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INFLUENCE OF MASS TRANSFER ON THE MOMENTUM TRANSFER IN CONDENSATION AND EVAPORATION PHENOMENA

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NOMENCLATURE

f_R, fanning factor;
E, enhancement factor;
$\dot{n}_A$, mass flux [kg/m² s];
$\bar{U}$, average velocity in tube or channel [m/s];
u_o, velocity of the liquid–gas-interface [m/s];
V, suction/blowing velocity [m/s].

Greek symbols

ρ, density [kg/m³];
Φ, defined in equation (5);
τ, shear stress [N/m²].

Subscripts

o, at the L–G-interface;
$\bullet$, at the L–G-interface with mass transfer.

THERE are many publications [1–4] but lately Razavi [5] has taken into account the influence of the mass transfer on the momentum transfer for condensation phenomena in the form of a relationship such as:

$$\tau_o^{\bullet} = \frac{f_R}{2} \cdot \rho_G \cdot \bar{U}^2 - \rho_G \cdot V \cdot \bar{U}. \tag{1}$$

The shear force at the liquid–gas interface is calculated by the above-mentioned authors with the help of such a relationship which does not take into account the effect of the V-component in the velocity profile into the boundary layer; that is to say the effect of suction velocity (condensation) or blowing velocity (evaporation). When the V-component is positive, it is blowing velocity (evaporation) and when negative, it is suction velocity (condensation), according to the chosen coordinate system as shown in Fig. 1.

With the assumption of the film theory the momentum conservation equation can be simplified and integrated to yield the following equations, with additional assumptions that with and without mass transfer through the boundary layer its thickness is not substantially effected [6].

$$1 + \frac{\dot{n}_A}{E_1 \cdot \frac{f_R}{2} \cdot \rho_G(\bar{U} - u_o)} = \exp\left[\frac{\dot{n}_A}{\frac{f_R}{2} \cdot \rho_G \cdot (\bar{U} - u_o)}\right], \tag{2}$$

with

$$\tau_o^{\bullet} = \tau_o \cdot E_1 \tag{3}$$

and

$$E_1 = \frac{\Phi}{\exp(\Phi) - 1}, \tag{4}$$

where

$$\Phi = \frac{\rho_G \cdot V}{\frac{f_R}{2} \cdot \rho_G \cdot (\bar{U} - u_o)} = \frac{\dot{n}_A}{\frac{f_R}{2} \cdot \rho_G \cdot (\bar{U} - u_o)}. \tag{5}$$

Equation (4) is yield factor E_1 (enhancement factor), which has a form of the Ackermann [7] function, originally developed to correct the heat-transfer coefficients. Such correction takes into account the deformation of the temperature profile into the boundary layer, generated by the presence of a mass flux. The friction factor f_R is a pure friction factor (friction against a smooth wall).

The factor E_1 must be applied only to correct f_R, because E_1 takes into account only the effect of the suction/blowing velocity V normally to the wall, but not the contribution of the shear stresses at the liquid–gas interface produced by the deformation of profile and the separation of the boundary layer associated with the presence of a wavy surface.

In order to make possible a comparison between both equations (1) and (3) equation (1) must be written rigorously in the form of equation (6a), because the significant factor is really $(\bar{U} - u_o)$.

$$\tau_o^{\bullet} = \frac{f_R}{2} \cdot \rho_G \cdot (\bar{U} - u_o)^2 - \rho_G \cdot V \cdot (\bar{U} - u_o) \tag{6a}$$

or

$$\tau_o^{\bullet} = \frac{f_R}{2} \cdot \rho_G \cdot (\bar{U} - u_o)^2 \cdot (1 - \Phi) = E_2 \tau_o, \tag{6b}$$

where

$$\tau_o = \frac{f_R}{2} \rho_G (U - u_o)^2. \tag{6c}$$

A comparison between equation (3) and equation (6b) can be seen clearly in Fig. 2.

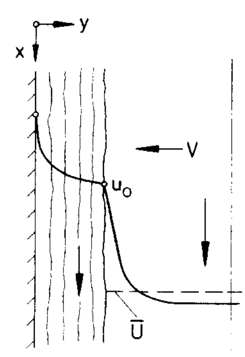

FIG. 1. Flow model and coordinate system.

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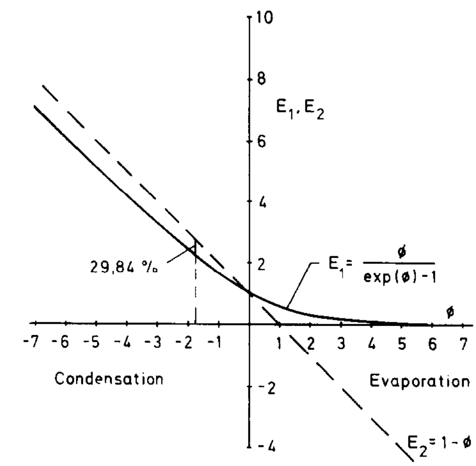

FIG. 2. The variation of the enhancement factors for the interfacial shear stress E_1 and E_2 with the mass transfer rate.

Both the equations possess the equal limits for $\Phi = 0$ and $\Phi \rightarrow -\infty$, but equations (3) and (4) for $\Phi \rightarrow +\infty$ yield $E_1 = 0$ whereas equation (6) yields $E_2 \rightarrow -\infty$. This $(-\infty)$, a change in sign, is not at all understandable. That means with conditions $\Phi > 0$ (by blowing velocity of gas phase) equation (6) produces the reversion of the shear stress, which is not at all feasible.

A negative abscissa of Φ, the uncoupled solution [equation (6)], predicts a greater enhancement factor with a maximum of 30% at $\Phi = -1.8$ as compared with the coupled solution [equation (3)]. In Fig. 2 the course of both equations can be seen. For practical purposes and in the case where $\bar{U}$ is much greater when compared to u_o, u_o can be neglected but not otherwise. It is recommended when the velocity of the steam phase when compared to the velocity of the interphase liquid–gas is much greater and not for small differences, i.e. only when $u_o/\bar{U} \rightarrow 0$.

For the case that $(\bar{U} - u_o)$ goes to zero E_1 and E_2 tends to infinity but $\tau_o^\bullet$ in both cases tends to zero as can be seen immediately from equations (3)–(6).

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TRANSIENT RESPONSE OF FINS BY COORDINATE PERTURBATION EXPANSION

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NOMENCLATURE

- b, fin thickness;
- c, specific heat;
- E, emissivity;
- h, heat-transfer coefficient;
- k, thermal conductivity;
- m, exponent of power law;
- N, fin parameter;
- q, heat-transfer rate;
- Q, dimensionless heat-transfer rate, $qx_0/bk\,(T_b - T_e)$;
- t, time;
- T, temperature;
- T_b, fin base temperature;
- T_e, environment temperature;
- x, distance from fin base;
- x_0, reference length;
- X, dimensionless distance, x/x_0.

Greek symbols

- α, thermal diffusivity, $k/\rho c$;