difficult for flow boiling.

Conclusions

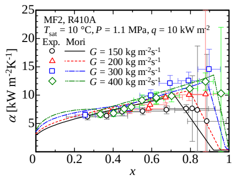
HTC of R32/1234ze(E) and R744/32/1234ze(E) are quantified for condensation and flow boiling.

- ➢ HTC degradation by the volatility difference is severer for flow boiling than that for condensation.
- ➢ HTC of the binary and ternary is way below that of R1234ze(E) alone.
- ➢ HTC of R744/32/1234ze(E) with GWP200 is slightly lower than the other zeotropic mixtures.
- ➢ For condensation, the mass transfer resistance mitigates with increasing mass velocity. However, for flow boiling, HTC was below the ideal HTC in the entire test range.

Thank you for your kind attention

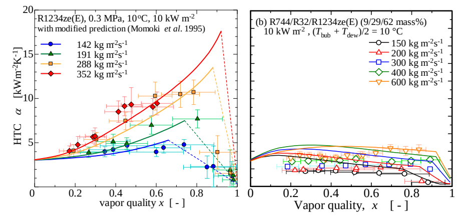
Evaporation HTC at 10 ^oC, 200 kg $m^{-2}s^{-1}$, 10 kWm^{-2}

16

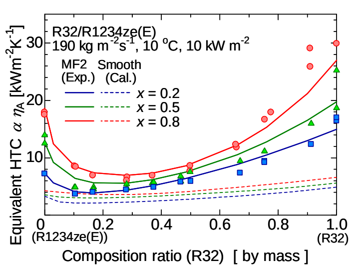


Evaporation HTC at 10 ^oC, 200 kg $m^{-2}s^{-1}$, 10 kWm^{-2}

17



18



- ✓ ら旋溝付管内の熱伝達率は平滑管よりも常に優位である.
- ✓ 非共沸冷媒に対しても，伝熱面積拡大や旋回流等の伝熱促進は明らかに有効.