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

Xin Gao, Torsten Berning, Søren K. Kær

Department of Energy Technology,

Aalborg University

Denmark

DEPARTMENT OF ENERGY TECHNOLOGY

AALBORG UNIVERSITY

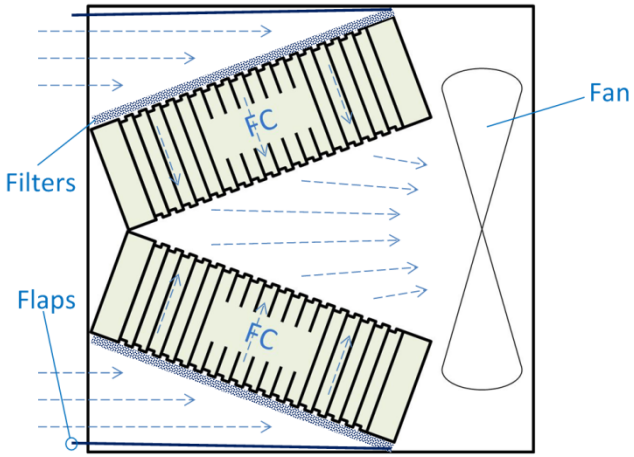
INDEX

- Introduction
- Results and discussions
- Main conclusions
- Future work

INTRODUCTION: A telecom backup power unit

A telecom backup unit powered by an air-cooled proton exchange membrane fuel cell:

ElectraGenTM-H2, Dantherm Power



Its inner top view and air flow through

INTRODUCTION: Fuel cell working principles

What are fuel cells (FCs)?

- Direct fuel-power electrochemical converters, still galvanic cells.

e.g., PEMFCs (Polymer Electrolyte Membrane FCs):

- Electrochemical half reactions:

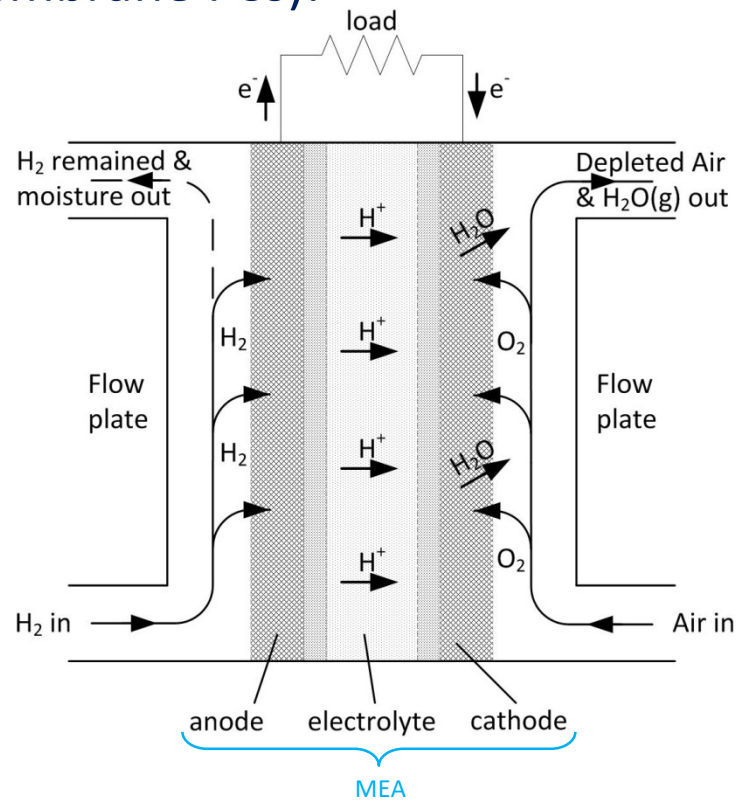
$$H_2 \rightarrow 2H^+ + 2e^- \text{ (anode)}$$

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O \text{ (cathode)}$$

- They are clean:
- Efficiency can exceed Carnot limit:

$$\eta_{HHV}^{ideal} = 83\%;\ \eta_{LHV}^{ideal} = 98\%;\ > \eta_{Carnot}^{max}$$

- $H_2 \longrightarrow P_e + Q_{out}$



INTRODUCTION: Motivations

Motivations:

1. An existing acute angle, its effects on the air flow distribution and the temperature uniformity; in turn harm the stack performance.

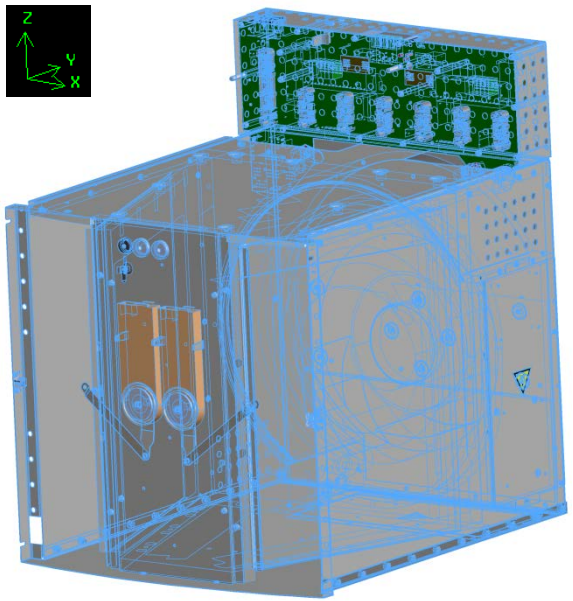
2. Where the preinstalled thermistor should be relocated?

3. 6 ℃ limit across the stack outlet surface is met?

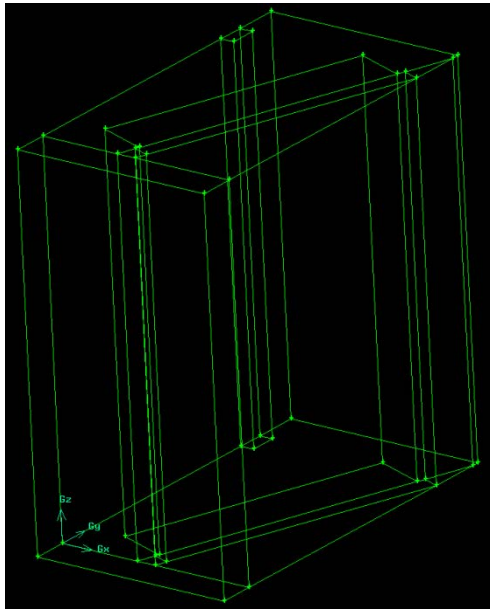
4. Design of an air bypass for a product safety certificate, and its effects on system performances.

INTRODUCTION: The 3D-CFD system model

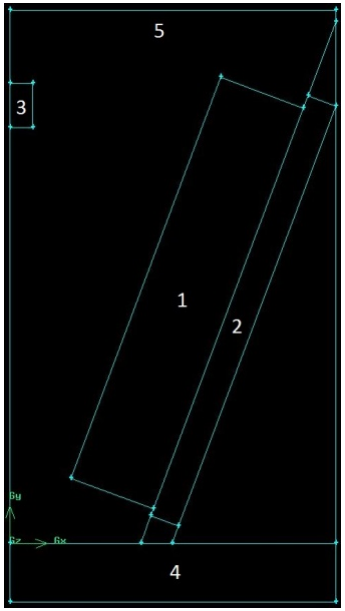
The calculation domain:



System CAD drawing



The calculation domain



Its top view

INTRODUCTION: The 3D-CFD system model

Main equations:

Continuity: $$\nabla \cdot (\rho \vec{u}) = 0$$

Momentum: $$\frac{1}{\varepsilon^2} \nabla \cdot (\rho \vec{u}\vec{u}) = -\nabla p + \nabla \cdot \vec{\tau}$$

Energy: $$\nabla \cdot (\rho C_p \vec{u} T) = \nabla \cdot (k^{eff} \nabla T) + S_T$$

Simulation settings:

Table 1 – Main settings in the 3D CFD model.

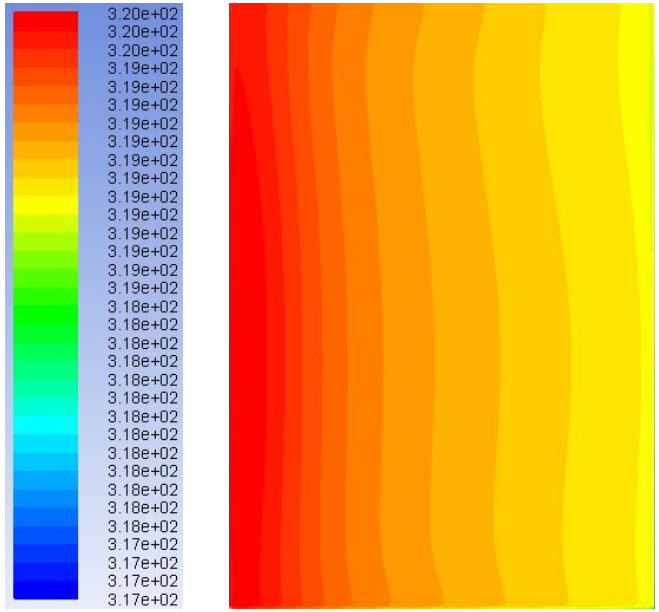
Property	Stack value	Filter value
Porosity	0.4	0.785
Permeability, m^2	1.27e-8	1.92e-8
Inertial resistance, 1/m	440	796.618
Material	graphite	synthetic fibre

Table 2 – Operating point.

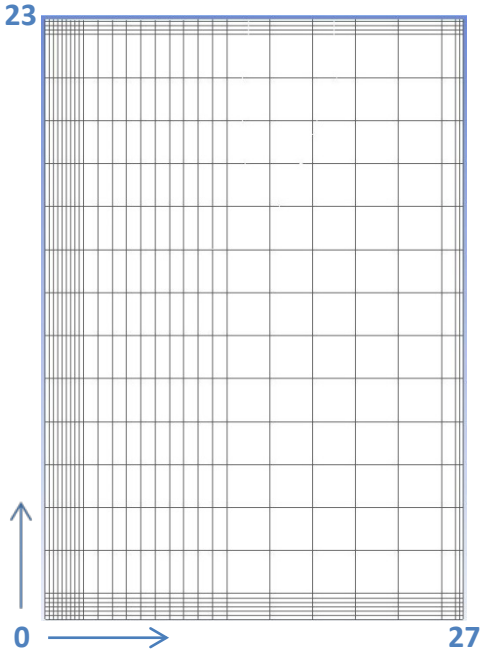
Property	Value
Ambient temperature, ^oC	12.82
Stack current, A	30
Cathode stoichiometry	42.53

RESULTS: Outlet surface temperature

Stack temperature distribution on outlet surface;



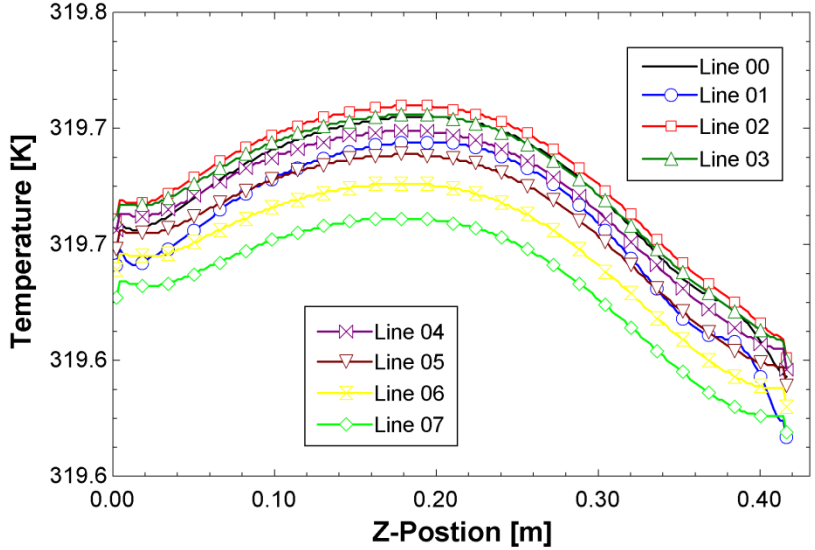
Temperature on stack outlet (right edge is stack rear), [K].



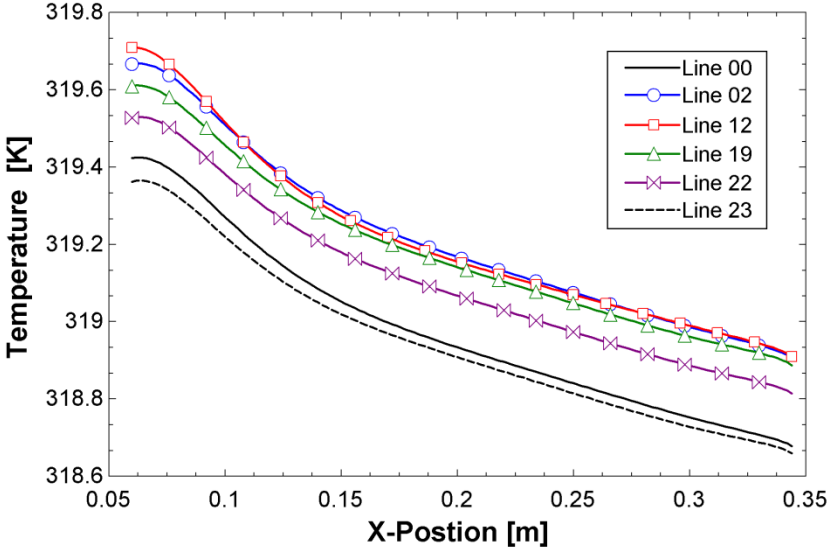
Lines drawn manually on stack outlet

RESULTS: Outlet surface temperature (cont.)

Stack temperature distribution on the drawn lines;



Vertical temperature distributions, [K].

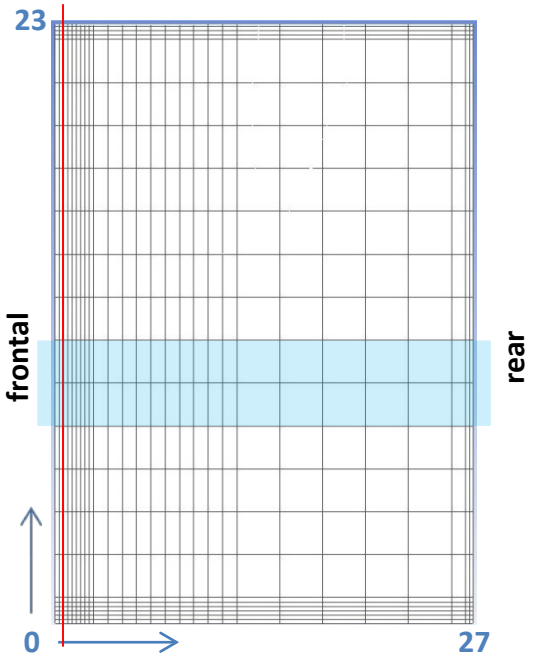


Horizontal temperature distributions, [K].

The conclusion: 6 ℃ limit across the stack outlet surface seems met.

RESULTS: Outlet surface temperature (cont.)

The peak temperature zone on outlet surface;



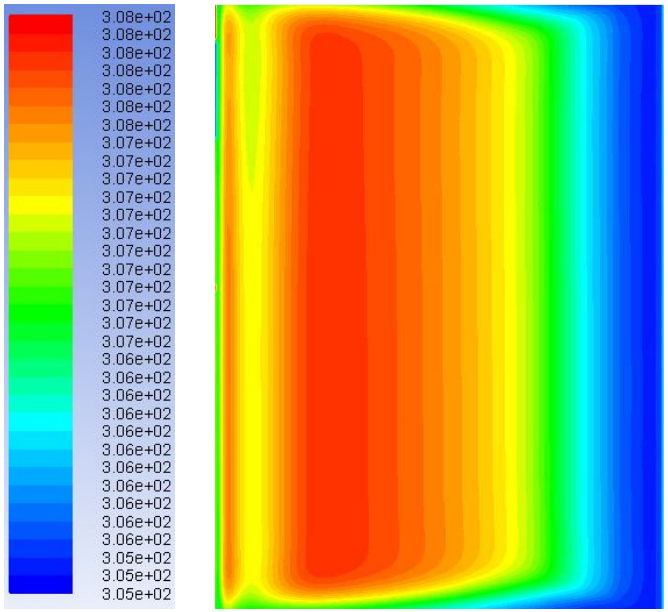
Hottest zone on stack outlet

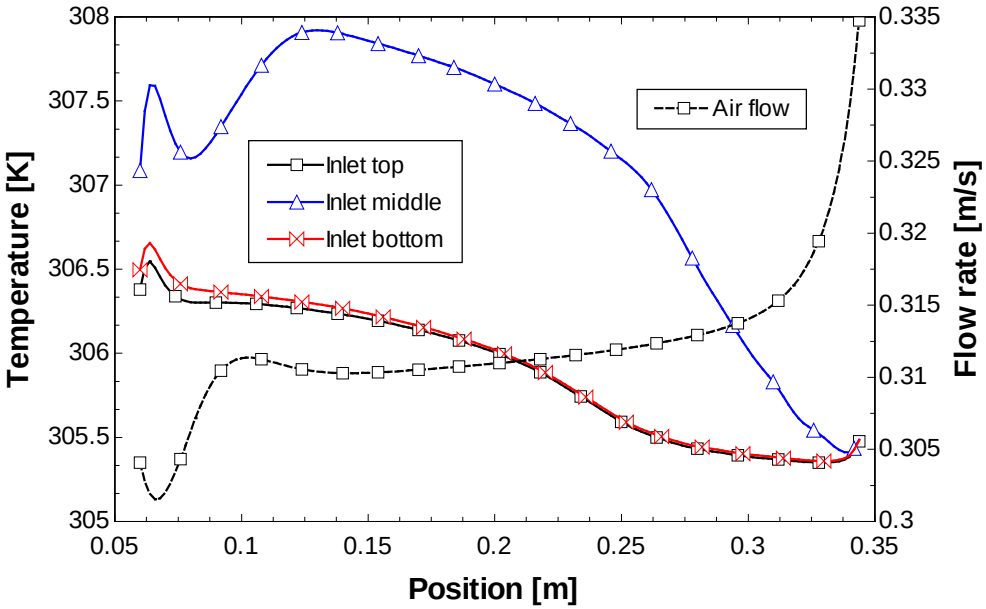
The conclusion: the pre-installed thermistor must be relocated.

The reason: air flow maldistribution, seen more clearly at inlet.

RESULTS: Inlet surface temperature

Temperature distribution on stack inlet;



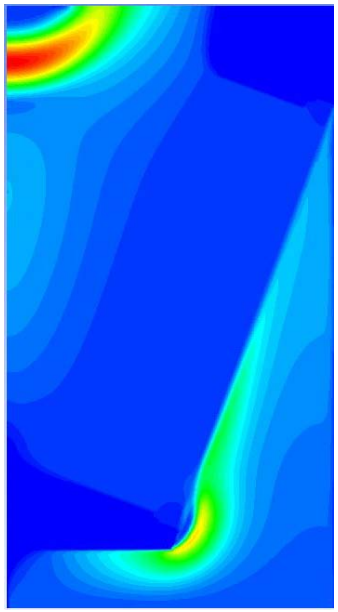


Inlet temperature distribution of the stack (right edge is the stack rear close to the centrifugal fan), [K].

Inlet temperature fluctuates violently, may need concern.

RESULTS: Inlet surface temperature (cont.)

Air flow distribution on stack inlet;



Inner flow distribution at the middle of the system, [m/s].

The sharp edge protrudes into the pathway of the intake air. This causes the air flow detaching from the surface and generates a low flow zone in the frontal region.

RESULTS: The air bypass

According to the KIWA safety code:

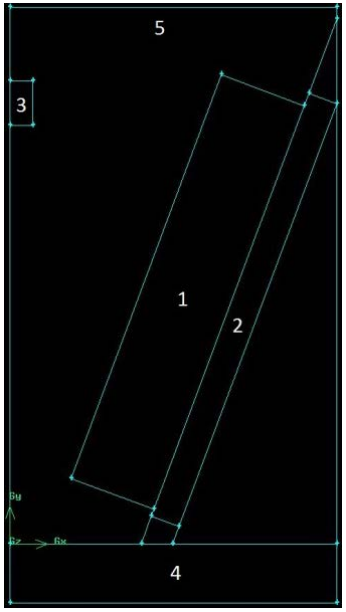
$$\dot{V}_{bypass} = 20.07[m^3/h],\ when\ I = 30[A],$$

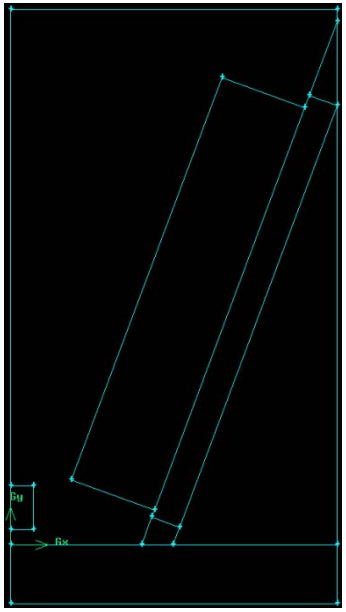
use the Bernoulli's principle finds out the bypass flow beforehand,

$$\Delta p_{sys} = \frac{\rho v^2}{2} \qquad \frac{v D_h^2 \pi}{4} = \dot{V}_{bypass},$$

then

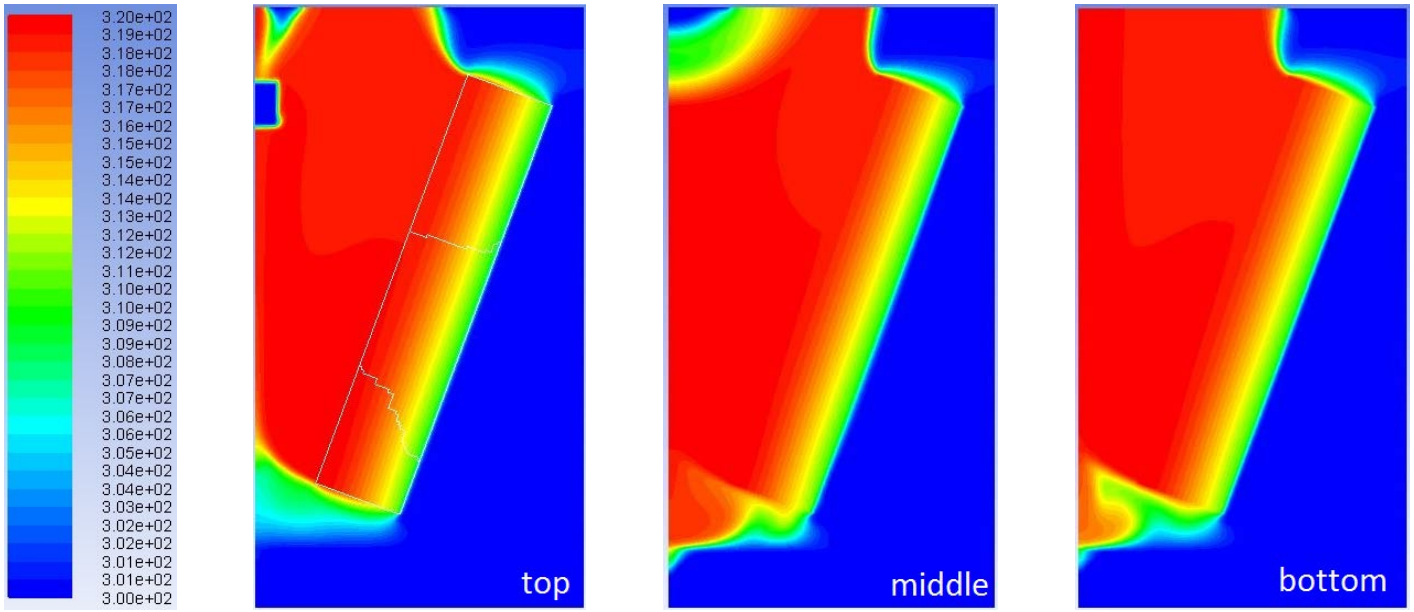
$$D_h = 0.03018[m],\ \dot{V}_{bypass}^{3D-CFD} = 26.05[m^3/h],\ under\ I = 30[A]$$





RESULTS: The air bypass (cont.)

The footprint of the air bypass in the 1st design:

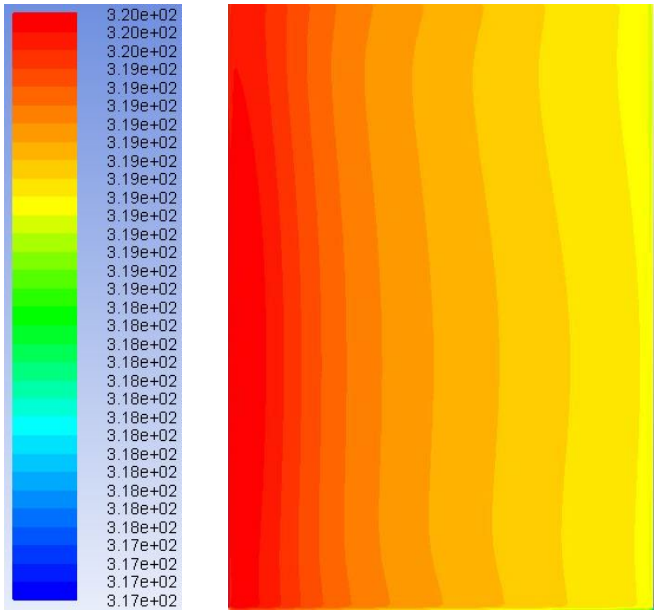


Inner temperature distribution (system centrifugal fan is on the top edge), [K].

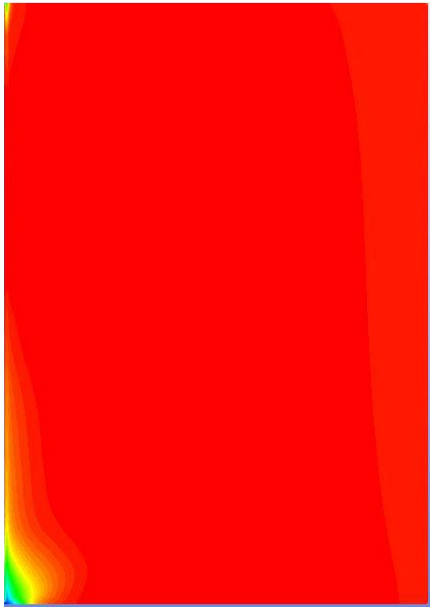
The conclusion: no effect on stack temperature distribution.

RESULTS: The air bypass (cont.)

Stack outlet surface temperature in the two cases:



Stack outlet temperature in the 1st case, [K]



Stack outlet temperature in the 2nd case, [K]

The bypass evener outlet temperature, but too much cooling for the bottom corner. Fins can be installed to direct the bypass away.

Main conclusions and future work

1. The 6 ℃ limit across the stack outlet surface seems met.
2. The pre-installed thermistor must be relocated. It is found out that the hottest spot of the stack is at the frontal edge on its outlet midline. This is totally different from the stack manual.
3. The sharp edge protruding into the pathway of the intake air needs to be redesigned and smoothed.
4. Inlet temperature fluctuates violently, may need concern.
5. Placing the air bypass in the back has no effect on stack temperature distribution.
6. Making the air bypass in the front can help smooth the stack outlet temperature, however there will be too much cooling for the bottom corner. Fins can be installed halfway to direct the bypass away.
7. The hottest spot can probably be also cooled down by the halfway fins. Detailed design needs further study.

Thank you!