Heat Transfer Performance Of HFO-1234yf - A Quick Overview

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Refrigerants

- **A refrigerant is a substance used in a heat cycle (heat engine, heat pump, and the like) usually including, for enhanced efficiency, a reversible phase transition from a liquid to a gas.**

- **Typical Refrigeration Cycle**

Condenser

Receiver   Compressor

Expansion Valve

Evaporator
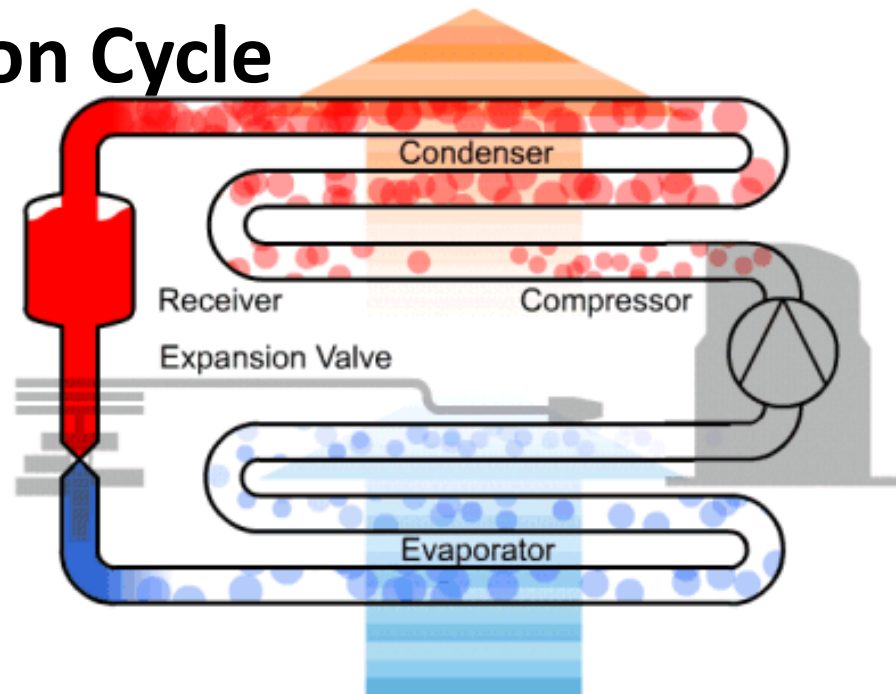
Refrigeration Cycle

Types of refrigerants

- **Refrigerants can be divided in two main groups:**
  - **synthetic** (basically halocarbon fluids: CFCs, HCFCs and HFCs) and **non-synthetic** (hydrocarbons, carbon dioxide, ammonia, water, air – so-called natural refrigerants).
  - **Natural,** such as hydrocarbons, carbon dioxide, ammonia, water, air and the like.

Synthetic refrigerants

- Refrigerators from the late 1800s until 1929 used the higher ***toxicity gases - ammonia, methyl chloride, and sulphur dioxide***. Fatal accidents occurred from time to time because of leakage from refrigerators.

- In 1928, CFCs and HCFCs were invented ***as substitutes for the higher toxicity and flammable refrigerants***. CFCs and HCFCs are a group of aliphatic organic compounds ***containing the elements carbon and fluorine***, and, in many cases, other halogens (especially chlorine) and ***hydrogen***.

- Most CFCs and HCFCs tend to be ***colorless, odorless, non-flammable, non-corrosive substances***. Because CFCs and HCFCs have low toxicity, their use eliminated the danger posed by refrigerator leaks.

Chlorofluorocarbons (CFC)

Inert, non-toxic, non-flammable compounds with low boiling points that once is called the perfect refrigerants.

- CFCs consist of ***chlorine, fluorine, and carbon***. The most common refrigerants in this group are R-11, R-12 and R-115 (within the blend R-502).

- Widespread use since the 1930s, in nearly all applications.

- Contain no hydrogen, CFCs are very ***chemically stable***, and tend to have ***good compatibility*** with most materials and traditional lubricants such as mineral oils

- Generally ***good thermodynamic and transport properties***, thereby offering the potential for good efficiency.

- However, because they ***contain chlorine***, CFCs are damaging to the ozone layer, and due to their long atmospheric life, ***the CFCs have a high ODP.***

- Similarly, they are ***strong greenhouse gases with high GWP***.

Hydrochlorofluorocarbons (HCFCs)

- HCFCs consist of ***hydrogen, chlorine, fluorine, and carbon***. The most common refrigerants in this group are R-22, R-123 and R-124 (within various blends).

- Widespread use since the 1930s, in nearly all applications, including commercial refrigeration, cold storage, transport refrigeration, stationary air conditioning and chillers.

- ***HCFCs Contain hydrogen, HCFCs are theoretically less chemically stable than CFCs***, but nevertheless tend to have ***good compatibility with most materials*** and traditional lubricants such as mineral oils.

- Good ***thermodynamic and transport properties***, thereby offering the potential for very good efficiency.

- As with CFCs, because of the chlorine content, they are ***damaging to the ozone layer*** , although ***with a relatively low ODP***.

- Similarly, they are ***strong greenhouse gases with high GWP.***

Hydrofluorocarbons (HFCs)

- HFCs consist ***of hydrogen, fluorine, and carbon***. The most common refrigerants in this group are R-134a, R-32, R-125 and R-143a (mostly within blends, such as R-404A, R-407C and R-410A).

- ***Large scale use since the 1990s***, in nearly all applications that have traditionally used CFCs and HCFCs, including domestic and commercial refrigeration, cold storage, vehicle air conditioning, transport refrigeration, stationary air conditioning and chillers.

- ***HFCs are generally chemically very stable, and tend to have good compatibility with most materials***.

- ***Not miscible*** with traditional lubricants, ***synthetic oils are needed***.

- Their ***thermodynamic and transport properties range from fairly to very good***, thereby offering the potential for good efficiency.

- ***HFCs contain no chlorine, do not damage the ozone layer***.

- However, due to their long atmospheric lifetime, they are typically ***strong greenhouse gases with high GWP***.

Environmental Effects of Refrigerants

- Depletion of the ozone layer in the stratosphere (CFC/HCFC)

- Global warming : (CFC/HCFC/HFC)

Refrigerants directly contributing to global warming when released to the atmosphere

Indirect contribution based on the energy consumption (CO_2 produced by power stations)

Refrigerants with zero ozone depleting potential (other than HFCs)

- **Perfluorocarbons**
  - They represent another group of fluorocarbons which contains five different fluids. One of these (R218) is occasionally used in refrigerant blends. Generally **PFCs are very stable**, but as a result **have very high GWP**.

- **Unsaturated HFCs**
  - Whilst conventional HFCs are saturated, there are a small number of **unsaturated HFCs, known as olefins**. **Generally, there are highly unstable**, but recently **a small number have been identified which are sufficiently stable** to be used as refrigerants, and have **low-toxicity and low flammability and low GWP**. The two receiving most interest are **R-1234yf and R-1234ze**; the former is being considered for use in MVAC systems, **but it is unlikely that they will be applied as refrigerant in other sectors** for several years.

- **Hydrofluoroethers (mainly for solvent)**
  - This group of fluorinated chemicals tends to be *__fairly stable__* and amongst them have a fairly wide range of boiling points, although they tend to be lower pressure fluids. They have been considered as use as refrigerants, but to date have not achieved market acceptance for various reasons.

- **Natural refrigerants**
  - Various hydrocarbons, ammonia and carbon dioxide belong to a group named "natural refrigerants". All natural refrigerants exist in material cycles present in the nature even without human interference. They have zero ODP and zero or negligible GWP.
  - **Some natural refrigerants: Ammonia (NH_3, R-717) , Carbon dioxide (CO_2, R-744) , Hydrocarbon...**

Ammonia as Refrigerant

- Advantages
  - ODP = 0, GWP = 0
  - Excellent thermodynamic characteristics: small molecular mass, large latent heat, large vapor density and excellent heat transfer characteristics
  - High critical temperature (132 °C) : highly efficient cycles at high condensing temperatures
  - Its smell causes leaks to be detected and fixed before reaching dangerous concentration
  - Relatively Low price
- Drawbacks:
  - Toxic
  - Flammable (16 – 28% concentration)
  - Not compatible with copper
  - Temperature on discharge side of compressor is higher compared to other refrigerants

Source: Manual for Refrigeration Servicing Technicians

Properties of most common refrigerants

These are properties of refrigerants mostly used:

Refrigerant	Chemical type	Molecular mass	NBP (°C)	Pressure at 35°C (kPa)	Critical temp (°C)	Safety class	ODP (MP)	GWP (100)	Refrigerant	Chemical type	Molecular mass	NBP (°C)	Pressure at 35°C (kPa)	Critical temp (°C)	Safety class	ODP (MP)	GWP (100)
R11	CFC	137.7	23.7	149	198	AI	1	4750	R404A	HFC	97.6	-46.2	1629	72	AI	0	3920
R12	CFC	120.9	-29.8	846	112	AI	1	10890	R407C	HFC	86.2	-43.6	1414	86	AI	0	1770
R22	HCFC	86.4	-40.8	1355	96.1	AI	0.055	1810	R409A	HCFC	97.4	-34.4	977	109.3	AI	0.05	1590
R114	CFC	170.9	3.6	292	145.7	AI	1	10040	R409B	HCFC	96.7	-35.6	1024	106.9	AI	0.05	1560
R123	HCFC	152.9	27.8	131	183.7	BI	0.02	77	R410A	HFC	72.6	-51.4	2071	71.4	AI	0	2090
R134a	HFC	102.0	-26.1	887	101.1	AI	0	1430	R413A	PFC/HFC/HC	104.0	-33.4	1067	96.6	A2	0	2050
R152a	HFC	66.1	-24	794	113.3	A2	0	124	R417A	HFC/HC	106.8	-39.1	1315	87.1	AI	0	2350
R290	HC	44.1	-42.1	1218	96.7	A3	0	3	R500	CFC/HFC	99.3	-33.6	980	102.1	AI	0.74	8070
R401A	HCFC/HFC	94.4	-32.9	961	107.3	AI	0.04	1180	R502	CFC/HCFC	111.6	-45.3	1464	81.5	AI	0.33	4660
R401B	HCFC/HFC	92.8	-34.5	1024	105.6	AI	0.04	1290	R600a	HC	58.1	-11.7	465	134.7	A3	0	4
R402A	HCFC/HFC/HC	101.6	-48.9	1733	75.8	AI	0.02	2790	R717	NH3	17.0	-33.3	1351	132.3	B2	0	0
R402B	HCFC/HFC/HC	94.7	-47	1635	82.9	AI	0.03	2420	R744	CO2	44.0	-54.4	>7300	31	AI	0	1
R403A	HCFC/PFC/HC	92.0	-47.7	1649	87	AI	0.04	3120	R1270	HC	42.1	-47.6	1469	91.1	A3	0	2
R403B	HCFC/PFC/HC	103.3	-49.2	1715	79.6	AI	0.03	4460									

Following table shows properties of alternative refrigerants compared to R22.

		Refrigerant physical properties					
		Cond.Press. MPa	ODP	GWP (IPCC4)	Life Year	Flamm -ability	Toxicity
R22		Single	1.73	0.05	1810	11.9	No	Low
HFC	R410A	Azeotrope	2.72	0	2090	5-29	No	Low
	R407C	Zeotrope	1.86	0	1770	5-29	No	Low
	R32	Single	2.80	0	675	5	Low*1	Low
	HFO1234ze	Single	0.88	0	6	11 days	Low*1	Low*3
	HFO1234yf	Single	1.16	0	4	7 days	Low*1	Low*3
	HFO mixture	**Under investigation**					Low
Non-HFC	Propane (R290)	Single	1.53	0	<3	Some days	High	Low
	CO2(R744)	Single	10.0	0	1	120	No	Low*2
	Ammonia (R717)	Single	1.78	0	0	0	Low	High

*1 According to ISO817 draft
*2 Practical limit is 0.1 kg/m³ according to EN378
*3 Based on latest data proposed for ASHRAE34

Carbon Dioxide as Refrigerant

- Non Flammable
- Non toxic
- Inexpensive and widely available
- Its high operating pressure provides potential for system size and weight reducing potential.

Drawbacks:

- Operating pressure (high side) : Above 80 bars
- Low efficiency

Hydrocarbon Refrigerants

- Used since the 1880's
- Zero ODP and negligible GWP
- Good substitutes for CFC's, HCFC's, and HFC's.
- Drop in solution
- Compatible with copper
- Miscible with mineral oil
- A third of original charge only is required when replacing halocarbons refrigerant in existing equipment
- Energy saving : up to 20% due to lower molecular mass and vapor pressure

Drawback :

- Flammable

Why R-1234yf?

- GWP = 4

- Similar to R-134a (property & production)

- Drop-in replacement of R-134a

HFO or Hydro-Floro-Olefin
2,2,2,3 Tetrafluoropropene
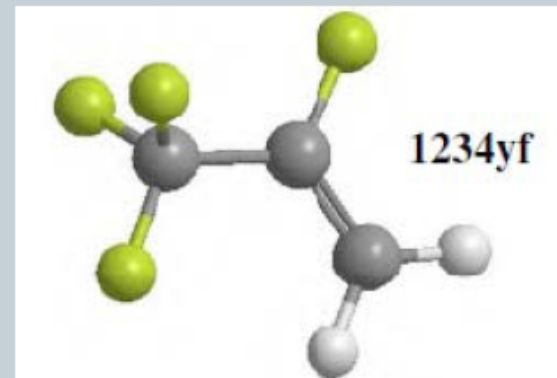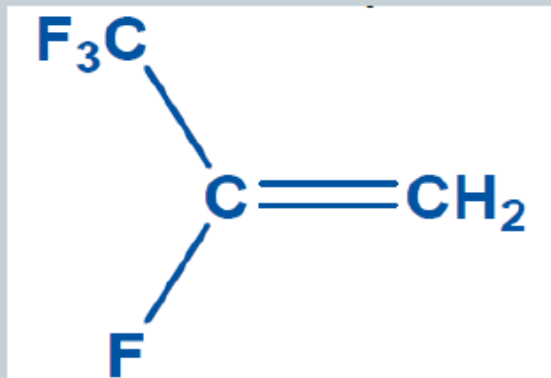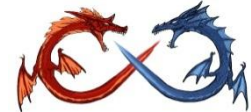
Table 1a – Fundamental constants of HFO-1234yf.

	molecular weight	critical temperature	Critical pressure
R-134a	102 g mol^{-1}	374.13 K	4.07 MPa
R-1234yf	114.042 g mol^{-1}	367.85 K	3.382 MPa

Table 1b – Thermodynamic and transport properties of HFC-1234yf.

T °C	Fluid	P kPa	ρ_L kg/m³	ρ_G kg/m³	μ_L μPa s	μ_G μPa s	k_L W/m K	k_G W/m K	i_{LG} kJ/kg	σ N/m	Cp_L kJ/kg K	Cp_G kJ kg K
0	R-134a	292.8	1295	14.43	271.1	10.73	0.092	0.01151	198.6	0.01156	1.341	0.0897
	R-1234yf	315	1175	17.17	220	11.44	0.0746	0.0091	162.3	0.0093	1.259	0.933
5	**R-134a**	**350**	**1278**	**17.14**	**254.4**	**10.94**	**0.0898**	**0.01195**	**194.8**	**0.01085**	**1.355**	**0.921**
	R-1234yf	**372**	**1160**	**20.8**	**206**	**11.67**	**0.073**	**0.0094**	**159**	**0.00868**	**1.275**	**0.957**
10	R-134a	414.6	1261	20.23	238.8	11.15	0.0876	0.0124	190.7	0.01014	1.37	0.946
	R-1234yf	436	1144	24.4	194	11.9	0.0713	0.0098	155.6	0.0081	1.293	0.983
20	R-134a	571.7	1225	27.78	210.7	11.58	0.0833	0.01333	182.2	0.00876	1.405	1.001
	R-1234yf	590	1111	33	171	12.36	0.0672	0.0106	148.3	0.0067	1.332	1.041
30	R-134a	770.2	1187	37.54	185.8	12.04	0.079	0.01433	173.1	0.00742	1.446	1.065
	R-1234yf	782	1075	44	152	12.86	0.0631	0.01143	140.1	0.00563	1.379	1.11
40	R-134a	1017	1147	50.09	163.4	12.55	0.0747	0.01544	163	0.0061	1.498	1.145
	R-1234yf	1017	1037	58.3	134	13.49	0.0586	0.0123	131.1	0.00462	1.437	1.196
50	**R-134a**	**1318**	**1102**	**66.27**	**143.1**	**13.12**	**0.0704**	**0.01672**	**151.8**	**0.0048**	**1.566**	**1.246**
	R-1234yf	**1301**	**993.3**	**76.7**	**118**	**14.12**	**0.054**	**0.01326**	**120.9**	**0.0035**	**1.515**	**1.31**

2010 International Symposium on Next-generation Air Conditioning and Refrigeration Technology, , Tokyo, Japan; *Yukihiro Higashi*
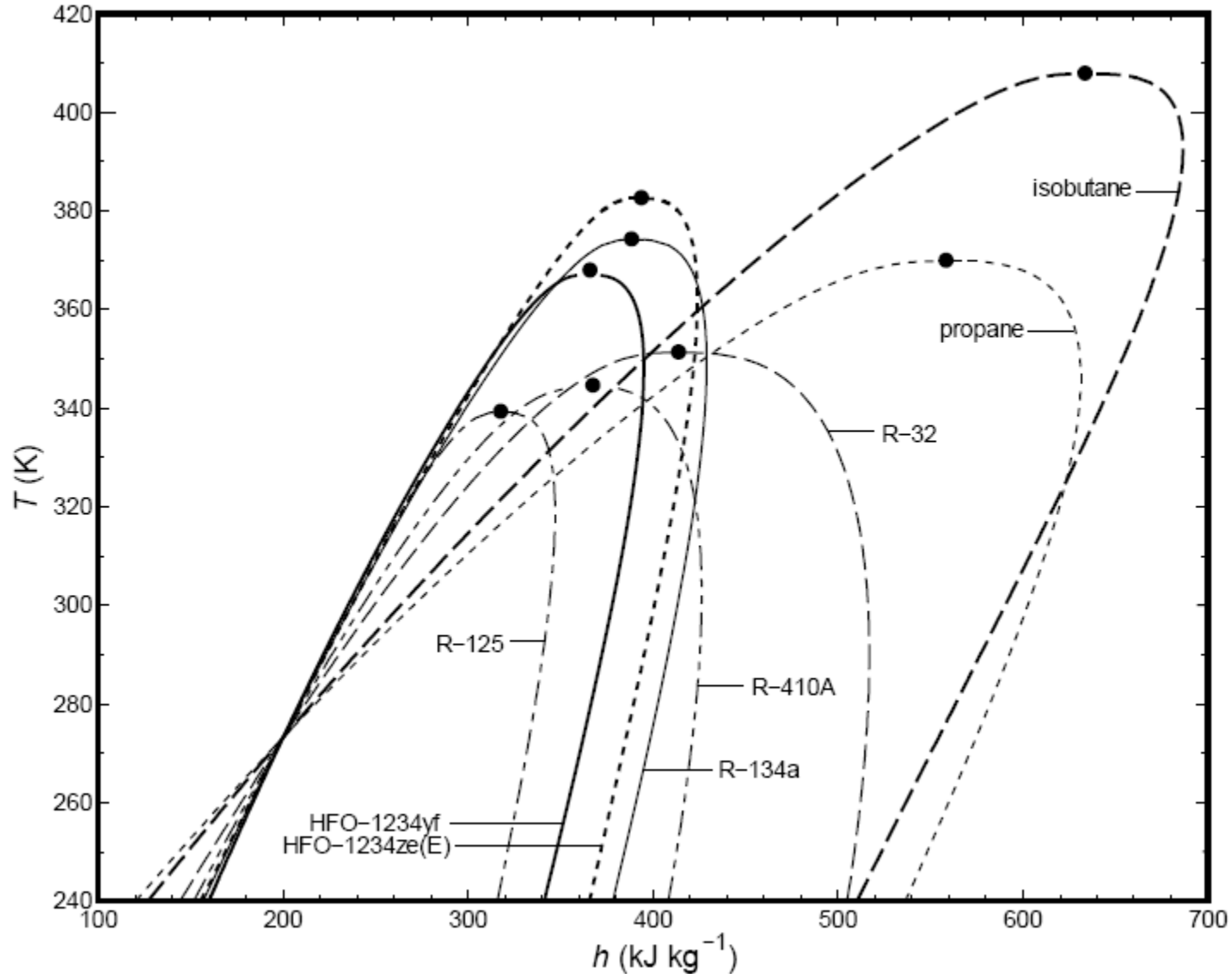
Experimental analysis of the low-GWP refrigerant R1234yf as a drop-in replacement for R134a in a typical mobile air conditioning system, Proc IMechE Part C: J Mechanical Engineering Science, 2012
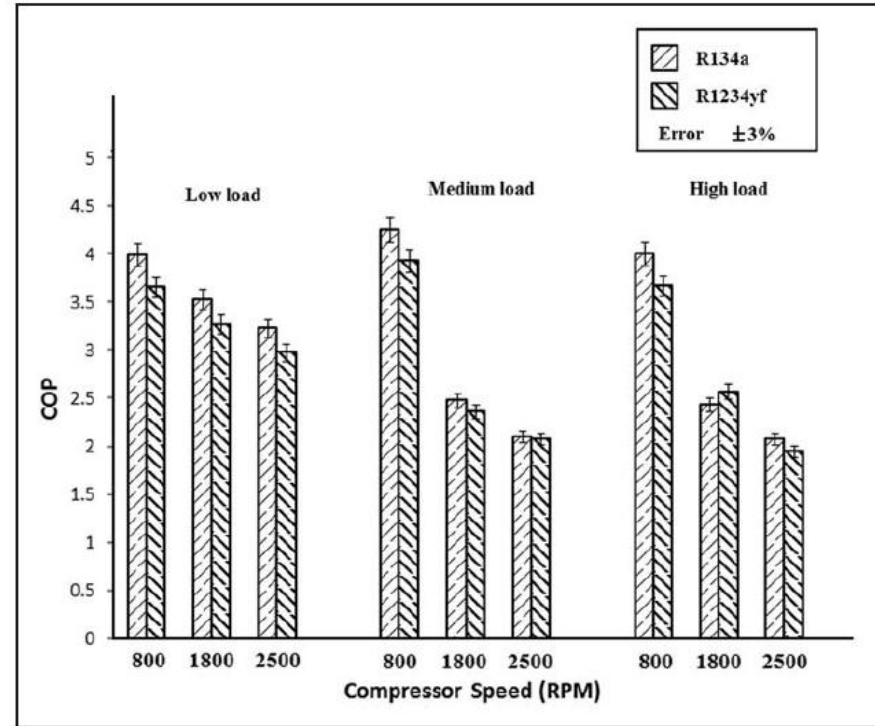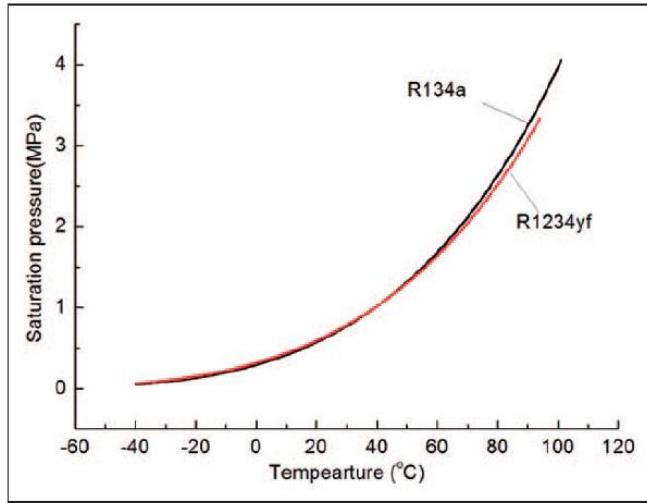
Comparison of COP between R134a and R1234yf systems.

Table I. Main physical properties of R134a and R1234yf.

Parameter	R134a	R1234yf
ODP	0	0
GWP	1300	4
Molar mass (g/mol)	102	114
Critical temperature ($^\circ$C)	101	95
Critical pressure (kPa)	4059	3382
Critical density (kg/m^3)	512	478
Normal boiling point ($^\circ$C)	−26	−29

ODP: ozone depletion potential; GWP: global warming potential.

Study of refrigeration system with HFO-1234yf as a working Fluid, Int. J. of Refrigeration
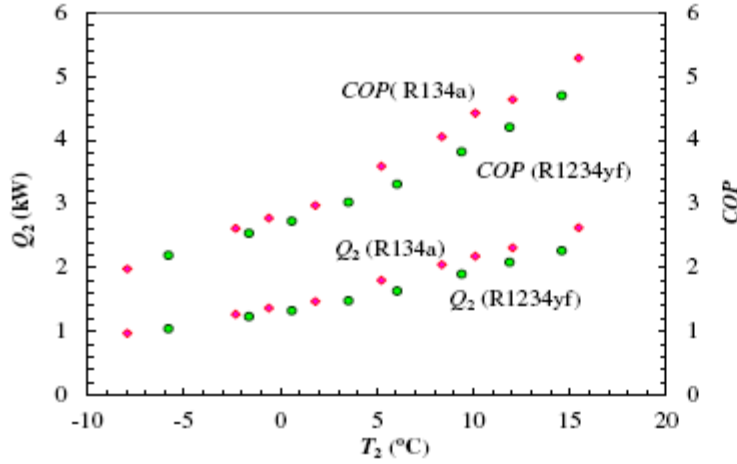
Fig. 6 — Cooling capacity and COP vs. T_2 at condenser temperature = 40 °C.
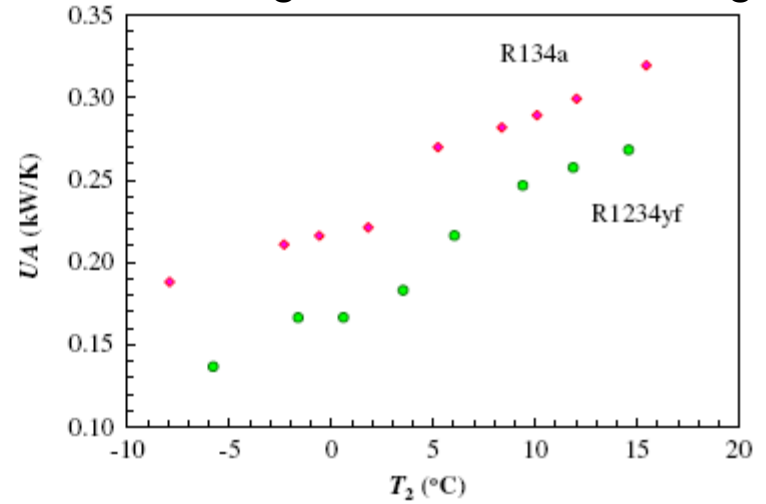
Fig. 8 — Heat transfer per unit temperature vs. T_2 at condenser temperature = 40 °C.
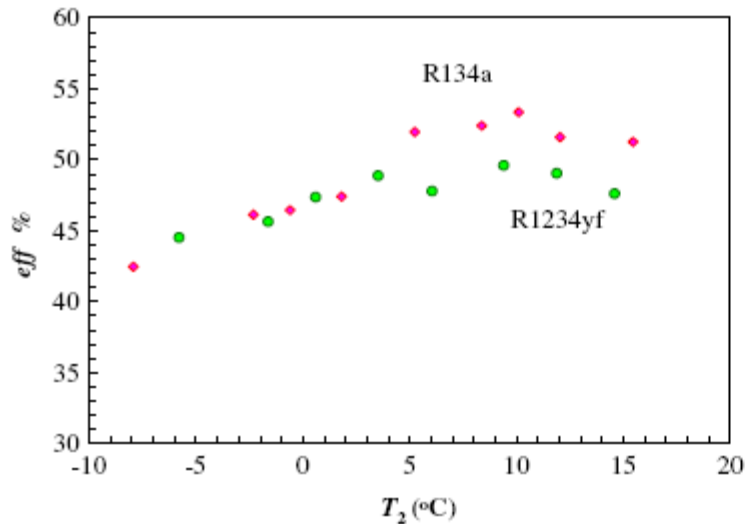
Fig. 7 — Efficiency vs. T_2 at condenser temperature = 40 °C.
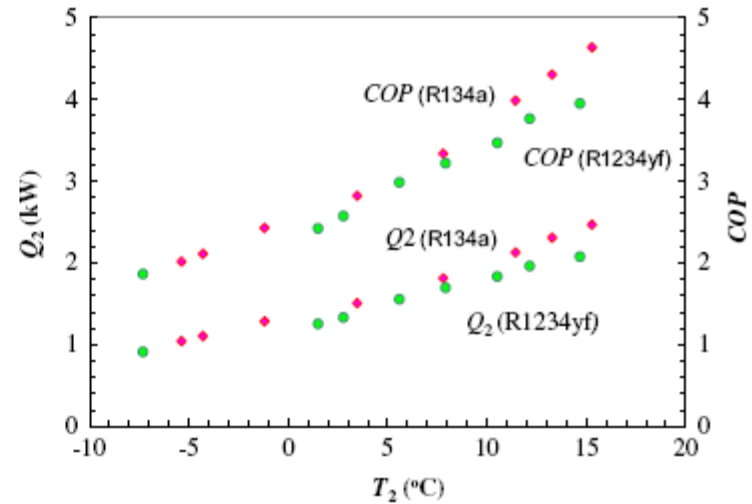
Fig. 9 — Cooling capacity and COP vs. T_2 at condenser temperature = 45 °C.

Heat Transfer Performance for R-1234yf

Nucleate boiling HTCs of HFC-134a and HFO-1234yf for smooth and microporous surfaces (from Moreno et al., 2011)

- The nucleate boiling HTCs of HFO-1234yf and R-134a are nearly identical at lower heat fluxes (q < 200 kW m^{-2}) while HFO-1234yf yielded lower heat transfer coefficients at higher heat fluxes and lower critical heat flux (CHF) as compared with R-134a.
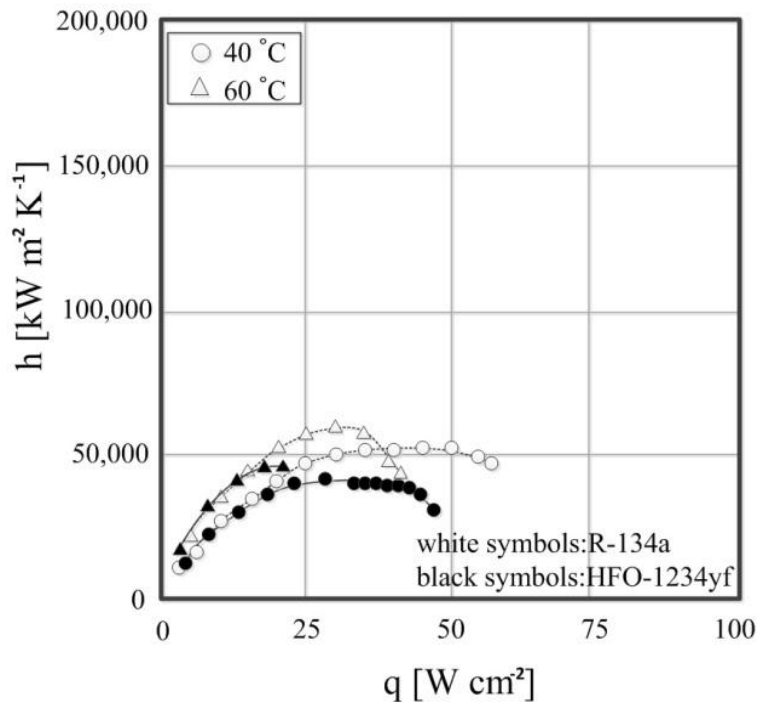
Ratio of critical hat flux for smooth and microporous surface
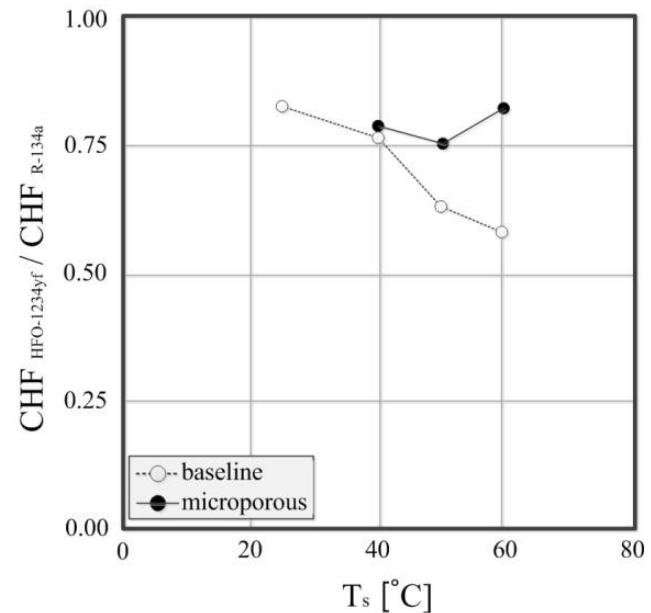
Typical Boiling Phenomenon
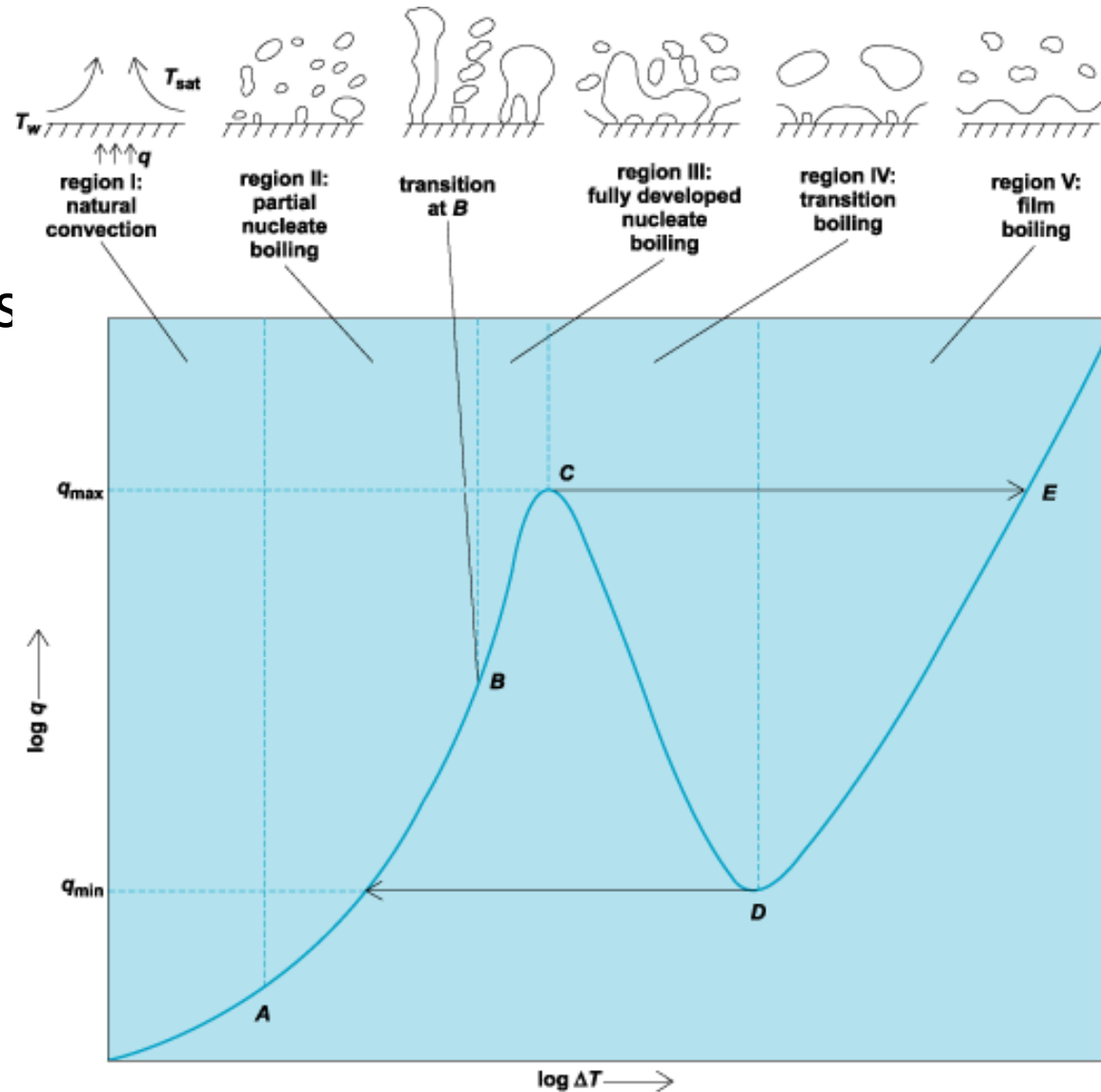
- *Active nucleate sites* and three mechanisms - ***bubble agitation, vapor-liquid change phenomenon, and evaporation*** are associated with basic mechanisms of the nucleate boiling heat transfer (Thome).

- The HFO-1234yf has a higher reduced pressure at the same saturation temperature.

- This is because its critical pressure is about 17% lower than of R-134a. In fact, at a saturation temperature of 40 $^\circ$C.

- The reduced pressure p* is approximately 20% higher than that of R-134a, thereby leading to a larger activation sites that would boost the heat transfer coefficient.

- The smaller bubble departure diameter ($\sim \left(\dfrac{\sigma}{g\left(\rho_L - \rho_G\right)}\right)^{0.5}$) of HFO-1234yf implies a lower bubble agitation, and a smaller vapor-liquid change contribution which offset the positive contribution from the higher reduced pressure. As a result, an almost identical heat transfer coefficient amid R-134a and HFO-1234yf is seen when q < 200 kW m^{-2}.

- It appears that the heat transfer coefficient for R-134a gradually surpass those of HFO-1234yf when q is above 200 kW/m². Moreno et al. [4] reported that the CHF for HFO-1234yf is appreciably lower than that of R-134a as shown in Fig. 1(c). Therefore they argued that at a higher heat flux (e.g. q > 200 kW m^{-2}) it is likely that the departure of HTC between R-134a and HFO-1234yf is mainly due to the local dryout of HFO-1234yf.

The effect of T_s on HTC for the baseline surface (smooth) and microporous surface is opposite. For the baseline surface (smooth surface), higher T_s brings about higher heat transfer coefficient due to larger activation sites. The activation sites for microporous surface are mainly controlled by the artificial cavity, thereby lifting the positive contribution of cavity activation, and a reversed influence of T_s.
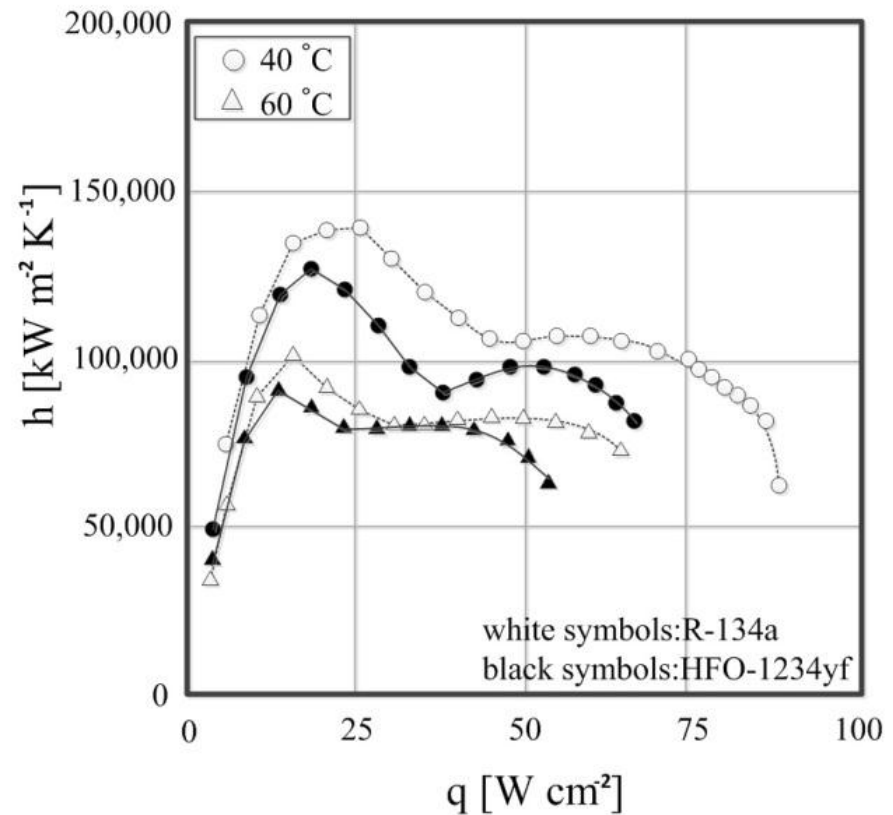
Nucleate boiling HTCs of HFC-134a and HFO-1234yf on flat surfaces
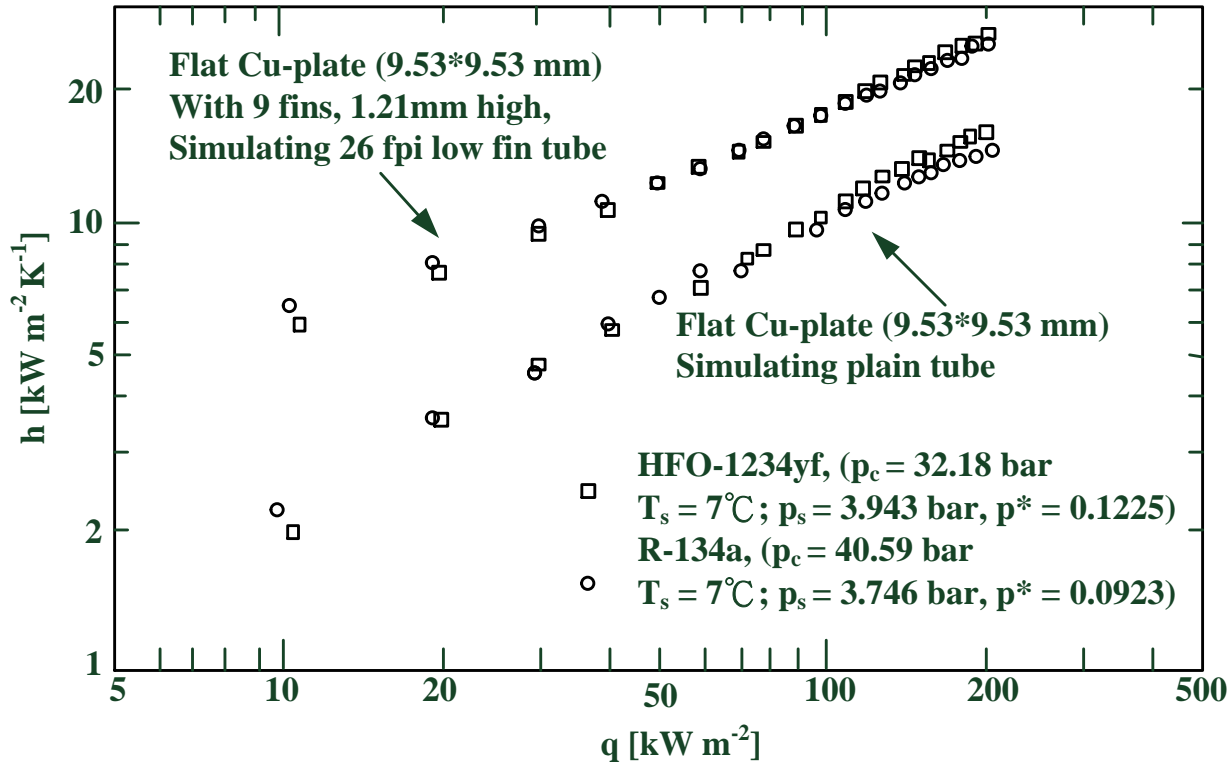
Park and Jung (2010) also found that the conventional boiling correlations can be used for the design of evaporators and boilers with HFO-1234yf.

•Nucleate boiling HTCs of HFC-134a and HFO-1234yf on two flat copper surfaces simulating a plain or low fin tube, respectively (from Park and Jung, 2010).
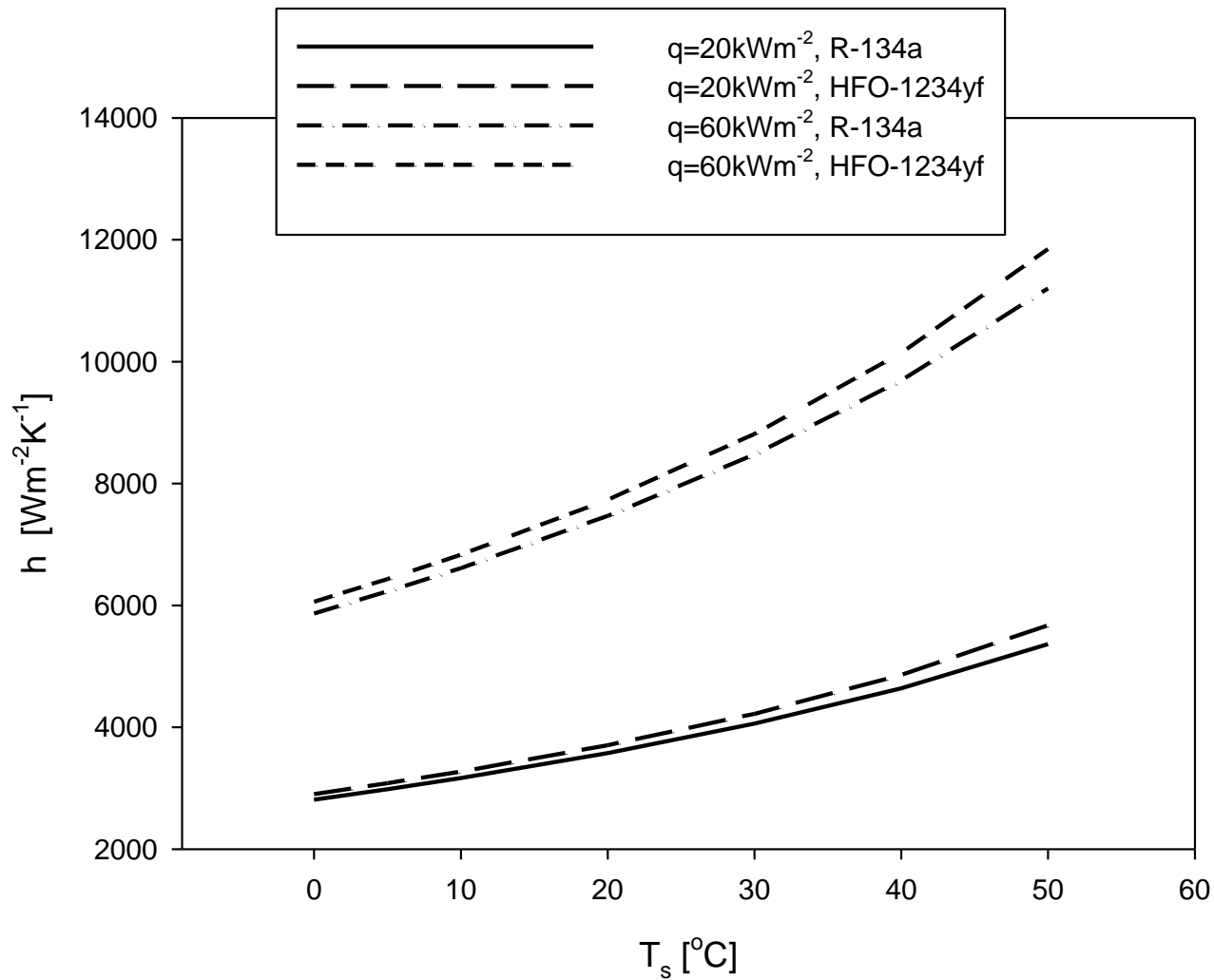
•Comparison of the calculated nucleate boiling HTCs of HFC-134a and HFO-1234yf on flat plate using the Cooper correlation.

Condensation HTC for R-134a and HFO-1234yf

Test results show that the condensation HTCs of HFO-1234yf are very similar to those of R-134a for all three surfaces tested as shown in the figure. At first glance, it seems that the condensation HTCs for HFO-1234yf is also identical to that of R-134 as nucleate boiling.
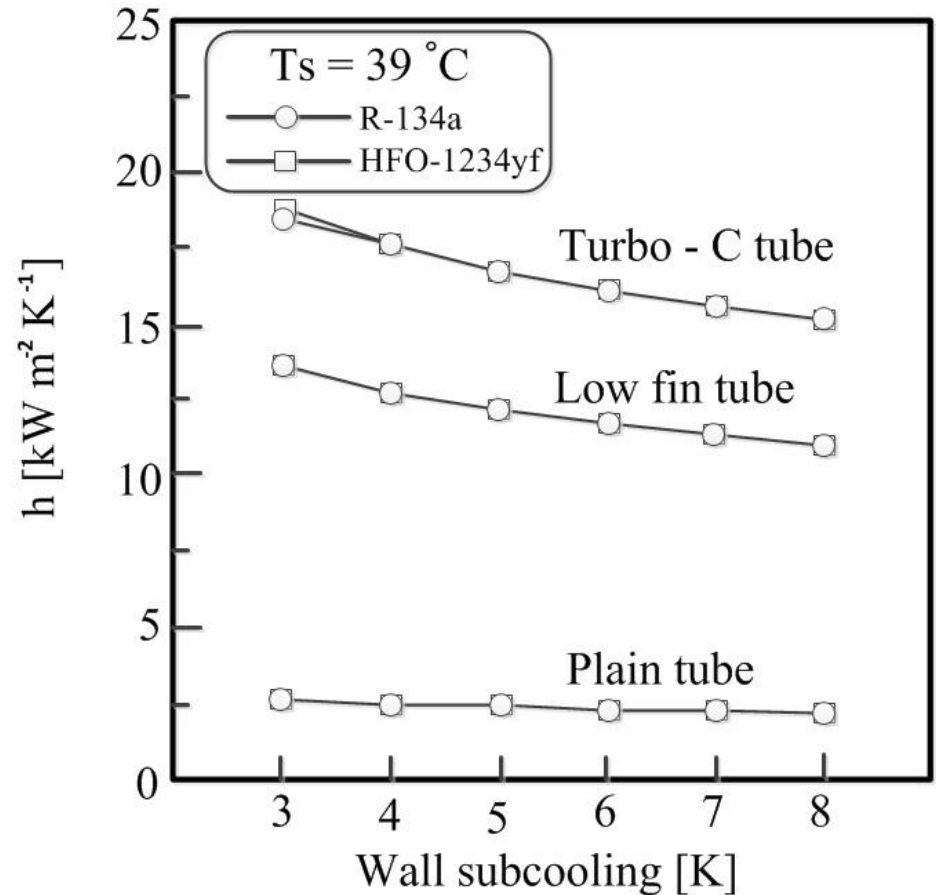
•External condensation HTCs of R-134a and HFO-1234yf on various tubes (from Park et al., 2011)

Nusselt Eq.

$$h_c = 0.728 \left[\frac{\rho_L (\rho_L - \rho_G) g i_{LG} k_L^3}{\mu_L (T_s - T_w) d_o} \right]^{\frac{1}{4}}$$

The comparison (using Nusselt Eq.) revealed that the measured data for R-134a and HFO-1234yf were 9.0% and 27.1% larger than the predicted values. Park et al. (2011) argued that the relatively large deviation associated with HFO-1234yf were from the large uncertainties of various properties of HFO-1234yf.
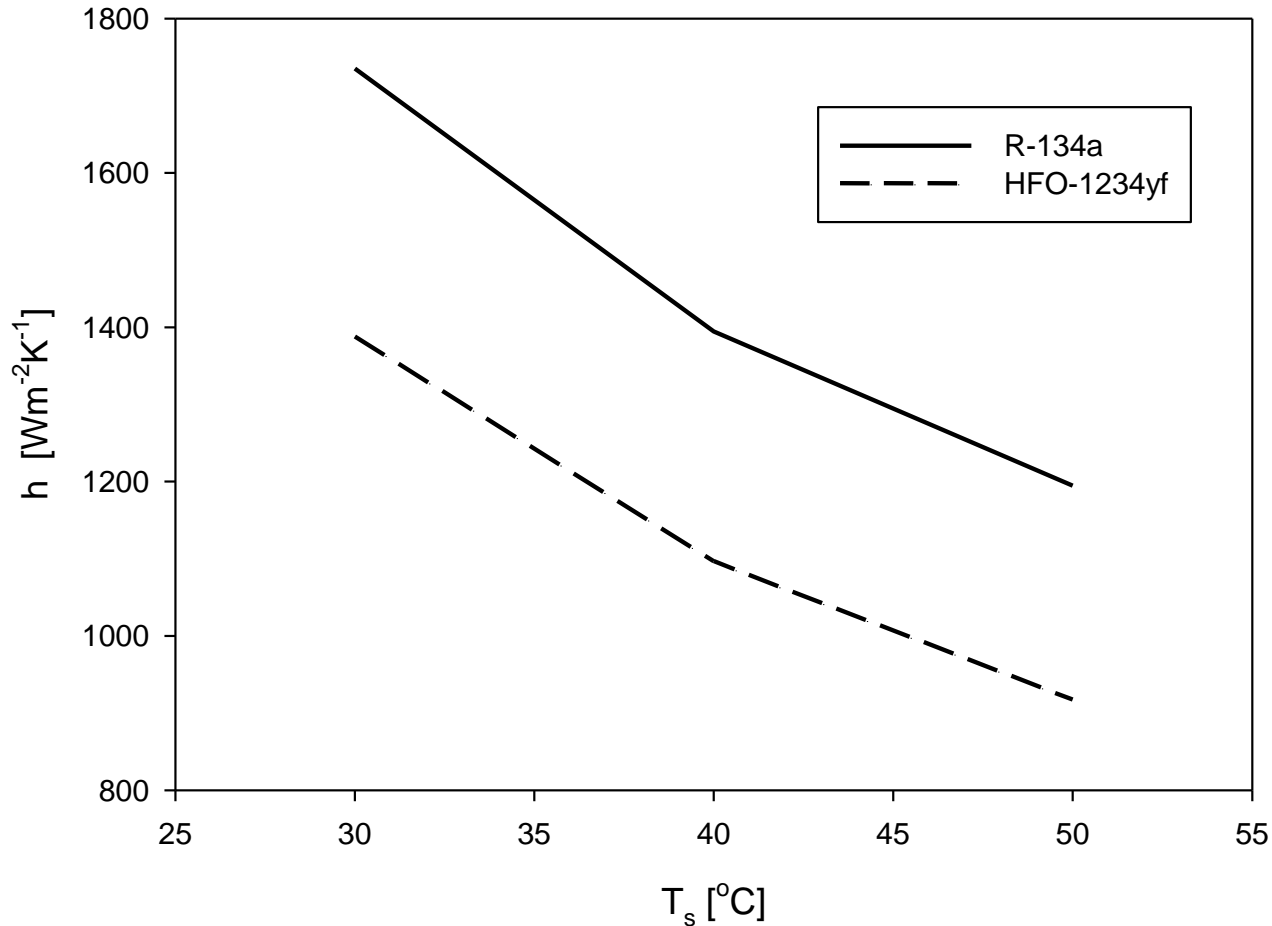
•Comparison of the calculated condensation HTCs of R-134a and HFO-1234yf using Nusselt equation for plain tube.

- Considerable departure of condensation HTC amid R-134a & R-1234yf using Nusselt Eq. while Park et al. (2011) shows similar HTCs for R-134a & R-1234yf.

- Possible reasons
  - Large uncertainty of their measurements. This is because their test tube is quite short (temperature difference at inlet and outlet is small) and temperature difference between the surface and saturation temperature ($T_s - T_w$) are comparatively small.
  - This is especially pronounced when enhanced tubes (low fin and turbo C) were used. In addition to the uncertainty,
  - Their relative short test length (L = 290 mm) which may cause some end effect (lateral conduction from the test tube to the flange) that inevitably promotes condensation. Note that most of properties influencing the condensation HTC suggest a lower condensation HTC of HFO-1234yf.

In-tube convective boiling heat transfer coefficients and pressure drop data of Saitoh et al. (2011)
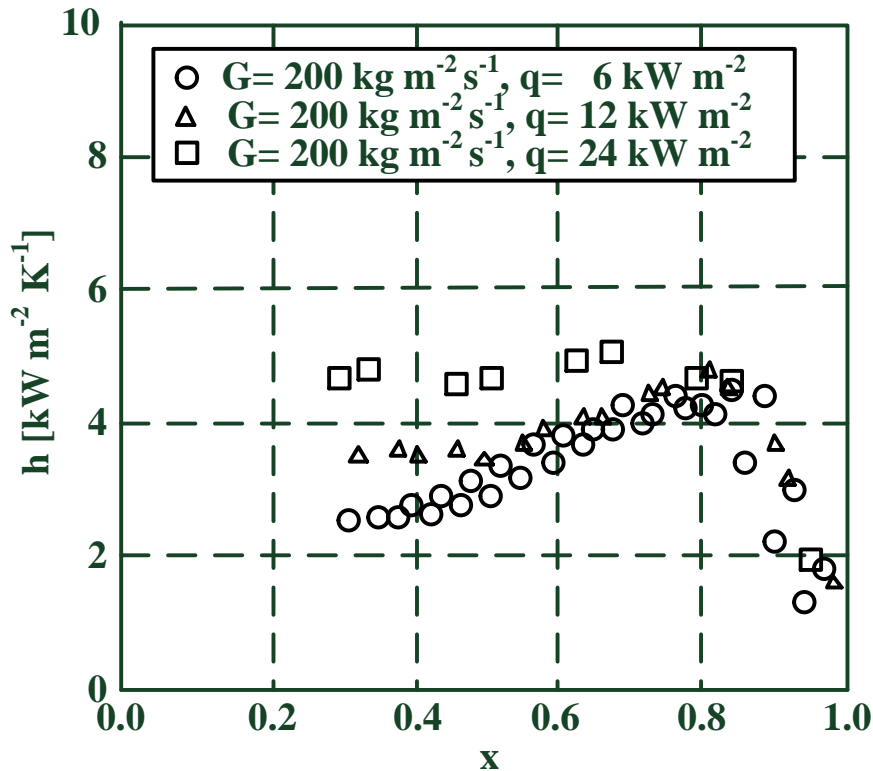
(a) Effect of heat flux on local heat transfer coefficient for HFO-1234yf.
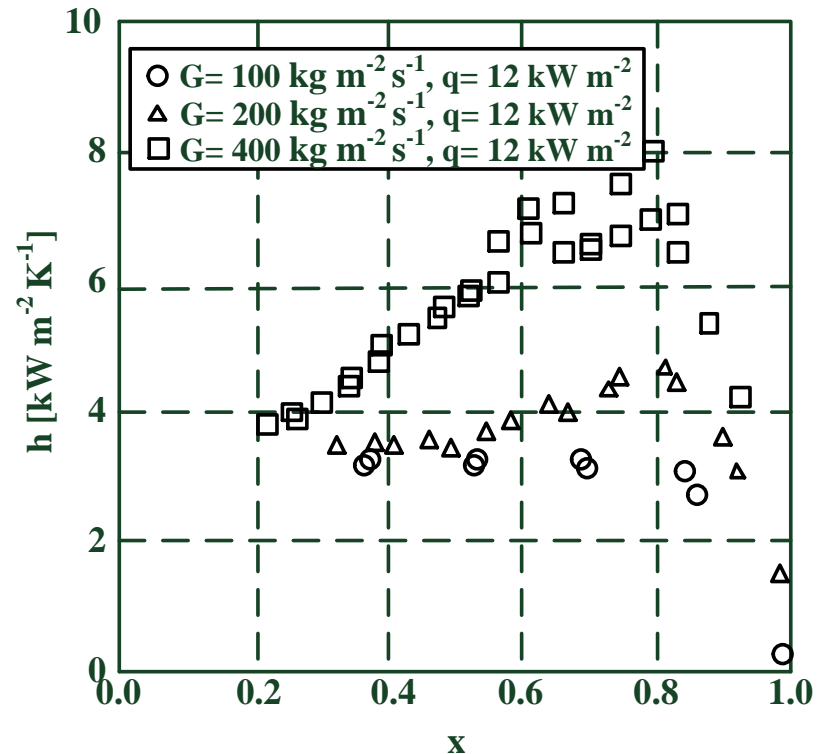
(b) Effect of mass flux on local heat transfer coefficient for HFO-1234yf.

In-tube evaporation

- In a smooth small-diameter horizontal tube (ID: 2 mm, T_s = 15 °C, q = 6~24 kW/m^2, and G = 100 ~ 400 kg/m^2 s, direct heating).

- At the lowest heat flux of 6 kW/m^2, the measured HTCs increased with the vapor quality, showing HTCs intensifies with increasing quality. The dryout quality was about 0.8 and did not change with heat flux. Increasing the heat flux from 6 kW/m^2 to 12 and 24 kW/m^2 showed that the HTC increases with heat flux at low vapor quality; thus, nucleate boiling is the dominant heat transfer coefficient mechanism at low vapor quality.

- The detectable rise of HTC vs. vapor quality for a low heat flux of 6 kW/m² is associated with the change of flow pattern since annular flow may prevail at high quality region. However, as claimed by the authors who argues that nucleate boiling is dominant heat transfer process when q = 12 and 24 kW/m², thereby showing a moderate change of HTC as vapor quality is increased.

- A rough estimation of the heat flux dependency is about $q^{0.42}$ which is generally much lower than the pure nucleate boiling where $h \sim q^{06\sim0.7}$. In this sense, it is expected that convective evaporation still plays certain role rather than pure nucleate boiling.

- The **_dryout_** occurs **_at a vapor quality of 0.8_** for all the conditions.

- In the high quality region (> 0.4), the heat transfer coefficients at both mass fluxes (200 and 400 kg/m² s) increased with the increasing vapor quality, and the heat transfer coefficient was higher at 400 kg/m² s than at 200 kg/m² s.

- **_At a mass flux of 100 kg/m² s, the effect of vapor quality on the heat transfer coefficient was weak_**. The results suggest that in the high vapor quality region, forced convective evaporation is dominant.

- In the **_lower quality region, x < 0.4, the HTC is rather insensitive to change of mass flux, indicating a nucleate boiling dominant regime_**. Figure c depicts a comparison between the boiling heat transfer performances of HFO-1234yf and R-134a at a mass flux of 300 kg/m² s and a heat flux of 12 kW/m².
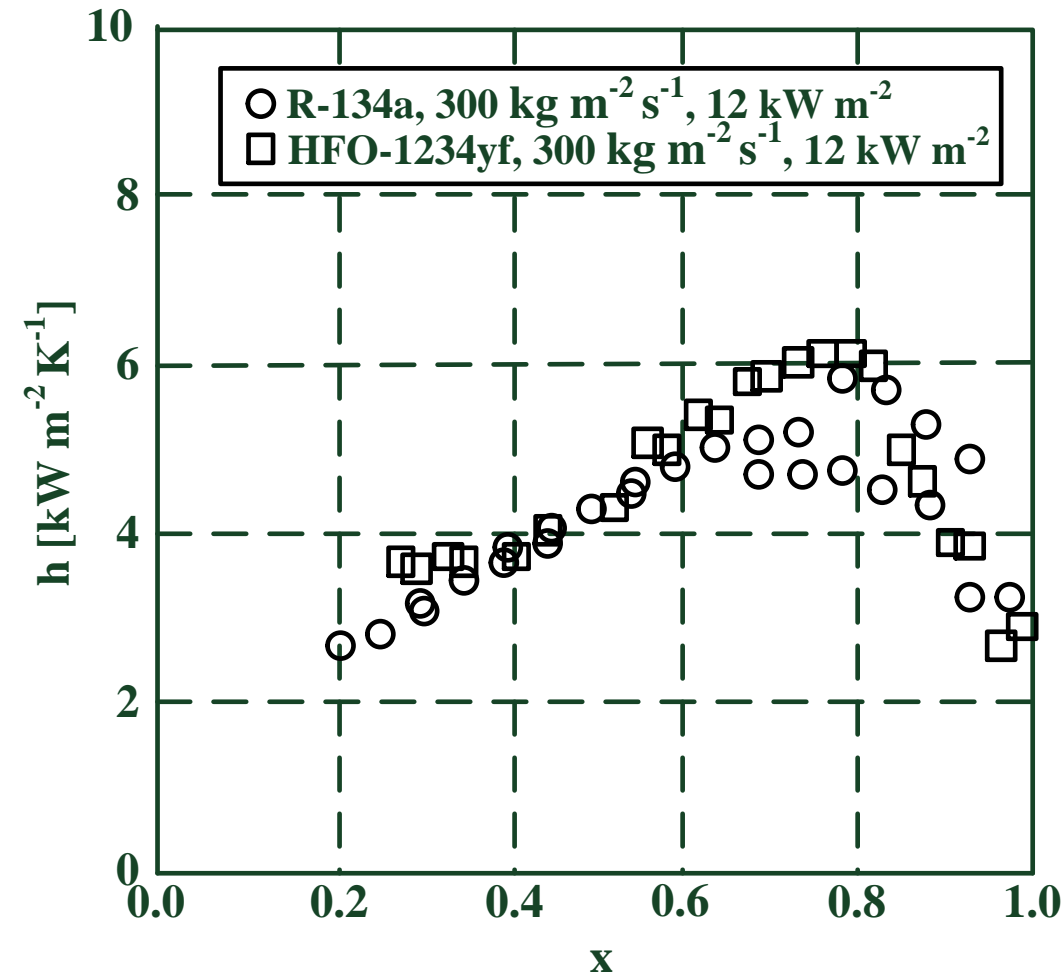
(c) Comparison of heat transfer coefficients between HFO-1234yf and R-134a at mass flux of 300 kg m^{-2} s and at a heat flux of 12 kW m^{-2}.
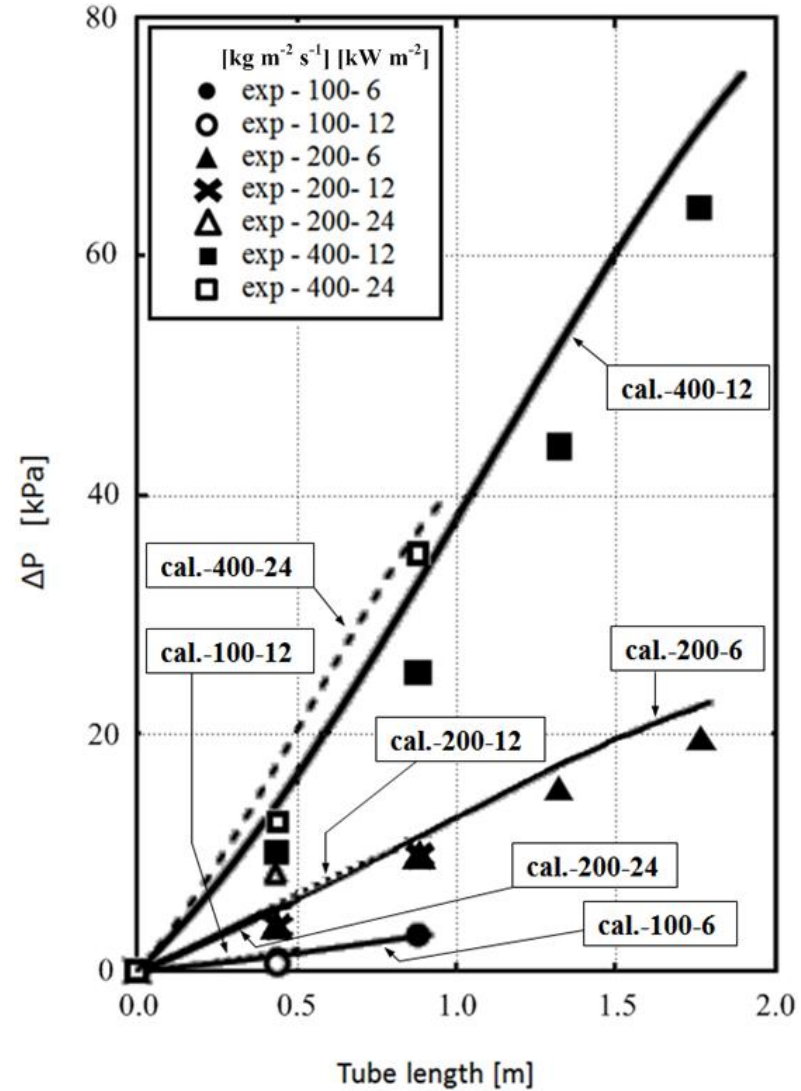
(d) Comparison of pressure drops between measured values and values calculated by the Lockhart Martinelli correlation for HFO-1234yf.

Top and side views of the R-134a flow patterns for T_s = 10 °C and D = 6.70 mm (from Padilla et al., 2011).
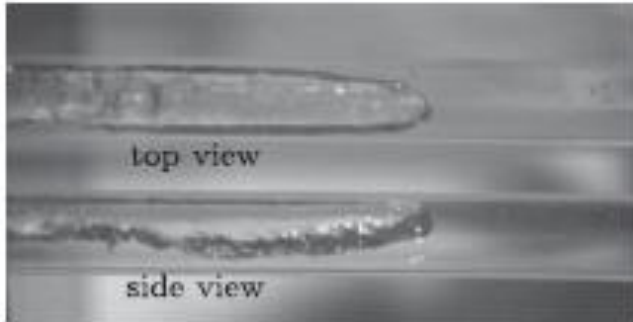
(a) Slug flow, x = 0.05, G = 300 kg m^{-2} s^{-1}
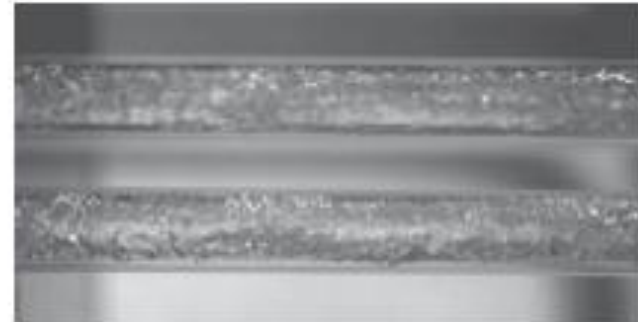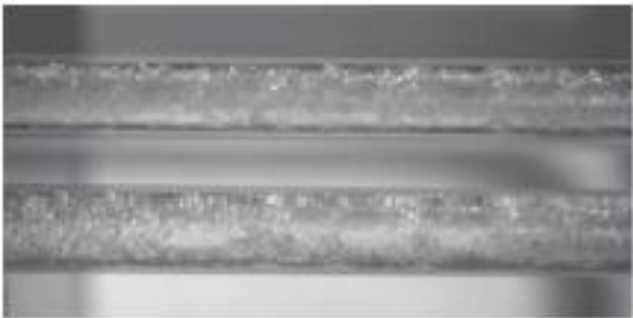
(b) Intermittent flow, x = 0.05, G = 300 kg m^{-2} s^{-1}

(c) Annular flow, x = 0.6, G = 300 kg m^{-2} s^{-1}
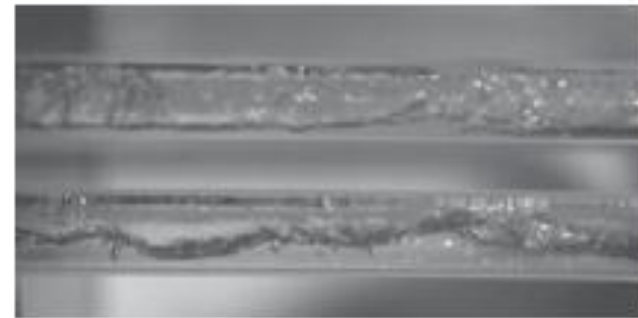
(d) Intermittent flow, x = 0.05, G = 500 kg m^{-2} s^{-1}
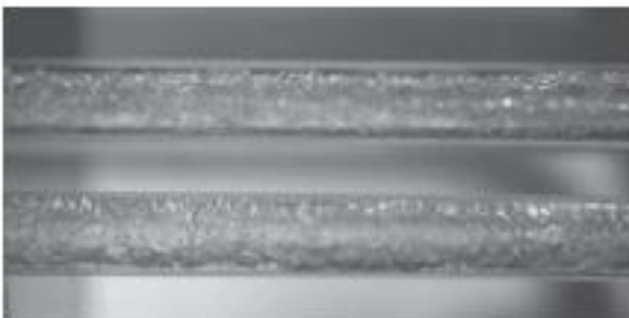
(e) Intermittent flow, x = 0.2, G = 500 kg m^{-2} s^{-1}
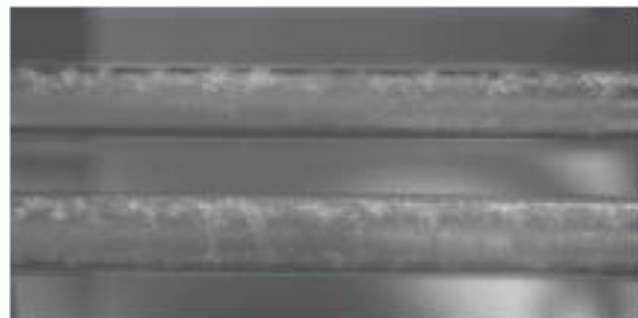
(d) Annular flow, x = 0.6, G = 500 kg m^{-2} s^{-1}

Top and side views of the HFO-1234yf flow patterns for T_s = 10 °C and D = 6.70 mm (from Padilla et al., 2011).

- That the flow patterns (Padilla et al., 2011) for both fluids are virtually similar, thereby resulting in a comparable convective boiling performance.
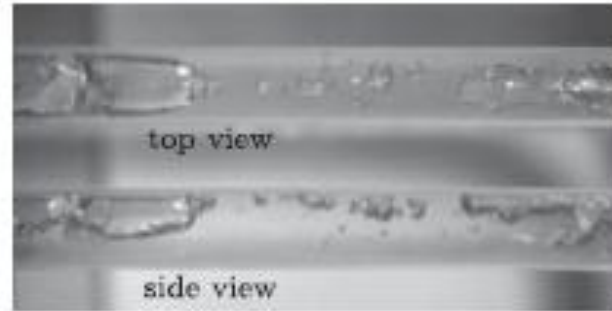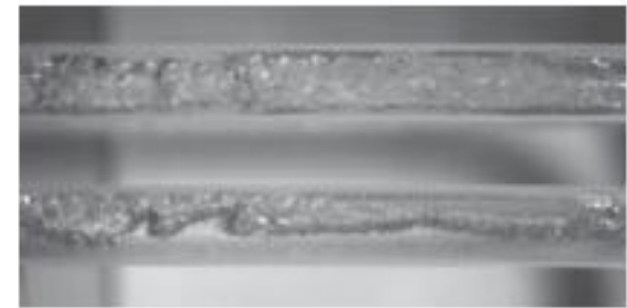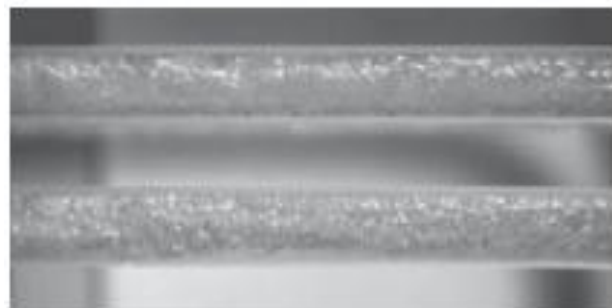
(a) Slug flow, x = 0.05, G = 300 kg m^{-2} s^{-1}
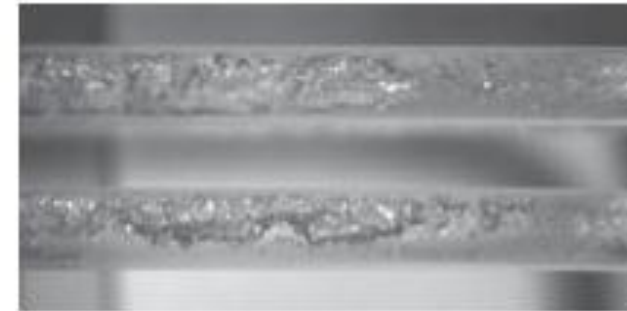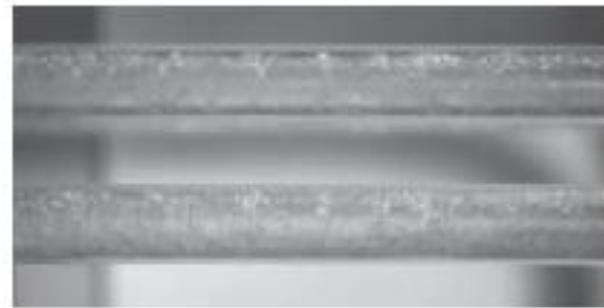
(b) Intermittent flow, x = 0.05, G = 300 kg m^{-2} s^{-1}

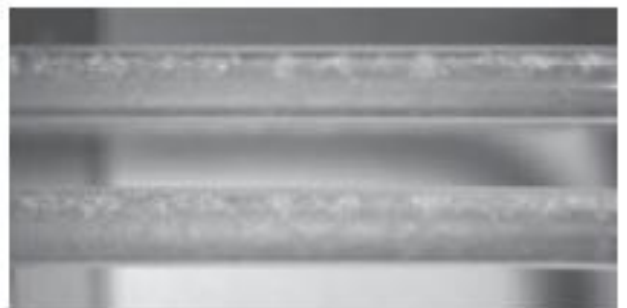(c) Annular flow, x = 0.6, G = 300 kg m^{-2} s^{-1}

(d) Intermittent flow, x = 0.05, G = 500 kg m^{-2} s^{-1}

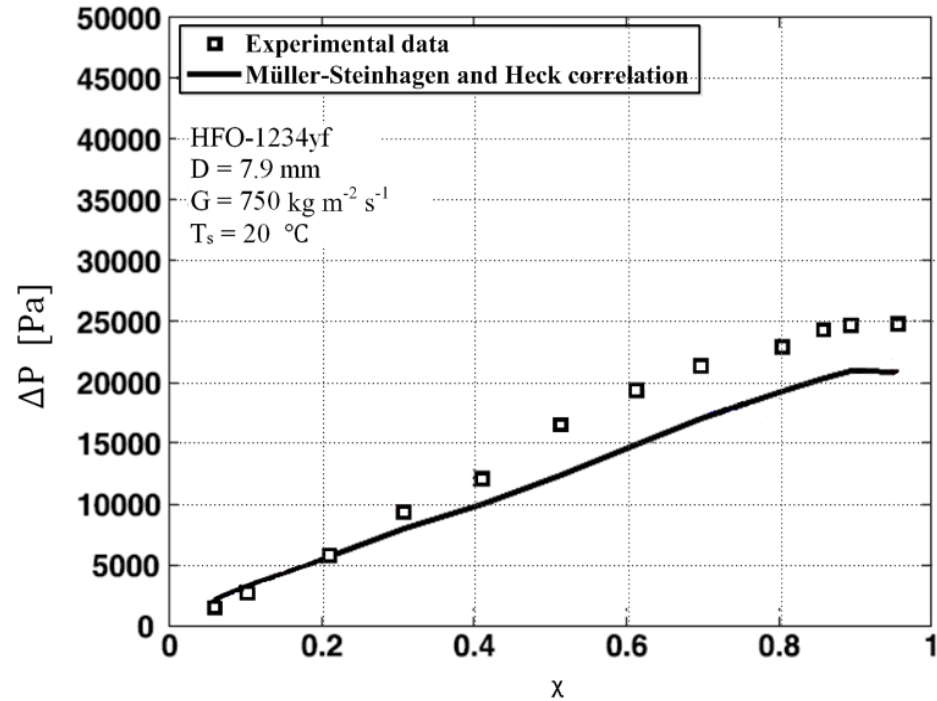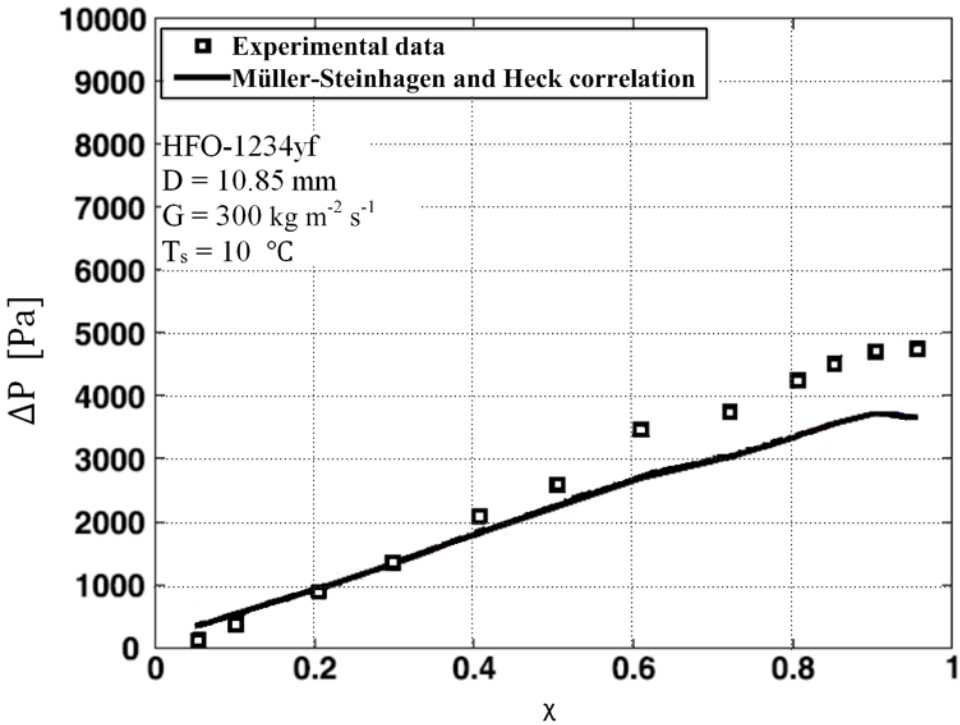(e) Intermittent flow, x = 0.2, G = 500 kg m^{-2} s^{-1}

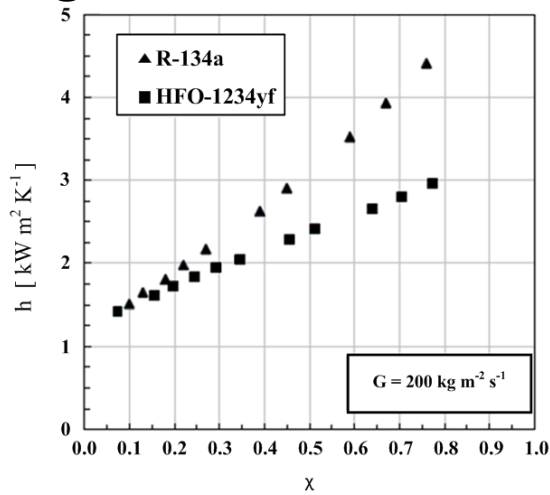(d) Annular flow, x = 0.6, G = 500 kg m^{-2} s^{-1}

Experimental pressure drop in straight tubes as a function of the vapor quality compared to different prediction methods (from Padilla et al., 2011).
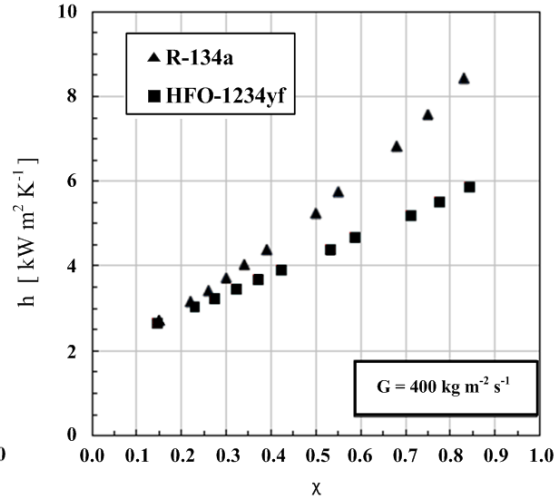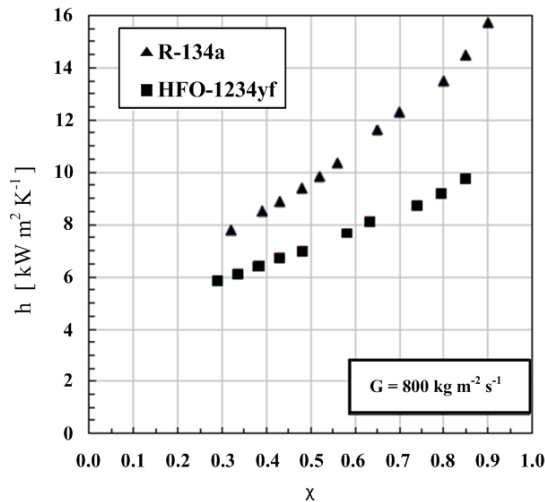
Experimental local condensation heat transfer coefficient and pressure drops versus vapor quality for HFO-1234yf and R-134a at 200, 400 and 800 kg m^{-2} s^{-1} mass velocity (from Col et al., 2011).
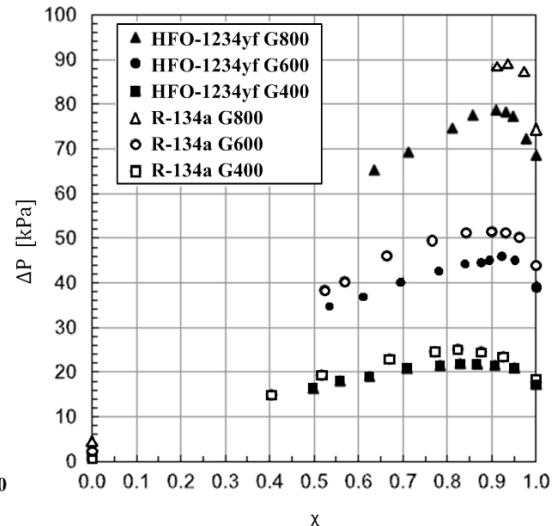

(a) h vs. x for G = 200 kg m^{-2} s^{-1}

(b) h vs. x for G = 400 kg m^{-2} s^{-1}

(c) h vs. x for G = 800 kg m^{-2} s^{-1}

(d) ΔP vs. x for G = 400, 600 and 800 kg m^{-2} s^{-1}.

- Except for the lowest values of vapor quality, R-134a displays a heat transfer coefficient higher than HFO-1234yf for all three values of mass velocities.

- At a mass flux of 200 kg m^{-2} s^{-1}, the heat transfer coefficient of HFO-1234yf is lower than that of R-134a by 15% at 0.4 vapor quality and by 30% at 0.8 vapor quality.

- One of the explanations about the pronounced difference in HTC between HFO-1234yf and R-134a at a higher vapor quality region is due to film thickness on the periphery.

- At higher vapor quality regime the annular flow prevails. the liquid density for R-134a is about 11% higher than that of HFO-1234yf (see Table 1(b)). This implies a thinner film thickness of R-134a provided the vapor quality is the same, thereby leading to a higher HTC for R-134a.

- A similar trend is found at 400 and 800 kg m^{-2} s^{-1} mass velocity as shown in Figs. (b) and (c).

- When comparing the heat transfer coefficient of HFO-1234yf to the one measured for R-134a, one can see that the latter fluid displays a higher coefficient at the same operating conditions, and this is related to the different properties of the two fluids.

- Additionally, as aforementioned in the nucleate boiling section, the higher reduced pressure of HFO-1234yf also contributed to decrease the associated condensation heat transfer coefficient, this can be easily seen from the well-known Shah correlation (1979).

Concluding remarks

- For nucleate boiling with q < 200 kW/m^2, the heat transfer coefficients (HTC) for R-134a and HFO-1234yf are comparable. And the HTC of HFO-1234yf is lower than that of R-134a when q is greater than 200 kW/m^2. The critical heat flux of HFO-1234yf is about 20~40% lower than that of R-134a.

- For external condensation, the only database shows that the HTC between HFO-1234yf and R-134a is negligible. However, it is found that the major thermophysical properties influencing condensing HTC suggest a lower HTC of HFO-1234yf. It is therefore recommended that further verifications should be made.

- For in-tube convective boiling, the experimental data showed that the difference in HTC for HFO-1234 and R-134a is quite small, and for the same flow condition (vapor quality, mass velocity, saturation temperature, tube diameter), the corresponding flow pattern for R-134a and HFO-1234yf are virtually the same.

- For in-tube condensation, it is found that the condensation HTCs for HFO-1234yf are inferior to those of R-134a, and the difference increases with the rise of vapor quality.

- The predictive correlations applicable for pressured drop for HFO-1234yf are not consistent, it is probably attributed to the difference in tube diameter in the publications.

Thanks for your attention
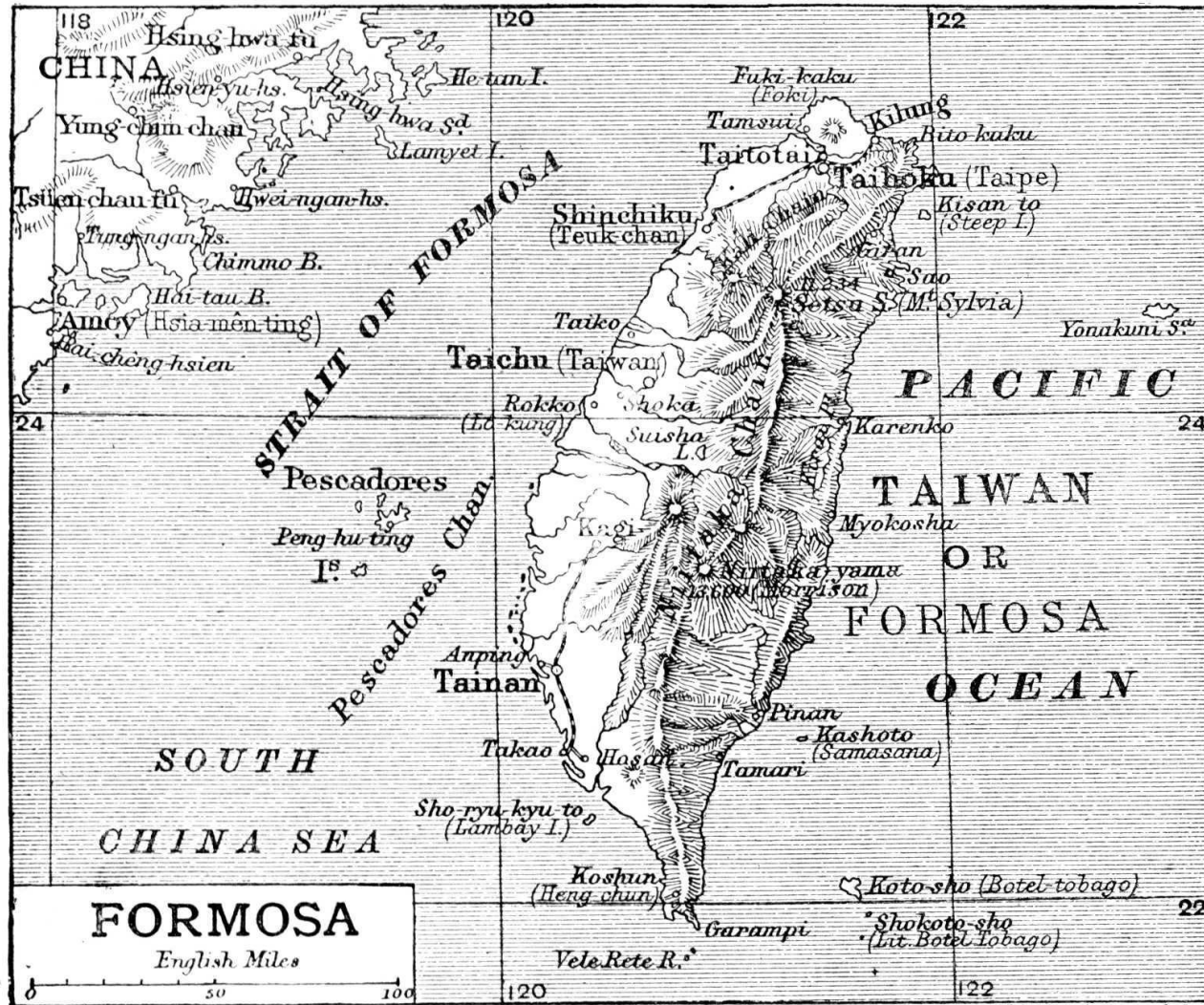
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