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Refrigerant- Lubricant Mixture Properties Influencing Bubble Dynamic Parameters and Heat Transfer Coefficient in Nucleate Pool Boiling

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ABSTRACT

We have been successfully developed a model regarding lubricant effect on individual processes of bubble nucleation, growth and departure period for nucleate pool boiling heat transfer. In this study, three type POE refrigeration lubricants with different refrigerant miscibility (POEA/POEB/POEC), two viscosity grades (ISO68 & 170), three kind of refrigerants (R-134a/R-1234ze/R-134yf), and three different saturated temperatures (-10°C/0°C/10°C) are taken into calculation under different heat flux ranging from 10 KW/m² to 80 KW/m². Based on this model, a knowledge of chemical structures and physical properties of lubricant and refrigerant is sufficient to get bubble dynamic parameters and predict the boiling performance near metal surface. According to calculating results, several key factors play an important role in pool boiling heat transfer and show drastic influence on bubble parameters and HTC, such as refrigerant type, saturated temperature, heat flux and lubricant concentration. Regarding lubricant chemical structure effect on heat transfer performance, it will be direct related to OCR and following influence on HTC in real evaporator environment. But if keeping same lubricant concentration, different results will appear. Various lubricant structures may provide different volume size, adsorption energy on metal surface and interaction force between refrigerant and lubricant, but these factors sometimes offset each other and lead to only a slight difference in bubble size, contact angle, surface coverage concentration, and HTC. The calculation indicates that the presence of lubricant imposes a negative effect on HTC during waiting period of bubble formation and departure period, but a positive effect on HTC may prevail in bubble growth period. Such two effects compete during the boiling process and could lead increase or impair heat transfer performance at a low lubricant concentration.

Keywords: heat transfer coefficient; lubricant; refrigeration; pool boiling model, bubble parameter

1. INTRODUCTION

Several type lubricants were used in refrigeration system, such as mineral oils (MO), alkylbenzene (AB), polyalkylene glycol (PAG), polyvinyl ether (PVE), and polyolester (POE). Since HCFC refrigerants are phased out based on ODP consideration, MO and AB oils almost could not be applied in HFC/HFO refrigeration system by their immiscible characteristics with refrigerants. In recent years, PAG, PVE and POE can be well structure-designed to provide suitable miscibility with HFC/HFO refrigerants under low and high temperature, and meet various refrigeration compressor requirements, such as solubility, working viscosity, lubrication, electrical insulation property, thermal and chemical stability (Rudnick, 2013). Regarding the influences of lubricant oils on the heat transfer characteristics of refrigerant, Shen and Groll (2005) intended to present a comprehensive summary of the various studies and tries to identify some general relationships regarding the influence of lubricants on the heat transfer and pressure drop of refrigerants. Wang et al. (2014) had summarized experimental data regarding to the influence of lubricant on the nucleate boiling heat transfer subject since 1980 from a total of 34 literatures. From their summary, it appears that the test results about lubricant on HTC are quite inconsistent. Depending on the lubricant, refrigerant, concentration, tube geometry, saturation temperature and supplied heat flux, the HTC can be augmented or impaired and it lacked some conclusive trend upon the lubricant addition. Zheng et al. (2001) provided ammonia/PAG (ISO 68) experiment data under smooth tube for oil concentration range from 0~10%. The experimental results showed that under a particular saturation temperature and heat flux, the heat transfer coefficient generally first decreased with an increase in oil concentration up to 5% and then followed by an insignificant increase in the coefficient with a further increase in oil concentration to 10%. Ji et al.

(2010) unveiled augmentations for R134a/PVE (ISO 68) lubricant mixtures on plain, integral fin and four enhanced tubes. Their test results also reveal a more pronounced drop with lubricant concentration especially for enhanced tube geometries. Mohrlök et al. (2001) conducted R-507/POE (ISO 32) mixture for nucleate boiling on smooth tubes with lubricant mass fractions up to 10% and observed that the HTC increases with the rise of lubricant mass fractions up to 3% at some lower saturation temperatures. Kedzierski (2001) concluded that lubricant with higher viscosity and poor miscibility will result in higher HTC in R134a/POE system. Spindler & Hahne (2009) measured ISO55/170 POE in R-134a, and the results show that the heat transfer coefficient (HTC) for 3% refrigerant-lubricant mixture is higher than the rest concentrations.

The objective of this study is to examine the parametric influences of lubricant on the nucleate boiling performance based the developed model by Hung et al. (2020). In addition, based on the developed model, the influences upon bubble parameters (bubble diameter, time, rate), and heat flux on HTC are investigated in details.

2. COMPARISON OF KEY FACTORS EFFECTING ON MIXTURE PROPERTIES FOR BOILING MECHANISM

The model of lubricant effect on individual processes of bubble nucleation, growth and departure described in detail by Hung et al. (2020). For illustrating the key factors effect on boiling, three type POE refrigeration lubricants with different refrigerant miscibility (POEA/POEB/POEC), two viscosity grades (ISO68 & 170), three kind of refrigerants (R-134a/R-1234ze/R-134yf), and three different saturated temperatures (-10°C/0°C/10°C) are taken into calculation under different heat flux ranging from 10 KW/m² to 80 KW/m². These basic properties of pure refrigerants are based REFPROP, and pure lubricants are shown in Table 1. The mixture properties are based on these data for further investigation.

Table 1 Basic physical data for the tested lubricants at different temperatures

Lubricant	Sat. temp (°C)	ρ_l (kg/m ³)	C_p (J/Kg-K)	k (W/mk)	η (cP)	α (m ² /s)	σ (N/m)
POEA 68	10	961.9	1803	0.1368	487	7.888E-08	0.0320
	0	968.9	1777	0.139	1213	8.074E-08	0.0326
	-10	975.8	1751	0.1417	3574	8.293E-08	0.0333
POEA 170	10	967.4	1794	0.1366	1607	7.871E-08	0.0316
	0	974.2	1767	0.1391	4683	8.081E-08	0.0322
	-10	979.9	1741	0.1422	16465	8.335E-08	0.0328
POEB 68	10	1026.2	1959	0.1501	355	7.467E-08	0.0379
	0	1033.6	1937	0.1523	750	7.607E-08	0.0387
	-10	1041.0	1916	0.155	1797	7.771E-08	0.0395
POEB 170	10	993.0	1853	0.1413	1316	7.68E-08	0.0339
	0	1000.1	1828	0.1436	3278	7.853E-08	0.0346
	-10	1007.4	1804	0.1465	9528	8.061E-08	0.0352
POEC 170	10	975.3	1865	0.1383	1409	7.603E-08	0.0335
	0	982.2	1839	0.1407	3715	7.79E-08	0.0341
	-10	988.9	1814	0.1437	11319	8.011E-08	0.0348

2.1 Surface coverage concentration

Based on the proposed model (Hung et al., 2020), the first important factor for consideration regarding the lubricant effect on heat transfer is surface coverage concentration. Surface coverage concentration is the actual lubricant concentration near the surface and it will influence the bubble point during waiting period, mixture properties near surface, and the parameters affecting the bubble dynamics inside oil-rich film. The calculation results are shown in Fig.1(a), Fig.1(b) and Table 2. From proposed model, it indicates that either raising χ_s (the adsorption energy difference between refrigerant-surface and lubricant-surface), χ_{12} (Flory-Huggins polymer-solvent interaction parameter) or r factor (real volumetric size ratio of lubricant relative to refrigerant in mixtures) all results in the rise of surface coverage concentration nearby the heating surface. Compare with Table 2, Fig. 1(a) shows the χ_s , χ_{12} and r factor in R-134a/POEA 170 mixture is larger than those in R-1234ze/POEA 170

mixture, yet the augmentations in surface coverage concentrations in R-134a/POEA 170 mixtures are more pronounced than that in R-1234ze/POEA 170 mixtures irrespective of bulk lubricant concentrations. On the other hand, the phenomenon between R-134a and R-1234yf mixtures are different from previous case. For lower oil concentrations, the surface coverage concentrations of R-134a/POEA 170 mixtures are larger than that of R-1234yf/POEA 170 mixtures due to slightly larger values of χ_s and χ_{12} . However, with the rise of oil concentration, surface coverage of R-1234yf/POEA 170 mixtures is marginally higher than R-134a/POEA 170 mixture due to larger r factor of R-1234yf mixture. Regarding the lubricant effect (Fig. 1(b)). Despite POEB 170 is more miscible than POEA 170 in R-134a (that leads to smaller values of χ_s and χ_{12}), the volumetric size of POEB 170 in R-134a is larger than that of POEA 170 (that means a large r factor). In summary, these three factors (χ_s , r, and χ_{12}) compensate with each other and yield identical surface coverage concentration accordingly. On the other hand, POEC 170 contains the highest coverage concentration in R-134a due to its immiscible property. For the same type POE lubricants with the same refrigerant, the χ_s and χ_{12} between POEA 68 and POEA 170 are almost the same, but the low viscosity POEA 68 contains a small r value, thereby resulting in a lower surface coverage concentration.

Table 2 – Interaction factors between refrigerant-lubricant, refrigerant-metal, and lubricant-metal

Refrigerant	Lubricant	Saturated temperature = 10°C				Saturated temperature = 0°C				Saturated temperature = -10°C			
		χ_s	χ_{12}	r	Energy Gap, MPa ^{1/2}	χ_s	χ_{12}	r	Energy Gap, MPa ^{1/2}	χ_s	χ_{12}	r	Energy Gap, MPa ^{1/2}
R-134a	POEA 68	0.3982	0.4926	35.0273	-0.6173	0.4000	0.4952	35.5147	-0.4073	0.4018	0.4979	35.9464	-0.1966
	POEA 170	0.3978	0.4972	50.8539	-0.2499	0.3996	0.5000	51.5653	-0.0331	0.4016	0.5028	52.2455	0.1916
	POEB 68	0.3984	0.4727	41.0697	-2.1845	0.3996	0.4746	41.6965	-2.0304	0.4009	0.4767	42.2503	-1.8689
	POEB 170	0.3966	0.4838	56.1536	-1.3033	0.3981	0.4862	56.9712	-1.1204	0.3998	0.4886	57.6822	-0.9286
	POEC 170	0.3984	0.5071	61.2098	0.5270	0.4001	0.5096	62.0981	0.7269	0.4019	0.5123	62.8915	0.9356
R-1234ze	POEA 68	0.3602	0.4553	30.4260	-3.5502	0.3604	0.4560	30.8990	-3.4933	0.3607	0.4569	31.3286	-3.4277
	POEA 170	0.3591	0.4592	44.2149	-3.2444	0.3594	0.4600	44.9019	-3.1797	0.3599	0.4611	45.5652	-3.0966
	POEB 68	0.3617	0.4371	35.6621	-4.9867	0.3610	0.4368	36.3022	-5.0116	0.3606	0.4366	36.8849	-5.0204
	POEB 170	0.3584	0.4427	49.2822	-4.5452	0.3582	0.4412	50.2946	-4.6601	0.3581	0.4399	51.2405	-4.7666
	POEC 170	0.3598	0.4692	53.1175	-2.4565	0.3599	0.4697	53.9803	-2.4166	0.3601	0.4705	54.7658	-2.3576
R-1234yf	POEA 68	0.3968	0.4920	24.7029	-0.6649	0.3974	0.4932	25.1547	-0.5684	0.3980	0.4945	25.5595	-0.4660
	POEA 170	0.3960	0.4962	35.8950	-0.3311	0.3966	0.4975	36.5555	-0.2303	0.3974	0.4989	37.1818	-0.1153
	POEB 68	0.4010	0.4770	28.6641	-1.8407	0.4010	0.4776	29.2269	-1.7947	0.4013	0.4784	29.7293	-1.7351
	POEB 170	0.3974	0.4852	39.4417	-1.1950	0.3977	0.4863	40.1784	-1.1136	0.3982	0.4873	40.8393	-1.0290
	POEC 170	0.3976	0.5073	43.0964	0.5445	0.3981	0.5084	43.9053	0.6324	0.3988	0.5097	44.6329	0.7354

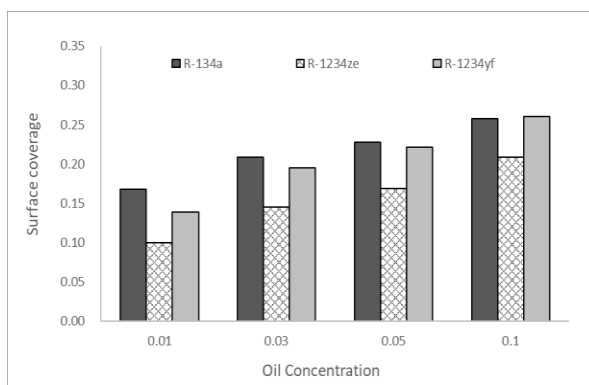


Fig. 1(a). Effect of bulk concentration on the surface coverage concentration for POEA 170 mixture subject to various refrigerants under 30 kW/m² and 0 °C.

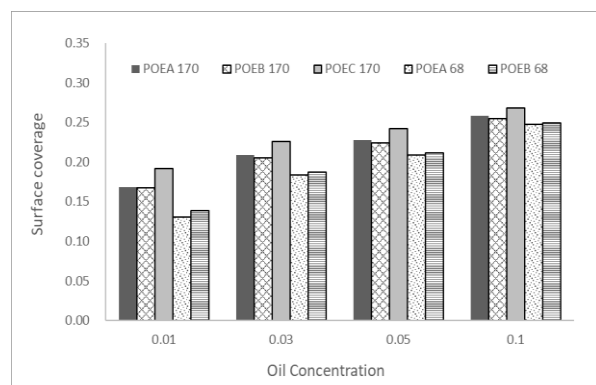


Fig. 1(b). Effect of bulk concentration on the surface coverage concentration for R-134a mixture subject to various lubricants subject to q = 30 kW/m² at Tsat = 0 °C

2.2 Boiling point elevation

Fig. 2(a) shows similar trend for the boiling point elevation against oil concentration, comparing surface coverage concentration shown in Fig. 1(a). In addition, there also appears several differences regarding lubricant effect as shown in Fig. 1(a) and Fig. 2(b) on the surface coverage concentration and boiling point elevation. In summary, these parameters which can promote surface coverage concentration usually can incur higher boiling point elevation and lead to higher wall superheat for initiating the bubble incipience as well as the waiting period, and impair the overall heat transfer performance accordingly.

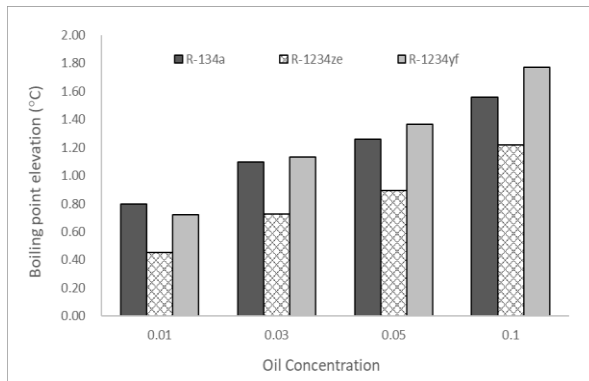


Fig. 2(a). Effect of bulk concentration on boiling point elevation for POEA 170 in different refrigerants under $T_{sat} = 0^\circ\text{C}$ and $q = 30 \text{ kW/m}^2$.

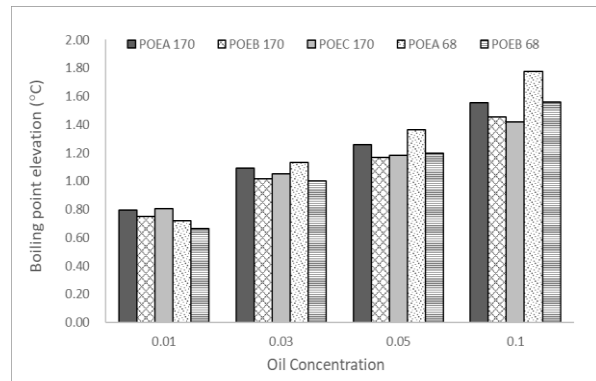


Fig. 2(b). Effect of bulk concentration on boiling point elevation for R-134a mixture subject to various lubricants under $T_{sat} = 0^\circ\text{C}$ and $q = 30 \text{ kW/m}^2$.

2.3 Surface (Interfacial) tension and contact angle

Fig. 3(a), despite identical chemical formula, R-1234yf possesses the lowest surface tension while R-1234ze yields the largest one among these three refrigerants. Fig. 3(b) shows the calculated interfacial tension vs. oil concentration. Apparently, the addition of lubricant reduces the interfacial tension and the reduction is especially pronounced at low oil concentration. This phenomenon is analogous to surfactant addition. In addition, also as disclosed in Fig. 3(a) and Fig. 3(b) where the contact angle is increased with the rise of saturation temperature. For the effect of refrigerant on contact angle, the tendency between surface tension and contact angle is different for the three refrigerants at different temperature as shown in Fig. 3(a). While for oil concentration effect, the tendency between surface tension and contact angle is the same under different oil concentration for specific refrigerant as seen in Fig. 3(b).

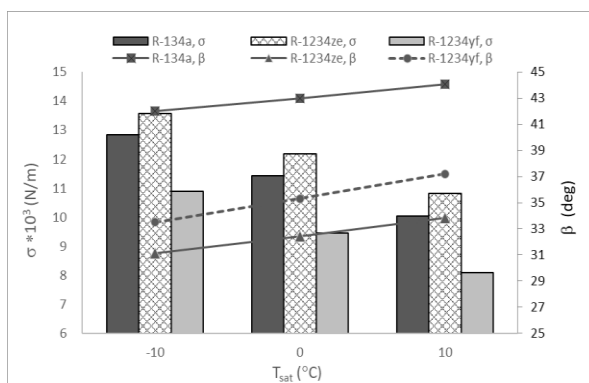


Fig. 3(a). Surface tension and contact angle of pure refrigerants at different temperature under $q = 30 \text{ kW/m}^2$.

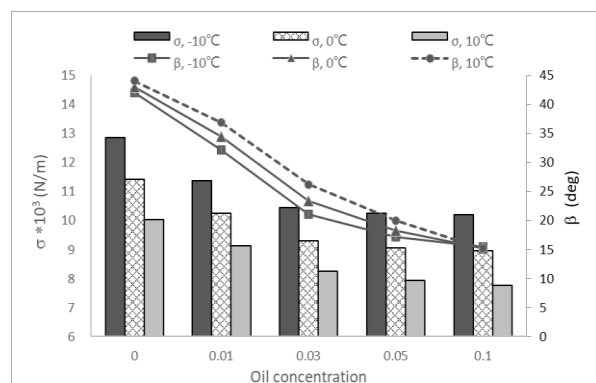


Fig. 3(b). Calculated interfacial tension and contact angle of R-134a/POEA 170 at different concentration and temperature under $q = 30 \text{ kW/m}^2$.

3. KEY FACTORS INFLUENCE ON BUBBLE DYNAMIC PARAMETERS

3.1 Bubble size and generating frequency

Based on our proposed model, bubble diameter is a function of surface tension, contact angle, mixture density, as well as Jakob number. While frequency is the reciprocal of bubble cycle time which includes periods of waiting, growth, and departure. The calculated results are shown in Figs. 4(a) and 4(b). As shown in Fig. 4(a), R-1234yf contains the smallest bubble diameter due to its lower surface tension, while R-1234ze contains the largest diameter. With addition of lubricant into refrigerant, the bubble diameters decrease quickly due to appreciably

reduction in interfacial tension (Fig. 4(b)). In addition, the increasing trend of bubble frequency is related to the reduction of bubble size amid different oil concentrations as appeared in Figs. 4(b). In the present calculation, the bubble size decreases slightly when raising the heat flux.

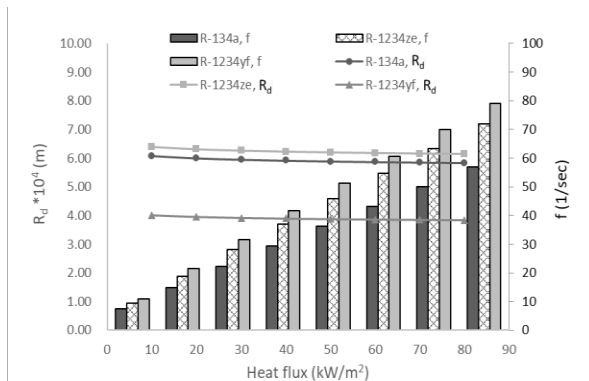


Fig. 4(a). Bubble radius and frequency vs. supplied heat flux for different refrigerants at 0 °C.

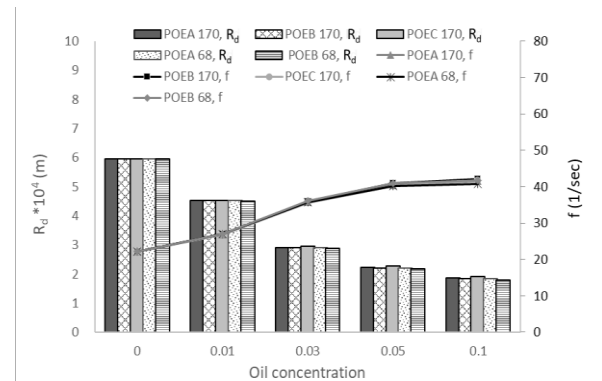


Fig. 4(b) Bubble radius and frequency of R-134a/lubricant mixture at $T_{sat} = 0$ °C and $q = 30$ kW/m².

3.2 Bubble density

The actual meaning of bubble density is the ratio of latent heat contributed from individual bubble to the overall heat supplied in specific area covering individual bubble. The calculated results of bubble density are shown in Figs. 5(a) and 5(b). By using bubble density, it becomes quite easier to check the heat transfer process. In Figs. 5(a), bubble density is decreased with the rise of heat flux. These results imply that heat transfer under low heat flux is more ‘effective’ than that under high heat flux, due to higher ratio of heat flux contributing to latent heat of bubble boiling, rather than to heat liquid mixture. In Fig. 5(a), bubble densities raised appreciably by oil addition, but the enhanced degrees are different under various heat flux and oil concentration. At a low heat flux (10 kW/m²) and oil = 3%, a plateau of maximum bubble density is encountered. However, at a high heat flux (80 kW/m²), the plateau of bubble density moves to oil = 1%. In Fig. 5(a). For R-134a or R-1234ze mixture, the maximum augmentation of bubble density is at an oil concentration of 3% at 0 °C and 30 kW/m², but the value of bubble density is at the same level for R-1234yf mixture around 0~3%, then it is decreased as the oil concentration is further increased.

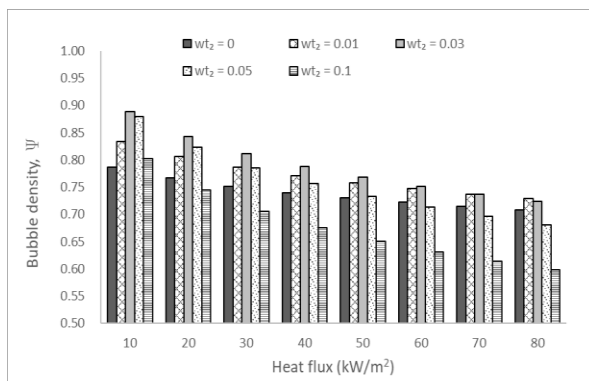


Fig. 5(a). Bubble density vs. supplied heat flux for R-134a/POEA170 at 0 °C.

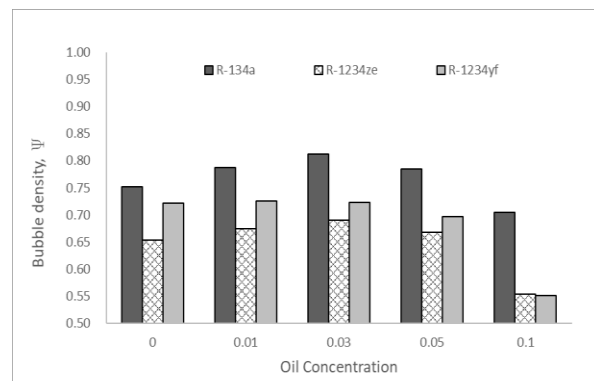


Fig. 5(b). Bubble density of various refrigerant/POEA170 mixtures vs. supplied heat flux at 0 °C.

4. OVERALL COMPARISON

4.1 Time comparison

In the initial stage, the bubble growth is governed by the momentum interaction between the bubble and the surrounding liquid. Consequently, the liquid inertia force casts a significant effect on the bubble growth. In the latter stage, however, the bubble growth is limited primarily by heat transfer to the bubble interface and the effect of the momentum interaction becomes less important. The viscous drag and the liquid inertia force are estimated to be several times smaller than the buoyancy force or the surface tension force when the bubble is about to depart. At a saturation temperature of 0 °C, Fig. 6(a) illustrated the comparison of overall bubble inception time for different refrigerants under various heat fluxes. All bubble inception times decrease as heat flux increase due to increasing in frequency when compared with Fig. 4(a). Besides, the tendency of inception time between

different refrigerants is also reversed to that of frequency. Fig. 6(b) shows the effect of oil concentration on each time period. By adding oil into refrigerant, the waiting time is increased due to boiling point elevation, and the departure time is also increased due to the rise of drag force. Conversely, the bubble growth time is decreased dramatically for a smaller bubble size. In summary, the total time of bubble cycle is reduced when oil is in presence.

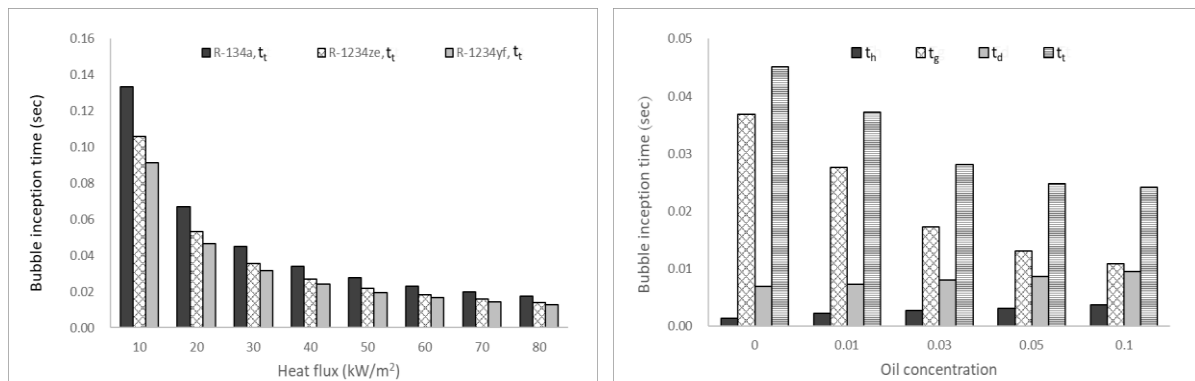


Fig. 6(a). Total bubble inception time vs. supplied heat flux for refrigerants at 0°C.

4.2 Temperature comparison

The calculating results regarding wall superheat of each period are shown in Figs. 7(a) and 7(b). In general, the total wall superheat is related to HTC and the bubble density. Fig. 7(a) shows the total wall superheat temperature in different refrigerants. For waiting period and growth period, R-1234ze possesses the largest wall superheat temperature, while for departure period, R-1234yf contains the highest value of wall superheat. After adding lubricant oil into refrigerant, as shown in Fig. 7(b) for R-134a/POEA170 mixture, the wall superheat of waiting period and departure period is increased with the rise of oil concentration, while the wall superheat is decreased at a lower oil concentration during growth period, but the trend is reversed to an increase wall superheat when the oil concentration is up to 10%. The tendency of overall wall superheat is the trade-off and combination result of each wall superheat of different period. This is similar to the tendency of bubble density and HTC.

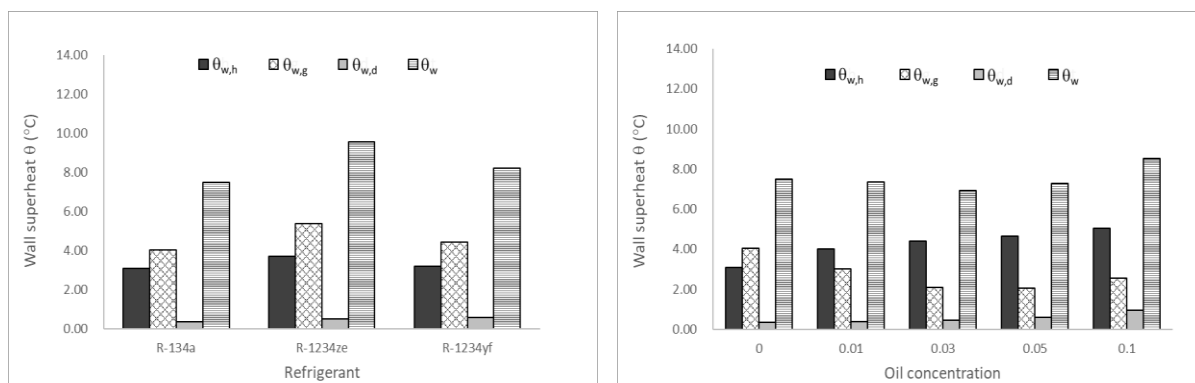


Fig. 7(a). The wall superheat for each time period subject to various refrigerants at $T_{sat} = 0^\circ\text{C}$ and $q = 30 \text{ kW/m}^2$.

Fig. 7(b). The wall superheat vs. oil concentration for each time period for R-134a/POEA170 mixture at $T_{sat} = 0^\circ\text{C}$ and $q = 30 \text{ kW/m}^2$.

4.3 HTC comparison

Based on above discussion, overall HTC are shown in Figs. 8(a) ~ 8(g). From Fig. 8(a), HTC is increased with the rise of heat flux, and HTC of R-134a is higher than that of R-1234yf, followed by R-1234ze. The calculation also showed in Fig. 8(b) that high saturation temperature will promote HTC. Figs. 8(c) ~ 8(e) show HTC in POEA 170 mixture with R-134a, R-1234ze and R-1234yf, respectively. Basically, the tendency is similar to the calculated results of bubble density. In R-134a/POEA 170 (Fig. 8(c)), HTC is enhanced by adding oil up to 5%, followed by a persistent decline with further addition of lubricant oil up to 10%. The maximum heat transfer enhancement is about 8% at 3% oil concentration. In R-1234ze/POEA 170 as shown in Fig. 8(d), the phenomenon is similar, the maximum enhancement is about 9% at 3% oil concentration. On the other hand, the HTC for R-1234yf/POEA 170 is different from the others, the HTC is decreased with the rise of oil concentration (Fig. 8(e)). The HTC is impaired from 5% at 1% oil concentration to 25% at 10% oil concentration at a saturation temperature of 0 °C. Fig. 8(f) showed the comparison of HTC subject to different type of lubricants for R-134a. The results

show that only slight difference in HTC is seen in different type R-134a/lubricant mixtures. By comparing Fig. 8(c) with Fig. 8(g), it can be found that the saturation temperature plays an important role on lubricant effect on HTC. Higher saturated temperature tends to impair the heat transfer performance upon oil addition.

Based on the aforementioned results, it seems to be inconclusive that oil concentration plays an important role on HTC, and the oil type shows only slight influence on it. Actually, oil concentration inside evaporator is related to refrigerant solubility in lubricant inside compressor, while oil type act as an important role for solubility. For the influence of solubility, volumetric efficiency and total efficiency of the compressor were higher for lubricant having a low solubility than that of high solubility at low-speed operation of the compressor. Ideally the lubricant should be confined within the compressor. However, some lubricant is entrained and transported along with the refrigerant to circulate around the refrigerant circuitry and other system components. During operational transients, the lubricant is redistributed throughout the various system components. The equilibrium distribution of lubricant depends on fluid properties, phase change processes, flow rates, geometries, and operating conditions, and impose influences on HTC. Once lubricant moves out of compressor, lubricant properties will dramatically influence mist droplet size, separation efficiency of oil separator, and oil circulation rate (OCR) in liquid line. Finally, oil properties, i.e. oil type effect, will affect oil concentration in evaporator, and results in enhancement or impairment upon heat transfer performance. Youbi-Idrissi (2003) investigated that the solubility of the refrigerant in oil can have a considerable effect on the evaporator performances. For two oils having the same viscosity grade, the evaporator performances decrease when the refrigerant-oil solubility increases. Another important property of oil will influence OCR drastically, that is miscibility. High miscible lubricant with refrigerant will lead to strong combining force, increasing OCR, then may increase or reduce HTC based on overall consideration. Popovic et al. (2000) studied the influences of lubricant miscibility on R-134a system performance. Under the same working conditions with the same lubricant viscosity grade, R-134a with a miscible POE resulted in 2% to 5% higher COPs than R-134a with an immiscible mineral oil. In addition, the cooling capacity with miscible POE was up to 2% higher than that of the pair with immiscible mineral oil.

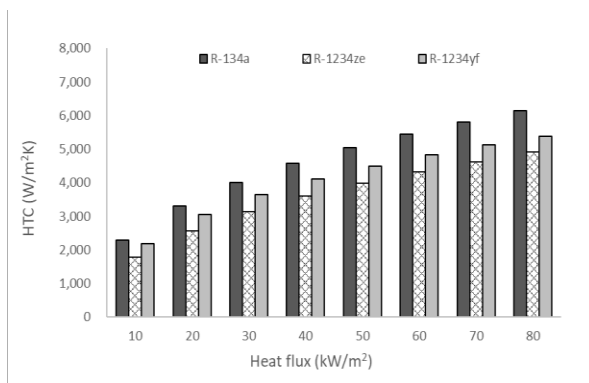


Fig. 8(a). Heat transfer coefficient vs. supplied heat flux for different refrigerants at $T_{sat} = 0$ °C.

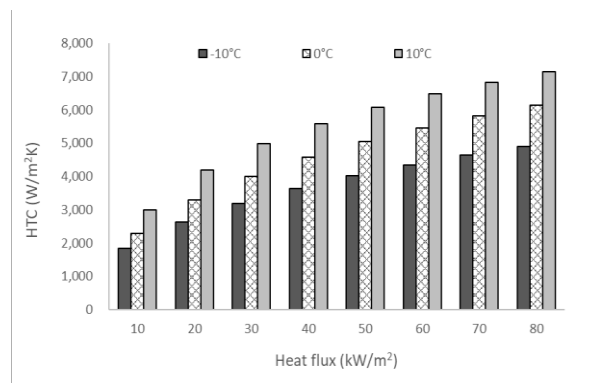


Fig. 8(b). Heat transfer coefficient vs. supplied heat flux for R-134a at various temperature.

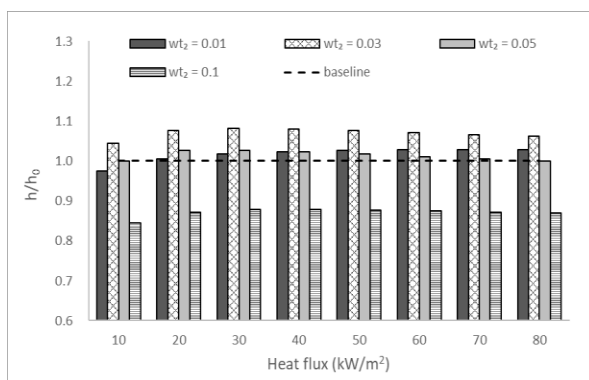


Fig. 8(c). Heat transfer coefficient vs. supplied heat flux for R-134a/POEA mixture at $T_{sat} = 0$ °C.

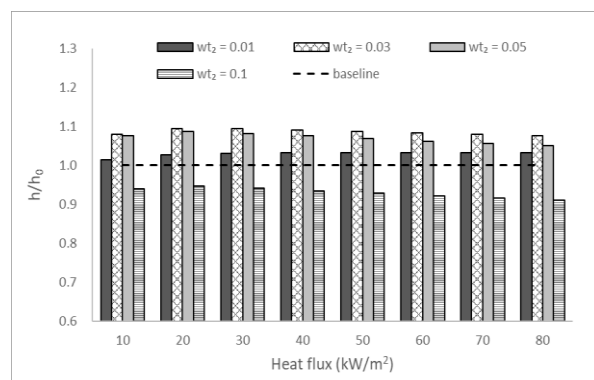


Fig. 8(d). Heat transfer coefficient vs. supplied heat flux for R-1234ze/POEA mixture at $T_{sat} = 0$ °C.

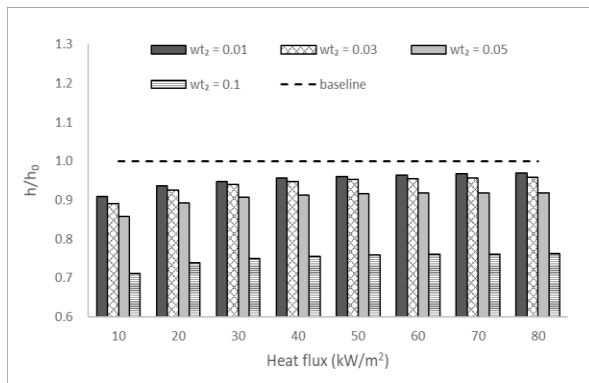


Fig. 8(e). Heat transfer coefficient vs. supplied heat flux for R-1234yf/POEA mixture at $T_{sat} = 0$ °C.

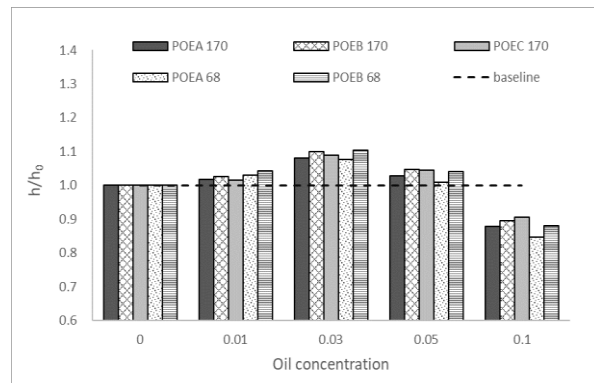


Fig. 8(f). Heat transfer coefficient of R-134a/lubricant mixture at $T_{sat} = 0$ °C and $q = 30$ kW/m².

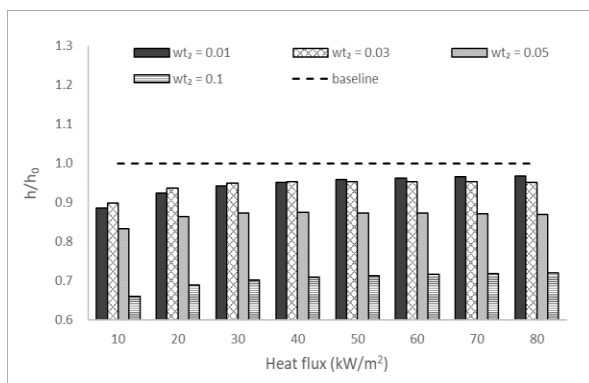


Fig. 8(g). Heat transfer coefficient vs. supplied heat flux for R-134a/POEA mixture at $T_{sat} = 10$ °C.

5. CONCLUSIONS

Calculation results based on the proposed model regarding the influence of lubricant on the pool boiling heat transfer performance are discussed in details. Several key factors play an important role in pool boiling heat transfer and show drastic influence on bubble parameters and HTC. Based on the foregoing discussion of the influences of key parameters on heat transfer performance, the following conclusions are drawn:

1. Adding lubricant oil into different refrigerants result in different phenomenon. Enhancement of HTC may appear in mixing POE with R-134a or R-1234ze mixture, but not in R-1234yf mixture.
2. High saturation temperature promotes high HTC for pure refrigerant, but the HTC is decreased drastically with oil addition.
3. The maximum heat transfer augmentation with oil-refrigerant mixtures occurs at certain oil concentration. Usually, a maximum plateau occurs around 3%~5% oil concentration in R-134a and R-1234ze mixtures. Yet the HTCs for all lubricant-refrigerant mixtures are impaired when oil concentration is up to 10%.
4. Higher heat flux tends to increase HTC, but it also reduced individual bubble density, thereby heat transfer contribution by individual latent heat transport is reduced.
5. Analysis of the key factors like surface coverage concentration, boiling point elevation, drag force and Reynolds number indicates that they all directly influence the wall superheat in waiting period, growth period, and departure period. These influences mainly attributed to the various refrigerant-lubricant properties, especially interfacial properties, such as interfacial tension, contact angle, energy gap and affinity.
6. Various lubricant structures may provide different refrigerant-lubricant properties. Yet these factors sometimes offset with each other and result in only a slight difference in bubble size, contact angle, surface coverage concentration, and HTC.

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