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Study of a micro-structured PHE for the thermal management of a Fuel Cell

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The quest for a clean solution that will effectively substitute the use of fossil fuels has led the scientific community to the choice of hydrogen as the dominant energy carrier for the years to come. Hydrogen fuel cells and among them, the Proton Exchange Membrane Fuel Cell (*PEMFC*) are the key energy convertors not only for portable but also for low-power stationary applications.

Due to the high voltage requirements of most applications fuel cell stacks are employed. Under normal electric load a *PEMFC* has an energy efficiency of about 50% ***[1]***, while the remaining energy content of hydrogen is transformed into waste heat, mainly at cathode, which must be effectively removed and used. The temperature distribution on the cooling plate and correspondingly on the membrane of the *PEMFC* is critical for the optimum operation of the unit as high local temperatures may lead to degradation of the membrane ***[2]***. Typically, a kW-class *PEMFC* stack can use either air or liquid cooling systems. Unavoidably air cooling does not permit waste heat recovery which increases significantly the total efficiency of the system. Thus optimal design of compact mini-scale Heat Exchangers (*HX*) for portable (i.e. automotive industry) and residential applications is a promising research field.

The present study investigates the effect of the geometrical characteristics of cooling *HX,* comprising micro-structured plates, on thermal management of fuel cell stacks. Corrugations with characteristic dimension in the micro-scale act as flow-field disturbance units and are expected to enhance heat transfer. A Computational Fluid Dynamic (*CFD*) code is employed to visualize the velocity field, the temperature distribution on the plate and the heat transfer characteristics of a cooling plate with corrugation patterns..

Four dimensionless groups are selected as the design variables (***Fig. 1a***), namely:

- The height to step ratio (*d/H*) that expresses the portion of the cooling channel filled with the corrugation's height.
- The corrugation aspect ratio (*l/d*) defined as the length of the step divided by its height.
- The Reynolds number inside the conduit, $Re = {}^{ud\rho}/_{\mu}$, where the characteristic length is the height (*d*) of the corrugation.
- The dimensionless offset (*off/x*) between two consecutive corrugations on the same plate, defined as the distance between the corrugations to the total length of the plate.

These design variables are used for creating a set of "computational experiments" based on a well-established Design of Experiments method, namely the *Box-Behnken* one ***[3]***. *Temperature uniformity* on the membrane and *pressure drop* are taken into account in the effort to locate the optimal set of values of the design variables. A small-scale experimental unit has been fabricated that "*simulates*" the thermal behavior of a typical *PEMFC* (***Fig. 1b***). The membrane of the cell has been replaced by a foil heater (*Minco Mica Heater*) that imposes a user-controllable stable heat flux.

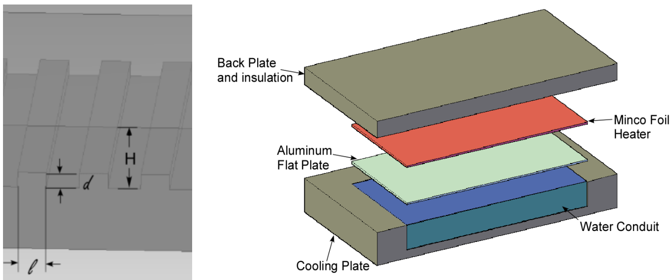

Figure 1. *a) Geometric parameters of a part of the computational domain of the cooling plate; b) exploded view of the experimental assembly.*

Temperature distribution on the cooling plate is monitored by embedded thermocouples. The *CFD* code has been validated with data acquired from the experiments for a flat plate *HX*. Preliminary results (***Fig. 2***) show that the proposed design greatly improves the temperature uniformity on the membrane of the *PEMFC* when compared to that of the flat cooling plate.

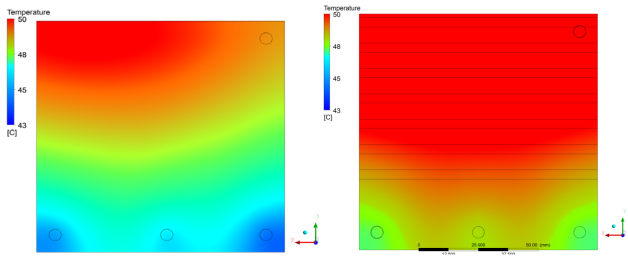

Figure 2. *Temperature distribution: a) flat plate and b) corrugated plate.*

The study, which is still in progress, is a part of a project exploring the potential heat recovery options in *PEMFC* stacks. The final results are expected to give useful insights concerning the thermal management of fuel cell systems.

References

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