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SHORTER COMMUNICATIONS

HEAT TRANSFER WITH GAS INJECTION AT THE SURFACE

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THE HEAT TRANSFER from a solid to a liquid is increased by the presence of gas bubbles at the solid liquid interface. This has been demonstrated in nucleate boiling, in gas injection and in electrolysis studies. The studies by Gose, Acrivos and Petersen [1, 2] are of particular interest. In their experiments a volume of gas was forced through a porous solid, thereby creating bubbles at the surface of the solid which then moved out into the bulk fluid. The resulting heat flux was measured for several liquids at different gas volume injection rates.

The apparent similarity between gas volume injection and saturated nucleate boiling led Sims, Aktürk and Evans-Lutterodt [3] to use the Kutateladze equation of nucleate boiling to predict the heat-transfer results of Gose, Acrivos and Petersen [1]. To make this calculation a gas injection velocity must be introduced and this was done by replacing the expression $q/\rho_v h_{fg}$ by an equivalent gas injection velocity, V_∞. This implies that the total heat flux in saturated nucleate boiling is due *solely* to latent heat transport† which is in disagreement with Jakob [4] and Rallis and Jawurek [5]. It should also be noted that Rallis and Jawurek [5] have shown that the latent heat transport is not proportional to the total heat flux.

Another comment is also noteworthy. Gas volume injection and saturated nucleate boiling may be similar when the two systems have the same injection velocity and the same number of bubble sources.‡ Matching the gas injection velocity alone will not result in similar systems.

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† Latent heat transport refers to the heat of vaporization which is absorbed by the bubble while it grows and is then transferred to the bulk fluid when the bubble leaves the heating surface.

‡ The gas injection velocity in nucleate boiling is defined by $N\overline{fV_d}$ where N is the number of bubble sources per unit of area and $\overline{fV_d}$ is the arithmetic mean of the product of the bubble frequency and the bubble volume at departure.

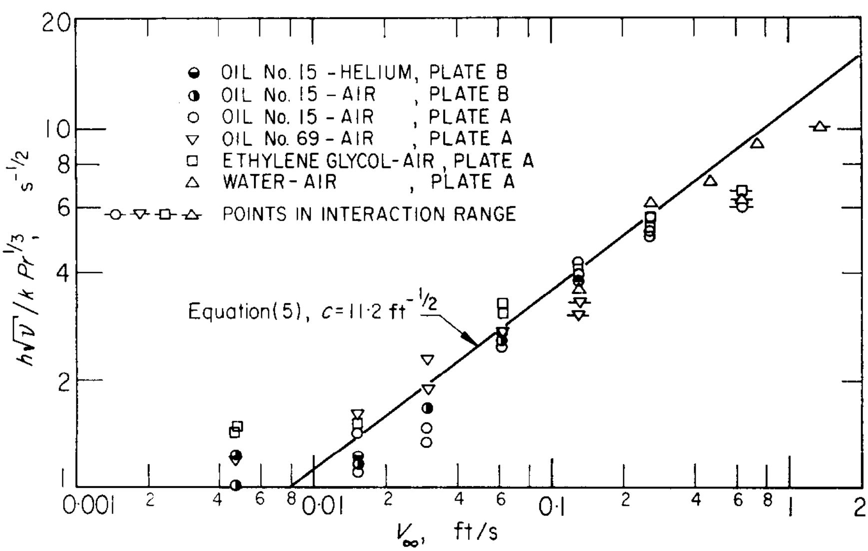

FIG. 1. Heat-transfer coefficient for gas injection.

Tien [6] has obtained good agreement with saturated nucleate pool boiling experiments using the basic heat-transfer relation

$$Nu = \text{constant } Pr^{\frac{1}{3}} Re^{\frac{1}{2}} \tag{1}$$

For gas injection the Reynolds number is given by $V_\infty L/\nu$ where V_∞ is the velocity of the injected gas, L is a characteristic length and ν is the kinematic viscosity. Thus equation (1) becomes

$$h = Ck\, Pr^{\frac{1}{3}} \left(\frac{V_\infty}{\nu}\right)^{\frac{1}{2}} \tag{2}$$

where C is a constant which has the dimensions of $(\text{length})^{-\frac{1}{2}}$. In Fig. 1 the experimental data (1) for the heat-transfer coefficient as a function of the gas injection velocity is presented. The gas injection velocity was defined as the volumetric gas flow rate divided by the area of the heat-transfer surface. Good agreement with the data for all the liquids tested is given by equation (5) with a value of 11·2 $\text{ft}^{-\frac{1}{2}}$ for C.

When there are important interaction effects, equation (5) is no longer valid. In Fig. 1, the experimental points with horizontal tags are in this range and are presented to emphasize this effect. Reference may also be made to Gose *et al.* [1]. For the small gas injection rates, free convection effects must also be considered.

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REMARK ON THE LAMINAR BOUNDARY LAYER WITH PRESCRIBED ENERGY FLUX

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INTRODUCTION

IN REFERENCE 1 Sparrow and Lin present an interesting analysis of boundary layers with prescribed heat transfer and then apply their analysis to flows with simultaneous convective and radiative heat transfer. One problem considered by them is that of a plate with arbitrarily prescribed laminar heat transfer; for this they employed an approximate solution given by Eckert and Drake [2] to form an integral equation and adjusted a constant so as to match the exact results obtainable for the case of uniform heat flux. It is the purpose of the present paper to give in principle an exact solution for this problem for the case of simplified transport properties and of unity Prandtl number; we include the words "in principle" because the solution is given in terms of eigenfunctions, only the first 10 of which have been provided by Fox and Libby [3]. However, additional functions can be readily obtain side if dered.

Rather than develop the solution which would correspond immediately to that of reference 1, we prefer to exploit techniques widely used in the aerospace literature and to demonstrate the solution in a somewhat more general form. First, we carry out the analysis in terms of two transformed variables, the so-called Levy–Lees variables, η and s which are related to the usual x, y Cartesian coordinates of the boundary-layer theory by