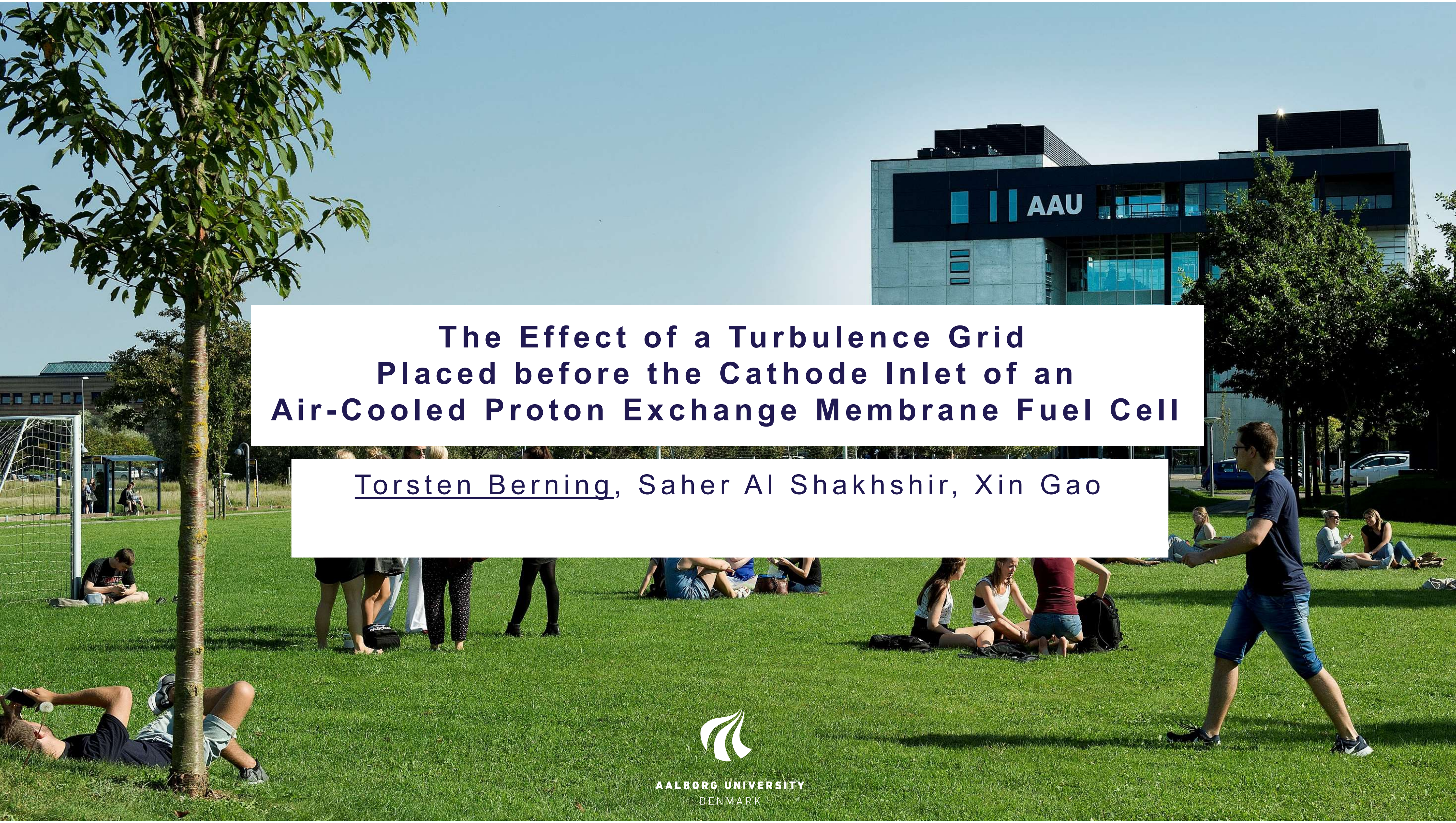

The Effect of a Turbulence Grid Placed before the Cathode Inlet of an Air-Cooled Proton Exchange Membrane Fuel Cell

Torsten Berning, Saher Al Shakhshir, Xin Gao

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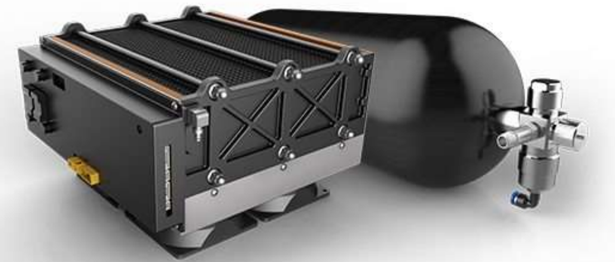
Air Cooled Proton Exchange Membrane Fuel Cells

- **Air-cooled Proton-Exchange Membrane Fuel Cells** have been developed over decades, e.g. by *Ballard Power Systems*.
- Simple, open cathode design, “self-humidifying MEA”, no secondary coolant loop required
- Power ranges is from a **few hundred Watts to a few kW**.
- Applications have been telecom back-up (e.g. *Ballard Europe*), materials handling (e.g. *Plug Power*) and more recently **unmanned areal vehicles** (e.g. *Horizon Energy Systems*, *MMC*).

HES Energy Systems

https://www.hes.sg/

MMC™



http://www.mmcuav.com/product/hydrogen-fuel-cell/

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Air Cooled Proton Exchange Membrane Fuel Cells

- Problems with AC PEMFC are the **high cost**, especially for drones **(> 10,000 $/kW)**.
- One reason for this is the **low gravimetric and volumetric power density**.
- The **areal power density** is in the range of **0.25 W/cm^2**.
- Depending on the operation the **life time is limited** (Ballard quotes up to 10,000 h of operation, depending on operation mode).

BALLARD®
PUTTING FUEL CELLS TO WORK

FCgen®–1020ACS

PRODUCT SPECIFICATIONS

Type:	PEM (Proton Exchange Membrane) fuel cell stack	
Typical Performance:[1]	Rated Power	43 W/cell
	Rated current	65 Amps
	DC voltage	660 mV/cell

The cell area is ≈ 200 cm^2.

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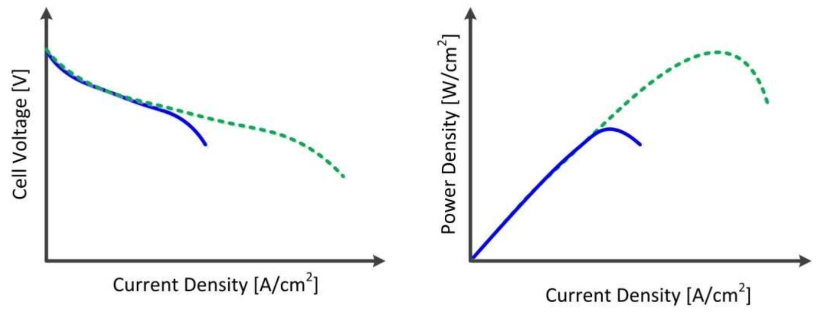
Objective

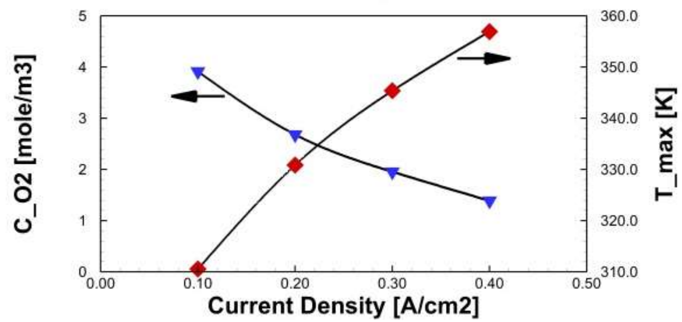
- **Increase the maximum current density** in an air-cooled PEMFC in order to increase the power density.

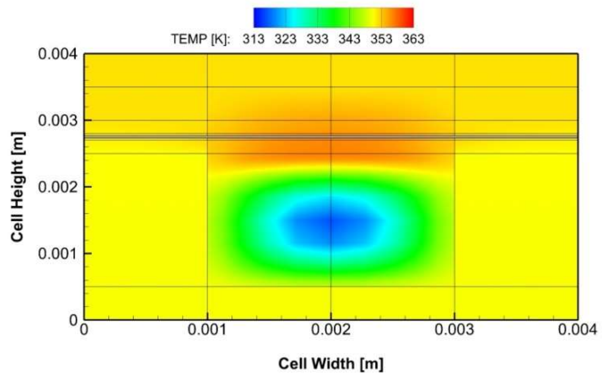
- The bottle neck was identified as **the heat transfer to from the CCL to the cathode air** in the flow channel leading to **membrane overheating**.

- The underlying idea was to **introduce a mixing effect to the air flow** and thereby increase the heat transfer rate and **obtain a lower temperature gradient**.

- This could be done using a **turbulence grid**.







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Turbulence Grids

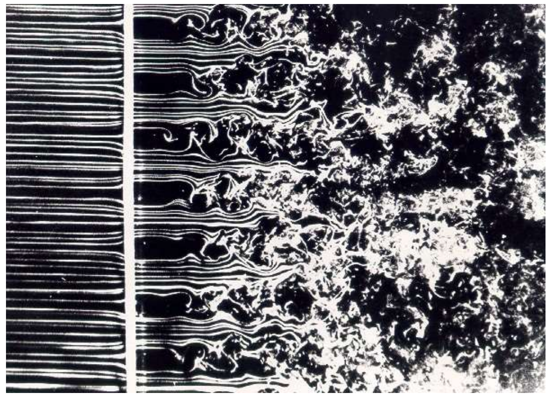
- **Induce turbulence** into otherwise laminar flow.
- Turbulence intensity is **proportional to the pressure drop**.
- Critical *Re number* is around **175** based on the **grid wire diameter** and the **intrinsic velocity**.
- An important characteristic length is the **fill factor**:

Grid rod diameter (S)

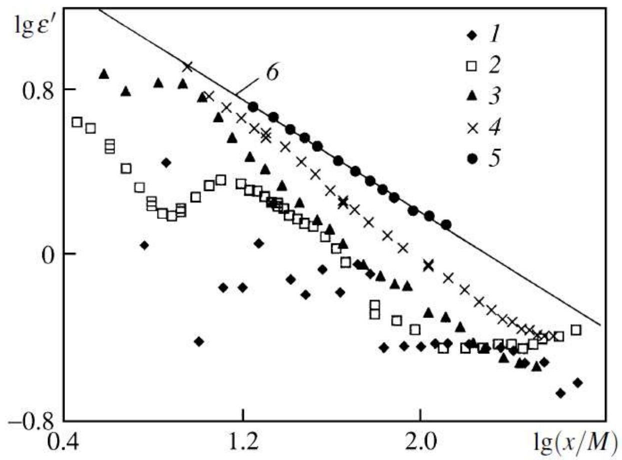
$$S = 1 - \frac{F_1}{F_0} = 1 - \left(1 - \frac{d}{M}\right)^2$$

Fill Factor (F)

Mesh size (P)



M Van Dyke, An Album of Fluid Motion, The Parabolic Press, Stanford, US, 1982.



N.P. Mikhailova et al., Fluid Dynamics, Vol. 40, No. 5, 714-725, 2005.

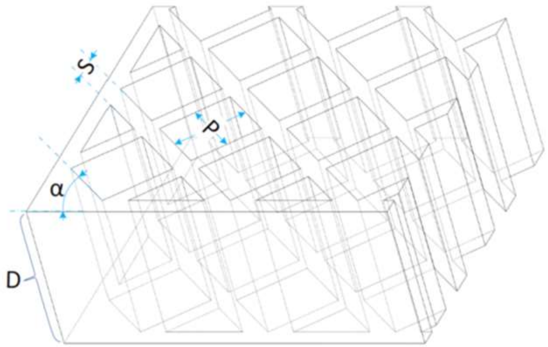
Fig. 2. Demonstration of the turbulence degeneration law $\lg \varepsilon'$ in the subcritical regime of flow past wicker grids: *1* — $Re_{dM} = 101$, *2* — 108, *3* — 115; *4* — 134, *5* — supercritical regime ($Re_{dM} = 583$); and *6* — Eq. (1.2) with $A = 36$ and $n = 0.7$

Parametric Study

- All grids were printed on a 3D printer.
- The stack was a degraded Ballard FCGen 1020ACS stack.
- The fan was operated at constant power.

Parameter	Unit	Values tested		
Grid pore size, P	[mm]	0.5	1.0	1.5
Pore angle, α	[°]	30	45	90
Grid thickness, D	[mm]	0.5	1.0	1.5
Rib width, S	[mm]	0.20	0.35	0.50
Distance from inlet	[mm]	3	10	20

Base Case



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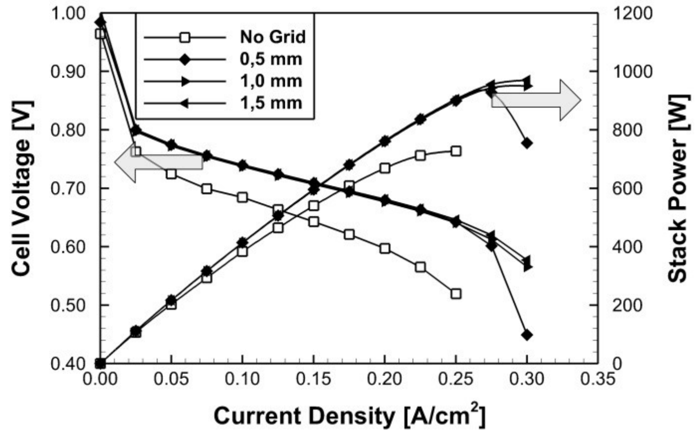
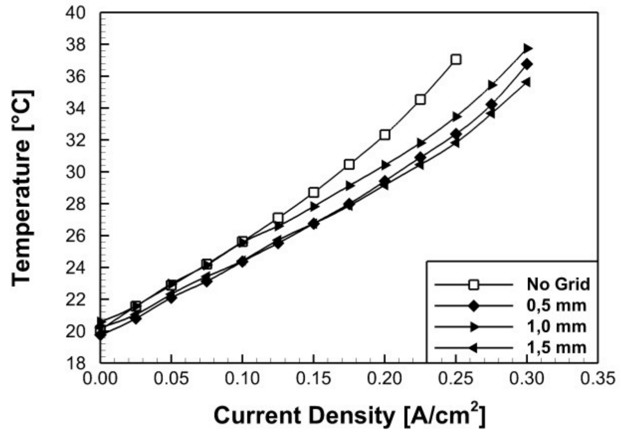
Effect of the Pore Size

- A clear performance improvement was obtained for all cases with the turbulence grid.
- A lower pore size leads to an increased fill factor, e.g. **F = 0.575** for P = 1.0 *mm* and **F = 0.910** for P = 0.5 *mm.*

$$F = 1 - \left(1 - \frac{S}{P}\right)^2$$

- The temperature inside the stack is clearly decreased, and this is probably the reason for the increase in current density.





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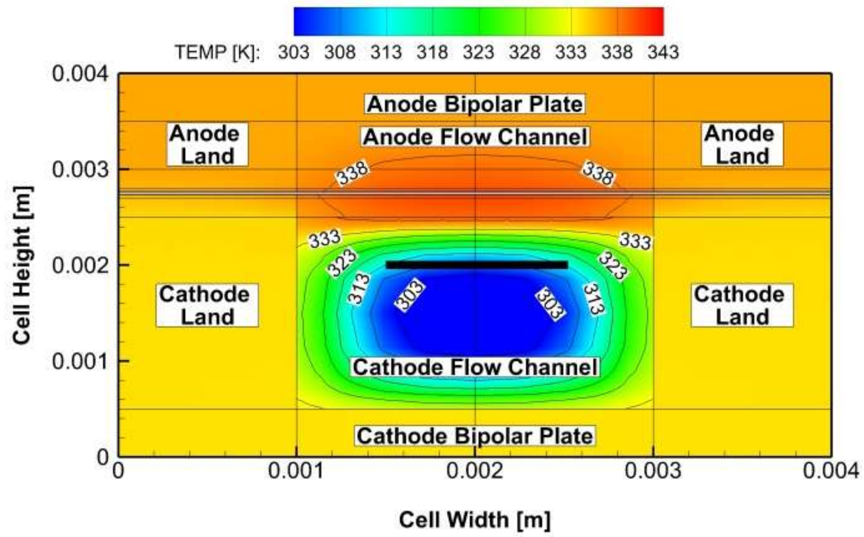
Temperature Readings

- The thermocouple was placed according to the manufacturers instructions inside the cathode flow channel.
- A high temperature gradient is predicted here, both down the channel and across the channel height and width.



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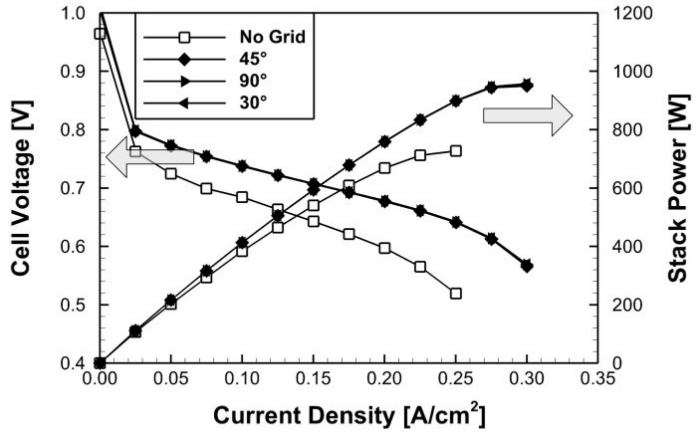
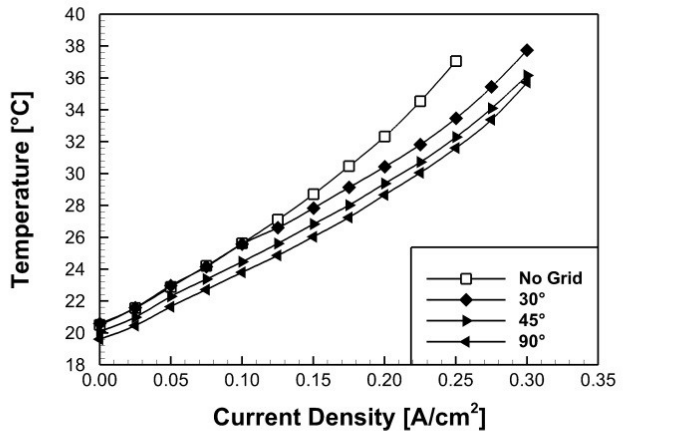
Effect of the Pore Angle α

- The pore angle was the only parameter where the Re number and the fill factor was left unchanged.
- The cell performance was identical.
- All data was averaged over three different runs.

➢ **Supports the theory that it is in fact turbulence that makes the difference**.





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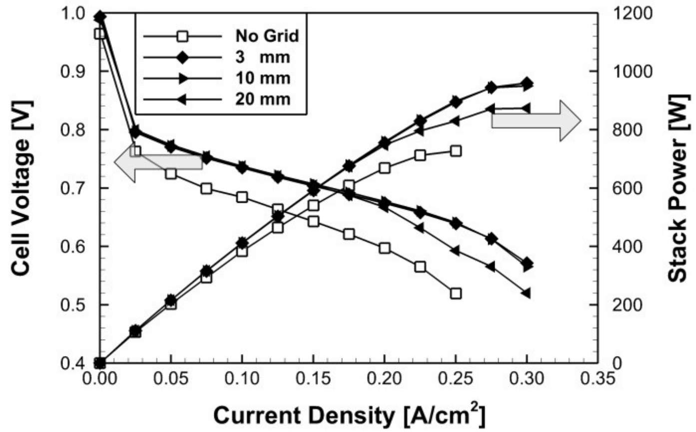
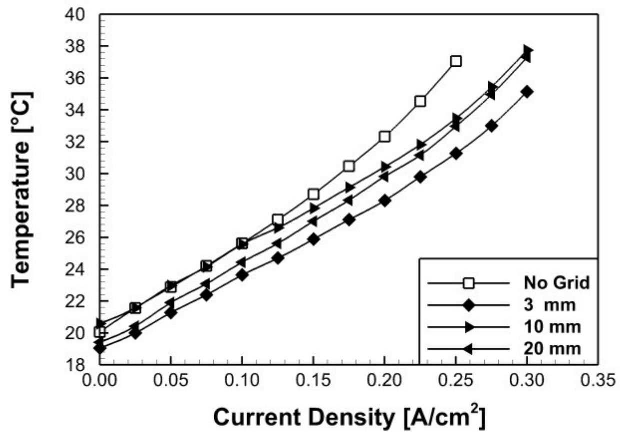
Effect of the Distance from the Inlet

- The most critical single parameter, as expected.
- When the distance becomes too large, no turbulence is carried into the cell and the stack performance becomes similar to the case without a grid.
- A problem were the metal rods that supply the compression.





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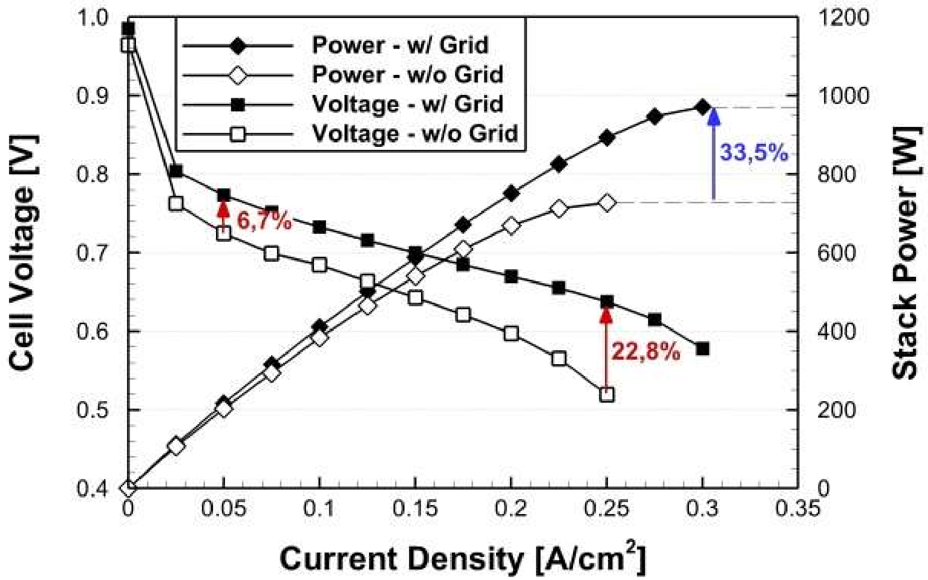
Best Case

- The power density was increased by **33.5%** and at the design point of operation the hydrogen consumption was decreased by more than **20%**.
- The best combination of parameters were the base case parameters but placed close to the inlet (3 mm).
- Note that the stack further degraded during the experiments, so no clear statement can be made other than the distance effect.
- The fan will have an influence on the results.



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Summary

- Placement of a turbulence grid before the cathode inlet of an air-cooled PEMFC improves the performance significantly at low cost.
- The temperature inside the flow channel measured by a thermocouple was substantially decreased.
- The **power density** was increased **by more than 30%,** the current density by 20% and the **efficiency at the designed operating point increased by 20%** (hydrogen consumption).

Future work/possibilities:

- Study multiple grids, use a larger fan, redesign the stack to easier accommodate turbulence.

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Follow-up

- A patent was claimed in 2019.
- During corona, we could not intensively work on this technology.
- We could not persuade an industrial partner to collaborate with us.
- When we needed to decide, whether to drop the patent or not, **we had to drop it**.

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(71) Applicant: AALBORG UNIVERSITET [DK/DK]; Fredrik Bajers Vej 5, DK-9220 Aalborg Ø (DK).

(72) Inventor: BERNING, Torsten; Klithavevej 8, DK-9480 Løkken (DK).

(74) Agent: PLOUGMANN VINGTOFT A/S; Strandvejen 70, 2900 Hellerup (DK).

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(54) Title: FUEL CELL ASSEMBLY WITH A TURBULENCE INDUCING DEVICE FOR REDUCTION OF A TEMPERATURE GRADIENT

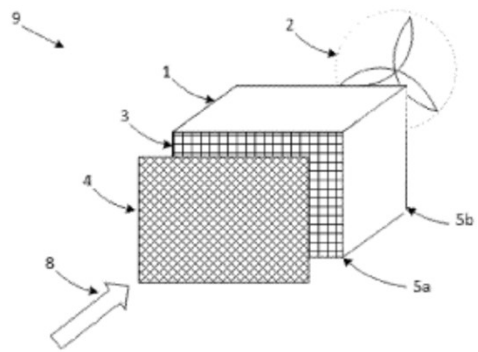


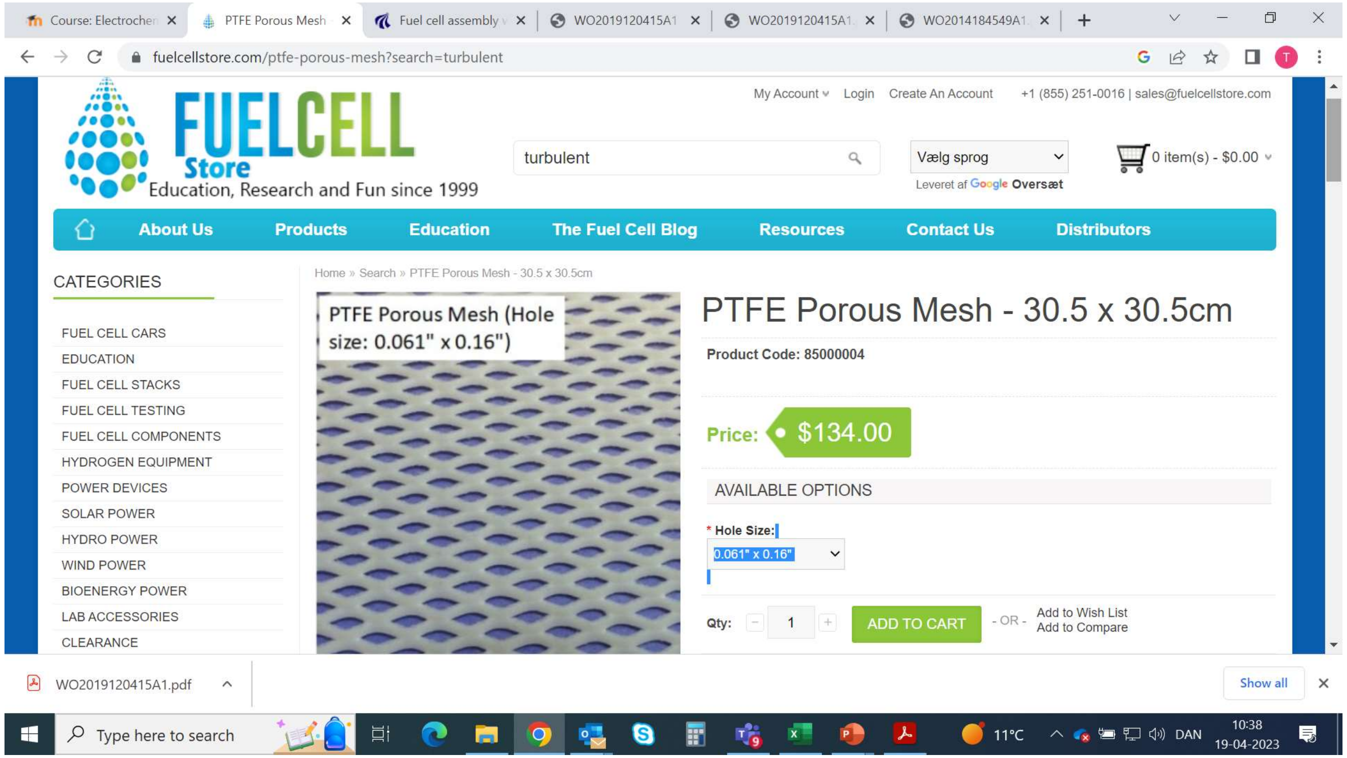
Figure 1

(57) Abstract: The present invention relates to an air-cooled fuel cell assembly (9) comprising a fuel cell (1) having a membrane electrode assembly disposed between an anode fluid flow plate and a cathode fluid flow plate, said cathode flow plate defining a flow channel for conveying oxidant to the membrane electrode assembly, said flow channel having an inlet and an outlet and said flow channel extending between two opposing perimeters (5a, 5b) of said fuel cell assembly (9), an air pump (2) arranged to generate air flow in said flow channel in a first direction (8), a turbulence inducing device (4) upstream, relative to said first direction (8), of said flow channel, said turbulence inducing device comprising a grid.

WO 2019/120415 A1

Follow-up

- … but the "**FuelCell Store**" is now selling turbulence grids ☺



https://www.fuelcellstore.com/ptfe-porous-mesh?search=turbulent

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