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Assessing fuel-cell coolant flow fields with numerical models and infrared thermography

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ABSTRACT

Proper thermal management is important to the successful operation and durability of proton exchange membrane fuel cell (PEMFC) systems. In liquid cooled fuel cell systems, the planar temperature distribution of the cell is largely controlled by the coolant flow field (CFF) design inside bipolar plates (BPPs). We characterize the temperature distribution of the coolant in two different CFF designs made out of Ti–6Al–4V titanium alloy by using infrared (IR) thermography and a coupled heat-transfer numerical model. Numerical models show that the two CFFs have nearly equivalent global heat transfer characteristics and temperature distributions but very different coolant flow characteristics; one design has uneven flow through parallel cooling channels and the other design has even flow through parallel cooling channels. These two designs are used to probe the capability of IR thermography to resolve subtle differences in temperature distribution in the CFFs. We find that the temperature distribution in CFFs measured using IR thermography matches the predicted numerical model results. We conclude that IR thermograph is a useful tool for characterizing CFFs because it can visualize local temperature differences caused by trapped bubbles in addition to the overall in-plane temperature distribution.

Introduction

Proton exchange membrane fuel cells (PEMFCs) produce electricity from the electrochemical reaction of H_2 fuel with the O_2 from air and operate at 50–80 °C. Even though PEMFCs have relatively high chemical to electrical energy conversion efficiencies, the remaining energy must be shed as low-quality heat to keep cells from overheating [1,2]. In high power PEMFCs, the heat is typically rejected to the environment by circulating a liquid coolant, e.g. ethylene glycol/water, through the PEMFC to an external radiator or heat exchanger [3]. Within the PEMFC, the coolant is typically distributed through channels, or coolant flow fields (CFFs) inside the bipolar plates (BPPs) that separate individual cells in a fuel cell stack. The opposite sides of the BPPs are used for reactant (H_2 and air) and product (H_2O) distribution.

The goal of CFF design is to produce a temperature profile with enough uniformity to support cell operation without overheating, while balancing temperature uniformity against the parasitic power requirements of pumping coolant through the design [4,5]. An added challenge unique to designing fuel-

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cell CFFs is that channel walls must also act as current vias between individual cells in a fuel cell stack. Numerous CFF designs have been developed over the years and resemble the designs of plate heat exchangers.

Several studies have numerically investigated what the optimal CFF design should be with regards to temperature profile and pressure drop [6,7]. In these studies, the optimum design is considered to be the design with the most uniform temperature distribution at similar pressure drops. Pressure drop is an important characteristic to consider because it relates directly to the parasitic power required to circulate coolant through the cell. Other studies have used either modeling or thermal imaging to determine the thermal properties of the whole PEMFC stack and how free convection affects stack temperatures [8–10].

Another change in thermal management of stacks is the migration of the BPP materials from carbon to metals. Metal is becoming the material of choice in PEMFC BPPs as it enables the production of cheaper and lighter BPPs [10–12]. Metals have other benefits such as low coolant crossover, plus their malleability and strength sustains higher stack compression forces and provides more ruggedness than carbon. The tensile strength of molded carbon is 20–60 MPa as compared to 515 MPa for 316L stainless steel, the most common BPP material [13–15]. Metal BPPs can have a decreased wall thickness because carbon BPPs need to be thicker and heavier to achieve the same strength and robustness as an equivalent metal BPP. The disadvantage of metals is that they have lower thermal conductivity than carbon-based materials: 16.3 W m^{-1} K^{-1} for 316L stainless steel and 6.7 W m^{-1} K^{-1} for Ti–6Al–4V titanium alloy vs. 95 W m^{-1} K^{-1} for Poco carbon or 275 W m^{-1} K^{-1} for expanded graphite (x,y plane) [16–18]. The thermal conductivity of graphite composite material which is often used in low temperature fuel cells as bipolar material is between 20 and 50 W m^{-1} K^{-1} [19,20].

We evaluate heat rejection in Ti metal BPPs herein using IR thermography of two different numerically-developed CFF designs with nearly equivalent global heat transfer characteristics but very different coolant flow characteristics; one with uneven coolant flow distribution the other with even coolant flow distribution. The coolant flow distributions within these CFF designs are calculated via computational fluid dynamics (CFD). The calculated coolant flow distributions are verified against dye flow experiments of the CFFs printed in plastic. A similar approach was used to study the gas channels in fuel cells [21]. Then, the effectiveness of IR thermography is characterized through comparison of a coupled heat-transfer numerical model to thermal images of the coolant in heated CFFs. Thermal images of the coolant are acquired by affixing an IR transmissive window to an open CFF to enclose the coolant for viewing while being heated from the side opposite the window. Ti–6Al–4V titanium alloy was examined in this work because it has a low thermal conductivity compared to other BPP materials and it is an important material for aerospace applications because of its high strength-to-weight ratio. The lower thermal conductivity of titanium alloy should highlight any difficulties with heat transfer making it an ideal material to test IR thermography's ability to resolve local temperature differences.

With this combined approach we are able to demonstrate the usefulness of IR thermography to characterize CFFs and verify the numerical models by providing experimental evidence for in-plane temperature distribution from titanium alloy BPPs under active coolant flow. The benefits and limitations of different visualization techniques relative to numerical modeling are discussed.

Experimental

Flow field design

The CFF designs for uneven and even coolant flow are shown in Fig. 1a and b, respectively. The CFF design for uneven

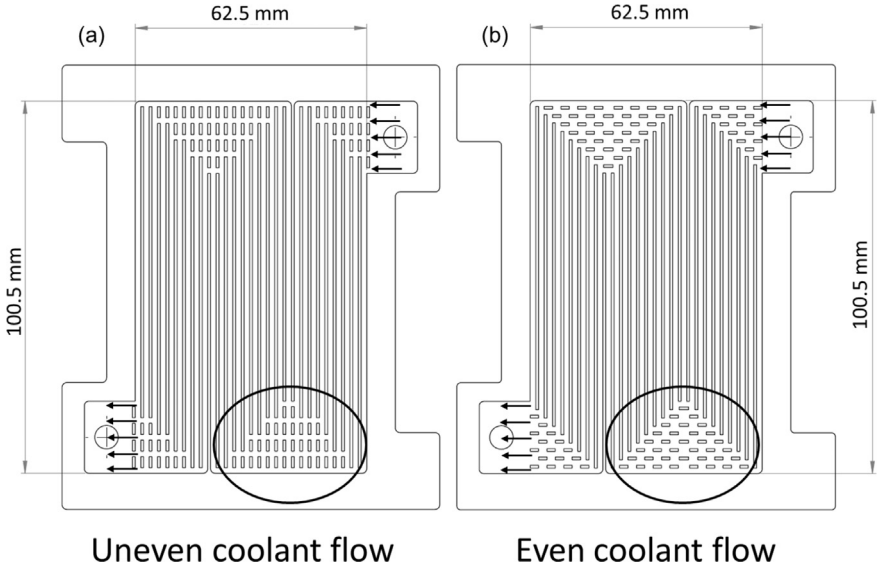

Fig. 1 – Computer aided drafting drawings of coolant flow fields with (a) uneven coolant flow and (b) even coolant flow. Circles identify the mixing zones in each design. The arrows denote the designated coolant inlets and outlets.