Proceedings of the 18th UK Heat Transfer Conference

9-11 September 2024, Birmingham

UKHTC2024-095

SINGLE BUBBLE NUCLEATE POOL BOILING FOR CLIMATE FRIENDLY COOLING SOLUTIONS

Marilize Everts[1*], M Welzl[2], D Brüggemann[2]

[1] Department of Mechanical Engineering, University College London, London WC1E 7JE, United Kingdom

[2]Chair of Engineering Thermodynamics and Transport Processes (LTTT), Center of Energy Technology (ZET), University of Bayreuth, Germany

1. ABSTRACT

The global attempt to decarbonise the transport sector, combined with our dependency on vehicles, created research opportunities for new technologies and developments and thermal management is a vital focus area. Nucleate pool boiling is known for high heat transfer coefficients and is an attractive direct cooling method. The purpose of this study was to investigate single bubble dynamics R1336mzz(Z) and R245fa for different saturation temperatures and heat fluxes. It was found that the bubble growth rate significantly increased with an increase in heat flux and decrease in pressure, while there was only a slight increase in the departure diameter. The higher surface tension of R1336mzz(Z) led to an increased bubble departure diameter compared with R245fa, while the bubble growth rate also increased and the bubble growth time decreased.

2. INTRODUCTION

The global attempt to decarbonise the transport sector, combined with our daily dependency on vehicles, created excellent research opportunities for new technologies and developments. The further development of electric vehicles relies heavily on multi-disciplinary research associated with alternative fuels and materials, batteries, power trains, etc., but the importance of thermal management and cooling systems cannot be overlooked. Owing to the higher heat transfer coefficients associated with nucleate pool boiling, immersion cooling of electronic components in a quiescent bath of fluorinated low-saturation temperature fluids became an attractive direct cooling method for thermal management. Many studies focused on surface modifications [1], nano-additives [2] and refrigerant mixtures [3] to further enhance the boiling performance. Furthermore, to minimise the impact on global warming, low global warming potential (GWP) refrigerants such as R1336mzz(Z) which is non-flammable (safety class A1) and has a low GWP of 2, have been developed. It was well pointed out by Fu et al. [4] that the development of sustainable heat transfer solutions and design principles requires insight into the fundamental mechanisms that governs refrigerant pool boiling on structured surfaces. However, to date, limited pool boiling investigations were conducted using R1336mzz(Z) and to the authors' best knowledge, bubble dynamics were only investigated from horizontal tubes or flat surfaces with re-entrant cavities. Single bubble pool boiling analysis is helpful to simplify the problem and gain an improved fundamental understanding of the bubble dynamics. Therefore, the purpose of this study was to experimentally investigate single bubble dynamics using low pressure refrigerants such as R245fa and R1336mzz(Z) for different heat fluxes (thus superheat values) at different saturation conditions (thus pressures).

*Corresponding Author: m.everts@ucl.ac.uk

3. METHODOLOGY

The experimental setup, which involved focused shadowgraphy, has been described in detail in Everts et al. [5]. To ensure single bubble nucleation, a single conical cavity was made in the centre of the test section with a cone indenter. The cavity diameter was measured to be 341 μm using an optical microscope (Olympus BX60M) and the cavity depth was calculated to be 295 μm from the known angle 60° of the cone indenter. The surface was polished to remove any scratches or burrs from the manufacturing process. Experiments were conducted using R245fa and R1336mzz(Z) at saturation temperatures of 35 °C and 45 °C (to investigate different pressures) and heat fluxes (to investigate different superheats of 3.3 °C, 4.7 °C, 6.3 °C, and 8.3 °C). The images obtained from the Photron Fastcam SA-X2 high-speed camera were post-processed using MATLAB. The bubble area was obtained from the Image Region Analyzer application and the equivalent bubble diameter was calculated to be the diameter of a spherical bubble with the same area ($D_{eq} = (4A/\pi)^{1/2}$).

4. RESULTS

To investigate the effect of superheat, Fig. 1(a) compares the bubble growth curves of R1336mzz(Z) at a fixed saturation pressure of 1.5 bar while the heat flux was varied to obtain superheated values of 3.3 °C, 4.7 °C, 6.3 °C, and 8.3 °C. This figure indicates that an increase in wall superheat significantly increased the bubble growth rate. Although the increase in departure diameter was almost negligible, the increased growth rate significantly reduced the growth time. To investigate the effect of pressure on the bubble growth of R1336mzz(Z), Fig. 1(b) compares the bubble growth curves at pressures of 1.05 and 1.5 bar at a superheated temperature of 6.3 °C. From this figure it follows that that an increase in saturation pressure reduced the bubble growth rate and increased the bubble growth time, while the bubble departure diameter also decreased.

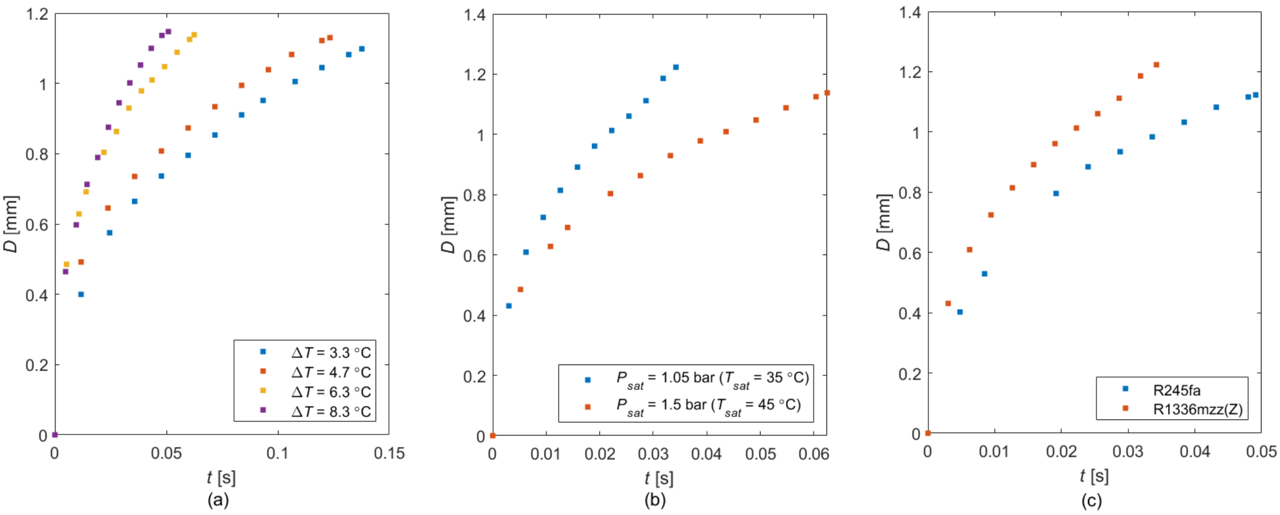
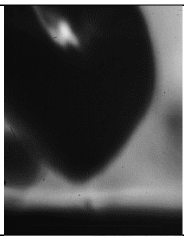
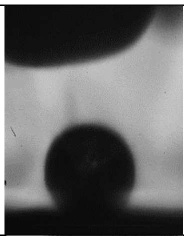
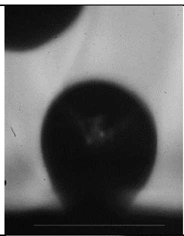
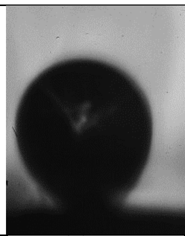
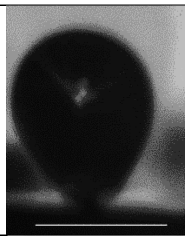
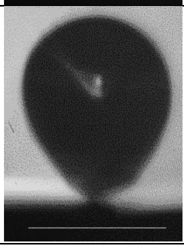
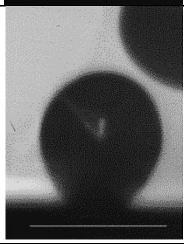
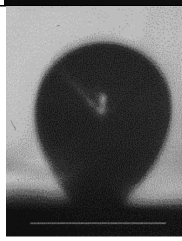
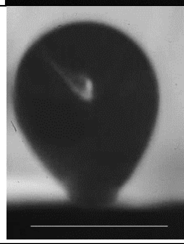


Fig. 1 Comparison of bubble growth rates for (a) R1336mzz(Z) at superheated values of 3.3 °C, 4.7 °C, 6.3 °C and 8.3 °C at a saturation pressure of 1.5 bar and (b) R1336mzz(Z) saturation pressures of 1.05 bar and 1.5 bar at a superheated value of 6.3 °C, and (c) R1336mzz(Z) and R245fa at a saturation temperature of 35 °C and superheated value of 6.3 °C.

To compare the bubble dynamics of R1336mzz(Z) and R245fa, Fig. 1(c) compares the bubble growth curves at a saturation temperature of 35 °C and superheated value of 6.3 °C, while Table 1 compares the bubble images at 0%, 25%, 50%, 75% and 100% of the bubble growth cycle. Although the bubble shapes of both fluids were comparable throughout the bubble growth cycle, it follows from Fig. 1(c) that the bubble growth rate of R1336mzz(Z) was higher than for R245fa which led to a slight increase in bubble departure diameter despite a reduced bubble growth time. When comparing the fluid properties, it was observed that the liquid densities were similar, while R1336mzz(Z) had a lower vapour density and higher surface tension than R245fa. As the surface tension has a significant effect on the bubble departure diameter [4], an increase in surface tension resulted in larger bubbles for R1336mzz(Z). It is known from literature that an increase in pressure leads to increased heat transfer coefficients as well as that the heat transfer coefficients of R245fa are higher than for R1336mzz(Z). This is consistent with the trends observed in Fig. 1(b) and (c) and it is interesting to note that a slower bubble growth rate does not necessarily imply lower heat transfer coefficients.

Table 1 Bubble growth comparison of R1336mzz(Z) and R245fa at 0%, 25%, 50%, 75% and 100% of the bubble growth cycle. The white horizontal line indicates a scale of 1 mm.

	0%	25%	50%	75%	100%
R1336mzz(Z)					
R245fa					

5. CONCLUSIONS

This paper reports the preliminary results of the single bubble dynamics associated with the nucleate pool boiling of R1336mzz(Z) and R245fa for different saturation temperatures and heat fluxes. It was found that an increase in heat flux and decrease in pressure led to a significant increase in the bubble growth rate and a minimal increase in the departure diameter. Although the shapes of the bubbles were comparable throughput the bubble growth cycle, the higher surface tension of R1336mzz(Z) compared to R245fa led to an increased bubble departure diameter, while the bubble growth rate also increased and the bubble growth time decreased.

REFERENCES

[1] L. Gao, L. Jizu, Y. Li, Y. Li, D. Gao, L. Shi, M. Bai, Experimental studies of the pool boiling heat transfer enhancement capability and mechanisms of the micro-pillared surfaces on copper substrate, *Experimental Heat Transfer*, 35(7) (2022) 979-992.

[2] L. Cheng, L. Liu, Boiling and two-phase flow phenomena of refrigerant-based nanofluids: Fundamentals, applications and challenges, *International Journal of Refrigeration,* 2013, pp. 421-446.

[3] J. Li, Z. Yang, Y. Duan, Experimental study on single bubble growth of R32 + R1234yf binary mixtures during saturated pool boiling, *Applied Thermal Engineering*, 219 (2023).

[4] W. Fu, Y. Chen, M.J. Inanlu, T.S. Thukral, J. Li, N. Miljkovic, Enhanced pool boiling of refrigerants R-134a, R-1336mzz(E) and R1336mzz(Z) on micro- and nanostructured surfaces.

[5] M. Everts, M. Welzl, D. Brüggemann, The effective use of focused shadowgraphy for single bubble nucleate pool boiling investigations, *Proceedings of the 9th European Thermal Sciences Conference*, 10 - 13 June 2024, Bled, Slovenia.