Improving the Performance of an Air-Cooled Fuel Cell Stack by a Turbulence Inducing Grid

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Improving the Performance of an Air-Cooled Fuel Cell Stack by a Turbulence Inducing Grid

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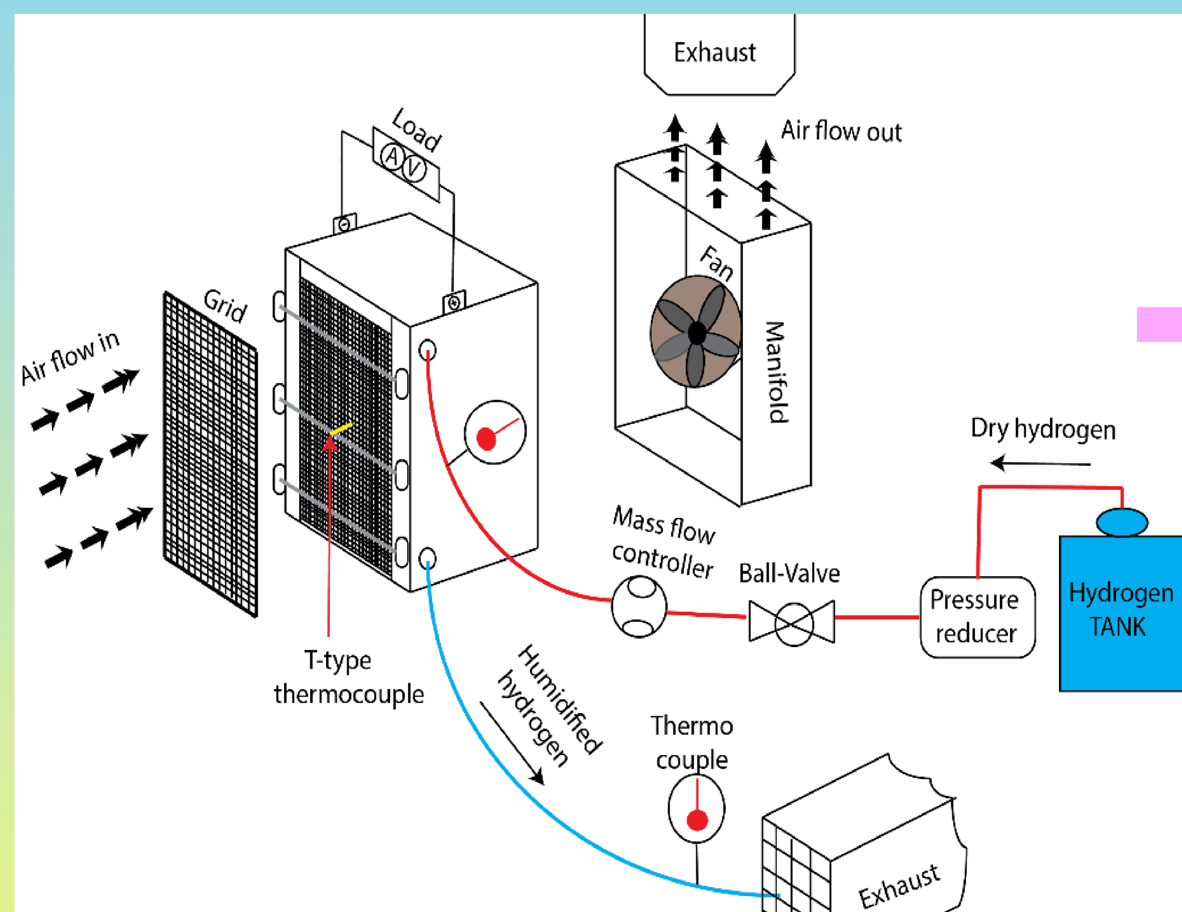
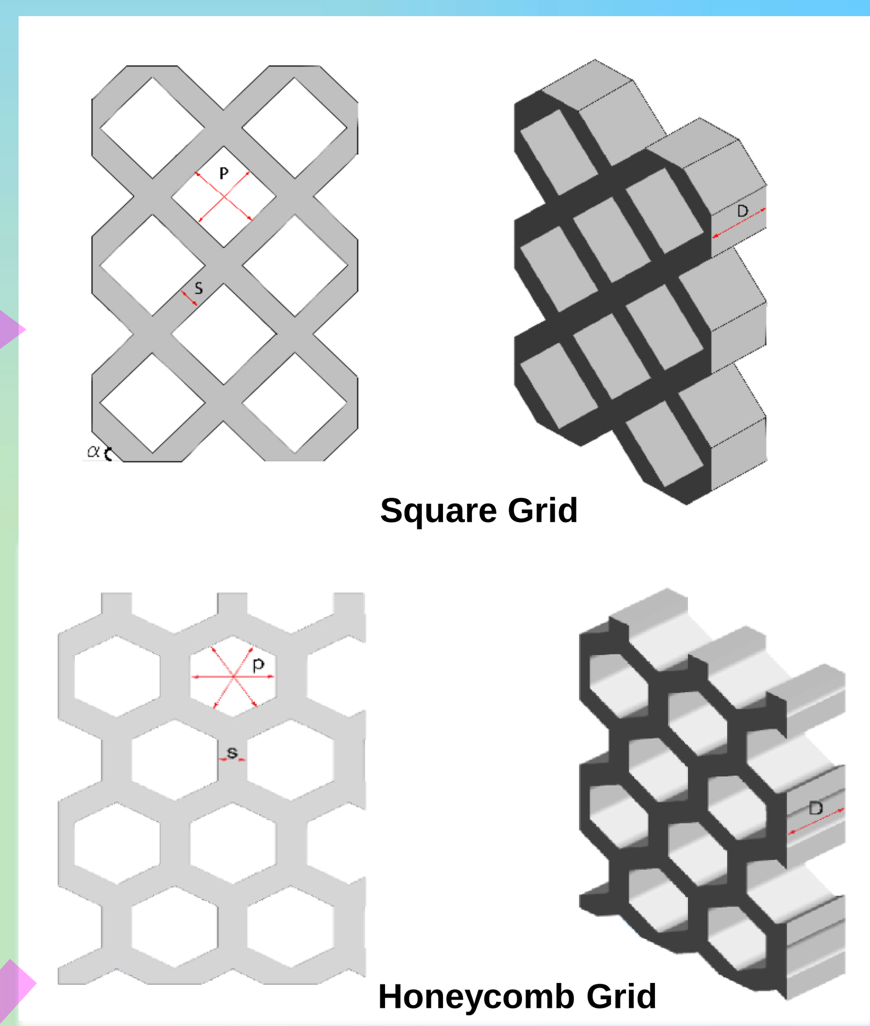
- Air-cooled proton exchange membrane fuel cells (ACPEMFC's) are gaining more popularity due to their :
  - Simplicity (run on dry H_2), and
  - Quick start-up.
- ACPEMFC's are commercialized and designed for applications in the range of up to few kWs such as telecom-backup systems and portable power.
- The stoichiometric ratios at the supplied Air into the cathode open channel is typically 40-60, because it is used for cooling the stack besides providing O_2 for the reaction,
- while at the supplied dry H_2 into anode channels it should be as low as possible to not waste hydrogen.
- One of the main drawbacks of ACPEMFC's is the relatively low maximum current density around 0.4 A/cm².
- It is highly desirable to operate at higher current densities and thereby increase the power density.
- This might be achieved by more efficient cooling.
- Thus, Turbulence grids are utilized to increase the mixing effect and thereby enhance the heat transfer in the cathode channels.
- In this work, the effect of the turbulence grid is demonstrated experimentally and numerically using CFD.



Experimental Set-up

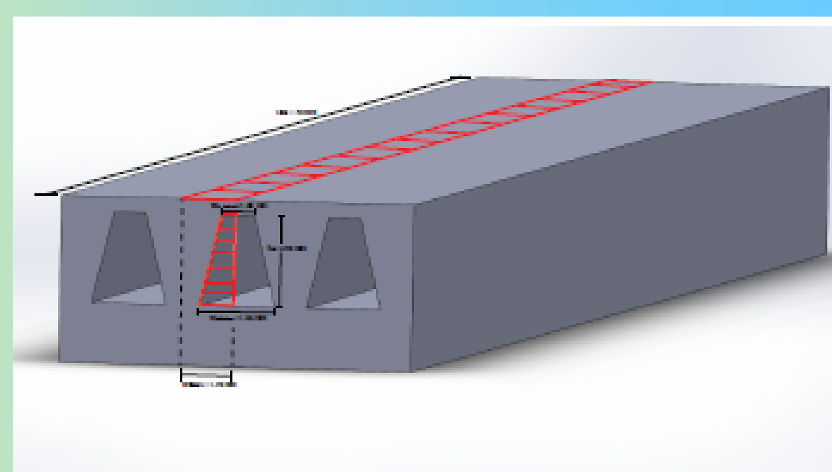


Square Grid

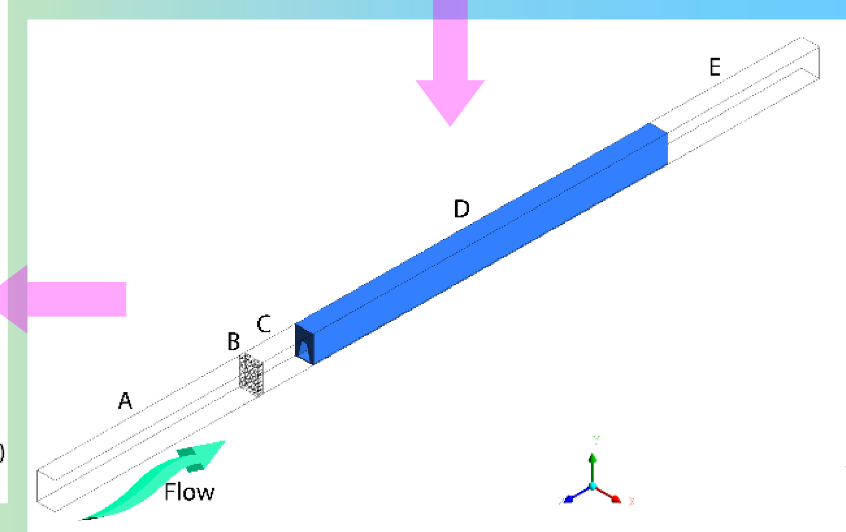
Honeycomb Grid

Dimensions of the honeycomb and square turbulence grid

Parameter	Dimensions Square Grid	Dimensions Honeycomb Grid	Unit
Grid pore size, P	1	1	[mm]
Grid rip width, S	0.6	0.6	[mm]
Grid thickness, D	1	1	[mm]
Grid fill factor, f	0.605	0.613	[-]
Grid pore angle, α	45	90	°C



Sketch of the half channel cross sectional area and half the geometrical area of the membrane included in the computational domain



Computational domain used in simulations.

Computational Fluid Dynamics (CFD)

Reynolds Average Navier Stokes Equations (RANS)

$$u = \bar{u} + u' \quad [1]$$

Where and are the mean and fluctuation velocity respectively. Likewise, for pressure and other quantities it is:

$$\phi = \bar{\phi} + \phi' \quad [2]$$

Where ø denotes a scalar such as pressure, energy or species concentration.

Substituting the expressions into the instantaneous continuity and momentum equations and taking the time average (dropping the overbar on the mean velocity) yields the following RANS equations for continuity and momentum [ANSYS, 2018c]:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \quad [3]$$

$$\frac{\partial u_j u_i}{\partial x_j} = \frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j}\right) + \rho g + \frac{\partial}{\partial x_j}\left(-\rho \bar{u}_i' u_j'\right) \quad [4]$$

where the term $\left(-\rho \bar{u}_i' u_j'\right)$ is the Reynolds stresses and are modelled with the turbulence model SST-k-ω, u is velocity is density; g is the gravitational constant and is the viscosity.

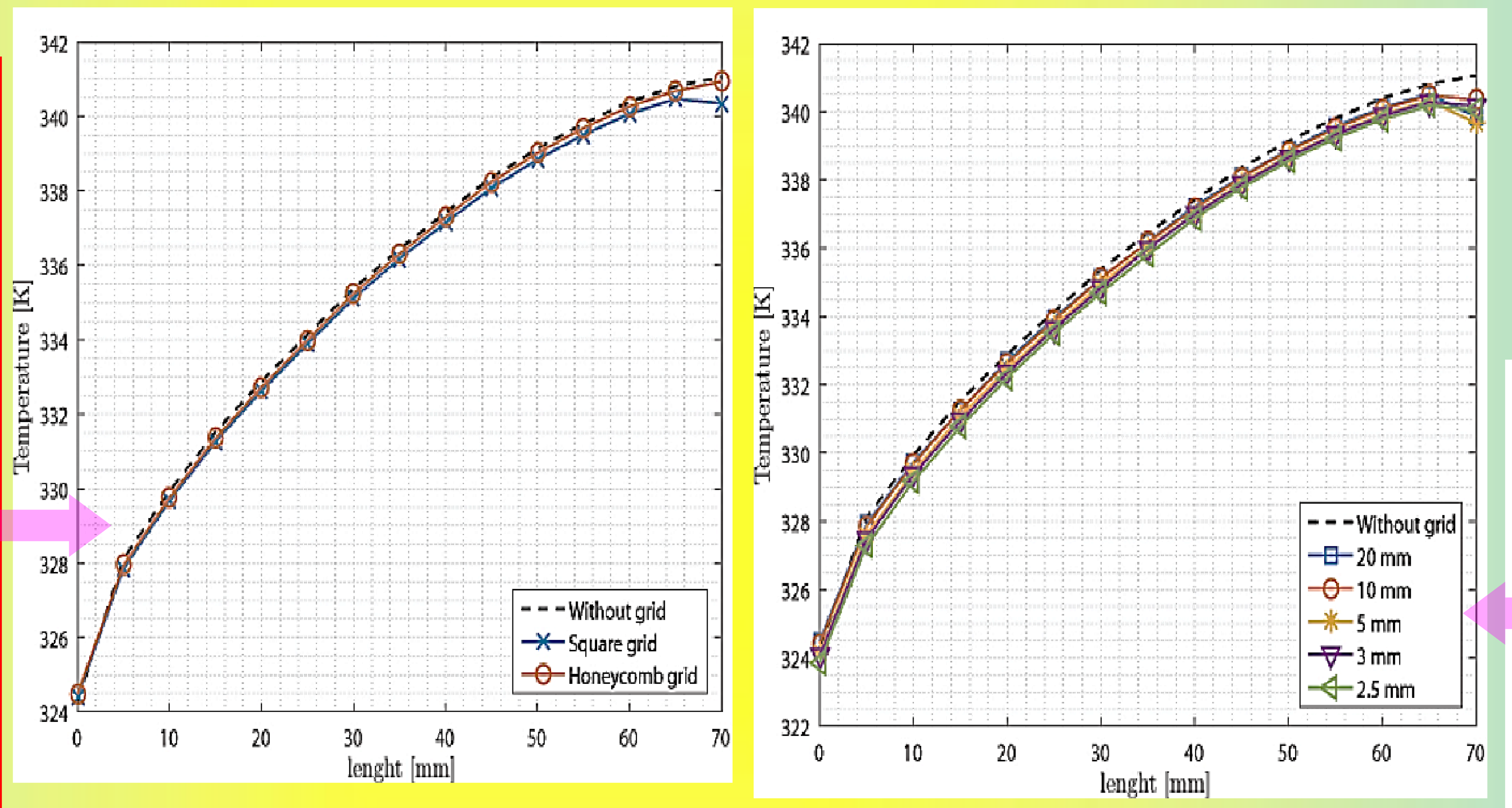
Energy Equations

The energy equation the fluid is given as:

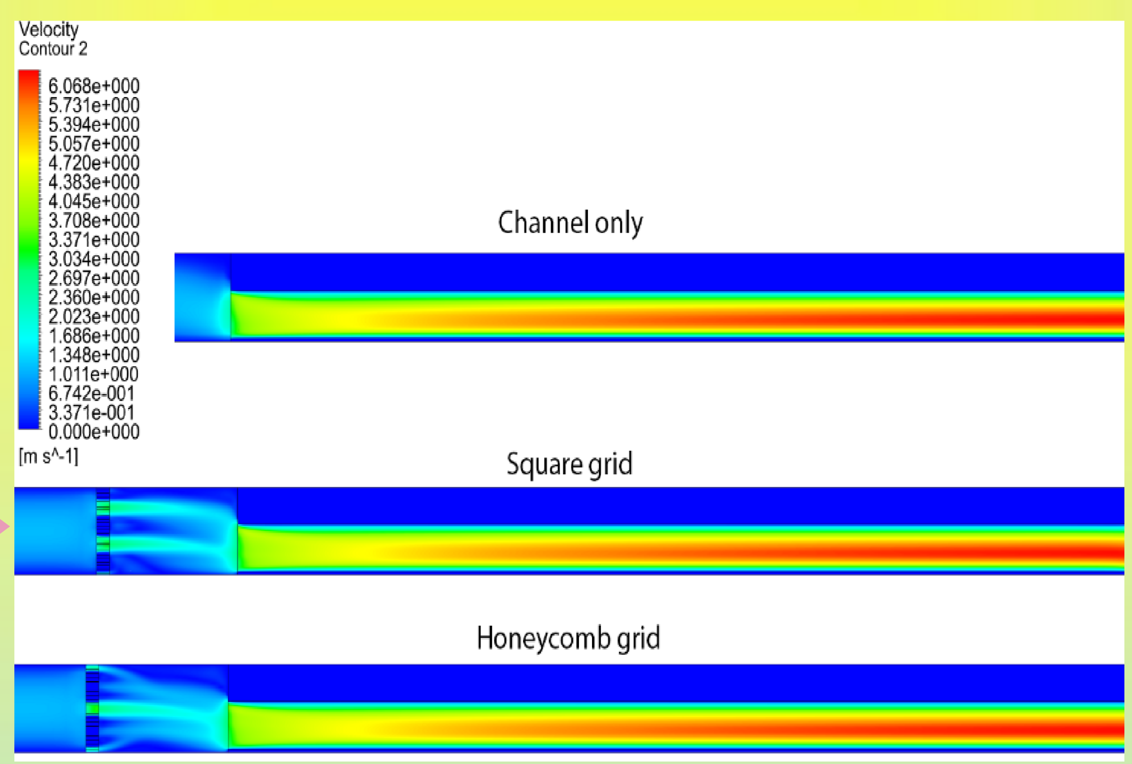
$$u_j \frac{\partial T_f}{\partial x_j} = \frac{1}{\rho c_{pf}}\frac{\partial}{\partial x_j}\left(k_f \frac{\partial T_f}{\partial x_j}\right) \quad [5]$$

Where c_{pf} is the fluid heat capacity k_f is the temperature of the fluid and is the thermal conductivity of the fluid. The energy equation for the solid region is given as:

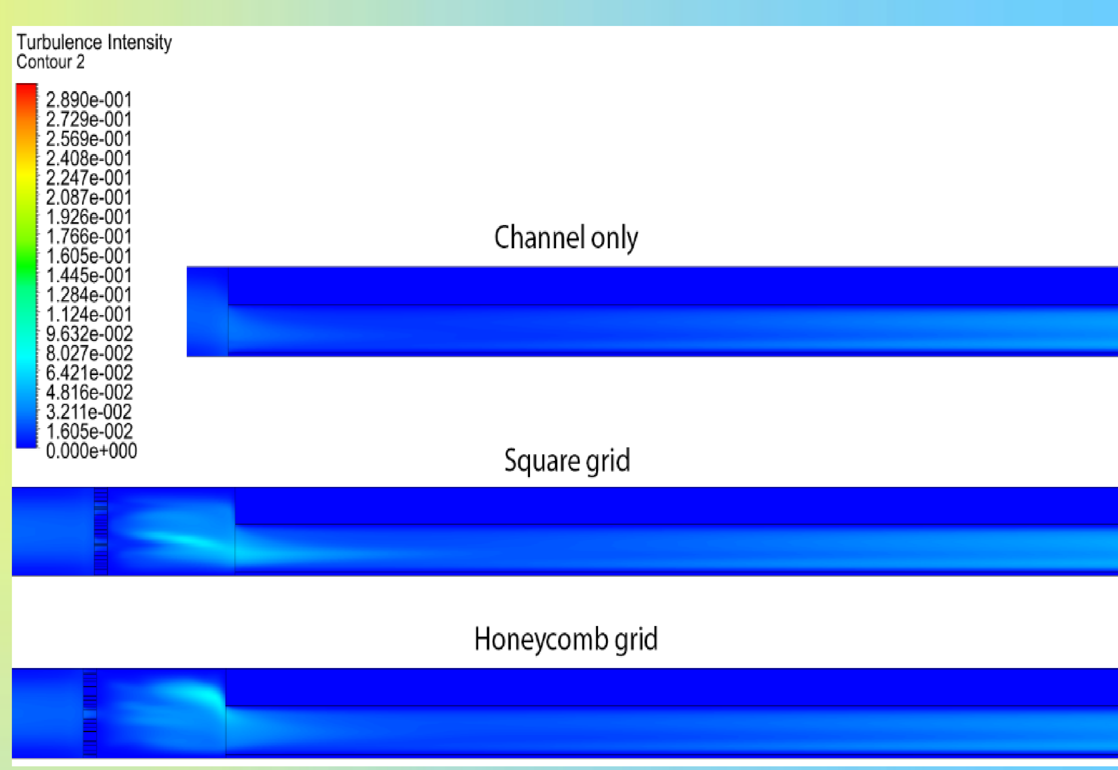
$$\frac{\partial}{\partial x_j}\left(k_s \frac{\partial T_s}{\partial x_j}\right) = 0 \quad [6]$$



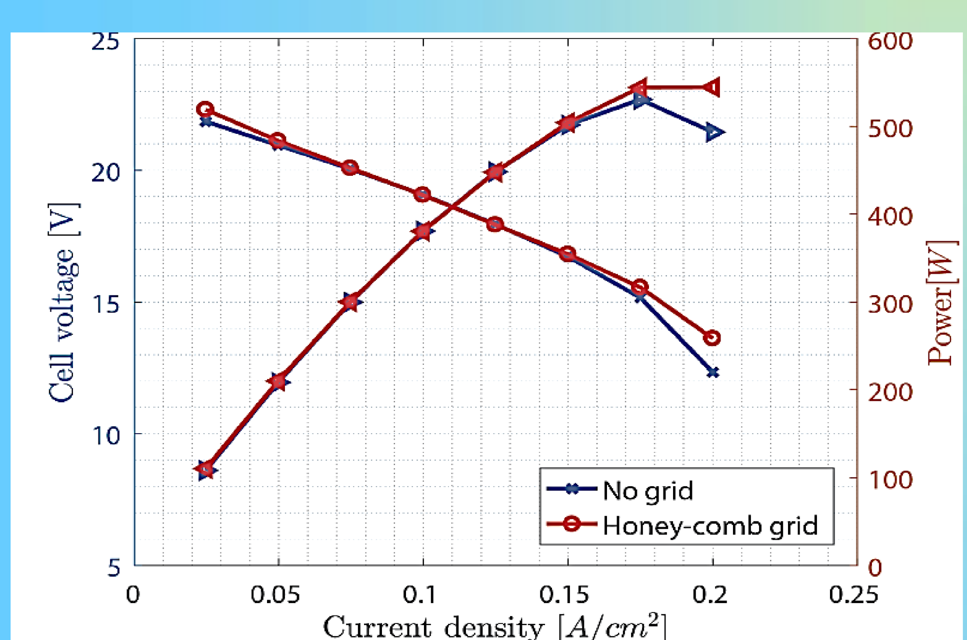
Temperature along the channel. On the left figure the distance between the grid and channel is constant at 10 mm. On the figure in the right side this distance is varied.



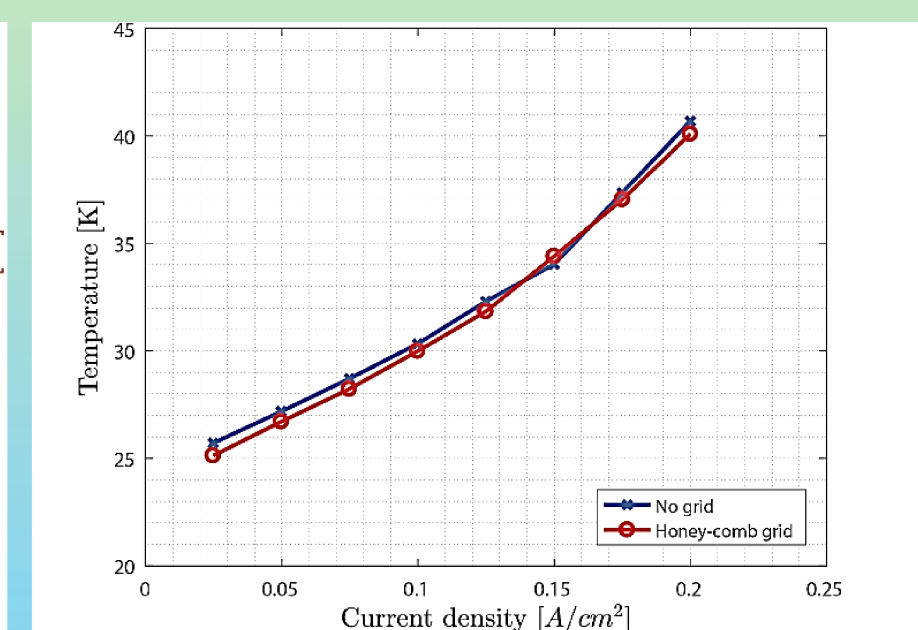
Velocity distribution along the channel.



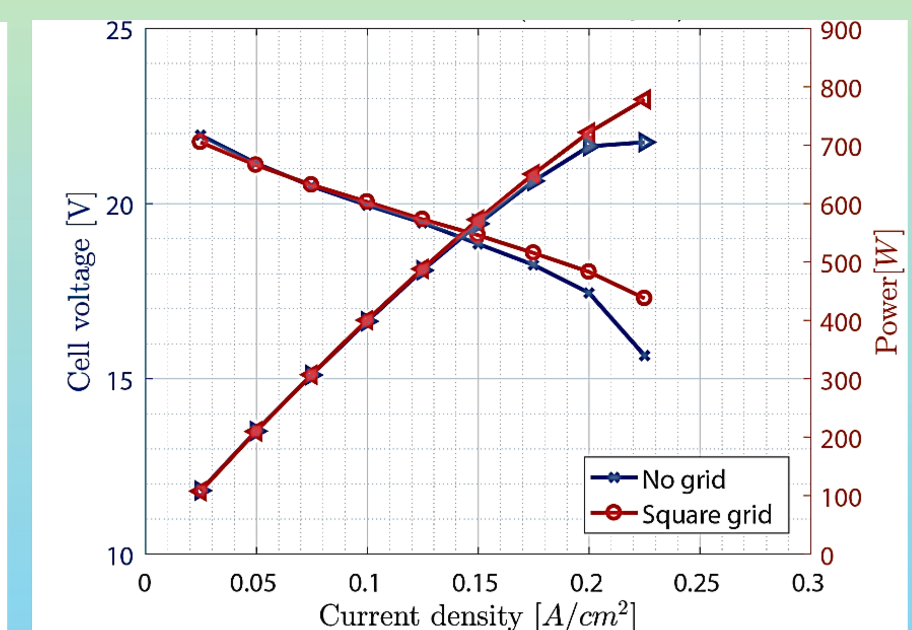
Turbulence intensity distribution along the channel.



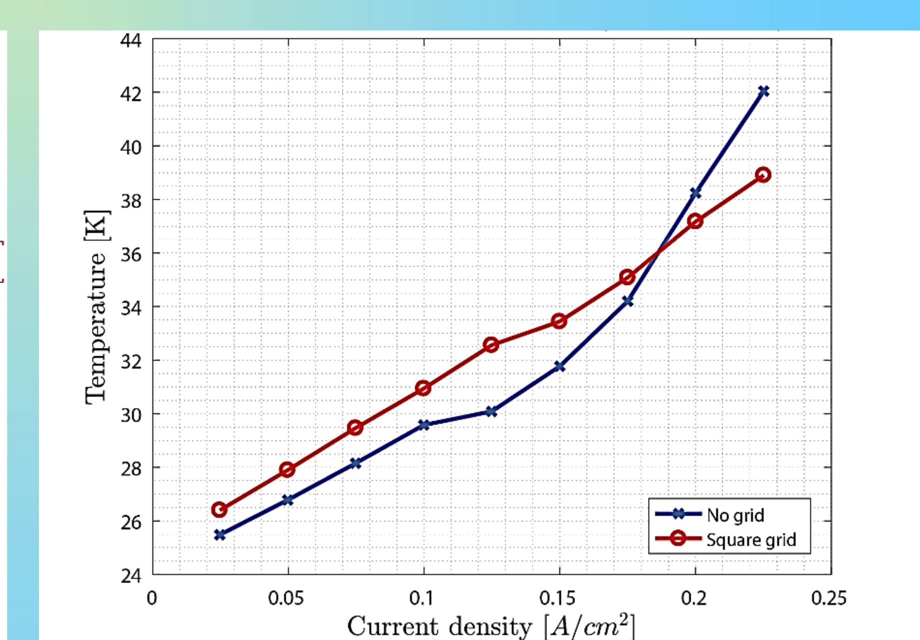
Polarization curve of the experiment with honeycomb grid and no grid



Temperature at the cathode inlet channel with honeycomb grid and no grid.



Polarization curve of the experiment with square grid and no grid



Temperature at the cathode inlet channel with square grid and no grid.

- There is a slight decrease in temperature when the two grids are implemented.
- The square grid effect on the temperature is larger.
- The effect of the grid is seen right after the grid and before the channel, and the velocity distribution is almost identical along the channel.
- The increase in turbulence intensity is highest for the case with the square grid.
- The honeycomb grid has increased the performance by 2.75 %, and the square grid has increased the performance by 10.42%
- The temperature of the air at the channel inlet is generally lower with the grid.
- The square grid indeed results in more effective cooling and higher performances.
- The experiment assisted the model by showing an improved performance of the air-cooled fuel cell stack by placing grids before the cathode inlet and furthermore resulted in decreasing temperatures.