A NEW DEFINITION OF BEJAN NUMBER

by

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A new definition of Bejan number will be generated by replacing the thermal diffusivity with the mass diffusivity.For example, the Schmidt number is the mass transfer analog of the Prandtl number. For the case of Reynolds analogy (Sc = Pr = = 1), both current and new definitions of Bejan number are the same. This new definition is useful and needed for diffusion of mass (mass diffusion).

Key words: *new definition, Bejan number, thermal diffusivity, mass diffusivity*

The Bejan numbers (Be) is named after Duke University Professor Adrian Bejan. It is used in fluid mechanics and heat transfer in general and represents the dimensionless pressure drop along a channel of length *L*. Historically, Bhattacharjee *et al.* [1] presented a systematic analysis of a pressure-driven wall jet. First, the researchers identified a model where the pressure gradient might become the dominant force in the wall boundary layer. They used numerical calculations to gain insight into the formation of the jet, and performed a simplified scale analysis for an idealized flow with favorable pressure gradient over a flat plate to identify the important non-dimensional groups. Using the scale analysis of the wall jet problem, they defined the dimensionless group:

$$\mathrm{Be} = \frac{\Delta P L^2}{\mu \nu} \tag{1}$$

where ΔP, L, μ, and ν are the pressure difference, the flow length, the dynamic viscosity, and the momentum diffusivity of the fluid, respectively. They named this dimensionless group "the Bejan number" in view of Bejan's contributions to the scale analysis of convection.

Later, Petrescu [2] defined the Bejan number (Be) as follows:

$$\mathrm{Be} = \frac{\Delta P L^2}{\mu \alpha} \tag{2}$$

where α is the thermal diffusivity of the fluid. This was similar to the new dimensionless group developed by Bejan and Sciubba [3] in their study on the optimal spacing between plates cooled by forced convection. Also, the same group appeared in the solutions to other electronic cooling problems involving forced convection [4]. In addition, the group defined in eq. (2) governed all the phenomena of contact melting and lubrication, in both internal and external contact configurations [5]. In the literature, the Bejan number is also named the pressure drop number.

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The researcher reported that the Bejan number was essential in at least four areas of heat transfer: electronic cooling, scale analysis of forced convection, second law analysis of heat exchangers, and contact melting and lubrication.

It is clear that the momentum diffusivity of the fluid (ν) in eq. (1) was replaced by the thermal diffusivity of the fluid (α) in eq. (2). There was almost no difference between eqs. (1) and (2) in the case of air cooled electronic packages (Pr = 0.72). Equation (2) was preferable to eq. (1) because of the many applications documented in the electronic cooling and contact melting literatures, and because $\Pr \geq 1$ in these applications. He commented that the Be group defined by eq. (2) was the forced convection ($\Pr \geq 1$) analog of the Rayleigh number (Ra) for natural convection in $\Pr \geq 1$ fluids. The optimal-spacing formulas developed for other geometries designed for forced convection: staggered plates [6], round cylinders in cross-flow [7, 8], and 3-D square pin fins on a heat generating surface cooled by impinging flow [9] reinforced this observation.

In the present note, the author suggests that the thermal diffusivity of the fluid (α) that was used by Petrescu [2] can be replaced by the mass diffusivity of the fluid (D) for mass transfer applications as:

$$\mathrm{Be} = \frac{\Delta P L^2}{\mu D} \tag{3}$$

For example, the Schmidt number (Sc) is the mass transfer analog of the Prandtl number (Pr). This new Be definition, eq. (3), is useful and needed in the design of structures for mass transfer.

For the case of Reynolds analogy (Sc = Pr = 1), it is clear that both current and new definitions of Bejan number, eq. (2) and eq. (3), are the same.

Finally, it can be seen that the new definition of Bejan number can be obtained from the Bejan number expression by simply replacing the thermal diffusivity (α) by the mass diffusivity (D). This shows what a powerful tool analogy between the quantities that appear in the formulation and solution of heat convection and mass convection that can be in the study of natural phenomena.

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