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LETTER TO THE EDITORS

Comments on "Effect of humid air flow rate on the filmwise condensation inside a vertical cooled pipe: numerical and experimental study"

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In a paper Pele *et al.* [1] reported a numerical and experimental study of forced convective turbulent flow of air–water vapour mixtures in a vertical tube, with laminar film condensation at the wall. Their theoretical model is based on local mass, energy and momentum balances (accounting for the diffusional mass flux to the wall), and correlations to determine the heat and mass transfer rates and exerted friction. The reported experiments involve the wall condensation of dilute water vapour in air.

The treatment is fairly trivial, in industry these type of heat and mass transfer computations for condensers are daily practice and can be found in textbooks [2, 3]. Though the treated problem is standard, still a large number of textual and technical errors are present, as will be explained below.

In the mass balance, equation (1) of ref. [1], the space between m_{vi} and ds is confusing and should have been avoided. In the energy balance, equation (2) of ref. [1], dT on the left-hand side and T in the numerator of the right-hand side should be provided by a subscript "m" in order to fit in with the nomenclature and equation (5) of ref. [1]. The momentum balance, equation (3) of ref. [1], contains U_g, which cannot be found in the nomenclature and should be replaced by u (to be consistent with their definition of the Reynolds number). Furthermore, the underlying assumptions of equation (3) of ref. [1] are not clearly explained. In ref. [4] a thorough derivation of this local momentum balance with mass transfer can be found. The meaning of the differential balances in h_v, h_E and h_g in Fig. 1 is not clear and seems not to be logical as the symbol h is defined as heat transfer coefficient. The relation

$$Nu = 0.023\,Pr^{1/3}\,Re^{4/5} \tag{1}$$

is named the Colburn analogy, but is in fact a Dittus–Boelter correlation (ref. [5]). The authors fail to explain how they determine the mass transfer coefficient h_D. From equation (1) and the Chilton–Colburn analogy it can be assumed that

$$Sh = Nu\left(\frac{Sc}{Pr}\right)^{1/3} = 0.023Sc^{1/3}\,Re^{4/5}. \tag{2}$$

It can be deduced that the mass transfer coefficient appearing in equation (4) of ref. [1] reads

$$h_D = \frac{Sh\mathbb{D}}{2R_i}. \tag{3}$$

This definition does not correspond to the mass transfer coefficient defined by Bird *et al.* [3] (referred to as "k_x"):

$$h_D = \frac{Sh\mathbb{D}c}{2R_i}. \tag{4}$$

$\mathbb{D}$ is the diffusion coefficient and c the molar density ($= p/\mathbf{R}T$ in the notation of ref. [1]). From equations (3) and (4) one can conclude that, in contrast to ref. [3], the molar density in the mass transfer coefficient has been excluded. Furthermore, in equation (4) of ref. [1], p_{vm} in the denominator should read p_{vi}. The mass flux in equation (4) of ref. [1], for small mass transfer rates, expressed in the variables used by Bird *et al.* [3], should therefore read

$$m_{vi} = M_v h_D \frac{p_{vm}-p_{vi}}{p-p_{vi}}. \tag{5}$$

So, the statement of the authors that their definition is similar to the one used by Bird *et al.* [3] is not correct. Moreover, their reference number after Bird *et al.* [5], is wrong and should read [6] in order to correspond to their list of references.

The authors neglect the effect of suction on the diffusional mass flux and exerted friction without discussion. The effect of suction on heat transfer is described by the Ackermann correction

$$\frac{h}{h_0} = \Theta(a) = \frac{-a}{e^{-a}-1} \tag{6}$$

with a as dimensionless mass flux, defined as

$$a = \frac{m_{vi}C_{pv}}{h_0}. \tag{7}$$

The authors state that the effect of mass flux on heat transfer can also be neglected. This is permitted since the vapour mass fraction and hence, the mass flux, is small. For vanishingly small m_{vi} (and a) the Ackermann correction Θ indeed tends to unity

$$\Theta(a) \to 1+\frac{a}{2}+O(a^2) \quad (a \to 0). \tag{8}$$

It is however not correct to set Θ equal to unity, thus taking the zero-order approximation of Θ for small a, while maintaining m_{vi} in the local energy balance

$$(q_g C_{pg}+q_v C_{pv})\frac{dT_m}{dz} = \pm h_0(\Theta(a)-a)(T_m-T_i)\frac{ds}{dz}. \tag{9}$$

This equation is the correct version of equation (2) of ref. [1], in which equation (5) of ref. [1] has been inserted. Equations (8) and (9) illustrate that it is false to take the zero-order approximation of Θ and first order approximation of a (which originates from the m_{vi} term in the energy balance).

A similar reasoning can be held for the momentum balance. The authors neglect the effect of suction on friction, but retain the mass flux in the momentum balance. From the expression derived in ref. [4]

$$\frac{dP}{dx} = -\frac{2\rho f\bar{u}^2}{D_h}\left(\Theta(b)-2\frac{\overline{u^2}}{\bar{u}^2}b\right) \tag{10}$$

with

$$b = \frac{2m_{vi}}{\rho f \bar{u}} \tag{11}$$

and equation (8) it follows that it is not allowed to set $\Theta(b)$ equal to unity for small b while retaining b (the momentum flux coefficient $\overline{u^2}/\bar{u}^2$ is practically unity for turbulent flow, see ref. [4]).

The authors do not explain how the interface temperature and (related) water vapour fraction are determined. These properties usually follow from an energy balance of latent and sensible heat fluxes to the gas–condensate interface, and heat transported away from this interface (through the condensate film and pipe wall to the coolant). The solution of the governing equations is not discussed either. Especially for countercurrent condensation this information is essential for the reader as the condensate film thickness at the entrance is not known *a priori*, and an iteration is required. For cocurrent condensation, on the other hand, standard marching schemes can be applied.

Pele *et al.* [1] start a discussion about the diffusivity coefficient and axial evolution of the boundary layer of diffusivity (equations (8)–(12) of ref. [1]). It is extremely difficult to follow this treatment as their aim and the derivation is not properly explained. If the aim of the authors is to include entry effects on transfer rates, I would like to refer them to the standard correlations found in ref. [5].

In the section Experimental Study the authors refer to thermocouples K for copper–constantan thermocouples, which are thermocouples T. Thermocouples K are made namely of chromel–alumel.

In the section Results, p. 1835, 2nd line, mv_i should be replaced by m_{vi}. Furthermore, the authors mention the saturated state of the air at the entrance of the tube. From ref. [6] it follows that for dilute and saturated mixtures of water vapour in air flowing in a tube the bulk properties become supersaturated since

$$\frac{Sh}{Nu\,Le} = Le^{-2/3} > 1 \tag{12}$$

$Le < 1$ for the considered mixture and by virtue of equation (2). As the authors did not account for fog formation in their model, the computed bulk properties at the exit should correspond to supersaturation (humidity > 100%). The authors find a humidity of 90% at the exit, which is not what I would have expected in view of equation (12). This suspicion is confirmed by the recently reported results by Peterson *et al.* [7]. Under similar experimental conditions as Pele *et al.* [1] these investigators noticed fog formation indeed. Supersaturation and fog formation may be the reasons why Pele *et al.* [1] have difficulties with the water (vapour) balances and find discrepancies between theory and experiments.

In the References section of Pele *et al.*'s paper [1] a large number of errors are found. Without pretending to be complete, a few examples are given in the following. In ref. 2, p. 1172 should be replaced by p. 1182. In ref. 4 the name F. Legeay-Desquelles should read F. Legay-Désesquelles. The second author's name of ref. 5 should read J. K. Aggarwal instead of J. K. Aggariwal. Also the title of this reference is not correct: the last words should read "...on a flat surface" instead of... "on a surface". The Ph.D. thesis of Dr A. C. Bannwart (ref. 8) stems from 1988 instead of 1984, and "Thèse" should be "Thèse de Doctorat". The mentioned authors (H. Hikita, K. Ishimi and H. Ikeki) of ref. 10 are not right, the right authors are H. Hikita, K. Ishimi, Y. Omotehara and T. Fukase. The page numbers of this reference are also missing, which are pp. 96–101. Furthermore, refs. 8 and 9 are not used in the paper at all.

Summarizing, Pele *et al.* [1] studied a standard problem, their paper is difficult to follow and contains a large number of textual and technical errors. Obviously, the paper has been written in haste and has not been prepared carefully.

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