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CONDENSATION ON A VERTICAL PLATE WITH SINUSOIDAL MICROFINS – FURTHER CONSIDERATIONS

John. W. Rose [1*], Lei Chai [2]

[1]School of Engineering and Materials Science, Queen Mary University of London, London E1 4NS, United Kingdom

[2]Institute of Energy Futures, Brunel University London, Middlesex UB8 3PH, United Kingdom

1. ABSTRACT

Recently-published experimental data for condensation of nitrogen on a vertical plate with sinusoidal fins and a subsequent analytical approach showed that, in the ranges of the data, the heat transfer coefficient increased as both pitch and height of the fins decreased. While the analytical result agreed well with the data, the resulting equation indicated that the heat transfer increased indefinitely as the pitch approached zero, as did a correlation given in the experimental paper. The present work addresses this deficiency and provides a result which may be used to determine optimum fin pitch and height.

2. INTRODUCTION

A recent experimental investigation of heat transfer during condensation of nitrogen on a vertical plate with sinusoidal microfins [1] prompted an analytical study [2], based on an earlier approach to the problem of condensation on microfinned tubes [3]. The resulting equation [2] was in good agreement with the experimental data for nitrogen and showed that the heat transfer coefficient increased with decreasing fin pitch and with decreasing fin height over the range of the data. The theoretical equation reduced to the Nusselt equation for a smooth surface when the fin height was set to zero, indicating an optimum fin height for a given fin pitch. However, the proposed expression indicated that the heat transfer continued to increase as the pitch approached zero rather than decrease to the Nusselt result as expected. The present study gives a modification of the earlier investigation so as to give the Nusselt result when either the fin pitch or fin height is zero.

3. ANALYSIS

The previous investigation [2] gave an expression for heat flux as a function of temperature difference and fluid properties:

$$q=\{\frac{\rho_f h_{fg} k_{\mathrm{f}}^3 \Delta T^3}{\mu_{\mathrm{f}}}[\frac{0.943^4 \Delta\rho g}{H}\left(\frac{l}{p}\right)^4+\frac{10\sigma}{l^3}\left(\frac{l-p}{p}\right)^{1/2}]\}^{1/4} \tag{1}$$

*Corresponding Author: j.w.rose@qmul.ac.uk

where q is the heat flux and ΔT is the vapour-surface temperature difference. The fluid properties have their usual meanings. The fin dimensions are l length measured over the fin surface, p the pitch and h the height. H is the height of the condensing surface. The derivation of Eq. 1 took account of the lateral surface tension driven flow due to the variation of condensate surface curvature over the fin as well as the vertical component due to gravity. Eq. 1 is in good agreement with the experimental nitrogen data but indicates that the heat flux continuous to increase as the pitch decreases towards zero, as did the correlation given in [1].

The experimental data [1] covered three values of fin pitch: (1 mm, 2 mm, 3 mm) for a fixed fin height of 0.3 mm, and three values fin height (0.3 mm, 0.6 mm, 0.9 mm) for a fixed fin pitch of 1 mm. The heat transfer was found to increase as both fin pitch and fin height decreased. As noted in [2], Eq. 1, while giving good agreement with the data and correctly giving the Nusselt result for zero fin height (when $l = p$), gives infinite heat transfer as the fin pitch approaches zero. In the present work Eq. 1 is amended in order to obtain a result in satisfactory agreement with the data, as well as giving the Nusselt flat plate result when the fin pitch or height are zero. This is achieved by amending the arbitrary expression involving the geometrical parameters used in [2] to give Eq. 2:

$$q = \{\frac{\rho_f h_{fg} k_{\mathrm{f}}^3 \Delta T^3}{\mu_{\mathrm{f}}}[\frac{0.943^4 \Delta\rho g}{H} + \frac{12\sigma}{l^3}\left(\frac{p}{l}\right)^{1/4}\left(\frac{l-p}{l}\right)^{1/2}]\}^{1/4} \qquad (2)$$

Eq. 2 is compared with the experimental data in Fig. 1 for a range of pitch with fixed fin height.

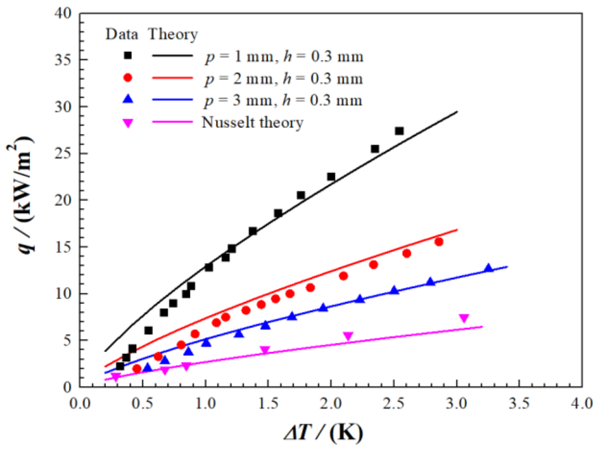

Fig. 1 q vs ΔT for different pitches for fixed height.

Using Eq. 2 and a digital representation of the relationship between l, p, and h for a sin function, the enhancement ratio q/q_{Nu}, which is independent of ΔT, may be found for a range of p with fixed h and for a range of h with fixed p. The dependence on pitch is shown in Fig. 2 together with the data points, the former result (Eq. 1) and the correlation of the data given in [1], expressed in the present notation, by Eq. 3.

$$\frac{q}{q_{Nu}} = 0.011(\frac{h}{H})^{-0.18}(\frac{p}{H})^{-0.9} \qquad (3)$$

As may be seen, Eq. 2 indicates an optimum fin pitch of around 0.1 mm for a fin height 0.3 mm. The earlier result and correlation both indicate that the enhancement ratio continues to increase without limit as pitch approach zero. A plot of q/q_{Nu} versus fin height for fixed fin pitch 0.3 mm has a relatively flat maximum with an optimum fin height between 0.3 mm to 0.4 mm.

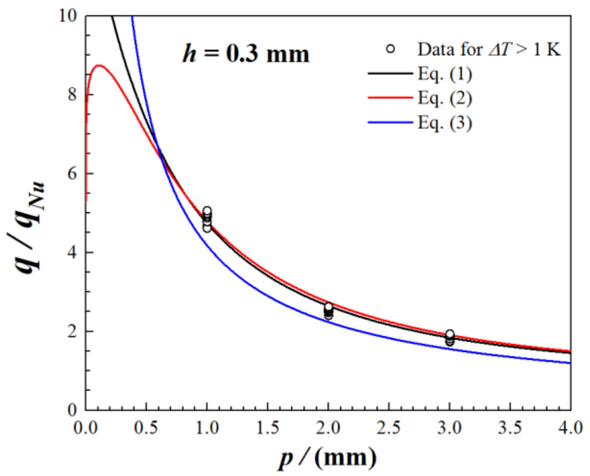

Fig. 2 q/q_{Nu} versus fin pitch for fin height 0.3 mm.

4. CONCLUDING REMARKS

An earlier theoretically-based equation for condensation on a vertical surface with sinusoidal microfins has been amended to give an equation which may be used to optimise fin dimensions.

REFERENCES

[1] S. Zhu, X. Zhi, C. Gu, K. Wang, L. Qiu, Enhancing heat transfer performance of nitrogen condensation on a vertical plate with microstructure. Int. J. Heat Mass Transfer 172 (2021) 121219.

[2] J. W. Rose and Lei Chai, Condensation on a vertical plate with sinusoidal microfins. Proc. ASME J Heat Transfer, 144 / 121601-1

[3] J. W. Rose, An approximate equation for the vapour-side heat-transfer coefficient for condensation on low-finned tubes. Int. J. Heat Mass Transfer, 37 (1994) 865–875.