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Influence of Surface Roughness on Nucleate Boiling and Critical Heat Flux of R-1233zd(E) at Varying Pressures

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Nucleate pool boiling is one of the most efficient heat transfer mechanisms and is widely utilised in industrial applications such as refrigeration, power generation, and advanced thermal management systems. The boiling heat transfer performance is primarily governed by bubble dynamics and associated heat transfer mechanisms, which are highly sensitive to surface microstructure. This study investigates the effect of varying surface roughness on the heat transfer coefficient (HTC) and critical heat flux (CHF) of refrigerant R-1233zd(E) under different saturation pressures of 1, 1.5, 2, and 2.5 bar. R-1233zd(E), a hydrofluoroolefin with zero ozone depletion potential, has emerged as a promising working fluid for sustainable thermal systems. Its favourable thermophysical properties make it particularly suitable for low-pressure applications such as organic Rankine cycles, refrigeration, and modern heat pump systems. In this work, four boiling surfaces were fabricated from oxygen-free copper with Ra values of 0.03, 0.46, 0.97, and 1.31 µm. The smoothest surface (Ra = 0.03 µm) served as the benchmark to quantify the effects of surface microstructure on boiling performance and to identify the transition from smooth to microstructure boiling behaviour. The remaining surfaces were roughened using different grit sandpapers. Comparative analysis of the HTC revealed that increasing surface roughness enhances boiling performance significantly, with the enhancement ratio varying with operating pressure and reaching a maximum of approximately 70% relative to the smooth surface for surface roughness of 0.97 µm. However, when roughness increased beyond Ra = 0.97 µm to 1.31 µm, the enhancement deteriorated, likely due to the fact that refrigerants are highly wetting and probably the large surface cavities are flooded with liquid, which can suppress further stable nucleation. In other words, refrigerants perform better with surfaces of nanostructures than microstructures. In contrast, surface roughness exhibited only a minor influence on the CHF, indicating that CHF is more strongly governed by fluid thermophysical properties and system pressure. This behaviour agrees with previous studies [1,2], which similarly reported that surface roughness improves boiling performance only within a limited range. Since surfaces with identical Ra values can exhibit distinct microstructures, the results confirm that roughness enhances heat transfer primarily when it promotes stable nucleation activity, which is governed by cavity geometry and surface wettability. These findings highlight the existence of an optimal roughness range and provide insight into the interplay between surface morphology and pressure in enhancing nucleate boiling heat transfer with R-1233zd(E). The predictive accuracy of established HTC correlations was found to be highly dependent on surface roughness. For the smooth surface and that of Ra = 1.31 µm, the correlations of Jung et al. [3] and Stephan and Abdelsalam [4] agreed well with experimental data at low to moderate heat fluxes but consistently overpredicted performance at higher fluxes, particularly between 2 and 2.5 bar. For rough surfaces (Ra = 0.46–0.97 µm), the correlations of Gorenflo et al. [5] and Cooper [6] exhibited better agreement across different operating conditions. The CHF predictions from Chang and Snyder's model [7] showed the closest overall alignment with experimental data for all surfaces and pressures. This indicates that for R-1233zd(E), CHF is predominantly governed by fluid thermophysical properties and system pressure, with surface microstructure playing a more secondary role.

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