A Two-Phase Pressure Drop Model Incorporating Local Water Balance and Reactant Consumption in PEM Fuel Cell Gas Channels

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A two-phase 1-D pressure drop modeling scheme that incorporates the effect of local channel saturation on flow regime is introduced. The model provides a basis for extending two-phase pressure drop correlations from fundamental studies to more complex conditions within PEMFC reactant channels. The need for additional studies beyond the fundamental level is highlighted and key factors that separate PEMFC reactant channel conditions are explained. A crucial concern in characterizing two-phase flow within PEMFC reactant channels is the local flow pattern transitions throughout the channel. The application of an elemental step-wise calculation scheme approach for the prediction of localized two-phase conditions allows for a more complete prediction of conditions within the channels. Additionally through the application of a control volume approach, the effect of water addition and mass consumption of reactants on pressure drop within PEMFC flow channels is investigated. The resulting modeling scheme shows the relative effects of relaxing several of the common assumptions made when modeling PEMFC reactant channels.

Introduction

Water and thermal management techniques remain as one of the key roadblocks in proton exchange membrane fuel cells (PEMFCs). The ability to model two-phase flow and pressure drop in PEMFCs is of significant importance to the fundamental study and optimization of PEMFC performance. Pressure drop has been repeatedly linked to overall fuel cell performance as noted by Bosco and Fronk (1), and directly affects cost and sizing of fuel cell subsystems. Within several regions of PEMFC operating conditions the potential for flooding hinders potential performance and operation at high current densities is subject to potentially sizeable mass transport losses. These factors lead to the need for more complex systems and expensive blowers for reactant delivery. Increasing accuracy in pressure drop modeling within the PEMFC field can significantly reduce this need. Extensive review of two-phase flow in microchannels has been summarized by Anderson et al. (2) and Kandlikar et al. (3).

Two-Phase Pressure Drop Studies

Flow in PEMFC flow channels is most closely related to flow with condensation within mini and microchannels. A primary consideration in characterizing two-phase flow within channels is the flow pattern transitions throughout the channels. The flow pattern provides the foundation for the fundamental pressure drop and heat transfer
characteristics. The majority of literature on two-phase flow regimes focuses on simultaneous air and water introduction at the inlet of the channel (4-17), unlike PEMFCs which experience continuous water introduction. As the quality changes along the PEMFC microchannel, progression between different flow patterns is seen and develops distinct flow regimes. Scaling of large tube correlations for pressure drop do not yield accurate results due to the dissimilar comparative magnitude of the gravitational, viscous, and surface tension forces between large scale tubes and microchannels (3).

Two-phase pressure drop has been investigated from two fundamental perspectives, classified as either homogenous or separated models. In homogenous models, the superficial velocity of both phases is considered to be equal and it follows that the fluid properties are estimated by a two-phase density and viscosity. These correlations were well reviewed by Saisorn and Wongwises (4). Notably, Dukler (5) proposed the two-phase viscosity as a function of volumetric quality in applying homogeneous flow model.

Conversely, in separated flow models the superficial velocity of each phase is calculated separately. A two-phase multiplier is utilized based on flow conditions to scale the single-phase pressure drop. Most notably, this form of modeling is strongly based on the model by Lockhart and Martinelli (6) which gave the two-phase multiplier ($\phi$) as:

$$\phi^L = 1 + \frac{C}{X} + \frac{1}{X^2}$$  \[1\]

for liquid single-phase pressure drop and:

$$\phi^G = 1 + CX + X^2$$  \[2\]

for gas single-phase pressure drop, where $X$ is given by:

$$X = \left(\frac{\mu_1}{\mu_g}\right)^{0.1} \left(\frac{\rho_g}{\rho_1}\right)^{0.5} \left(\frac{1-x}{x}\right)^{0.9}$$  \[3\]

Chisholm (7) later provided a basis for predicting $C$ (the Chisholm parameter) based on the liquid and gas Reynold’s numbers. This parameter has become the primary basis for furthering two-phase pressure drop correlations. Five notable studies are summarized in Table I, each of which updated the correlation for the Chisholm parameter.

In 1996, Mishima and Hibiki (8) conducted experiments with 1 to 4 mm hydraulic diameter channels with both circular and rectangular cross-sections. Over a wide range of superficial velocities, turbulent flow was observed in both the liquid and gaseous phases. The Chisholm parameter was then correlated to hydraulic diameter. In 2006, English and Kandlikar (9) observed laminar flow conditions, and similarly correlated hydraulic diameter to the Chisholm parameter.

In 2001, Lee and Lee (10) conducted experiments varying aspect ratio with channels of hydraulic diameter from 0.78 to 6.67 mm. They proposed a Chisholm parameter as a function of three non-dimensional parameters. In 2010, Saisorn and Wongwises (11) added quality as an additional non-dimension parameter to Lee and Lee’s model and provided alternative constants and exponents. In 2012, Grimm et al. (18) utilized a test section that provided continuous water introduction in lieu of simultaneous introduction at the entrance. The study provided modifications to English and Kandlikar (9) model to incorporate mass quality, as well as a three part flow regime separated model based on Lee and Lee’s (10) work.
<table>
<thead>
<tr>
<th>Investigator</th>
<th>Hydraulic Diameter</th>
<th>Orientation / Cross-section</th>
<th>Superficial Velocity Range</th>
<th>Key Conditions / Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mishima and Hibiki (1996)</td>
<td>1-4 mm</td>
<td>Vertical Upwards</td>
<td>0.0896 &lt; j_g &lt; 79.3 m/s</td>
<td>Observed turbulent flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.0116 &lt; j_l &lt; 1.67 m/s</td>
<td>Correlated C to D_h</td>
</tr>
<tr>
<td>Lee and Lee (2001)</td>
<td>0.78, 1.90, 3.64, 6.67 mm</td>
<td>Horizontal / Width constant at 20 mm</td>
<td>0.03 &lt; j_g &lt; 18.7 m/s</td>
<td>Correlated C to a function of ( \psi, \lambda, ) and Re</td>
</tr>
<tr>
<td>English and Kandlikar (2006)</td>
<td>1.018 mm</td>
<td>Horizontal / 1.124 x 0.930 mm</td>
<td>3.19 &lt; j_g &lt; 10.06 m/s</td>
<td>Observed laminar flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.0005 &lt; j_l &lt; 0.0217 m/s</td>
<td>Investigated surfactants</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Correlated C to D_h</td>
</tr>
<tr>
<td>Saisorn and Wongwises (2010)</td>
<td>0.15, 0.22, 0.53 mm</td>
<td>Horizontal / Circular</td>
<td>0.37 &lt; j_g &lt; 42.36 m/s</td>
<td>Added mass quality to correlation proposed by Lee and Lee</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.005 &lt; j_l &lt; 3.04 m/s</td>
<td></td>
</tr>
<tr>
<td>Grimm et al. (2012)</td>
<td>0.51 mm</td>
<td>Vertical / 0.4 x 0.7 mm</td>
<td>0.5 &lt; j_g &lt; 29.5 m/s</td>
<td>Incorporated continuous water introduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.5 x 10^{-3} &lt; j_l &lt; 1.5 x 10^{-3} m/s</td>
<td></td>
</tr>
</tbody>
</table>

While all of these two-phase pressure drop studies provide a basis for investigating PEMFC reactant channels, their range of applicability is very narrow. While most work in two-phase pressure drop focuses primarily on simultaneous air and water introduction at the inlet of the channel, this is not representative of PEMFC gas channels. Continuous water introduction from the reaction through the gas diffusion layer and condensation of water vapor from the flow stream play a primary role in a changing quality along the channel. The continuous water introduction creates a variable liquid mass flow rate, which creates the potential for flow regime changes along the channel. Furthermore, mass consumption of reactant gases is neglected in all the previous studies reported in Table I. The consumption of species along the channel creates a variable reactant mass flow rate, which further causes changes in local flow patterns.

In many of these studies, channel dimensions are not representative of typical PEMFC reactant channels. The hydraulic diameter of a typical PEMFC reactant channel is on the order of 500 \( \mu \)m, while most studies have hydraulic diameters of greater than 1 mm. The cross-section of the PEMFC reactant channels is typically rectangular or trapezoidal with a narrow range of aspect ratios, while typical studies are often circular and include aspect ratios well outside the range for use in PEMFC.

It has been shown in several studies (11-13, 19-20) that the material and consequently surface energy of the flow channel affects flow pattern transitions. Typical materials that have been used in PEMFC reactant channels are stainless steel, graphite, and gold plating. However, most two-phase pressure drop studies used alternative materials; Grimm et al. (18), English and Kandlikar (9), and Lee and Lee (10) all used Lexan channels, while Saisorn and Wongwises (11) used fused silica tubes, and Mishima and Hibiki (8) used both glass and aluminum.

A final key parameter that has not been well investigated in two-phase pressure drop in microchannels is elevated temperatures. It is well known that PEMFCs typically have improved performance at 80°C (21). However, all of the most prominent two-phase pressure drop studies have been conducted at room temperature (4-11).
In this work, a method to fully incorporate these key conditions and operating parameters is presented. The relative effect of several areas that have not been previously considered is shown through an iterative approach.

**Model Framework**

**Model Formulation**

Due to the unique conditions inside PEMFC gas channels, an exhaustive model is needed to provide accurate prediction of pressure drop within an operating PEMFC. Key factors, including mass consumption, temperature variation, local flow patterns, and the method of water introduction must be integrated into traditional two-phase pressure drop correlations to increase the applicability to the PEMFC field.

The presence of variable flow rates of both reactants and product water merit a 1D analysis with element division along the flow length to evaluate the effects of local water saturation and flow pattern transition on pressure drop. The use of an elemental approach allows for the identification of flow pattern transitions along the channel length, which have been shown to significantly affect local pressure drop (8-12, 18). For the proposed model, 14 elements are utilized to represent a typical PEMFC reactant channel, as presented in Figure 1.

**Figure 1. Schematic of element division in the proposed PEM fuel cell pressure drop model.**

The single-phase entrance region and the two-phase exit region are represented by elements 1 and 14 respectively. Elements 2 through 13 are distributed evenly along the active area. These elements are grouped into four segments which correspond to key visualization areas in both future in situ and ex situ investigations (18, 22-23).

At each element, a mass flow balance is applied on the control volume to determine the liquid water and reactant flow rates. The mass fluxes of reactants, liquid water, and water vapor are shown in Figure 2. In each control volume, liquid water and water vapor are treated separately in order to account for the effects of temperature and relative humidity on the reactant stream’s fluid properties. At typical PEMFC operating temperatures, a significant portion of the product water can be transported as water vapor if the inlet stream is not fully humidified.
Figure 2. Control volume for mass flow balance.

An added feature in this model is the incorporation of mass consumption along the channel length. This has been assumed to be negligible by many studies including (18, 24). Due to the combined fact that O\textsubscript{2} comprises only 21% of the cathode reactant stream at the inlet and a stoichiometric ratio of 2 or higher is generally employed, the mass consumption on the cathode is typically ignored. While this assumption holds reasonably well on the cathode side, it does not properly predict the non-linear pressure drop on the anode side.

When a dry reactant inlet stream is assumed, the mass flow of liquid product water into a dry reactant stream will cause an increase in the reactant stream’s relative humidity based on evaporation rates. Conversely, mass consumption along the channel causes a reduction in the mass flow of water vapor that can be held within the stream causing condensation within the channel. This effect is accounted for using a limiting factor for evaporation based on local flow conditions. For this investigation, thermal equilibrium is assumed such that the limiting factor is 1.

One of the key factors to consider in PEMFC reactant channel’s local conditions is the linkage between anode and cathode reactant channels. This linkage results in mass flux of water between anode and cathode due to electro-osmotic drag, thermo-osmosis, hydraulic permeation, and back diffusion, as well as the variable reduction of mass flow rate along the channel due to local reaction rates. Without expanding this model to include predictive cell performance, the effects of reaction rates are captured through the use of local current density. In order to encapsulate the effect of electro-osmotic drag and back diffusion, the net water transport is represented as m, the fraction of product water to the cathode.
Governing Equations

Minor Losses. While many previous studies offer idealized measurement of pressure drop, PEMFC research requires multichannel measurement and accounting for minor losses in the manifold. This yields an overall pressure drop given by:

$$\Delta P_{tot} = \Delta P_{in} + \Delta P_c + \Delta P_{er} + \sum_{k=\alpha}^b \left( \Delta P_{E,k} \right) + \Delta P_e + \Delta P_{ex}$$ [4]

where $\Delta P_{tot}$ is the total pressure drop in the PEMFC, $\Delta P_{in}$ is entrance region effects, $\Delta P_c$ the contraction effects entering the channel, $\Delta P_{er}$ is the entrance region, $\Delta P_{E,k}$ is the pressure drop at each element $k$ over the active area, $\Delta P_e$ is the expansion effects, and $\Delta P_{ex}$ is the pressure drop in the exit region. The pressure drop due to entrance region effects is:

$$\Delta P_{in} = \left. \frac{K_{in} \rho_g U_g^2}{2} \right|_{k=0}$$ [5]

where $U_g$ is the superficial velocity of reactant, $\rho_g$ is the density of the reactant, and $K_{in}$ is the entrance effects constant. The entrance effects constant is a function of channel dimensions and can calculated by:

$$K_{in} = 0.6796 + 1.2197\alpha + 3.3089\alpha^2 - 9.592\alpha^3 + 8.9089\alpha^4 - 2.9959\alpha^5$$ [6]

where $\alpha$ is the aspect ratio of the channel cross-section. The contraction and expansion effects entering the channels, respectively, are given by:

$$\Delta P_c = \left. \frac{N_c K_c \rho_g U_g^2}{2} \right|_{k=0}$$ [7]

$$\Delta P_e = \left. \frac{N_c K_e \rho_g U_g^2}{2} \right|_{k=k_{max}}$$ [8]

where $N_c$ is the number of channels per manifold and $K_c / K_e$ are loss coefficients. $K_c / K_e$ are functions of area ratio and Reynold’s number which for microchannels can be obtained from an investigation by Kays and London (25). The pressure drop within the entrance region ($k=1$) is:

$$\Delta P_{er} = fRe \left. \frac{2L_{er} \mu_g W_{tot}}{\rho_g A_c D_h^2} \right|_{k=1}$$ [9]

where $L_{er}$ is the length of the entrance region, $W_{tot}$ is the total inlet reactant mass flow rate, $A_c$ is the cross-sectional area of the channel, and $D_h$ is the hydraulic diameter of the channel. The friction factor, $fRe$, is given by:

$$fRe = 24(1 - 1.3553\alpha + 1.9467\alpha^2 - 1.7012\alpha^3 + 0.9564\alpha^4 - 0.2537\alpha^5)$$ [10]

Control Volume Analysis. At each element, the mass flow balance is evaluated to calculate the local two-phase flow conditions. The mass consumption of species within
each element is governed by Faraday’s Laws. Thus, the general equation for rate of mass consumption is:

\[ W_{\text{consumed}} = \frac{i_k A_r}{n_F} (M_{\text{reactant}}) \]  \[ 11 \]

where \( i_k \) is the local current density, \( A_r \) is the active reaction area per element, \( n \) is the number of electrons transferred per mole of species, \( M_{\text{reactant}} \) is the molar mass of the reactant of interest, and \( F \) is Faraday’s constant. Applying this equation to a generic element on each of the cathode and anode sides respectively yields:

\[ W_{\text{air},k} = W_{\text{air},k-1} - \frac{i_k A_r}{n_{c a} F} (M_{\text{air}}) \]  \[ 12a \]

\[ W_{H_2,k} = W_{H_2,k-1} - \frac{i_k A_r}{n_{a n} F} (M_{H_2}) \]  \[ b \]

where \( W_{k-1} \) is the mass flow rate from the previous element. Similarly, applying Faraday’s Laws to the total water flow rate within each element yields:

\[ W_{H_2O,an,k} = W_{H_2O,an,k-1} + \frac{i_k A_r M_{H_2O}}{n_{H_2O} F} (1 - m) \]  \[ 13a \]

\[ W_{H_2O,ca,k} = W_{H_2O,ca,k-1} + \frac{i_k A_r M_{H_2O}}{n_{H_2O} F} (m) \]  \[ b \]

where the scaling factor \( m \) denotes the fraction of product water transported to the cathode gas channels. The simplified form is used to quantify the net water transport across the membrane due to several transport mechanisms with varying dependence on the local operating conditions. While a value of \( m \) can be obtained from in depth analysis of electro-osmotic drag, back diffusion, hydraulic permeation, and thermo-osmosis, it can also be obtained more directly from experimental data or as a net drag coefficient. Depth of analysis in this parameter should be judiciously selected, as these factors introduce significant complexity and require further investigation (26).

Within each element, the local saturation pressure can be calculated through a polynomial fit:

\[ P_{\text{sat},k} = [-2846.4 + 411.24T - 10.554T^2 + 0.16636T^3]_k \]  \[ 14 \]

where \( T_k \) is the temperature at each element (21). Utilizing the local saturation pressure, element pressure, and net flow of reactant through the element, the maximum flow rate of water that can be evaporated into the stream is calculated by Equation 15.

\[ W_{H_2O,g,k}^{\text{max}} = \left[ \frac{W_{\text{reactant}} \left( \frac{P_{\text{sat}}}{P} \right)}{1 - \left( \frac{P_{\text{sat}}}{P} \right)} \right]_k \]  \[ 15 \]

The rate of evaporation and magnitude of change in water mass flow rate can affect whether this value is achieved in each element which is accounted for using a limiting factor. The assumption of thermal equilibrium forces the limiting factor to 1 which
reduces the equation for gaseous water mass flow rate to a simple logic statement as shown in Equation 16.

\[
W_{H_2O,g,k} = \begin{cases} 
W_{H_2O,k}^\text{max} & W_{H_2O,g,k}^\text{max} \geq W_{H_2O,an,k} \\
W_{H_2O,k}^\text{max} & W_{H_2O,g,k}^\text{max} < W_{H_2O,an,k}
\end{cases}
\]  

[16]

The assumption of thermal equilibrium could be relaxed to capture the effect of air flow rate on local relative humidity in each element through further investigation. The local humidified reactant properties, most notably density and viscosity, can be calculated through a number of widely available correlations, which were summarized well by Tsilingiris (27).

Using local fluid properties, the generic equation for the Lockhart-Martinelli parameter is:

\[
X_k = \left( \frac{\mu}{\mu_g} \right)^{0.1} \left( \frac{\rho_g}{\rho_{liq}} \right)^{0.5} \left( \frac{1-x}{x} \right)^{0.9}
\]  

[17]

where \( \mu_e \) is the viscosity and \( \rho_g \) is the density of the humidified reactant stream. The mass quality ratio, \( x \), for the cathode and anode sides respectively is given by:

\[
x_{ca,k} = \left[ \frac{W_{air}+W_{H_2O,g}}{W_{air}+W_{H_2O}} \right]_k
\]  

[18a]

\[
x_{an,k} = \left[ \frac{W_{H_2}+W_{H_2O,g}}{W_{H_2}+W_{H_2O}} \right]_k
\]  

[b]

Many widely available correlations for the Chisholm parameter can be used, however none have been developed specifically for PEMFC conditions. Using the correlation proposed by English and Kandlikar (9), the Chisholm parameter is:

\[
C = 5(1 - e^{-0.319D_h})
\]  

[19]

where \( D_h \) is the hydraulic diameter. This was later modified by Grimm et al. (18) through the use of:

\[
C = A \left( \frac{1-x}{x} \right)^b
\]  

[20]

where \( A \) is given by:

\[
A = 0.0856(U_L)^{-1.202}
\]  

[21]

and where \( b \) is given by:

\[
b = 0.0856(U_L)^{-0.526}
\]  

[22]

The two-phase pressure drop is then calculated using the correlation proposed by Lockhart (6) shown in Equations 23 and 24:
\[ \phi_{g,k}^2 = [1 + CX + X^2]_k \]  

\[ \Delta P_{E,k} = \left[ \phi_g \Delta P_g \right]_k \]  

where \( \Delta P_g \) is the single-phase gas pressure drop, which is given by:

\[ \Delta P_{g,k} = \left[ fRe \frac{2L_e \mu_g W_{tot}}{\rho_g A_c D_h^5} \right]_k \]  

Additionally, it should be noted that in the case of mist flow a homogenous two-phase pressure drop model can be substituted. The two-phase viscosity can be calculated by:

\[ \mu_{tp} = \left[ \beta \mu_g + \mu_l (1 - \beta) \right]_{k=1} \]  

where \( \beta \) is the volumetric quality which is given by:

\[ \beta = \frac{Q_{air} + Q_{H_2} L_{g}}{Q_{air} + Q_{H_2} L_{o}} \]  

as proposed by Dukler (5). The two-phase density is given by the ratio of mass quality to phase density, as shown in Equation 28.

\[ \rho_{tp} = \left[ \frac{x}{\rho_g} + \frac{(1-x)}{\rho_l} \right] \]  

By modifying Equations 23 and 24 to represent the exit region, the pressure drop can be represented by Equations 29 and 30.

\[ \Delta P_{g,ex} = fRe \frac{2L_{ex} \mu_g W_{tot}}{\rho_g A_c D_h^5} \]  

\[ \Delta P_{ex} = \phi_{g,max} \Delta P_{g,ex} \]  

The summation of these \( \Delta P \) values along the length of the channel provides the total PEMFC pressure drop (Equation 4).

**Results and Discussion**

**Case Study Selection**

In order to investigate the effects of local water balance and reactant consumption on pressure drop within PEMFCs, gas channels representative of current automotive industry design and performance targets are simulated. The PEMFC flow channel design features, such as aspect ratio and channel geometry, were utilized from a previous water management investigation (28). The key dimensions of the simulated PEMFC flow channels are given in Table II.
TABLE II. Key Flow Channel Dimensions

<table>
<thead>
<tr>
<th></th>
<th>Cathode Flow Channels</th>
<th>Anode Flow Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Depth</td>
<td>0.4 mm</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>Channel Width</td>
<td>0.7 mm</td>
<td>0.7 mm</td>
</tr>
<tr>
<td>Channel Spacing</td>
<td>0.5 mm</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>Channel Length</td>
<td>233 mm</td>
<td>233 mm</td>
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<tr>
<td>Geometry</td>
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<td>Rectangular</td>
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<tr>
<td>Number of Channels</td>
<td>22</td>
<td>11</td>
</tr>
<tr>
<td>Flow Field Geometry</td>
<td>Straight with 11° sw</td>
<td>Straight with 11° swback</td>
</tr>
</tbody>
</table>

In the initial investigation, a current density of 1.0 A/cm² is used for Figures 3-5, with a stoichiometric ratio of 2 for the cathode and 1.5 for the anode. Local element temperature and current density are held uniform in order to prevent ambiguity and show the direct effects of consumption and local saturation while clearly illustrating the need for further research in this area. In Figure 2, the effect of the incorporation of mass consumption along the channel length is shown.

Due to the combined fact that O₂ comprises only 21% of the cathode dry reactant stream at the inlet, the change in superficial gas velocity along the length remains relatively low, generally less than 10%. However, along the anode flow channels the superficial gas velocity changes significantly with a 68% reduction in superficial gas velocity. If traditional models are used, this causes a significant over prediction of pressure drop towards the outlet of the flow channels. The change in superficial velocity also causes a significant change in quality, as shown in Figure 4.
In Figure 4a, there is a significant decrease in mass quality long the anode flow channel. Despite most product water being transported to the cathode side, the mass quality does not decrease as sharply due to the more uniform superficial gas velocities. In Figure 4b, the effect of applying thermodynamic equilibrium at each element is shown. On the cathode side, the quality remains at 1 for nearly 40% of the channel length due to the streams capacity to remove product water as vapor. This change in quality prediction can cause a noteworthy change in the definition of the flow pattern maps, meriting further investigation into a well-defined limiting factor for evaporation.

In Figure 5, the cathode reactant stream’s ability to remove product water based on inlet relative humidity and PEMFC temperature is shown. This illustrates as the temperature range approaches typical PEMFC operation local channel mass quality approaches 1, as a significant portion of product water can be removed in vapor form. However primarily two-phase pressure drop models have been studied at lower mass qualities (6-8), thus further two-phase pressure drop research is needed in high mass quality flows.
Summary

In this study, the state of PEMFC flow channel two-phase pressure drop modeling is briefly reviewed and key considerations for PEMFC flow channels are identified. A methodology to fully incorporate these key considerations and operating parameters through the use of an iterative approach is presented. The relative effect of several areas that have not been previously considered is shown and areas in need of further research are highlighted.

- The lack of data within typical temperature operating ranges limits applicability of most two-pressure drop studies for PEMFC applications.
- The effect of consumption of reactants along the channel is shown to create significant changes in flow conditions along the length of a PEMFC flow channel. While consumption does not introduce unreasonable errors on the cathode side, without accounting for consumption the non-linear pressure drop along the channel cannot be predicted on the anode side.
- Continuous water introduction, gas consumption, and local temperatures play a primary role in a change in quality along the channel. This creates the potential for flow regime changes along the channel. Thus necessitating local flow pattern prediction within PEM fuel cell pressure drop models.

These unique conditions merit a step-wise modeling approach to predict local water saturation, flow patterns, and pressure drop.

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References