# Experimental Verification of Pressure Profiles in Fuel Cell Cavities

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To study heat and mass transfer in fuel cells, we must have a good description of fluid motion in the geometrically complex gas compartments (*2*). We have already shown that a good description of such a motion can be obtained by the use of Darcy's law (*1, 3*) because the flow is slow. To describe two-dimensional motion we need two permeabilities. These can be either measured or obtained by the solution of the creeping flow equations. Unfortunately the solution of the three-dimensional Navier-Stokes equations, even for the typical geometric element involved in, for example, Allis-Chalmers plates, is excessively time-consuming with present generation computers (*3*). Therefore we decided to take the empirical approach. We measured the two permeabilities.

## PRESSURE DROP MEASUREMENTS

The apparatus and procedure for making pressure drop measurements have already been described (*1*) for the case of an actual oxygen plate. In this study the inlet and outlet ports of an Allis-Chalmers hydrogen plate were cut and distributor systems (called slotted ribs in Figure 1) introduced before and after the fuel cell plate (Section II in Figure 1). The purpose of the distributors was to obtain one-dimensional flow in the test section. The permeability was calculated using Equation (34) of Gidaspow and Sareen (*1*), where for one dimensional flow $\partial P/\partial y_A = \Delta P/L$. It was experimentally verified that $\Delta P/L$ was a constant by measuring pressure differences at several locations, as indicated in Figure 1. Then, in terms of the units defined in the Notation, we obtain

$$k_y = \frac{1}{3.23 \times 10^5} \frac{W}{\Delta P} \frac{\mu L}{V_g \rho} B \qquad (1)$$

To obtain the permeability $k_x$, the fluid was allowed to flow in the $x$-direction. This permeability is computed from Equation (1) by replacing the length $B$ with the width of the plate $A$. By this method the values of the permeabilities were calculated to be $k_y = 2.2 \times 10^{-7} \pm 1.7 \times 10^{-9}$ sq. ft. and $k_x = 1.78 \times 10^{-6} \pm 1.2 \times 10^{-8}$ sq. ft.

Having obtained the values of the permeabilities, it is now possible to verify the applicability of Laplace's equation to describe the flow inside the cavities. The Laplace's equation (*1*) to be verified is

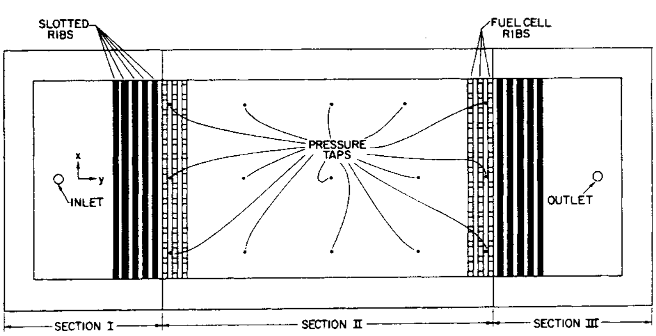


**Fig. 1. Cell for evaluation of $k_y$.**

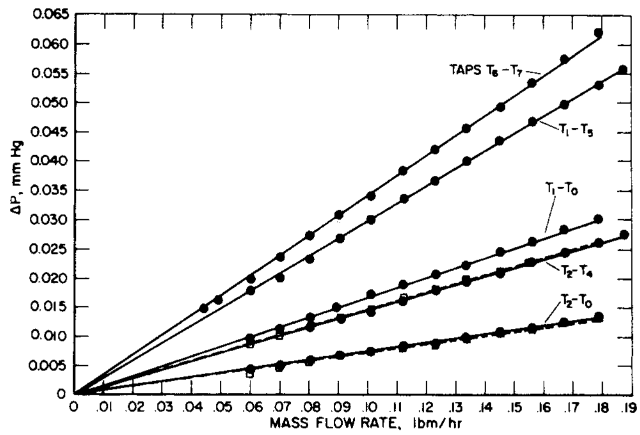


**Fig. 2. Pressure drops for hydrogen plate. For circles, positions shown; for squares, upper line $T_0 - T_5$, lower line $T_0 - T_4$.**

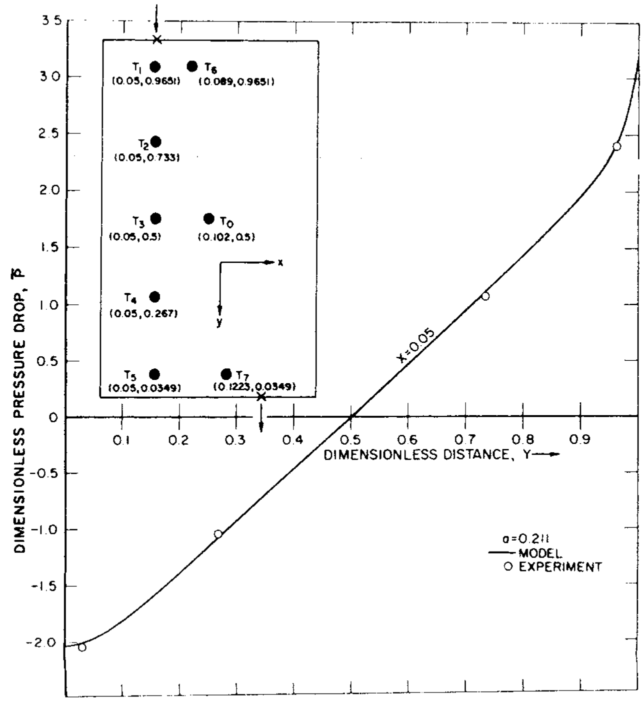


**Fig. 3. Pressure profile. "$a$" = 0.211 ($A/B$ = 0.6, $k_x/k_y$ = 8.11) $A$ = 0.3385 ft., $B$ = 0.5618 ft., $V_g$ = 7.255 x $10^{-4}$ cu. ft., sink coordinate (0.15825,0), source coordinate (0.05275,1).**

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$$k_x \frac{\partial^2 P}{\partial x_A^2} + k_y \frac{\partial^2 P}{\partial y_A^2} = 0 \qquad (2)$$

with the boundary condition that the gradient of pressure is zero on all the boundaries except at the source at $(x_A', B)$ and at the sink at $(x_A'', 0)$, where we have constant input and output, respectively. The solution to this boundary value problem was already given in reference *1*.

Pressure drop measurements were made at various points on an actual Allis-Chalmers hydrogen plate as shown in Figure 3. The pressure drop vs. flow rate relationships between the different points of measurement are shown in Figure 2. The pressure profile generated along $x = 0.05$ was matched against a theoretical profile, and the results are graphically presented in Figure 3. It should be noted that, in order to plot each experimental point shown in Figure 3, it was necessary to generate a complete flow rate vs. pressure drop profile as shown in Figure 2. The maximum deviation between the experimental and theoretical values is $\pm 5\%$. An error of this magniutde is conceivable on the basis of errors in pressure drop, flow rate readings, and volume of gas in the chambers. This verification enables us to use Darcy's law for description of fluid motion in fuel cell cavities with confidence.


## ACKNOWLEDGMENT

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## NOTATION

$a$ = dimensionless width of plate, $A/B \sqrt{k_y/k_x}$
$A$ = width of plate, ft.
$B$ = length of plate, ft.
$k_x, k_y$ = permeabilities in the $x_A$ and $y_A$ directions respectively, ft.$^2$
$L$ = distance between points for pressure drop measurement, ft.
$P$ = pressure, lb.$_f$/sq.ft.
$\Delta P$ = pressure drop, mm. Hg.
$\overline{P}$ = dimensionless pressure drop, $\dfrac{\Delta P g_c V_g \sqrt{k_x k_y}}{QAB\mu}$
$Q$ = volumetric flow rate, cu.ft./sec.
$V_g$ = volume of fluid in gas compartment, cu.ft.
$W$ = mass flow rate, lb.$_m$/hr.
$x$ = dimensionless space coordinate, $(x_A/B)\sqrt{k_y/k_x}$
$x_A$ = actual space coordinate, ft.
$y_A$ = actual space coordinate, ft.
$\mu$ = viscosity, lb.$_m$/ft.-sec.
$\rho$ = density, lb.$_m$/cu.ft.

## LITERATURE CITED


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# Note on the Feedback Control of a Stirred Tank Reactor


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Huber and Kermode (*1*) recently presented a "predictive feedback" regulator control analysis for linear, lumped, single-variable process systems containing time delays and a sample-hold combination. Some additional insight into this regulator scheme can be obtained from an analysis of the information flow in the system. The process model used by these authors can be represented by the signal flow diagram of Figure 1. Conventional feedback control of this process is shown by the dashed line of Figure 2, which corresponds to Figure 1 of the cited reference.

## PROPOSED CONTROL SCHEME

In the method proposed by Huber and Kermode, two more control functions are added to reduce the effects of the operator D on the control quality. This control scheme is illustrated in Figure 3, where the two controllers are shown as $F_1$ and $F_2$. This Figure 3 corresponds to Figure 4 of the cited reference. The controller $F_1$ is specified as the negative of the transmission path $(g_1/g_2)D$ from $\hat{\theta}$ to $\hat{x}^*$. This exactly eliminates the transmission from $\hat{\theta}$ to $\hat{x}^*$. The controller $F_2$ is then specified as being equal to the

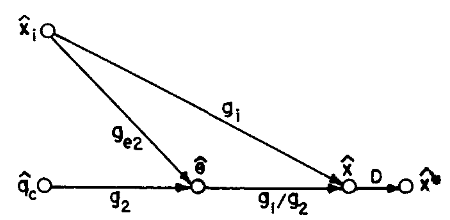


Fig. 1. Continuous flow stirred tank reactor model.

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