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Response to the comments of Hooman et al.

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Our thanks to Hooman et al. (2007) [3] for their comments on our published paper "Flow, thermal, and entropy generation characteristics inside a porous channel with viscous dissipation". Below we respond to their comments.

Brief overview

The paper "*Flow, thermal, and entropy generation characteristics inside a porous channel with viscous dissipation*" by Mahmud and Fraser [4] presents analytical expressions for velocity, temperature, heat transfer, and entropy generation rate with some numerical verifications for some special cases of the governing momentum and energy equations. The model is developed considering background physics of complicated thermoacoustic interactions between fluid and stack systems. A brief discussion of possible extensions to real thermoacoustic problems is also presented. Energy streamline patterns inside the channel are presented for some limited cases. Analytical expressions, graphical results, and tabulated data are suitable for further benchmarking and comparison. Analytical models are developed that depend on specific cases. Analytic models can be developed for other cases, but this is future work.

Detailed response to Hooman et al. comments

(a) If one looks carefully, one will find that the missing $\sqrt{Da}$ term in Eq. (10) appears in front of $\sinh(1/\sqrt{Da})$ in Eq. (12) of Mahmud and Fraser [4]. Eq. (12) is plotted in Fig. 3 of Mahmud and Fraser [4] where it is observed that the velocity is zero at both walls (no slip boundary condition) and the velocity gradient is zero at the centerline of the channel (symmetry). In the limit of large Da ($Da \to \infty$), the velocity profile approaches as expected a Poiseuille flow profile; that is, $\lim_{Da\to\infty}(u/u_{\text{av}}) = 1.5(1 - y^2)$ with $u_{\max}/u_{\text{av}} = 1.5$ at the channel centerline.

(b) It is observed from Figs. 4(a)–(b) of Mahmud and Fraser [4] that the boundary conditions are well satisfied ($\Theta(-1) = 0$ and $\Theta(1) = 1$) for both walls, hence the $1/2$ had to be present when Figs. 4(a)–(b) were calculated.

(c) *Singularity in Nu concern*: During the heat transfer study, we used a different than traditional definition [7] of Nusselt number as given in Eqs. (19)–(22) of Mahmud and Fraser [4]. The main reason for considering a non-traditional definition was to get a global expression of Nusselt number (Eq. (22)) which is independent of Ec, Pr, and Φ. However, it is not a complicated job to find a traditional Nusselt number expression once the analytical expressions for velocity and temperature are available. Now, if one recalls the characteristics of hyperbolic trigonometry functions (that is, $\sinh(-x) = -\sinh(x)$ and $\cosh(-x) = \cosh(x)$) it can be shown that the Nu^* distribution (see Fig. 1 below which is a modified version of Fig. 6 of Mahmud and Fraser [4]) at the bottom wall is simply a mirror image of the top wall Nu^* distribution. In short, the expression for Nu^*

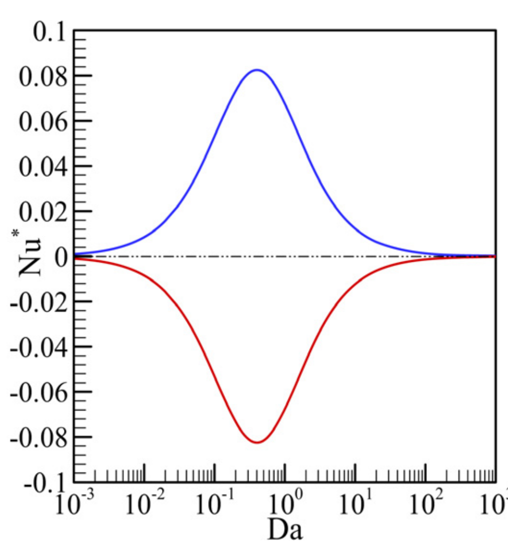

Fig. 1. A modified version of Fig. 6 of Mahmud and Fraser [4].

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in Eq. (22) of Mahmud and Fraser [4] is for the top wall and for the bottom wall the negative sign in front of Nu^* expression will become a positive sign. The existence of a singularity in the Nusselt number expression [5] is purely mathematical. This singularity arises due to the appearance of $(T_w - T_m)$ in the denominator of the Nusselt number definition; nothing to do with the physics of the problem. Nield [5] recognizes that the 'singularity' issue is a definition issue only. Now, Hooman et al. state "*Nusselt number behavior differs in having a singularity in the developing region, not only for flow in porous media but also for the clear fluid case*." There is no Nusselt number singularity issue in Refs. [2] (Ref. [11] of Hooman et al.) and [6] (Ref. [15] of Hooman et al.).

(d) *Dependence of Nu on Re, Pr, and Ec not shown concern*: The product of the pressure gradient and Reynolds number is correlated to Darcy number as shown in Fig. 2 and Eq. (11) [4], and this product is expressed as Φ. Because the pressure gradient is a function of the solution to the governing equation, Φ effectively replaces Re. The independent parameter Da determines the magnitude of Φ $(Re \times \partial p/\partial x)$ through the correlations reported in Eq. (11) or Fig. 2 [4]. In Fig. 5 [4], Nusselt number is expressed as a function of Da for selected $Ec \times Pr$ $(= Br)$. Fig. 5 [4] effectively provides information on Nusselt number dependence on Ec and Pr through Br. Therefore, the paper does provide information on Re, Pr, and Ec number dependences. The authors provide an alternate definition of Nusselt number (Nu^*) in Eq. (22) [4] that is a function of Darcy number only, and so the authors with their own alternate definition of Nu have already shown the uncoupling of Re, Pr, and Ec possibility. We believe Figs. 5 and 6 are sufficient to understand the nature of Nusselt number variation. Similarly, temperature distributions in Figs. 4(a) and (b) are sufficient to understand at least the nature of variation of temperature along the channel cross-section. It seems unnecessary to report a temperature distribution for all possible combinations of expressing parameters.

(e) *Darcy dissipation term concern*: The second Law modeling of heat transfer problems in porous media with viscous dissipation is a complicated and challenging problem. This complication and challenge always provides a chance to remodel or modify an existing model. The state of current porous media research is largely empirical. As for the validity of a porous media model, it cannot be proved without reliable experimental data. A good discussion on this issue is available in Adeyinka and Naterer [1]. Therefore, the disappearance of the Darcy term in Eq. (23) [4] when $n = 1$ is an admitted weakness of the porous media model selected, however, the porous media model used is one of the existing models considered by researchers. Hooman et al. identify a legitimate concern with the porous media model when $n = 1$. The authors believe that proposing improvements to the porous media model used is an excellent endeavor for future research. Do note, however, for example, in Fig. 4(a) [4] that at large Da the temperature distribution approaches the linear conduction result as expected so it is not clear if addressing the large Da concern would noticeably change the results. As said, investigating the effect at an alternative porous media model is a good idea for future research.

(f) *Thermal boundary condition concern*: The analytical model for temperature is a 1D model where temperature is a function of the y direction only and is valid only for the fully developed flow region. Inlet and outlet boundary conditions for the energy equation are therefore not required as suggested by Hooman et al. for there is no x dependency.

(g) *Energy streamline dimensional space concern*: For a particular set of parameters (Da, Ec, etc.) it is really unimportant which equation (dimensional or non-dimensional) one should use to calculate an energy streamline. The important information from energy streamlines is contained in the distribution pattern which will not vary in dimensional or non-dimensional space. Energy flux is constant as it flows between two energy streamlines just as mass flux is constant for incompressible flow between two fluid streamlines.

(h) *Energy streamline depends on more than Da concern*: It is agreed that the energy streamline depends on more parameters than Da. The intent of Fig. 12 [4] was to simply show some typical examples of energy streamline patterns. To reproduce Fig. 12 one would set $Ec \approx 1$, $Pr \approx 1$. In discussing Fig. 12 [4] the authors stated, "the magnitude of velocity increases along the axial direction in the developing region -----". This should read "the magnitude of centerline velocity increases along the axial direction in the developing region -----".

(i) *Darcy like dissipation term concern*: In Eq. (32) of Mahmud and Fraser [4] the Darcy like dissipation terms $\rho u \frac{u^2+v^2}{2}$ and $\rho v \frac{u^2+v^2}{2}$ are in fact simply the components of volume averaged velocity based kinetic energy flux density. These terms should not be divided by the porous medium permeability as suggested by Hooman et al. It is noted, however, that the solution to u and v does depends on Darcy dissipation.

(j) *Grid independence and code validation concern*: Academically it is reasonable position to take to request that grid independence and code validation be required in computational papers. The authors report on the numerical method and its reliability in Ref. [26] of Mahmud and Fraser [4], as noted in Section 2 of the paper.

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