A COMPUTATIONAL FLUID DYNAMICS ANALYSIS OF AIR FLOW THROUGH A TELECOM BACK-UP UNIT POWERED BY AN AIR-COOLED PROTON EXCHANGE MEMBRANE FUEL CELL

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ABSTRACT

Proton exchange membrane fuel cells (PEMFC's) are currently being commercialized for various applications ranging from automotive to stationary such as powering telecom back-up units. In PEMFC's, oxygen from air is internally combined with hydrogen to form water and produce electricity and heat. This product heat has to be effectively removed from the fuel cell, and while automotive fuel cells are usually liquid-cooled using a secondary coolant loop similar to the internal combustion engines, stationary fuel cell systems as they are used for telecom back-up applications often rely on excessive air fed to the fuel cell cathode to remove the heat. Thereby, the fuel cell system is much simpler and cheaper while the fuel cell performance is substantially lower compared to automotive fuel cells.

This work presents a computational fluid dynamics analysis on the heat management of an air-cooled fuel cell powered commercial telecom back-up system produced by Dantherm Power A/S, Denmark. The analysis is carried out with the commercial CFD solver Fluent (ANSYS Inc.). The fuel cell stack is modeled as a porous medium to accurately match the pressure drop, and it includes a heat source to account for the product heat. An important result is the predicted distribution of the temperature over the fuel cell stack, and a comparison between the modeling results and experimental validation will be made. Finally, the effect of various operating parameters on the temperature distribution in the telecom back-up power box will be investigated.

KEYWORDS: Fuel cell; Air-cooled; Heat management; Computational fluid dynamics, Optimization

1. INTRODUCTION

Decarbonisation and sustainability of power and heat generation in residential and industrial sectors have attracted a great deal of attention toward green hydrogen and fuel cells [1,2]. One of their applications that are already practical and very attractive is to power telecom back-up units, e.g. as shown in Fig. 1 [3]. The ElectraGen^{TM}-H2 system is manufactured by Dantherm Power A/S, Denmark [4]. Inside the system, there are two 2.5*kWe* low-temperature proton exchange membrane (LT-PEM) fuel cell stacks where oxygen from air is internally combined with hydrogen to form water. The main product of this electro-chemical reaction is electricity and the byproduct is waste heat which can sometimes be used as a heat source. In the current case, the fuel cell stacks are are air-cooled and laid symmetrically in a V-shape facing the intake air. The fact that these systems are air-cooled means that a much higher amount of air than is required for the electro-chemical reaction is blown through the system and therefore the composition of the air does not change to an appreciable amount. However, the temperature of the air increases substantially while passing the stack.

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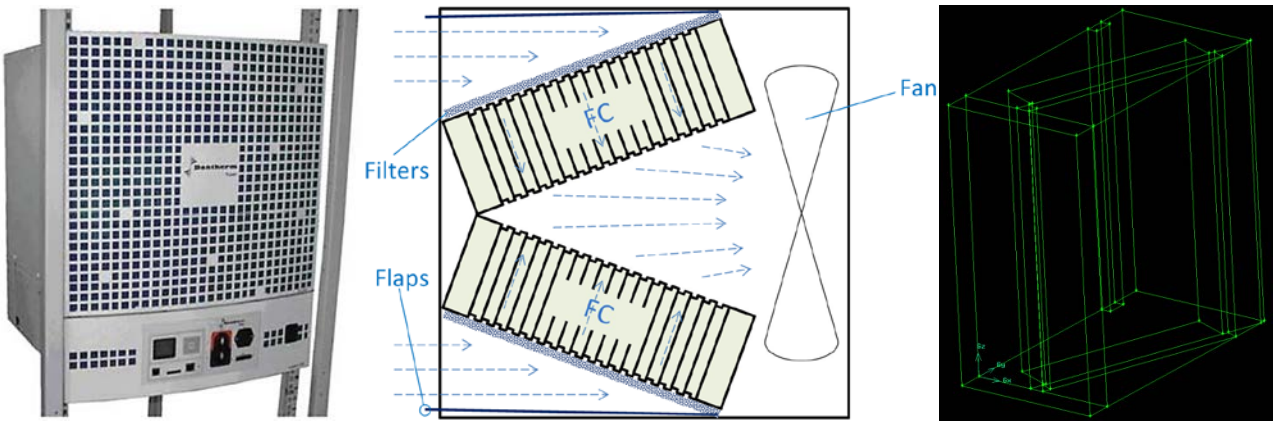

Fig. 1 – Left, a telecom backup power system, ElectraGenTM-H2; Middle, its inner top view and air flow through; Right, the calculation domain in ANSYS Fluent®.

A single fuel cell stack can contain several hundred single cells, each being around 2*mm* high. Table 1 lists the essential information of the system. In the current design there is an acute angle instead of a right angle between the stack inlet and the air flow. Intuitively, an acute angle will disturb the air flow distribution and the temperature uniformity; in turn deteriorating the stack performance. How significant the effects are is the first question to answer. The acute angle also raises the possibility that the preinstalled thermistor in each stack may have to be relocated. It is installed to monitor the hottest spot in a stack, which is usually the central point on the outlet surface. Whether it is still the case in these ElectraGen^{TM}-H2 systems is the second question. The last thing to be made sure is that the temperature difference across the stack outlet surface must not exceed the 6 ℃ limit as specified according in the stack manual. The exploration of the answers to all the above three questions embodies this work.

Table 1. Essential features of the system.

Features	Description
Maximum power, *kWe*	5.0 (2×2.5)
Ambient temperature, ℃	-40 to +46
Ambient humidity	0%RH to 100%RH
Cooling method	Air-cooled
Fuel	0.36 bar (gauge) hydrogen, purity ≥ 99.95%,

Three-dimensional computational fluid dynamics (3D CFD) modeling is chosen as the main approach because it is a low-cost and fast method to reach the results, and yields complete information of the flow field [5]. In the literature, comprehensive multiphysics models (e.g. [6,7]) have shed important understanding of the micro-phenomena inside the various components of a segment of a single cell. However when up to the system level, as there are tens or even hundreds of cells in a single stack to simulate, studies based on a comprehensive model suddenly become too computational expensive to be feasible [7]. In this regard, the stack model has to be simplified and fewer phenomena should be simulated. In the current study, since only the heat management and the inner temperature profiles of a ElectraGen^{TM}-H2 system are of special interests, each stack is simplified as a block of lumped porous medium. Detailed model settings are given in the following section.

2. MODEL SETUP AND VALIDATION

As mentioned above, the two pairs of stacks and filter panels are modelled as porous medium. The only two differences in settings lie in that 1) the two stacks are treated as porous media with a non-zero permeability only in the through-the-stack direction whereas the filter panels are treated isotropic; 2) there is a heat source in the two stack domains counting for the waste heat production. Their pressure drops are both described by the Darcy-Forchheimer equation. Other settings are presented in Table 2. Equilibrium heat transfer is assumed in these porous domains.

Table 2. Main settings in the 3D CFD model of the system.

Property	Stack value	Filter value
Porosity	0.4	0.785
Permeability, m^2	1.27e-8	1.92e-8
Inertial resistance, *1/m*	440	796.618
Material	graphite	synthetic fibre

Because of the high stoichiometric flow ratios that means that the air composition does not change very much, electrochemical reactions are currently not included in the current model. Thanks to system symmetry, only half of the system is meshed and simulated in ANSYS Fluent®, as illustrated in Fig. 1. A structured mesh with 2*mm* cell length is applied to model the 68*mm* long channels. A grid independence test was performed and it is found out that the calculated pressure or temperature deviation is less than 0.03%, compared to a structured mesh with 1*mm* long cells.

A base case is set up for model validation. The operating point of the system in the base case is: ambient temperature 12.82℃ stack current output 30*A*, and cathode stoichiometry 42.53. In this case, Reynolds number of the air flow can reach maximum 10389 regionally. The stack current output determines the amount of waste heat that is picked up by the air. Because the mesh is too coarse to capture the turbulent boundary layers, the k-omega based shear-stress-transport (SST) model is activated in the solver. Curvature correction is also checked due to the fact that there are sharp corners and sudden flow expansions existing. The convergence criterion is set to 1e-5 in the continuity equations. Validation of the model is carried out on the filter and stack pressure drop and the stack temperature. In experiments, the pressure drops falling on the filter and the stack under 30*A* are 6.78*Pa* and 29.04*Pa* respectively. By comparison, in the 3D CFD simulation, these figures are 6.54*Pa* and 28.00*Pa*. The measured stack temperature is 41.93℃. Calculated by pure heat transfer in the model the average stack temperature is 42.51℃, which matches the measurement perfectly. Therefore, the model can be considered validated and of high accuracy.

3. RESULTS AND DISCUSSION

The temperature distribution inside the system and especially on the stack cathode outlet surface is simulated and depicted as follows. The stack rear is the part of the stack that is close to the centrifugal fan.

The left picture in Fig. 2 gives the temperature distribution on the stack outlet surface and the right plot shows the distribution on the top, on the midline and at the bottom of the outlet surface. It can be seen that the predicted outlet temperature is quite uniform. The maximum difference is only about 1℃, which is far less than the 6℃ limit. However, the predicted difference here is only about one third of the experiment value. One possible reason is that the assumption of equilibrium heat transfer is not true in reality. Another fact is that in experiments there is liquid product water observed. The latent heat from phase change potentially can affect the temperature distribution. A more comprehensive model is needed for future study on this deviation.

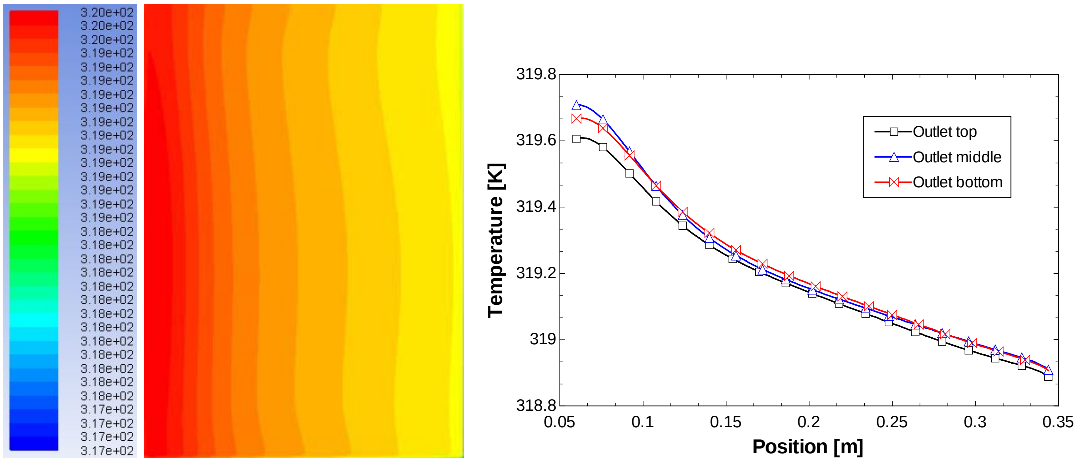

Fig. 2 - Temperature distribution on stack outlet surface (the right edge is the stack rear), [K].

It can also be noticed that the highest temperature appears in the frontal region near the system air inlet on the midline half of the stack height. This indicates clearly that the preinstalled thermistor has to be moved. The fact that the hottest spot is not positioned as usual is probably because there is a sharp edge protruding into the pathway of the intake air, which is formed by the system box front and the frontal surface of the filter panel. This causes the air flow detaching from the surface and generates a low flow zone in the frontal region, as shown by the dark blue portion within the stack domain in Fig. 3, left. This non-uniformity in air flow distribution actually has been faded out on the stack outlet surface, as shown in Fig. 3, right. Because when air flow reaches the outlet, it is already warmed up. Hereon, heat conduction inside the stack has replaced heat convection and dominates the heat transfer process.

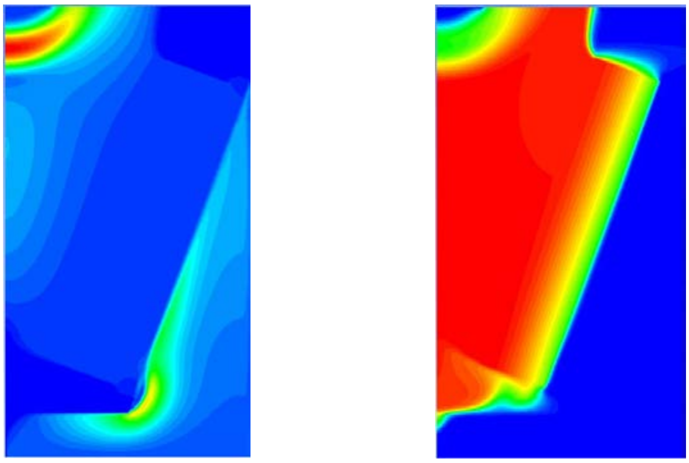

Fig. 3 – Left, inner flow distribution on mid-plane of the system, [m/s]; Right, inner temperature distribution on the mid-plane, [K].

The inlet surface temperature distribution reflects the air flow unevenness more directly. As illustrated in the right plot in Fig. 4, the stack inlet temperature on the midline changes almost simultaneously with the midline air flow distribution. Furthermore, the inlet temperature on top and bottom of the stack is about 2 ℃ lower and much evener. This is because in these two boundary layers, heat convection between the stack and surrounding is the main player and facilitates the heat rejection. Referring to the temperature deviation discussed above, the temperature variation on the stack inlet is probably rather significant. Whether this affects the stack performance and lifetime, or some design modification can compensate this should be subject of the future work.

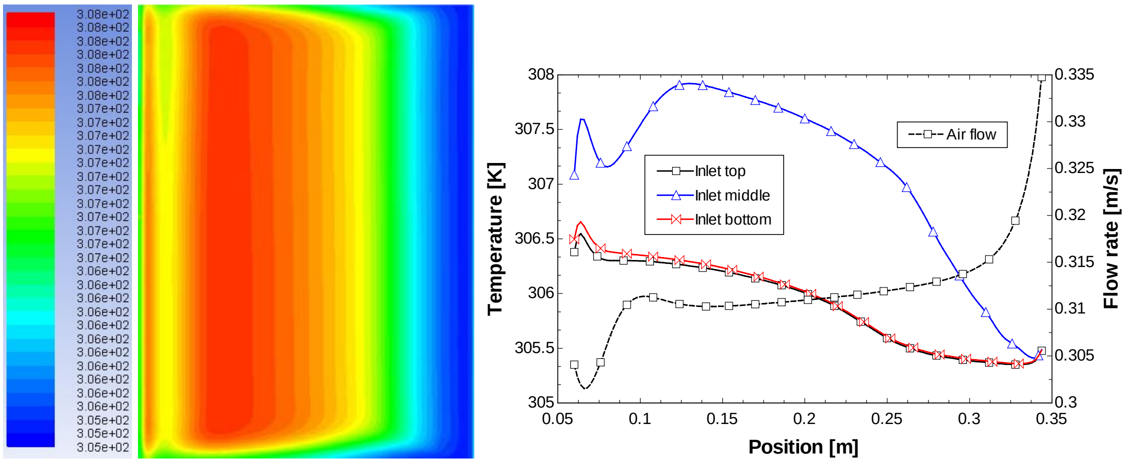

Fig. 4 - Stack inlet temperature distribution (the right edge is the stack rear close to the centrifugal fan), [K].

4. CONCLUSIONS AND FUTURE WORK

The 3D CFD model of the new 5*kWe* system works and is validated by experimental data with very good accuracy. It reveals the fact that the acute angle affects the temperature uniformity of the stack, and the hottest spot of the stack is at the frontal edge on its outlet midline. The preinstalled thermistor should be moved accordingly. According to the model, the maximum temperature difference on the stack outlet surface is far below the 6℃ limit. However, this conclusion still needs further investigation. The inlet surface temperature varies more significantly and potentially can affect the stack performance and lifetime. This is worth further study.

5. ACKNOWLEDGMENT

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6. REFERENCES

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