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Letter to the Editor

Comments on "Flow distribution in U-type layers or stacks of planar fuel cells" by W.H. Huang, Q.S. Zhu [J. Power Sources 178 (2008) 353–362]

The above paper concerns the flow distribution and pressure drop in U-type layers or stacks of planar fuel cells [1]. Their model neglected the inertial term, retaining the friction. Then, an analytical solution was obtained. It should be pointed out that neglecting of the inertial term cannot be justified through an assumption of the laminar flow. The inertial effect on flow distribution has been proved both experimentally and theoretically.

Flow distribution and pressure drop in this type of manifold systems are classic issues in chemical, mechanical and civil engineering [1–3]. It is well known that the flow distribution in U-type manifolds is formulated as a second order nonlinear ordinary differential equation [2]:

$$\frac{dw_i}{dx}\frac{d^2w_i}{dx^2} + \frac{2-\beta_i}{\zeta}\left[1-\frac{2-\beta_e}{2-\beta_i}\left(\frac{F_i}{F_e}\right)^2\right]\left(\frac{F_c n}{F_i}\right)^2 w_i\frac{dw_i}{dx} + \frac{1}{2\zeta}\left[\frac{f_i}{D_i}+\frac{f_e}{D_e}\left(\frac{F_i}{F_e}\right)^2\right]\left(\frac{F_c n}{F_i}\right)^2 w_i^2 = 0 \quad (1)$$

where F_i, F_e and F_c are the cross-sectional areas of the intake header, exhaust header and the channel (m^2), respectively, f_i, f_e and f_c the frictional coefficients of the intake header, exhaust header and the channel, respectively, β_i and β_e the average velocity ratio in header of the intake header and the exhaust header, respectively, D_i and D_e the diameter of intake header and exhaust header (m), respectively, w_i the normalised axial velocity in intake header, n is the number of channels, ζ average total head loss coefficient for channel flow, and x normalised axial coordinate in the intake header.

The above equation is general in U-type manifold, including fuel cell stack. The second term in the left hand of Eq. (1) represents a momentum contribution known as the momentum term, and the third term does the friction contribution as the friction term.

Bajura and Jones [3], and Bassiouny and Martin [2] had stressed the effect of the inertial term and solved Eq. (1) after neglecting the frictional term (the third term). Kee et al. [4] and Maharudrayya et al. [5] retained the frictional term, but neglected the inertial term. Huang and Zhu [1] followed the approach of Maharudrayya et al. They used two constants, K_1 and K_2 a second order differential equation was derived as follows (for notional convenience, w_i replaces $\hat{u}_{f-layer}$):

$$\frac{d^2w_i}{dx^2} - 2K_1K_2w_i = 0 \quad (2)$$

Eq. (2) can be derived from Eq. (1) after neglecting the inertial term. It can be clearly seen that their two dimensionless constants of K_1 and K_2 are always positive. Therefore, Eq. (2) has only one solution compared with the three possible solutions of Eq. (1) as a second order nonlinear ordinary differential equation which depends on the polynomial discriminate of the coefficients of the friction and inertial terms.

The effects of the friction and inertial term can be estimated by [6]:

$$\frac{\text{friction term}}{\text{inertial term}} \approx \frac{f\rho w_i^2(a+b)}{\Delta(\rho abw_i^2)/\Delta x} = O\left(\frac{2f_iL}{D_i}\right) \quad (3)$$

where a and b are width and height of intake header (m), respectively, L header length (m), and ρ fluid density (kg m^{-3}). The friction factor, f, is given by the empirical correlation:

$$\mathrm{Re} f = 13.84 + 10.38\exp\left(\frac{-3.4a}{b}\right) \quad (4)$$

The friction factor of the laminar flows is below 0.028 using Eq. (4) for square shape when Re = 500. D_i/L should be 0.056 by Eq. (3) if the inertial term can be compared to the frictional one in terms of order of magnitude. Similarly, the friction factor is 0.014 when Re = 1000. D_i/L should be 0.028 when the inertial effect is comparable to the frictional one. The inertial term becomes non-negligible since the inertial effect will be equal to or greater than the frictional that if the ratio of the hydraulic diameter to its length is increased to be closed to or above 0.028. In practice, this estimate did not take the effect of the manifold structure on the friction and the pressure recovery factors into account. Because the branching flow results in a sudden expanding flow passage, the flow boundary layer could not be fully developed in the manifold system. The friction factor is smaller than that calculated by Eq. (4). Therefore, the practical error will be larger than the above estimate. The effect of the inertial terms on the flow branching and the spatial distribution has been proved by Oxarango et al. [7] and Kamisli [8] through the integration solution of the Navier–Stokes equations. Wang et al. [9,10] had analysed the effect of the manifold structures on the friction and the pressure recovery factors. The friction factor will be dependent on three ratios: the channel diameter to the header diameter, the spacing length to the header diameter, and the sum of the areas of all the channels to the cross-sectional area of header. The pressure recovery factor was formulated as follows:

$$k = \alpha + 2\beta\ln\frac{w}{w_0} \quad (5)$$

where k is pressure recovery factor, α and β are coefficients.

They reported that the pressure recovery factor was an order of 0.5–1. These have been confirmed by many experimental data [9–13].

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Recently Wang [14] defined two constants for Eq. (1):

$$Q = \frac{2-\beta_i}{3\zeta}\left[1-\frac{2-\beta_e}{2-\beta_i}\left(\frac{F_i}{F_e}\right)^2\right]\left(\frac{F_c n}{F_i}\right)^2 \tag{6}$$

$$R = -\frac{1}{4\zeta}\left[\frac{f_i}{D_i}+\frac{f_e}{D_e}\left(\frac{F_i}{F_e}\right)^2\right]\left(\frac{F_c n}{F_i}\right)^2 \tag{7}$$

Eq. (1) is reduced to the following equation:

$$\frac{dw_i}{dx}\frac{d^2w_i}{dx^2}+3Qw_i\frac{dw_i}{dx}-2Rw_i^2=0 \tag{8}$$

An analytical solution of Eq. (8) has been obtained by Wang [14] without neglecting the inertial and the frictional terms. The results showed that the inertial term does make a contribution to the flow momentum change. It may cause a significant error if the inertial term is neglected, particularly for a short manifold.

Furthermore, Wang has proved that there are three solutions for Eq. (1) rather than one solution. It is clear that the neglecting of the inertial terms has lost two solutions with the triangular function and the exponent function using Eq. (2). These two solutions have been proved experimentally [8–13]. It is not surprising that the phenomena of pressure rise cannot be captured by their model because there is no flow branching effect. Taking into account the above arguments, the problem is still open in the literature but one thing is sure: the inertial term in the flow equations is very important and the model cannot be corrected for the fluid branching effect without it. Hence, their models may cause a significant error.

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