CD adapco Group
OVERVIEW

CD adapco Group

The CD adapco Group in Short

The CD adapco Group is a global partnership of companies specializing in CFD software as well as industrial computer aided engineering (CAE) services. Our mission is to be a full service provider of software tools and engineering services to assist our clients in integrating virtual technology into their overall engineering process.

Our main centers, adapco in New York and Computational Dynamics Ltd in London are involved in the development of the industrial CFD code, STAR-CD, as well as several innovative new CFD codes and associated CAE tools. Over 400 experienced professional staff and CFD specialists are employed, We have subsidiary offices providing local CFD support, training and CFD/CAE consultancy and engineering services throughout the world.

CD adapco Group

WORLD-WIDE CD adapco Group ORGANIZATION

- Established in 1980 - 1987
- Global staff of 400 researchers and engineers, 50% with PhD
  - Development 30%
  - Technical support and engineering services 40%
  - Sales and Marketing 20%
- Computational Dynamics Ltd
  - Head quarters in London
  - 3 offices in Europe
  - 1 office in USA
- adapco
  - 5 offices in USA
- CD-adapco Japan
  - 2 offices in Japan
  - 1 office in China
- CD-adapco France
- CD-adapco Korea
- Agents and distributors throughout the rest of the world

- Global user base of over 3000
- Annual turnover of over $40,000,000
- Average annual growth of around 20%
- Largest supplier of CFD technology to the automotive industry
- Largest supplier of CFD technology in Germany and Japan
- Second largest supplier of CFD technology in the world
- Group's long-term aim is to remain the best CFD technology supplier on the market
  - Recognizing the changing needs of the industrial users
  - Developing the best tools to address the industrial users needs

STAR CD
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About **adapco**

Organization

CFD Consulting Group providing flow and thermal analyses using CFD tools and methods

FEA Consulting Group providing thermal, structural, and dynamic analyses using FEA methods

Advanced Methods Development Group providing leading edge analysis method development and solutions for multi-physics and other challenging applications

Software Development Group providing general purpose and application specific pre- and post-processing tools

Software Sales Group providing software licenses, training, and user support for engineering software

adapco's Quality System is certified as conforming to the ISO 9001 standard. Our certification extends to all five of adapco's service groups.

CD adapco Group

adapco CFD Applications Group

adapco's CFD Applications Group provides World Class analysis support to New Product Development and Product Upgrade Design Teams

Support includes

- Flow path performance evaluation and optimization
- Heat transfer analysis to predict temperatures or provide Boundary Conditions for FEA analyses
- Specialty applications such as reacting, fluid-solid interaction, and two-phase flows

CFD Group Make-up

- Degrees in Mechanical or Aerospace Engineering with concentrations in CFD or Numerical Heat Transfer
- 60% Master's Degrees, 30% PhD, 10% Bachelor's Degrees
- Members of the group have an average of nine years experience in CFD with an average of five years at adapco

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INDUSTRIAL LINKS AND PARTNERSHIPS

- ENGINSOFT
  - FRONTIER (optimization)
- FLOWMASTER International
  - FLOWMASTER (1D/3D coupling)
- Gamma Technology
  - GT-Power (1D/3D coupling)
- INTES
  - PERMAS (fluids structures interaction)
- LMS International
  - SYSNOISE (aeroacoustics)
- Collins and Aikman
  - COMET ACOUSTICS
- Reaction Design
  - CHEMKIN (complex chemistry)
- Siemens Axiva
  - MiXpert (mixing vessels simulation)

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ACADEMIC LINKS AND PARTNERSHIPS

- Imperial College
  - General CFD technology
- U Hamburg-Harburg
  - Marine hydrodynamics
- U Karlsruhe
  - Aeroacoustics
- Penn State University
  - Aeroacoustics
- U Leeds
  - Combustion technology
- UMIST
  - Turbulence modeling technology
- RWTH-Aachen
  - Combustion technology
- TU Berlin
  - Turbulence modeling, aeroacoustics
- U South Carolina
  - PEM Fuel cell technology
- U Stanford
  - Turbulence modeling technology
- U Wisconsin
  - Combustion technology
- U Nevada Las Vegas
  - Surface chemistry technology

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PRODUCT POSITIONING

Analysis Functionality

Transient
Compressible

Steady State
Incompressible

R&D Engineer

STAR-CD /HPC
Comet

Development
Engineer

es-tools

Design
Engineer

Comet-Works
STAR/ProE

Analysis Sophistication

One specie
Single phase
k-ε turbulence
model

Multiple species
Multiphase
Advanced turbulence
models
Stiff chemistry

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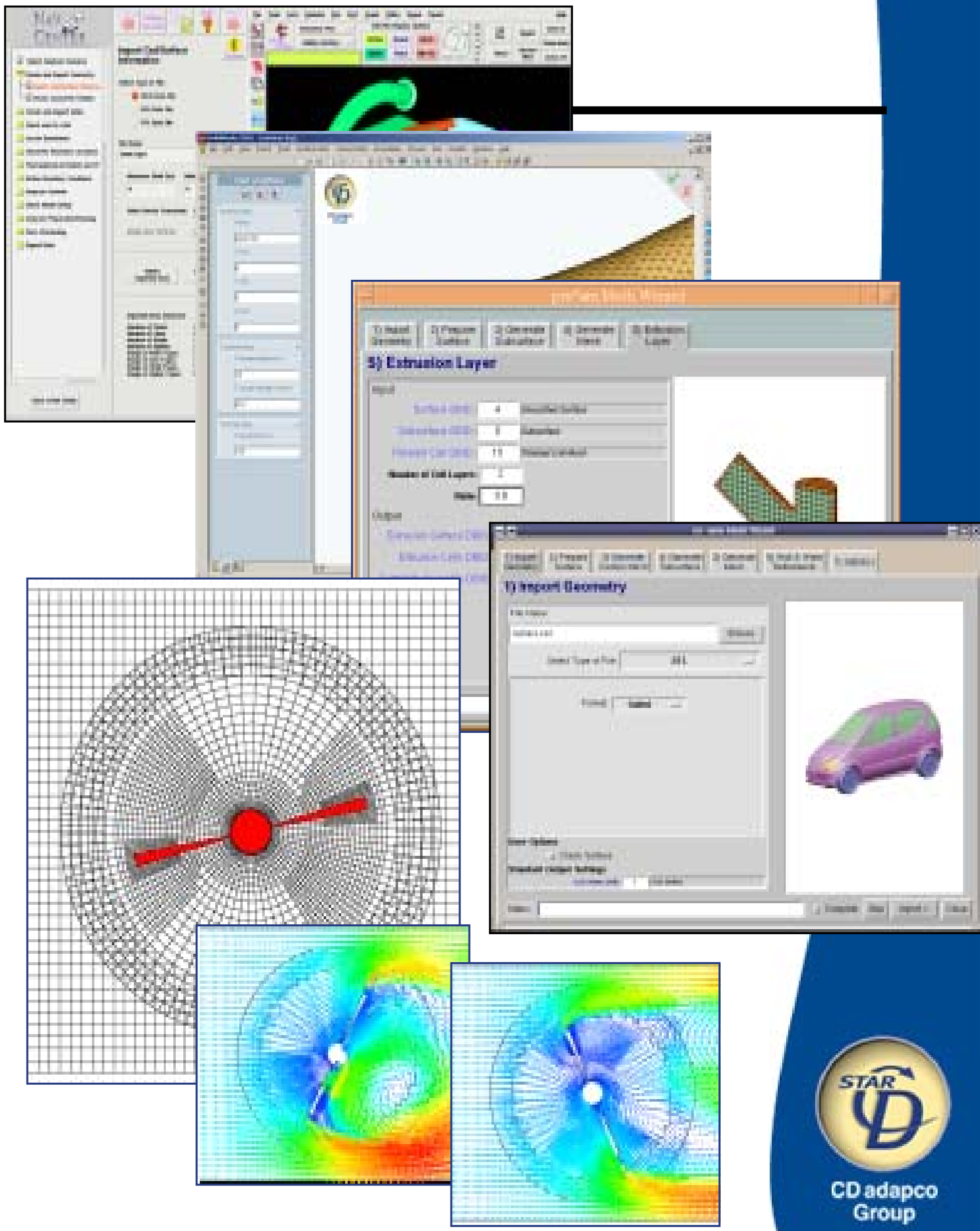
Group

ADDRESSING THE NEEDS OF INDUSTRY

- Easy to use and learn and graphical use interface
  - Both general and application specific
- Flexible CAD interface and CAD/CAE integration
  - Including surface cleaning and repair
  - Code coupling
- Automatic meshing
  - Both general and application specific
- Complete mesh handling flexibility
  - Any cell shape or grid structure
  - Any mesh movement
- State of the art numerics and solvers
  - Stability and accuracy
  - Speed and efficiency
- Extensive physics modeling capability
  - Both general and knowledge based tuning
- Utilization of latest computer technology
  - Hardware optimization
  - Parallel processing
- Advanced analysis and post-processing tools
  - Innovative data processing and visualization
- Technical support and know-how
  - Knowledgeable, experienced and industry aware engineering team



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Software Product Summary

- General solvers and CFD analysis codes
  - STAR-CD
  - COMET
  - Two new solvers under development
- General pre/post-processor GUI
  - PROSTAR
- CAD
  - pro-surf
  - pro-cad
- Automatic Mesh Generation
  - pro-am
- Integration
  - STAR/ProE
  - STAR-Works
  - COMET-Works

expert system es-tools

Knowledge based expert systems

- **es-aero**
- **es-uhood**
- **es-aftertreatment**
- **es-pass**
- **es-ice**
- **es-brake**
- **es-turbo**
- **es-fsi**
- **es-pemfc**

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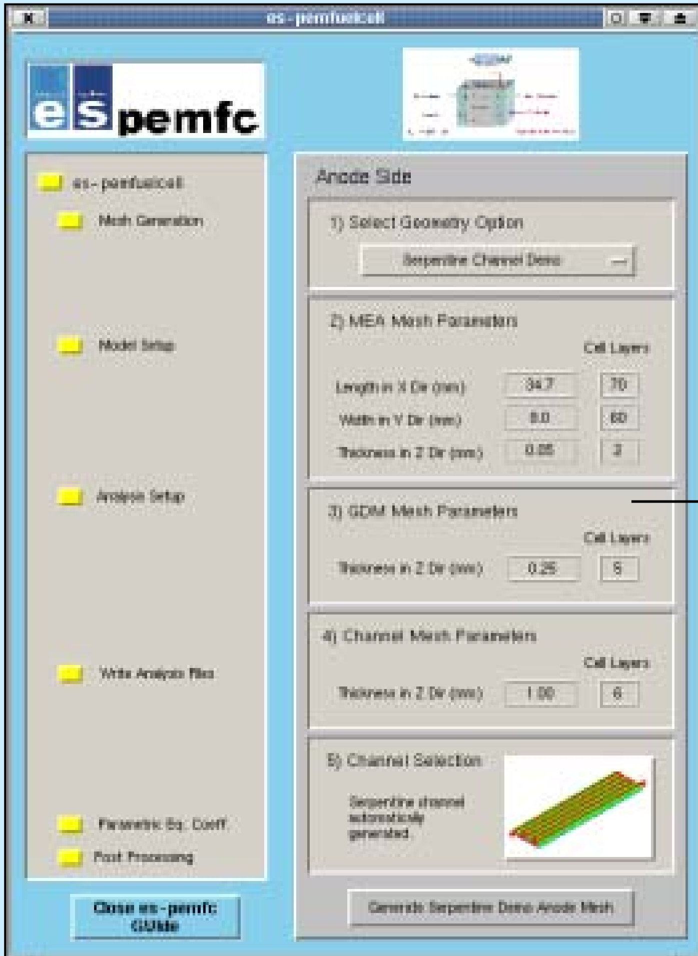
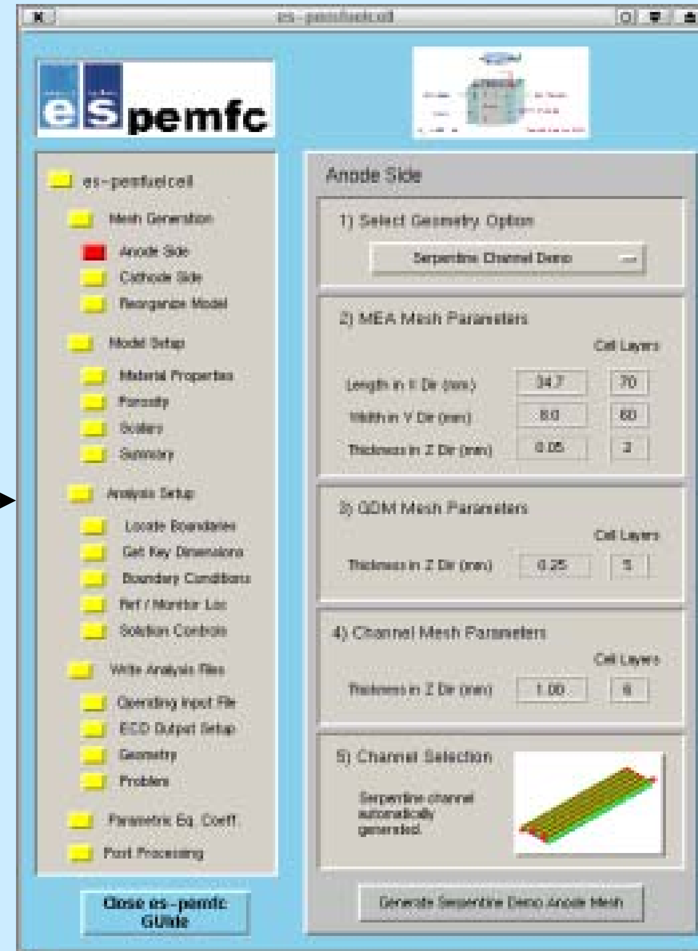
Samples of PEM Fuel Cell GUI

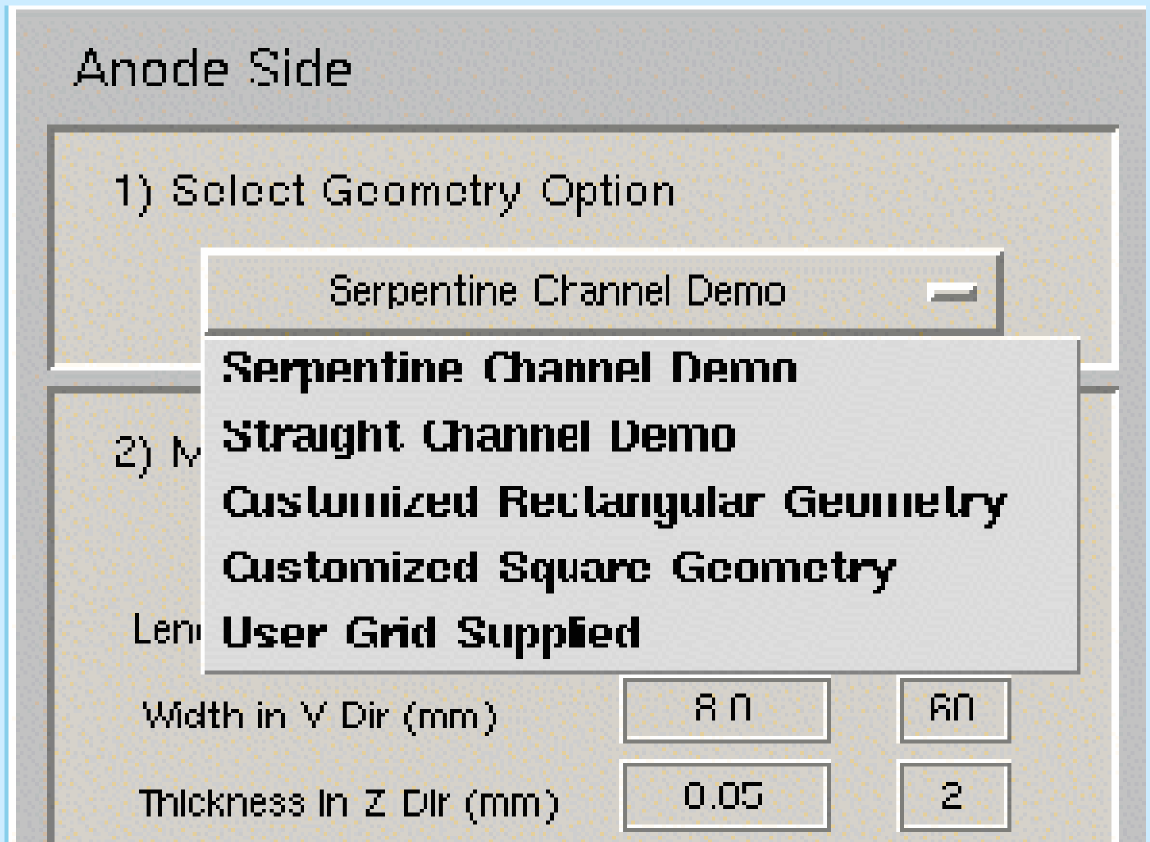
Process-oriented GUI steps user through all needed set-up and post processing for PEM analysis

es-pemfc Panel



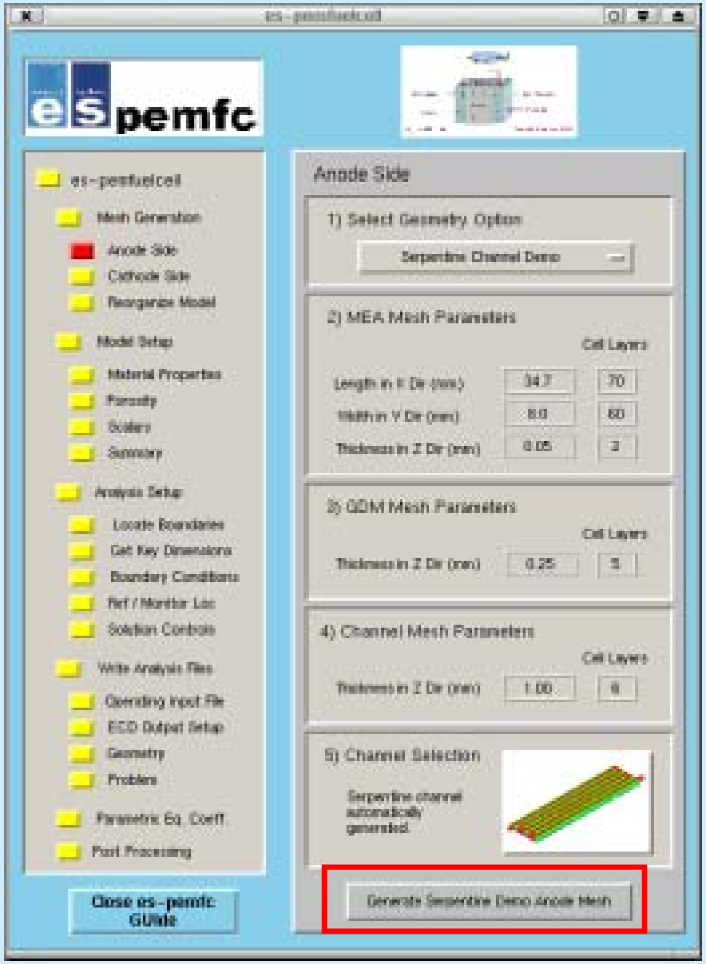


Anode Options

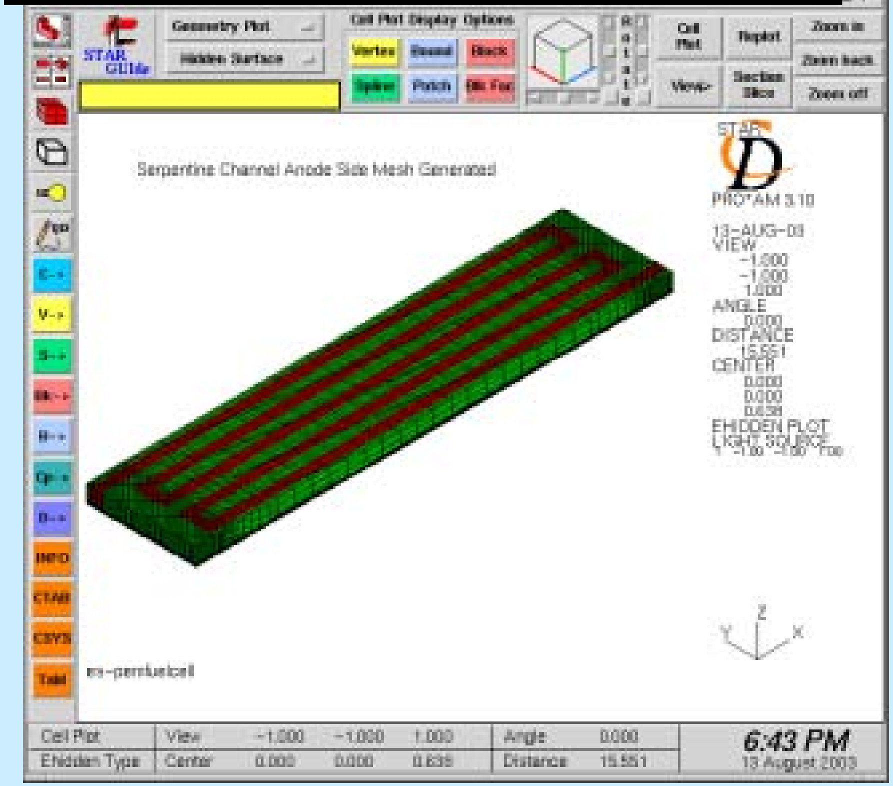


Included in GUI are two complete demonstration analyses with realistic input, user defined rectangular or square geometry with auto mesh generation, plus flexibility to import complex grids generated by user by other means

Serpentine Demo

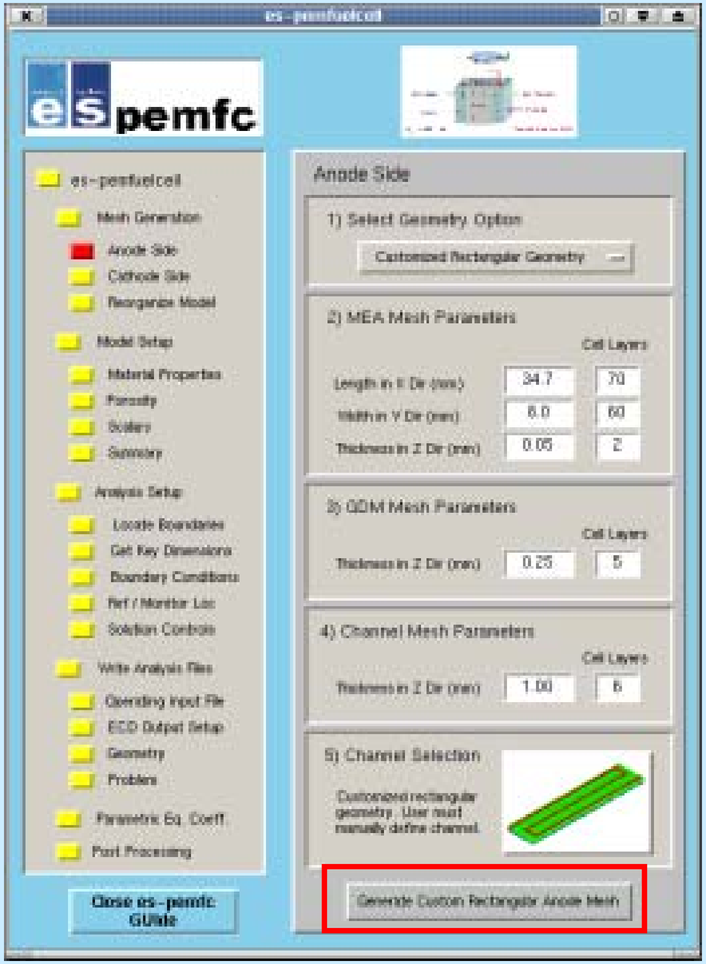


Mesh generation example for Serpentine Demo analysis

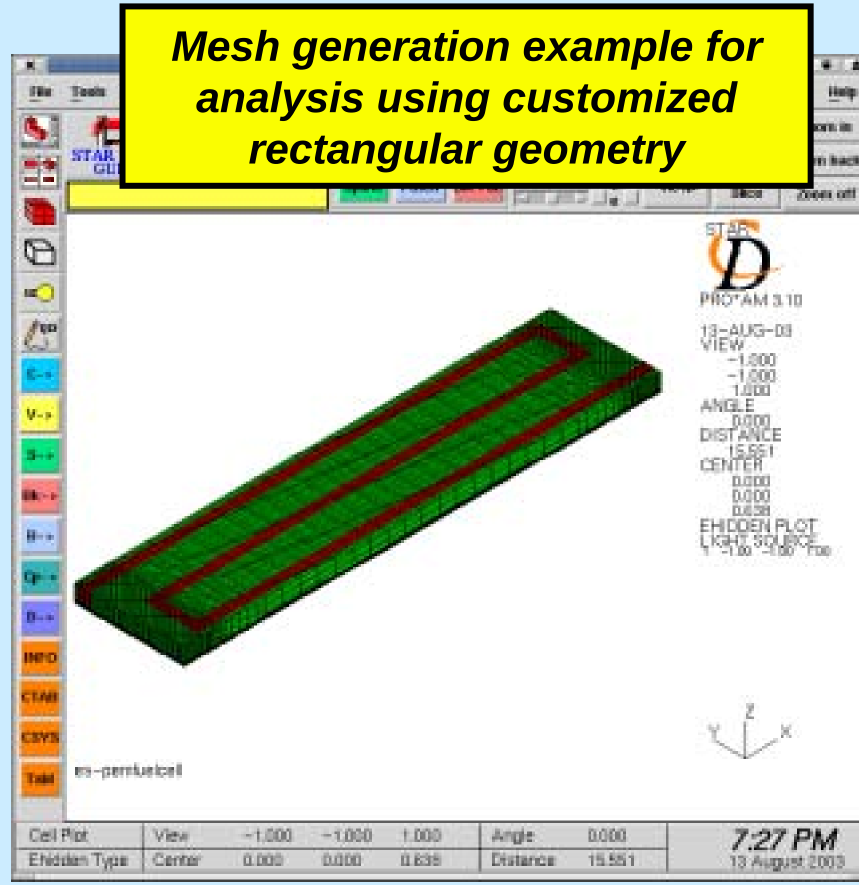


Construct Anode Side Mesh

Custom Rectangular Geometry



Mesh generation example for analysis using customized rectangular geometry



Construct Anode Side Mesh

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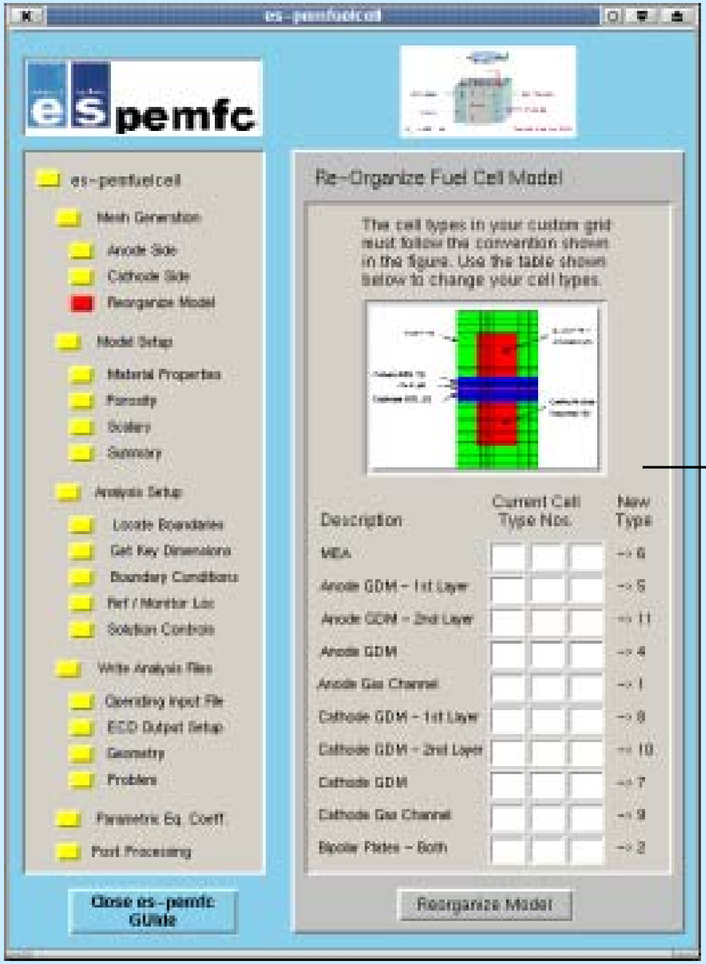
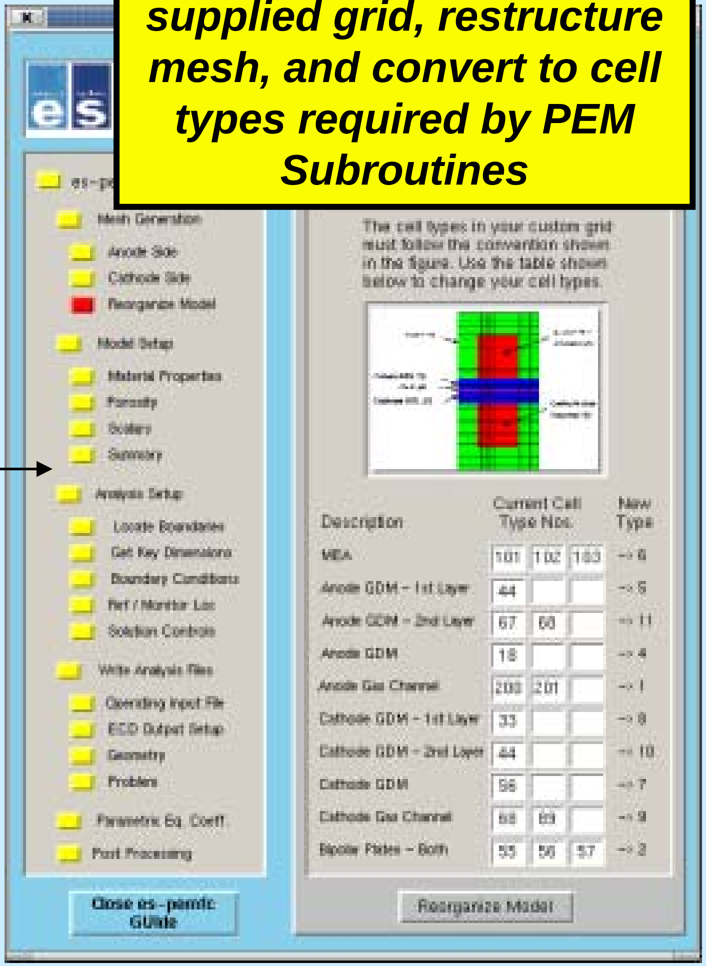
User Grid Supplied

Facility to import user supplied grid, restructure mesh, and convert to cell types required by PEM Subroutines

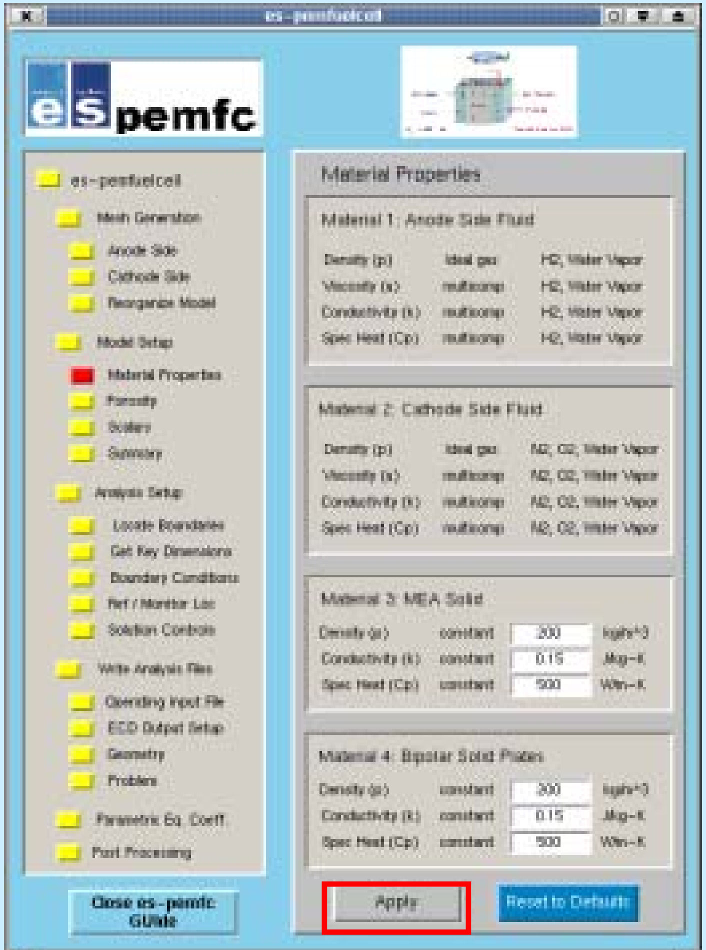


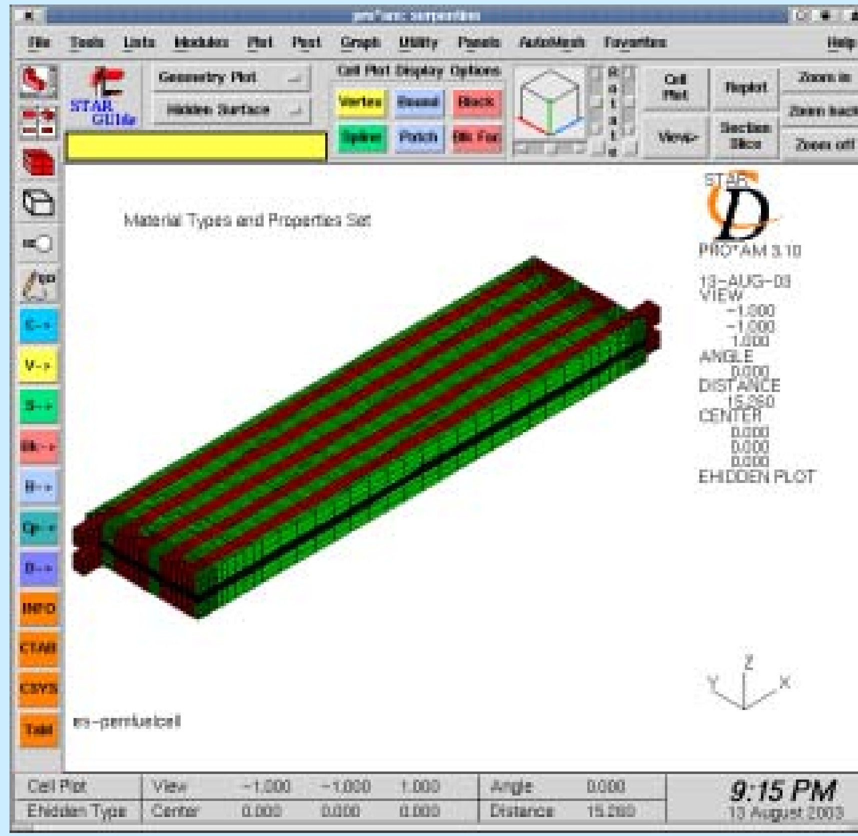


Steps 3: Restructure Model

Material Properties

Material Property specification with realistic defaults





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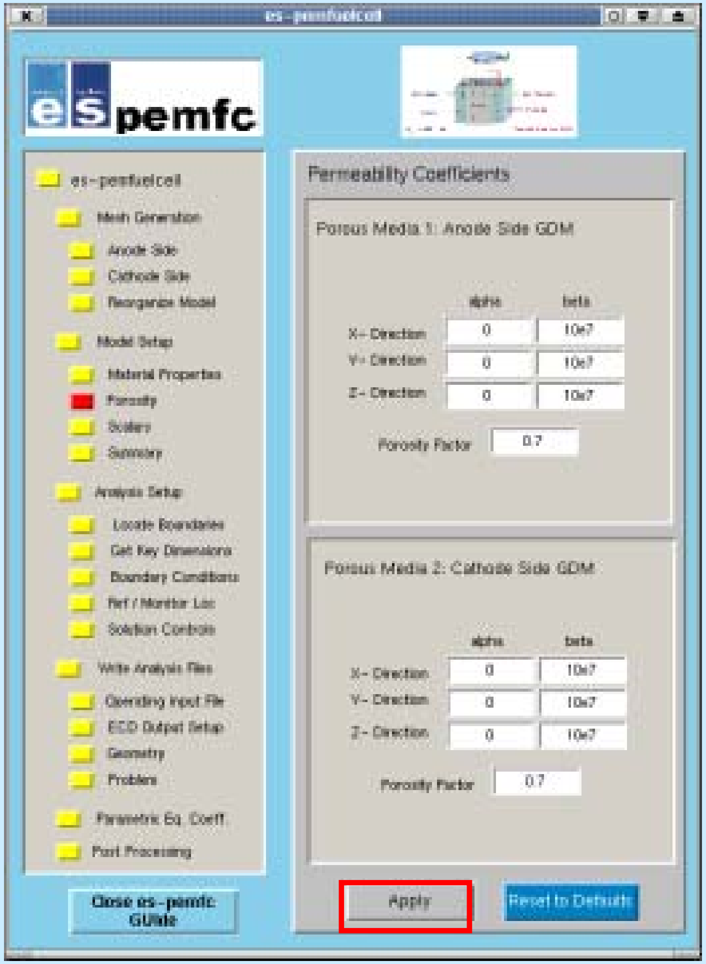
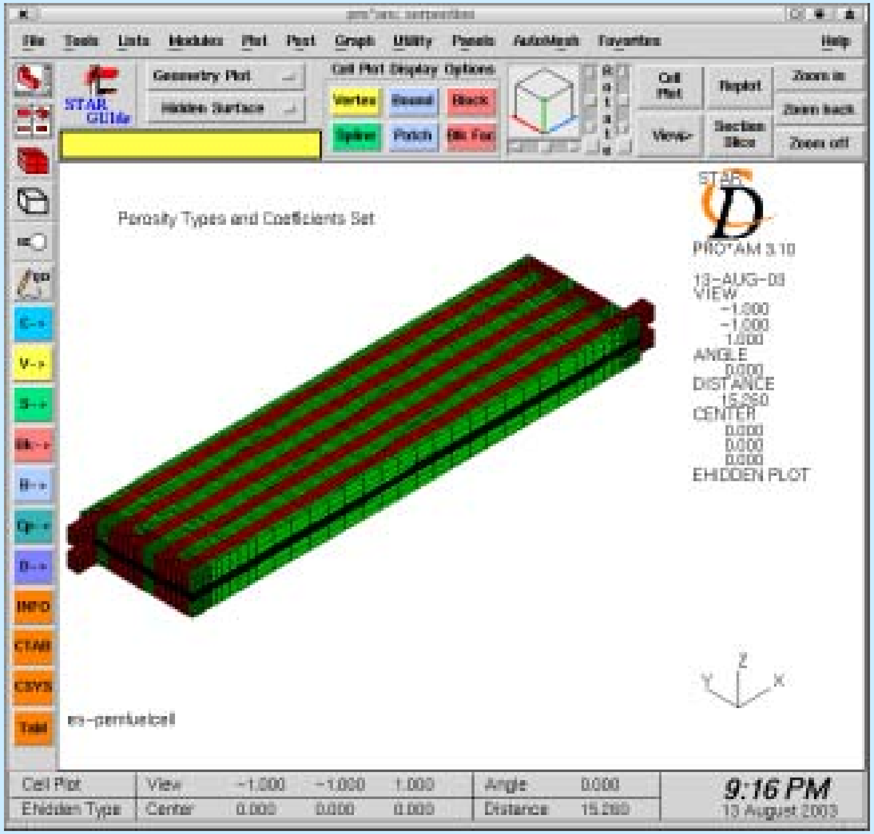
Porosity

Porosity specification with realistic defaults





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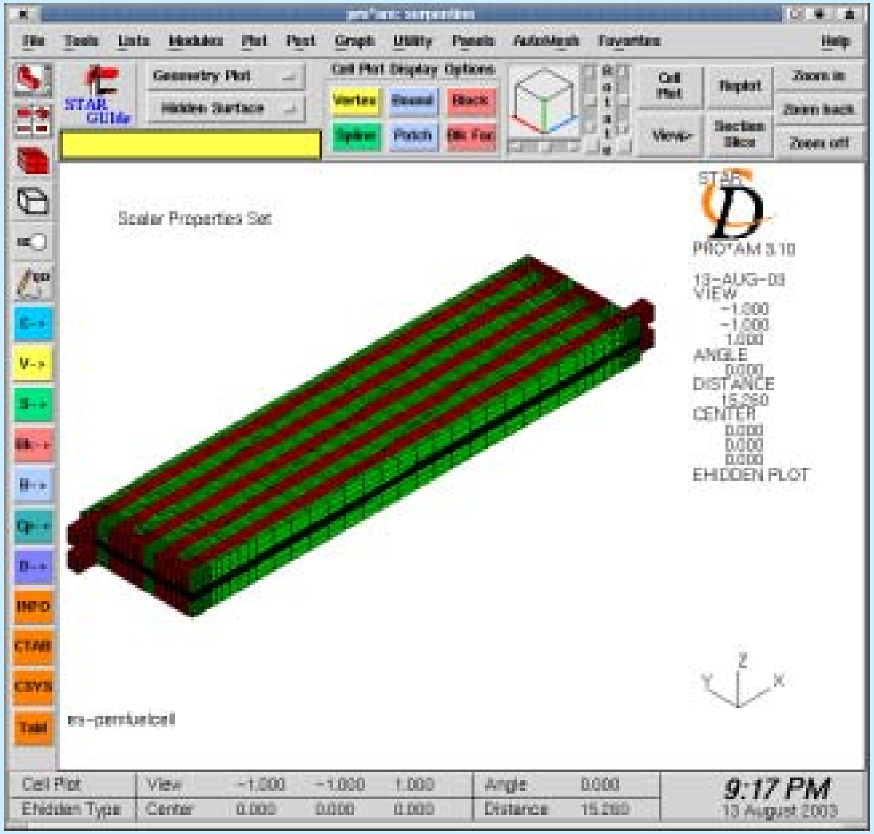
Scalars

Automatic set-up of scalars needed by PEM Subroutines for electrochemistry



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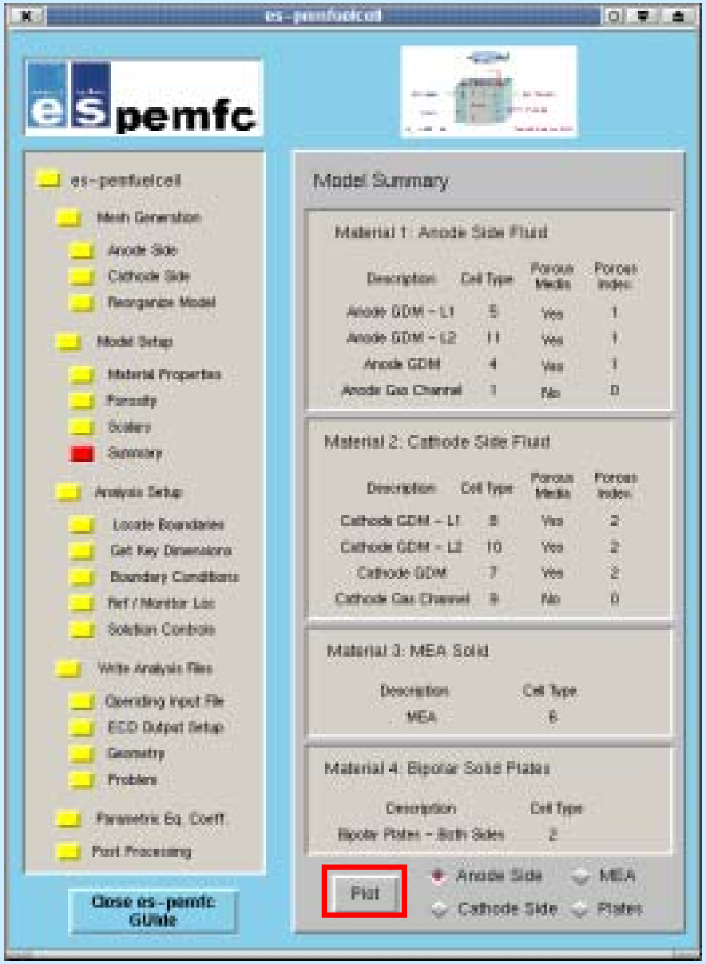
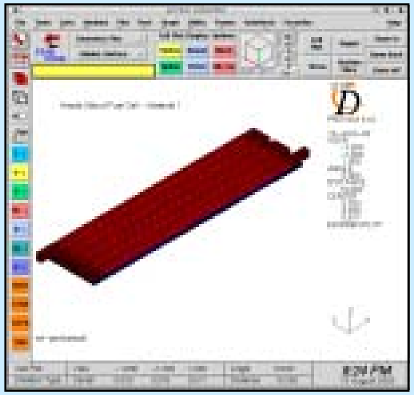
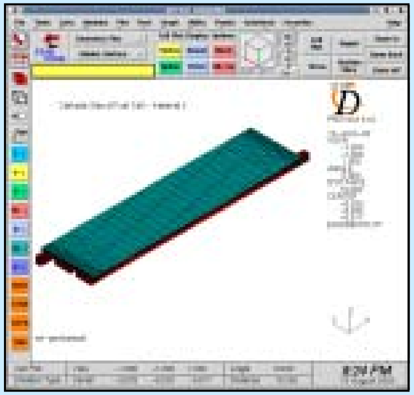
Model Summary

Summary panel to quickly check cell types and material properties

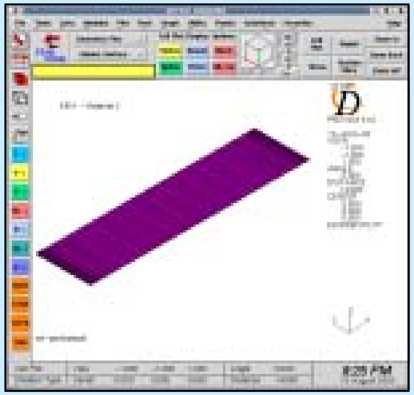




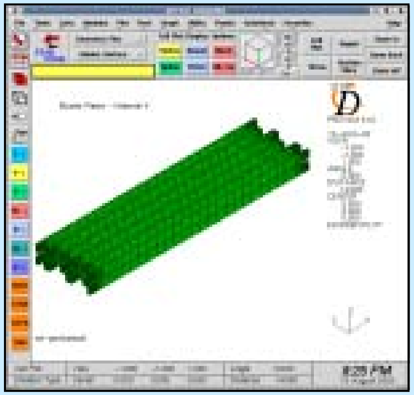
Anode Side



Cathode Side



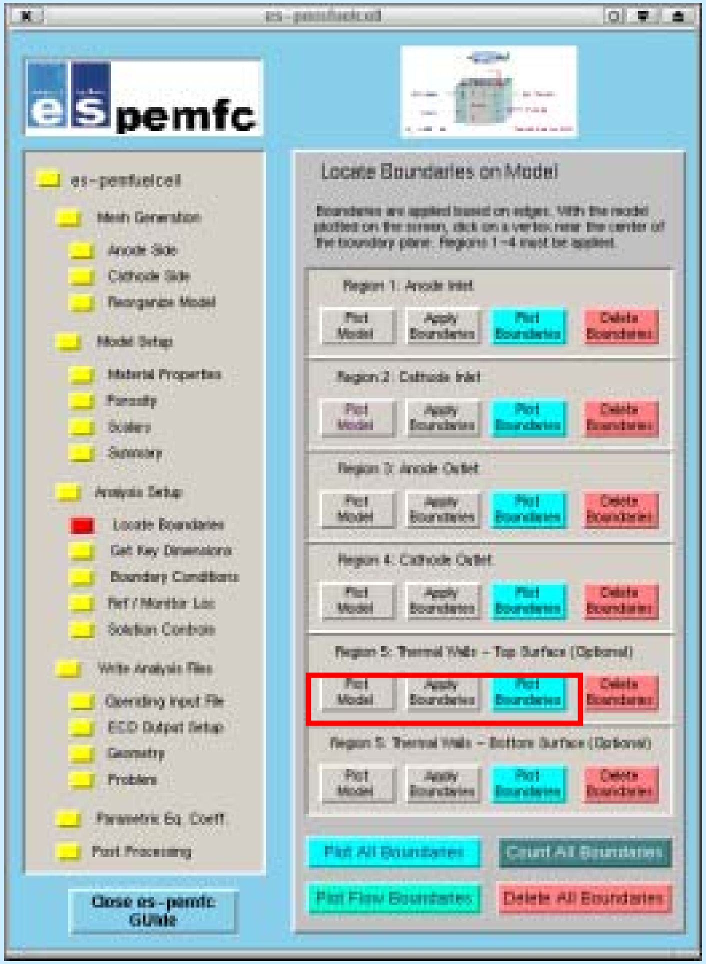
MEA

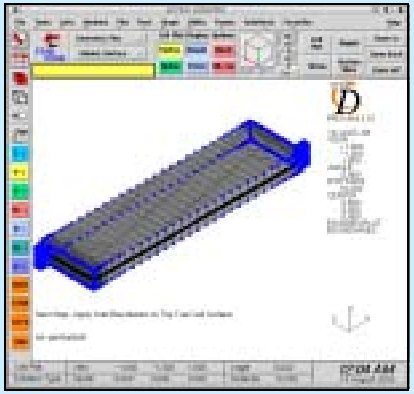


Bipolar Plates

Locate Boundaries

Graphical boundary condition locator



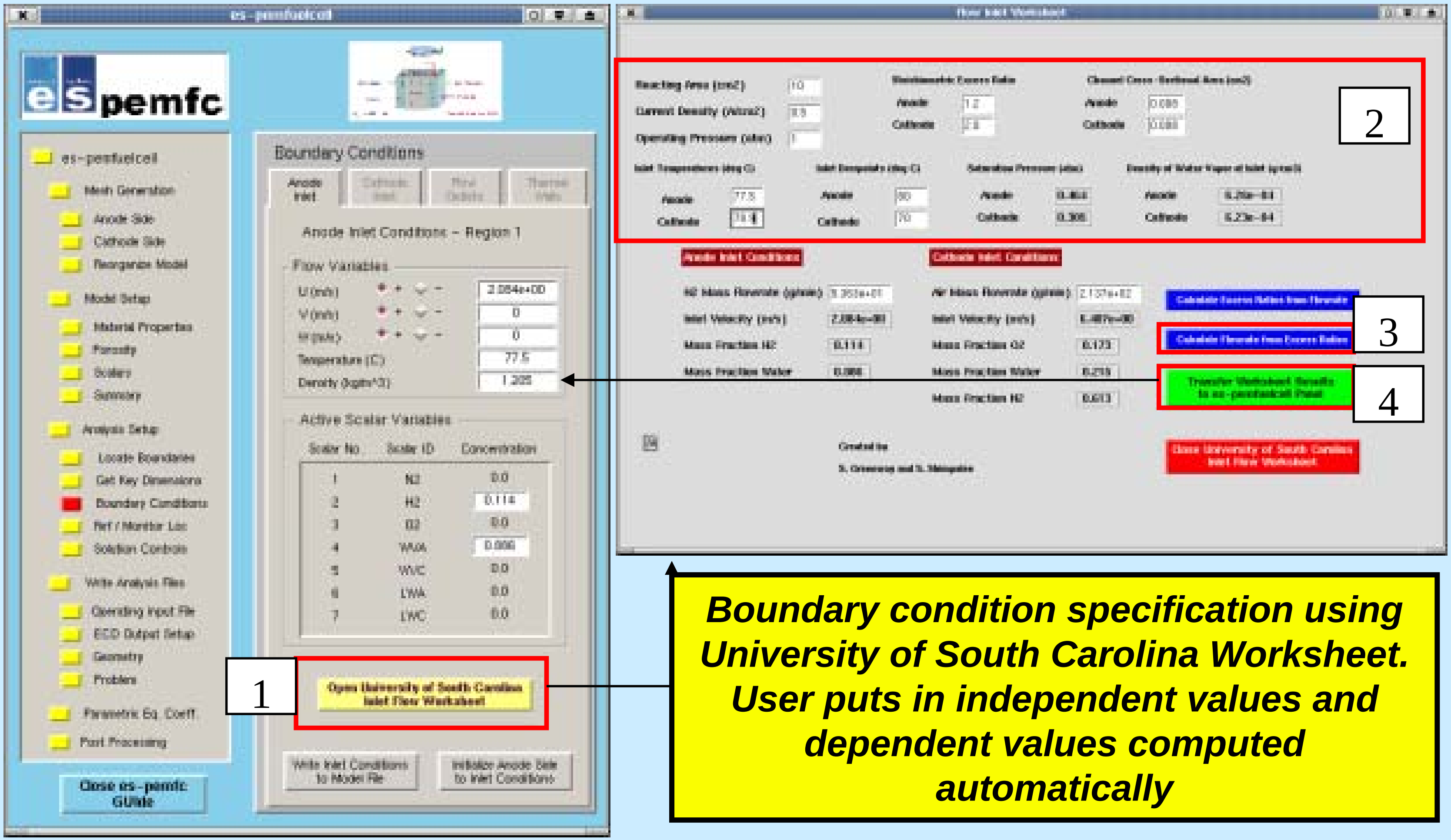


Plot Model

Apply Boundaries

Plot Boundaries

Boundary Conditions



Boundary condition specification using University of South Carolina Worksheet. User puts in independent values and dependent values computed automatically

Flow Inlet Worksheet

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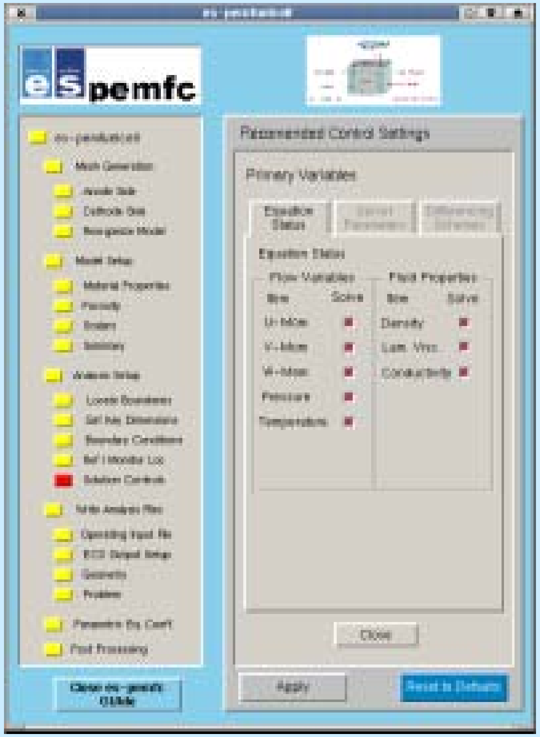
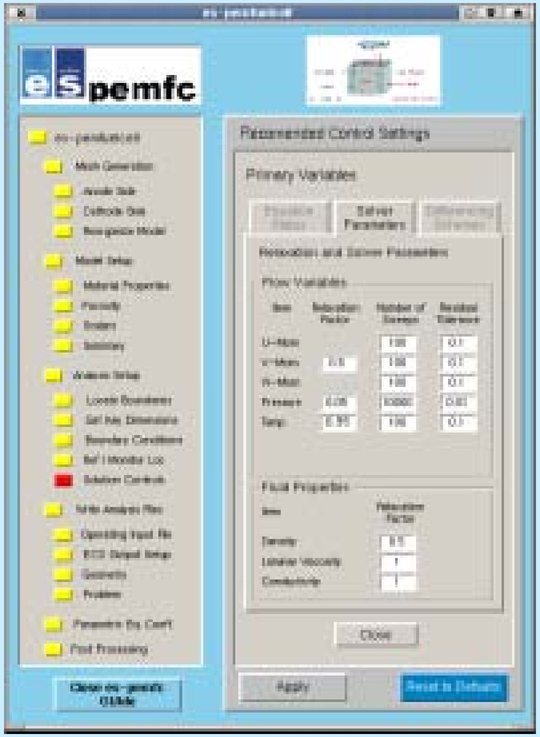
Control Settin

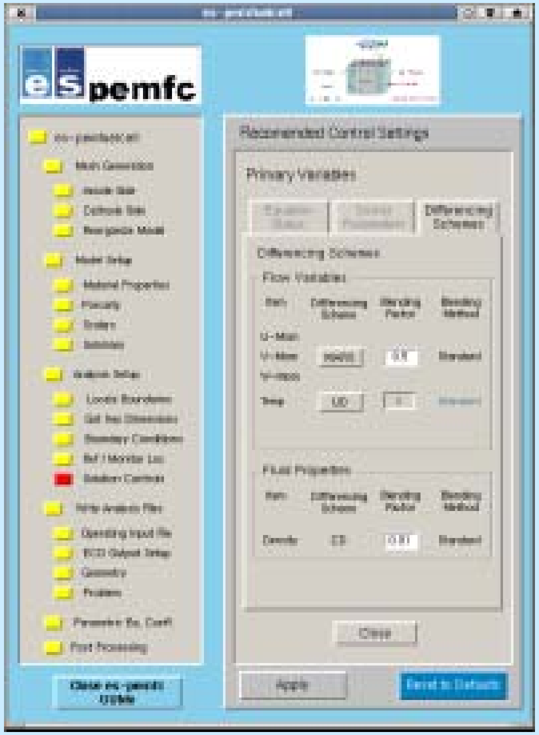
es-pemfc Control Panels apply default the solver and differencing scheme choices recommended for PEM fuel cell analysis (may be different than STAR-CD defaults)



Equation Status



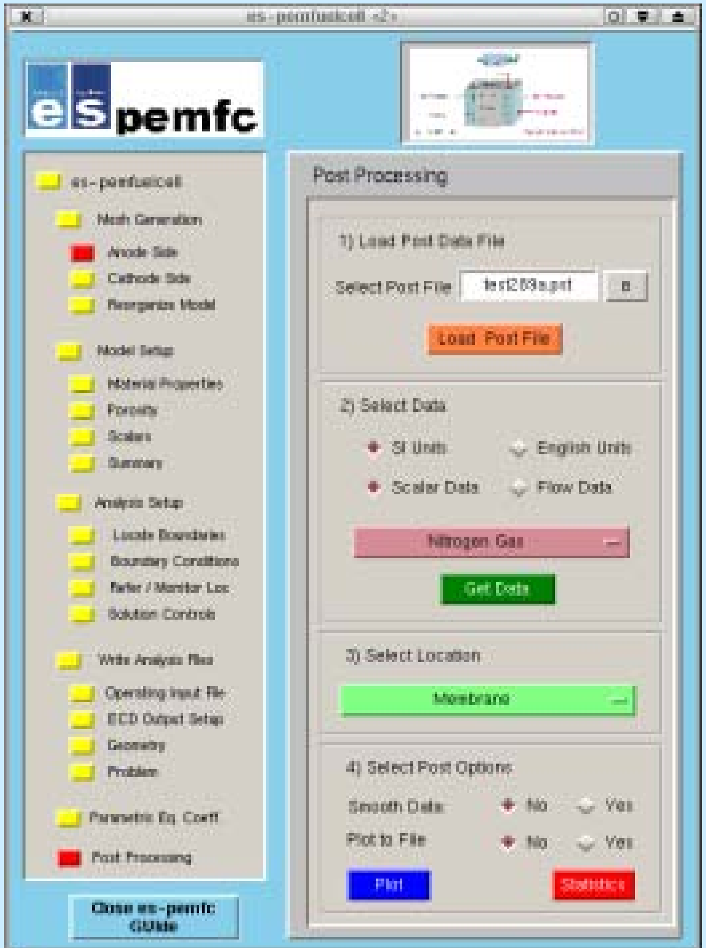
Solver Parameters

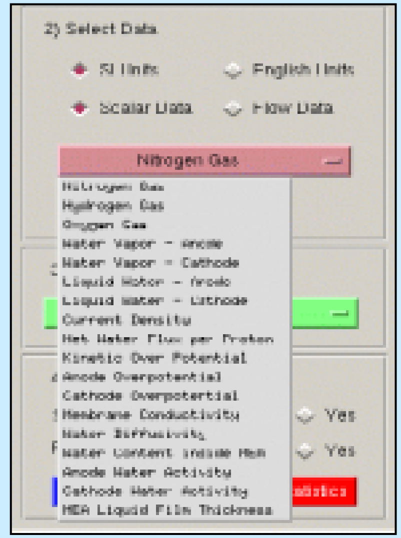


Differencing Schemes

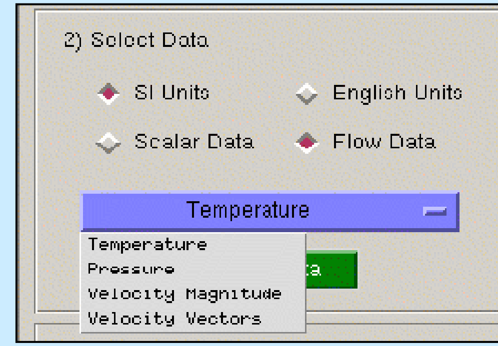
Custom Post-processing

Post Processing

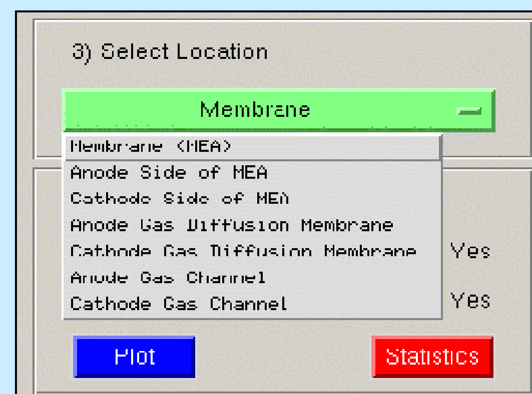




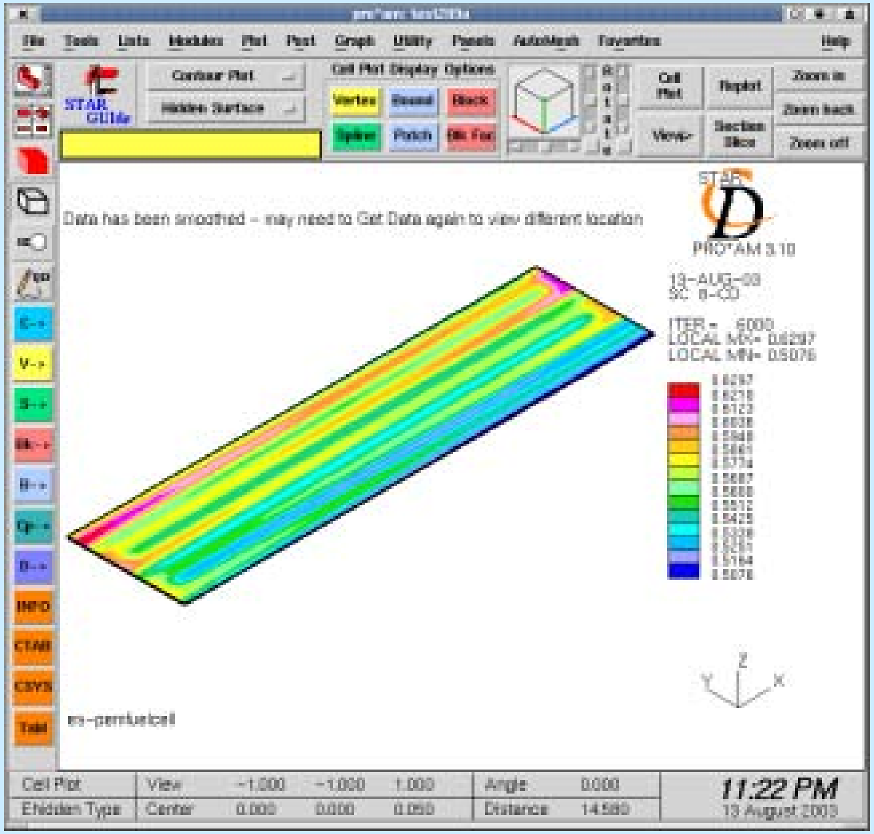
Scalar Data



Flow Data



Post Processing – Ex. 1a



Plot: CD – Anode Side of MEA

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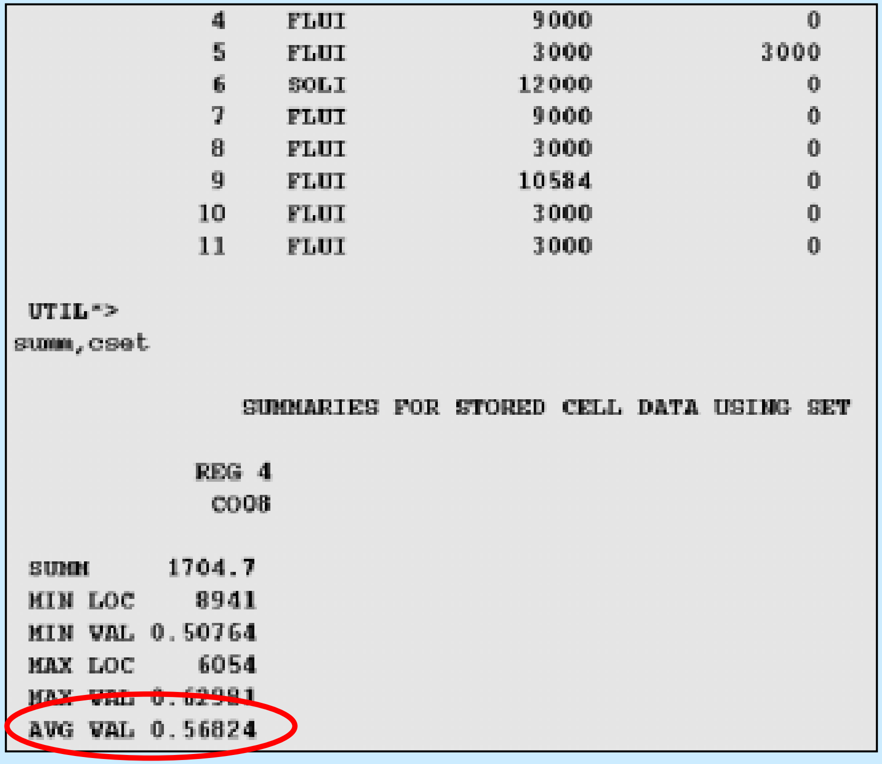
Post Processing – Ex. 1b

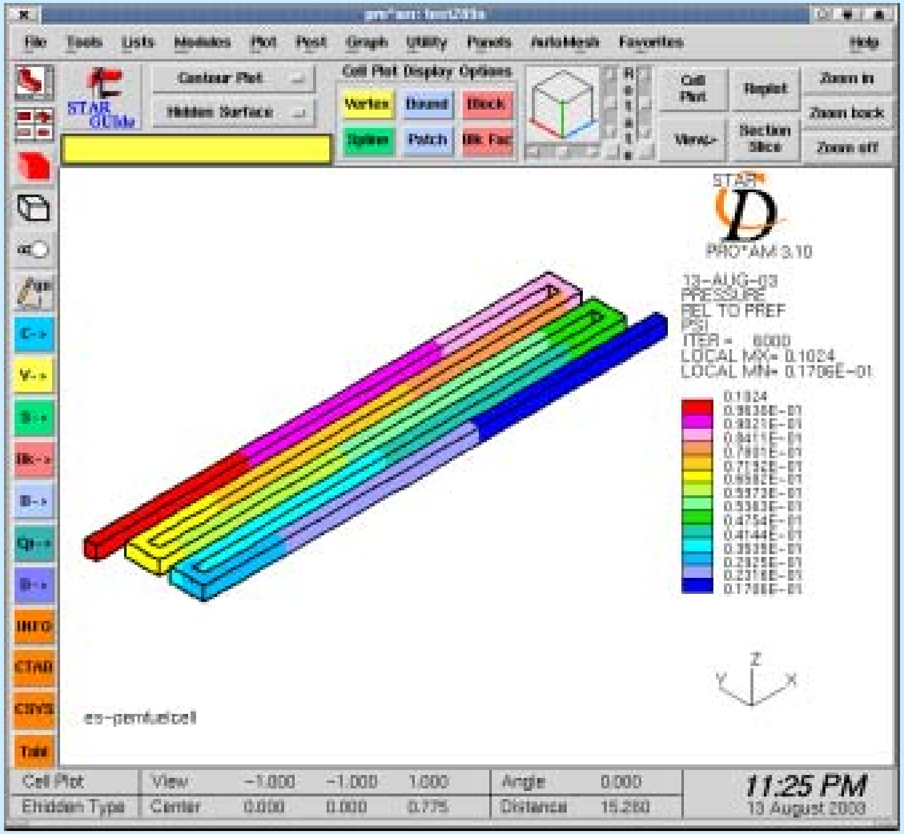


4	FLUI	9000	0
5	FLUI	3000	3000
6	SOLI	12000	0
7	FLUI	9000	0
8	FLUI	3000	0
9	FLUI	10584	0
10	FLUI	3000	0
11	FLUI	3000	0

```
UTIL*>
summ,cset

          SUMMARIES FOR STORED CELL DATA USING SET

        REG 4
         C008

SUMM       1704.7
MIN LOC      8941
MIN VAL  0.50764
MAX LOC      6054
MAX VAL  0.62981
AVG VAL  0.56824
```

Statistics: CD – Anode Side of MEA

Post Processing – Ex. 2



Plot: Pressure – Anode Gas Channel

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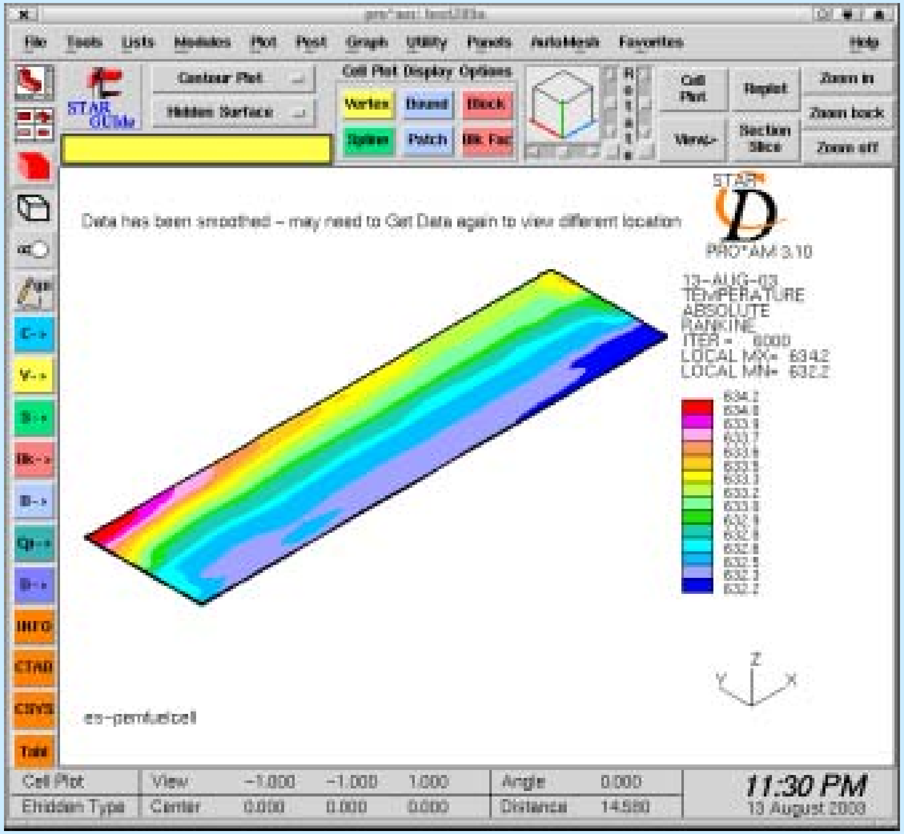
Post Processing – Ex. 3



Plot: Temperature – MEA

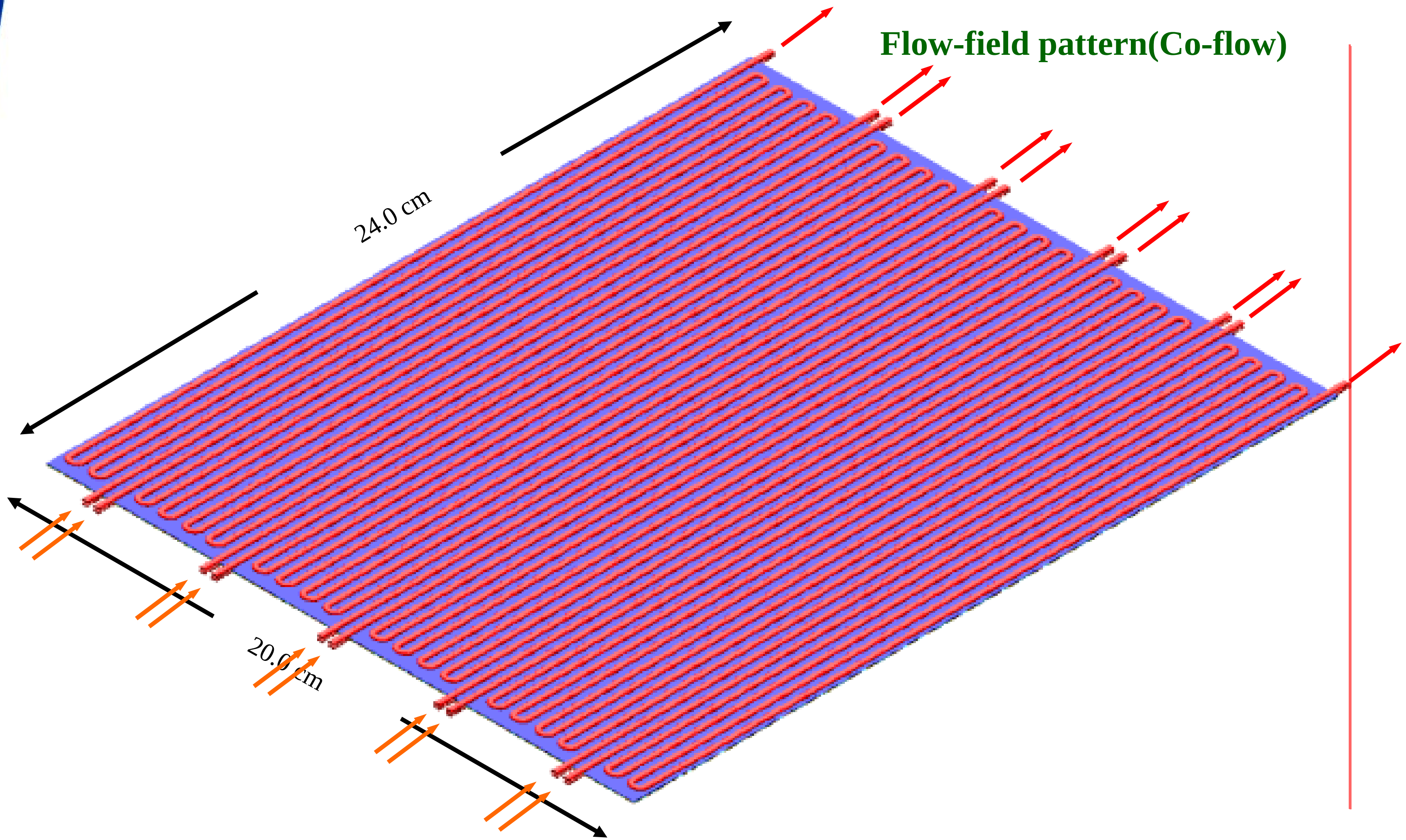
Predicting Water and Current Distribution of a Commercial-size PEMFC

Objectives

- Model the performance of an 480-cm^2 patented automotive flow-field under humidified and dry cathode conditions
- Examine water and current distributions for the two cases and determine causes of the performance differences
- Report the metrics for problem solutions

480-cm^2 PEMFC components used for computational analysis

(J. A. Rock, U.S. Patent # 6,099,98)



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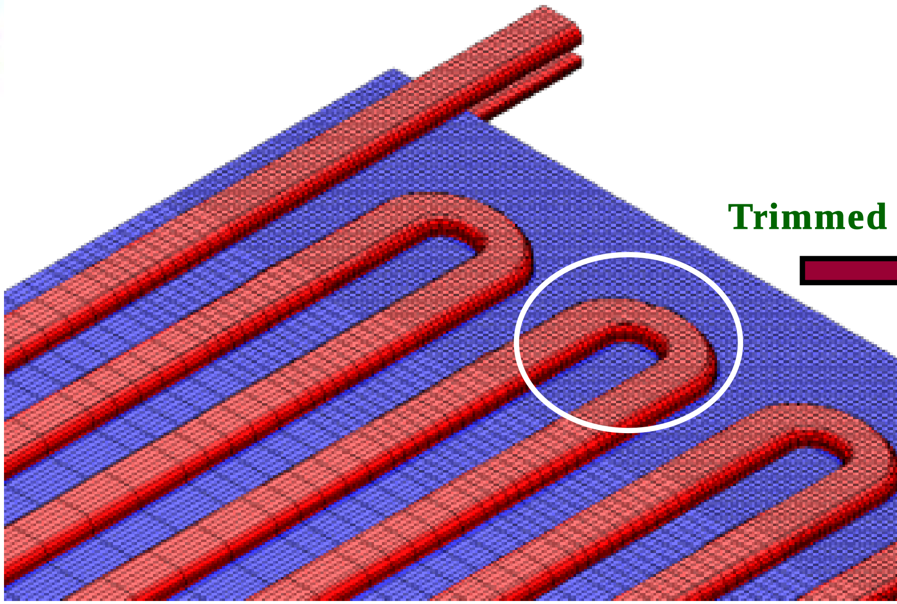
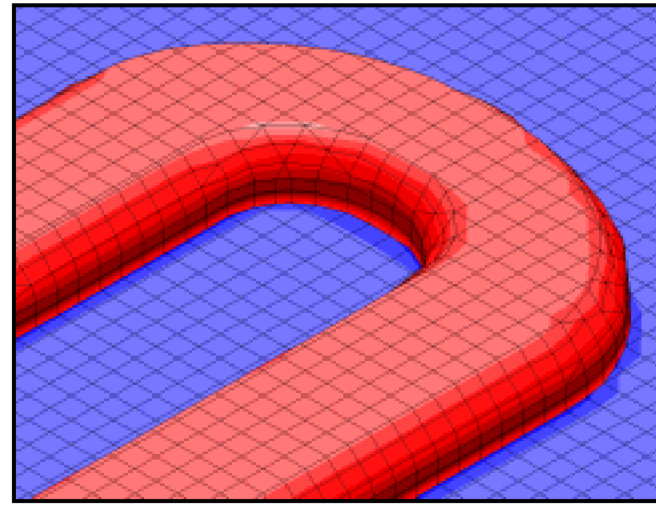
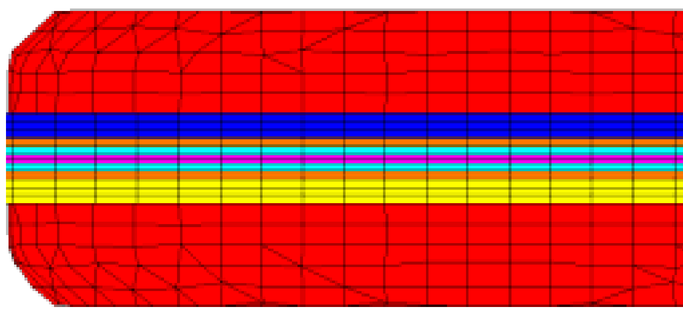
Meshing and geometry details





Cross-section view



Geometry detail

- Total cell = 4,951,440. Number of channel = 10. Number of pass = 5. Channel length = ~120 cm.
- MEA thickness (membrane+catalyst layers) = 0.050 mm. GDL thickness = 0.250 mm (permeability = 1E-12 m^2 with 0.7 porosity).
- Flow channel area = ~1.1 mm^2, Reaction Area = 480 cm^2.

Computational Procedure

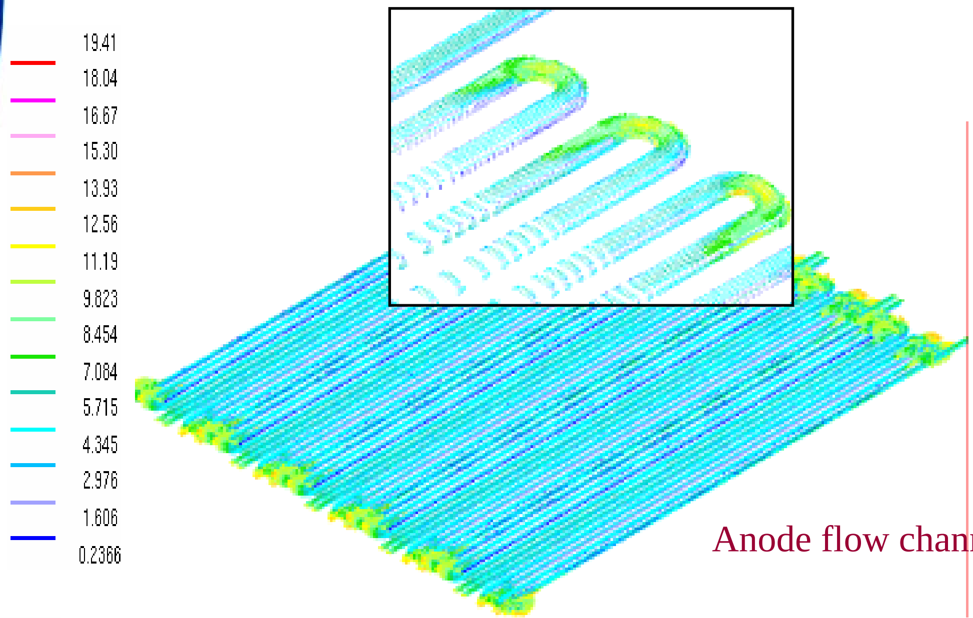
- Computations were carried out in parallel on a Linux Cluster
- A commercial version of STAR-CD with integrated PEMFC electrochemistry subroutines was used for the calculations
- MPICH was used for message passing between the nodes
- The effect of the number of processors used on calculation time was measured

Condition of Interested

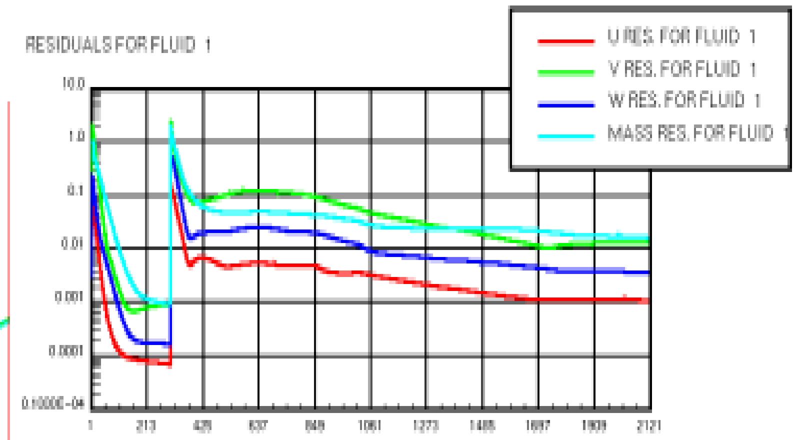
- Normal condition:
  - 1.2/2.0 stoich, 40%H_2/Air
  - 70^{o}C/70^{o}C anode/cathode dew point temperature (i.e 100% relative humidity both anode and cathode)
  - 70^{o}C cell temperature
  - 101 kPa back pressure

- Cathode By-pass (Cathode bypasses humidifier):
  - 1.2/2.0 stoich, 40%H_2/Air
  - 70^{o}C/by-pass anode/cathode dew point temperature (i.e 100% relative humidity annode, 0% relative humidity cathode)
  - 70^{o}C cell temperature
  - 101 kPa back pressure

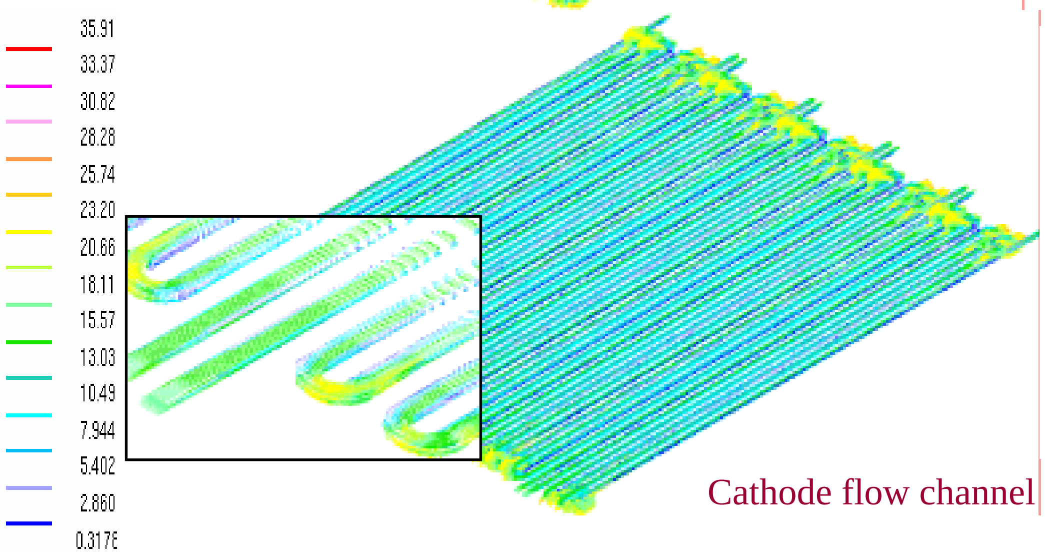
Velocity vectors, velocity magnitudes, and residuals plots for anode and cathode



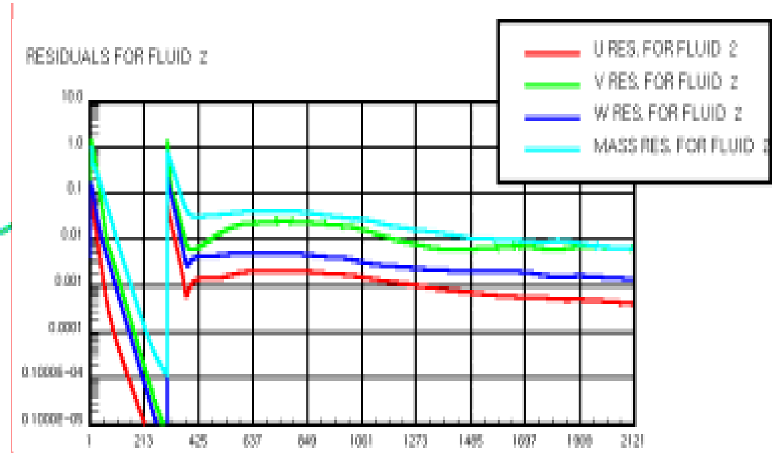
Anode flow channel



Anode residuals

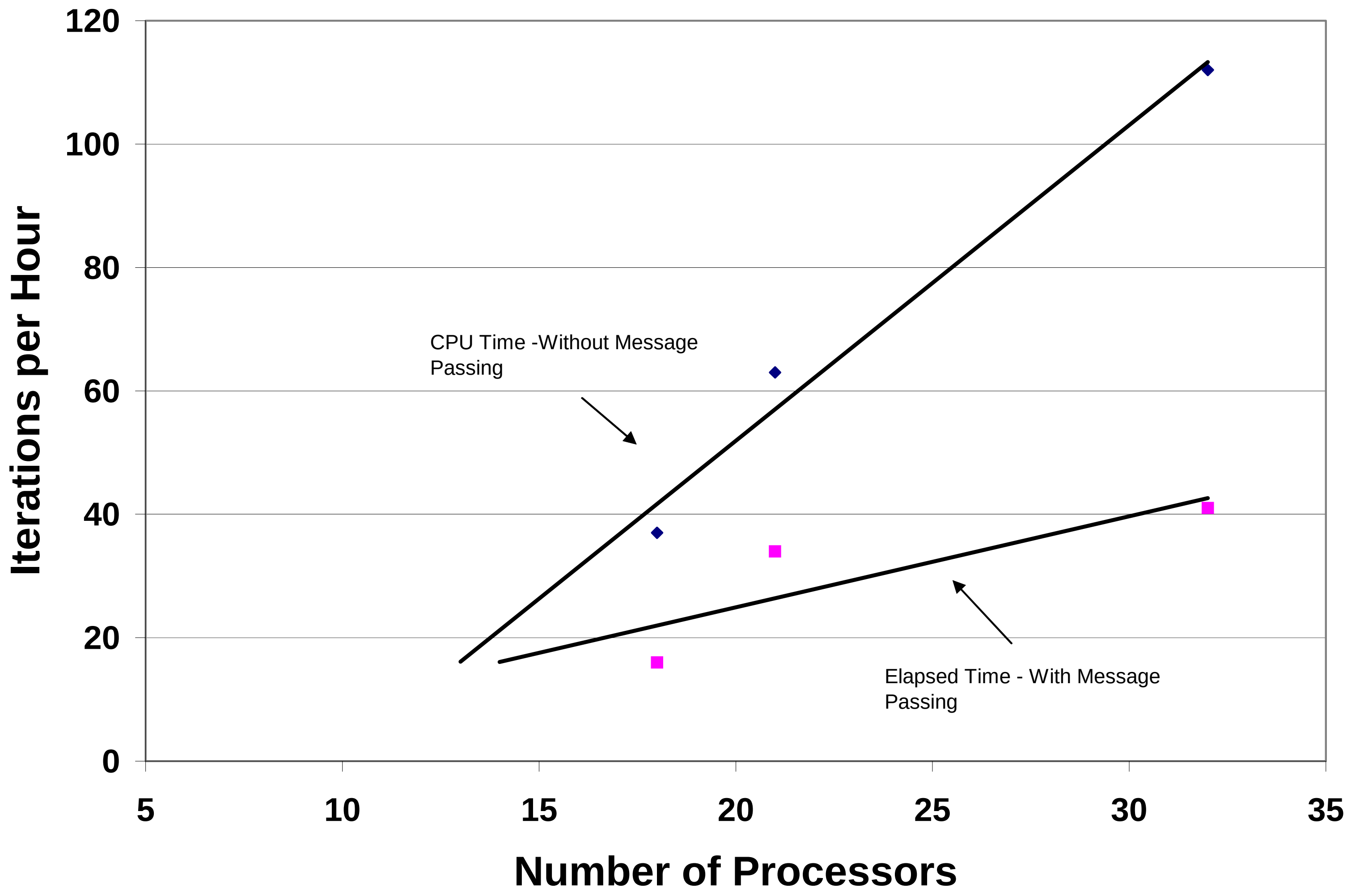


Cathode flow channel

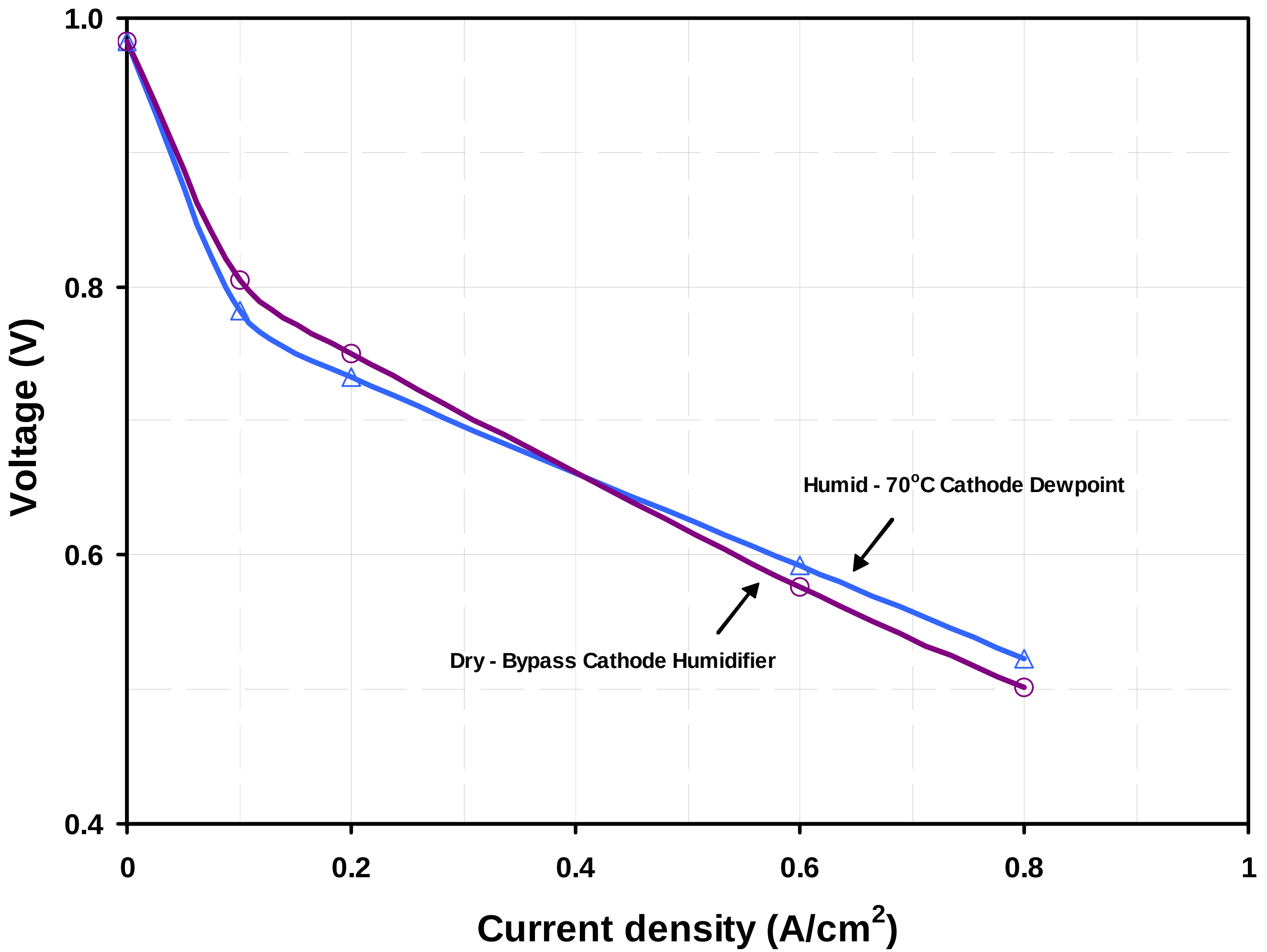


Cathode residuals

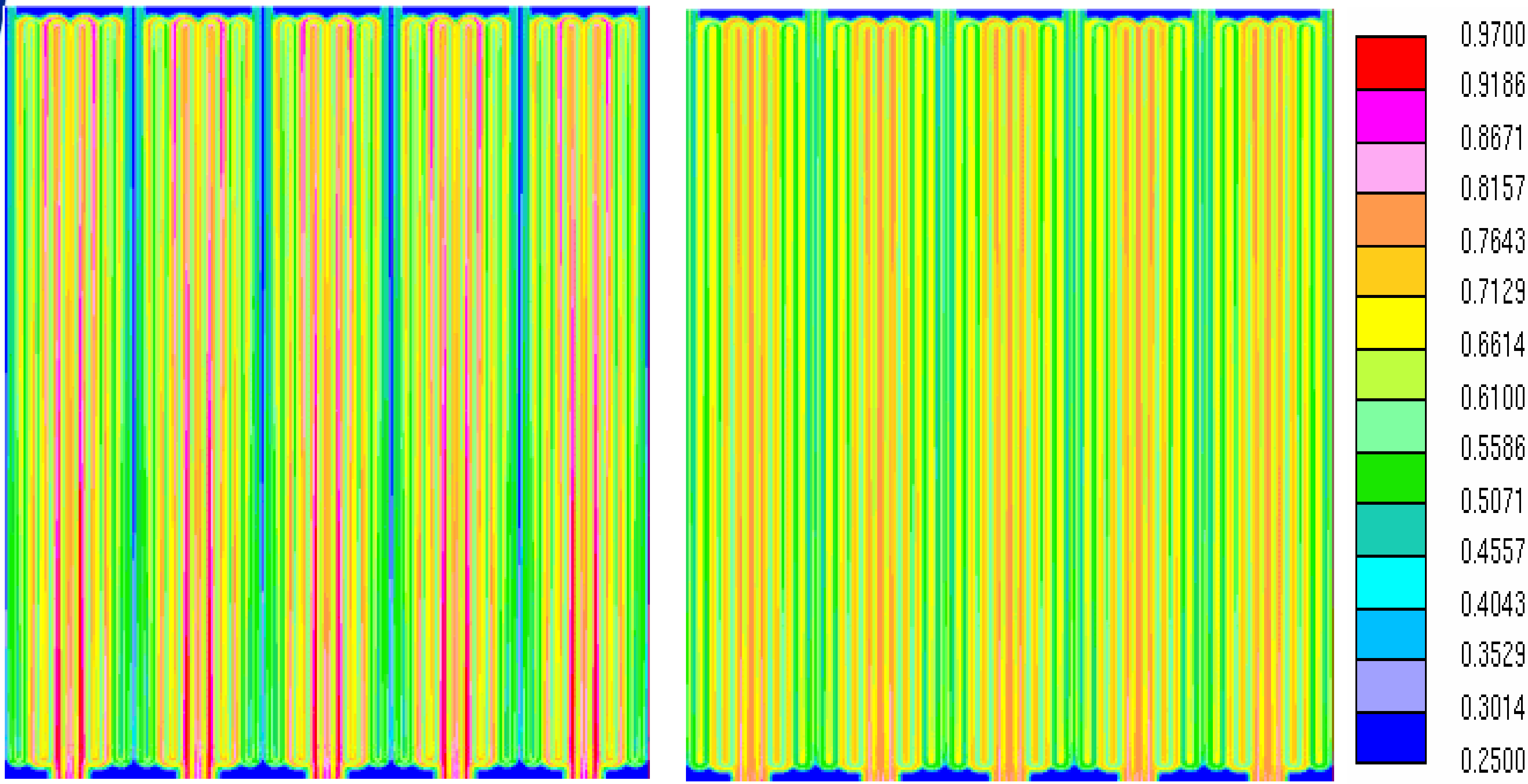
Parallel performance



Polarization curves for PEM fuel cell.
(Tcell = 70 ºC, Pressure(A/C) = 1/1 bar, Stoic.= 1.2/2.0)



Local current density (A/cm^2) distribution on MEA surface at I_{avg} of 0.6 mA/cm^2 between Normal case and Cathode by-pass case



Normal case

I_{avg} = 0.6 A/cm^2, Vcell = 0.59V

Cathode by-pass case

I_{avg} = 0.6 A/cm^2, Vcell = 0.57V

Net water flux per proton (α) distribution on MEA surface at I_{avg} of 0.6 mA/cm^2 between Normal case and Cathode by-pass case

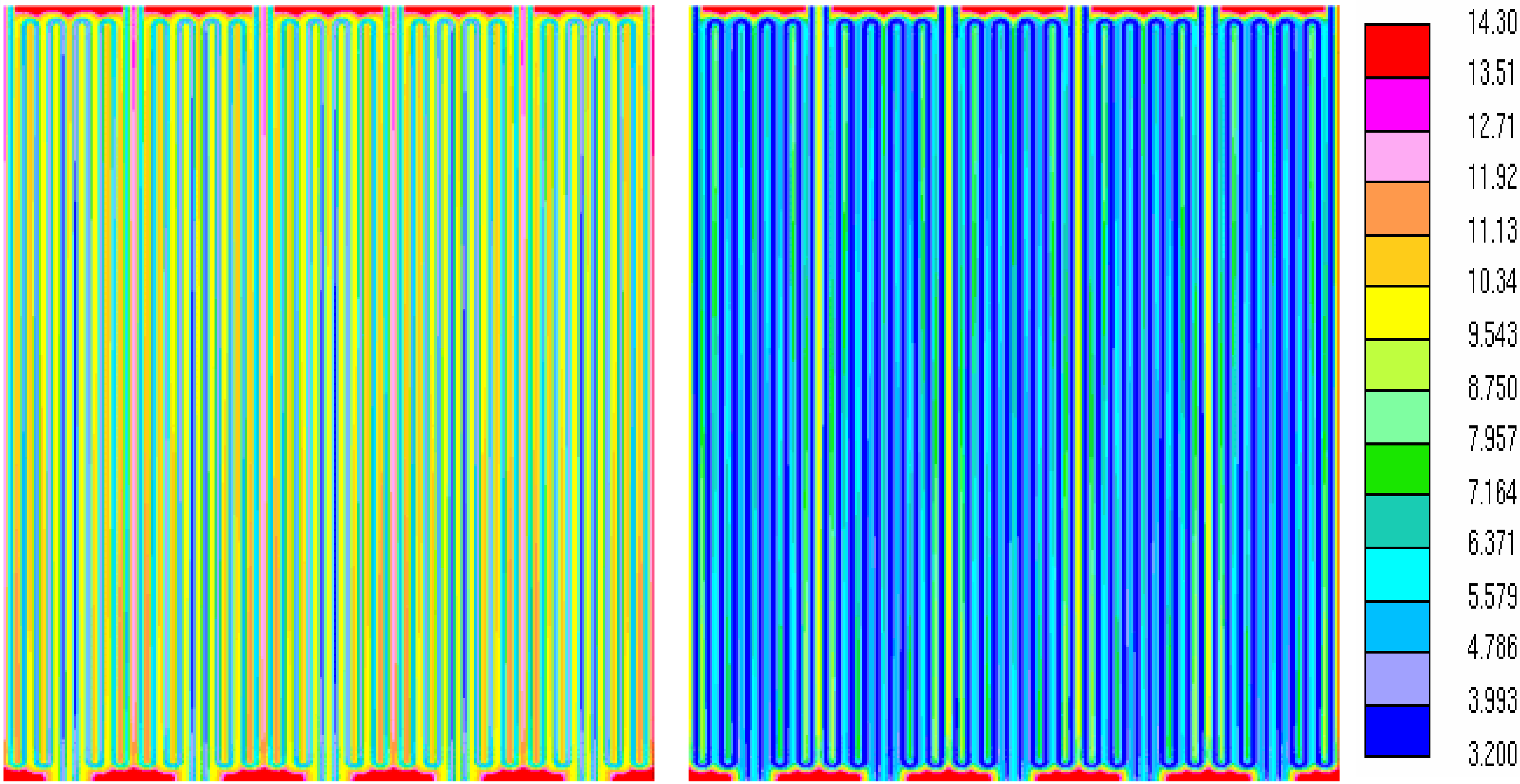
Normal case

α_{avg} = -0.13, Vcell = 0.59V

Cathode by-pass case

α_{avg} = -0.0028, Vcell = 0.57V

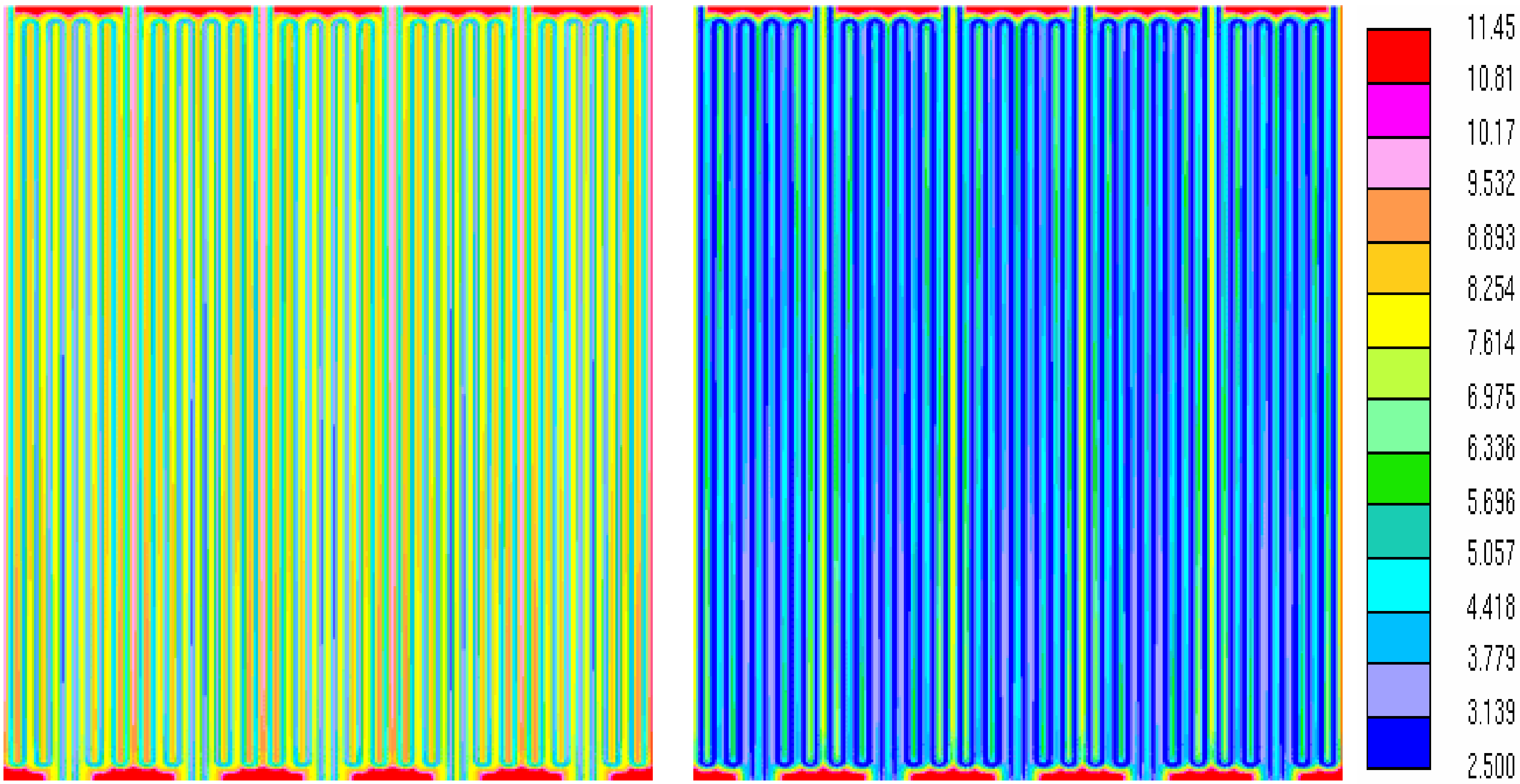
Water content (λ) distribution on MEA surface at I_{avg} of 0.6 mA/cm^2 between Normal case and Cathode by-pass case



Normal case
λ_{avg} = 8.6, Vcell = 0.59V

Cathode by-pass case
λ_{avg} = 5.9, Vcell = 0.57V

Membrane conductivity (S/m) distribution on MEA surface at I_{avg} of 0.6 mA/cm^2 between Normal case and Cathode by-pass case



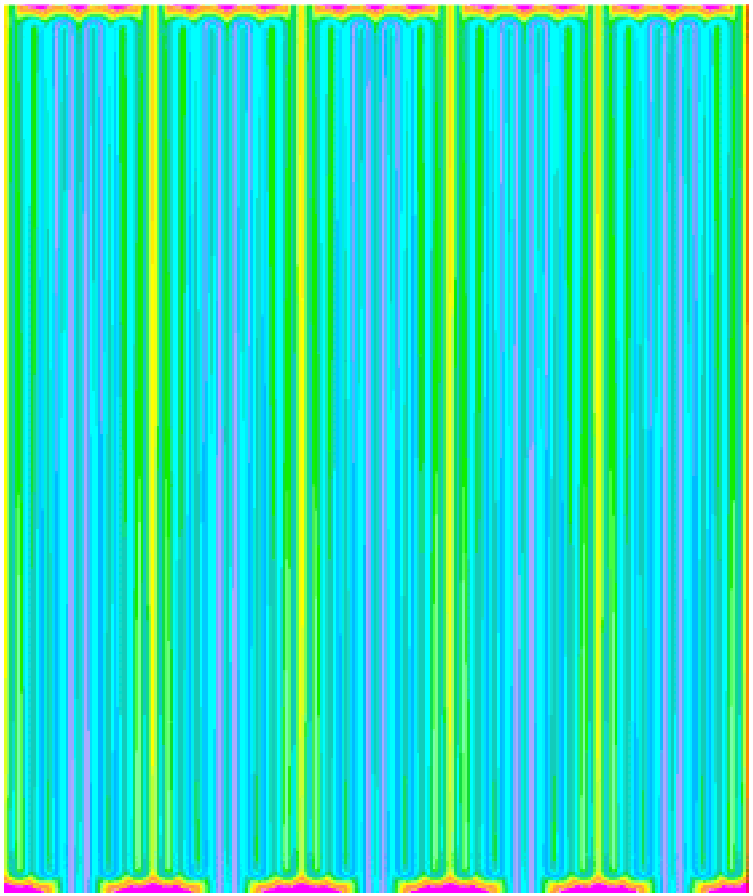
Normal case

σ_{avg} = 6.89, Vcell = 0.59V

Cathode by-pass case

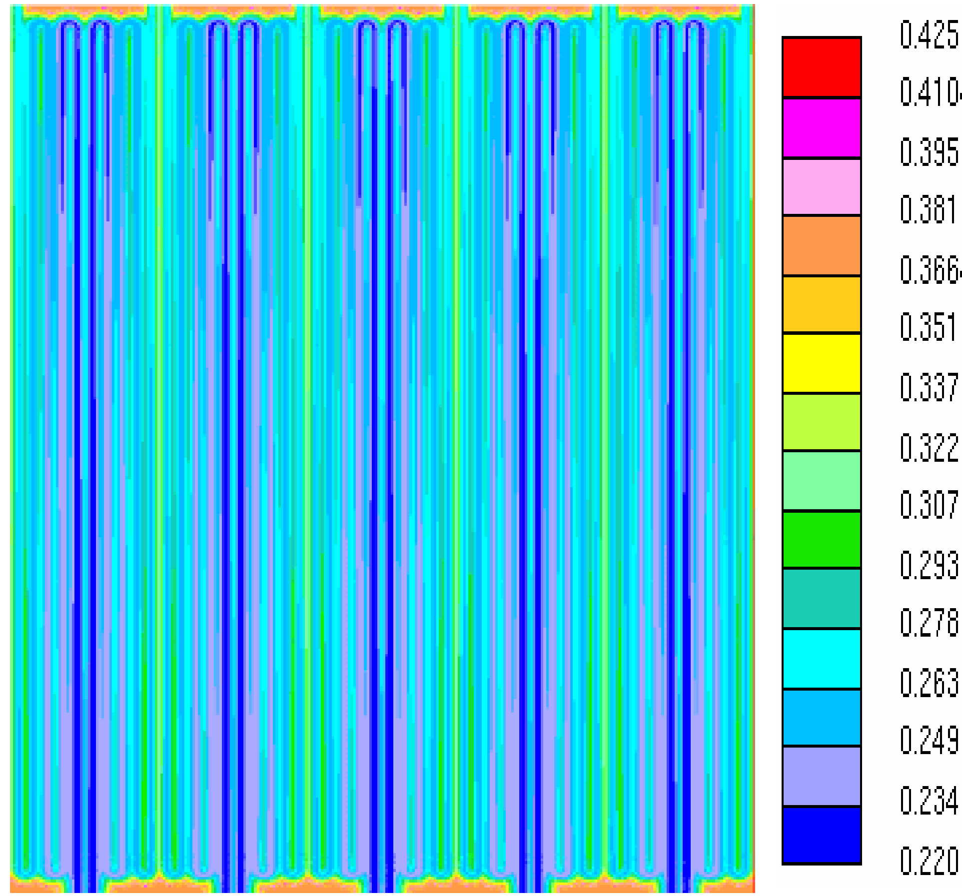
σ_{avg} = 4.60, Vcell = 0.57V

Cathode over-potential (V) distribution on MEA surface at I_{avg} of 0.6 mA/cm^2 between Normal case and Cathode by-pass case



Normal case

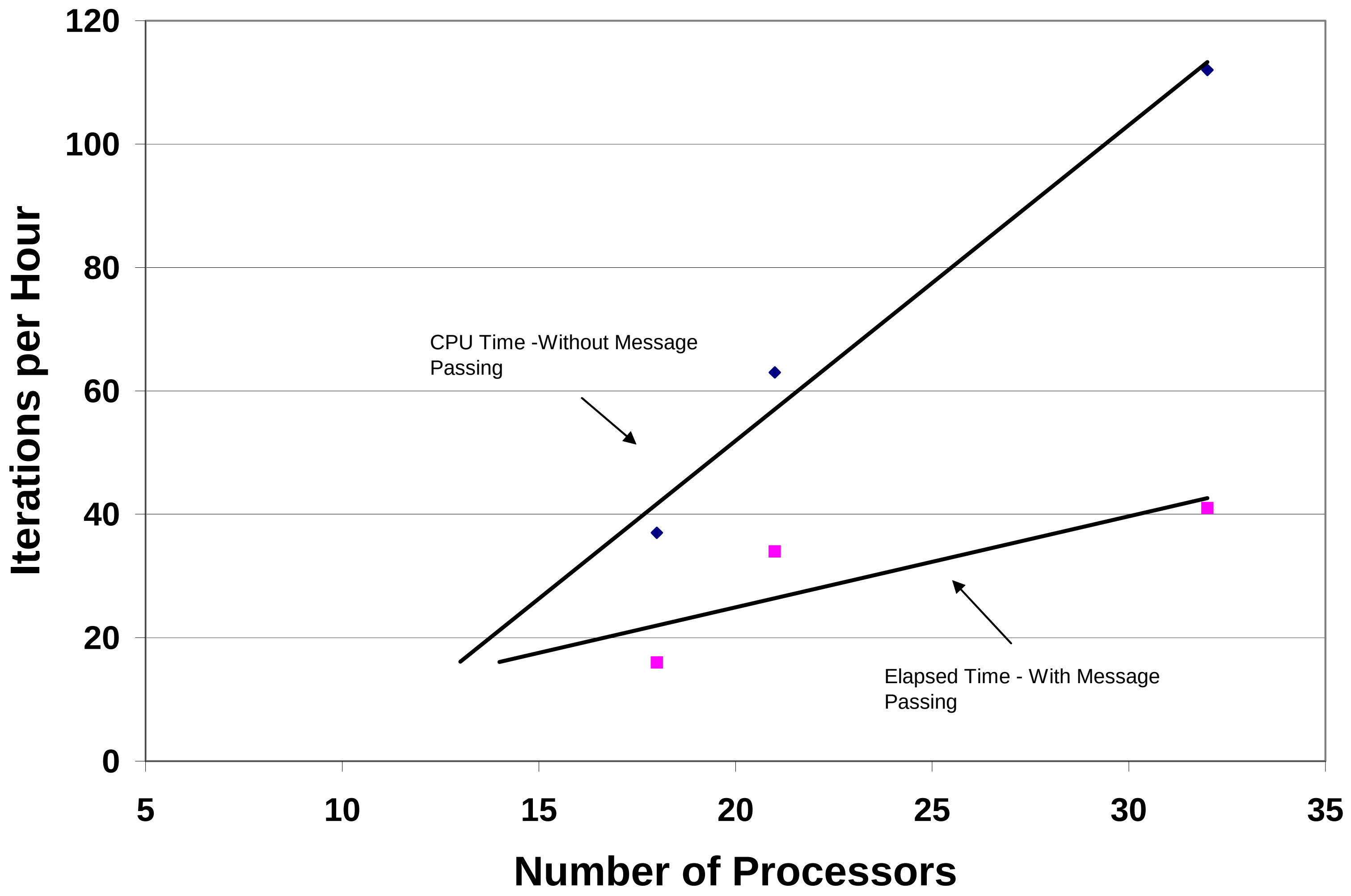
$\eta_{O2,avg}$ = 0.28, Vcell = 0.59V



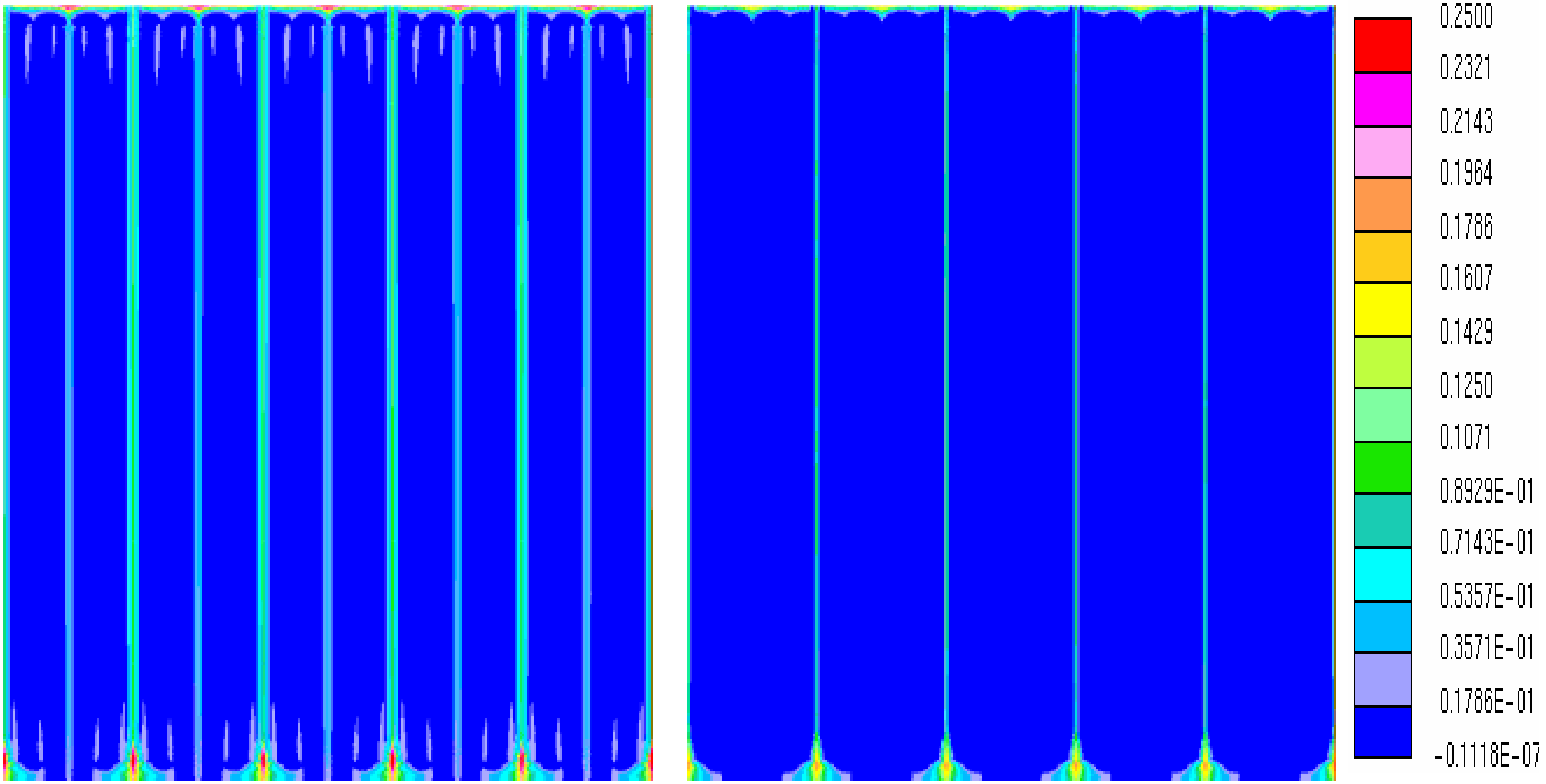
Cathode by-pass case

$\eta_{O2,avg}$ = 0.24, Vcell = 0.57V

Parallel performance



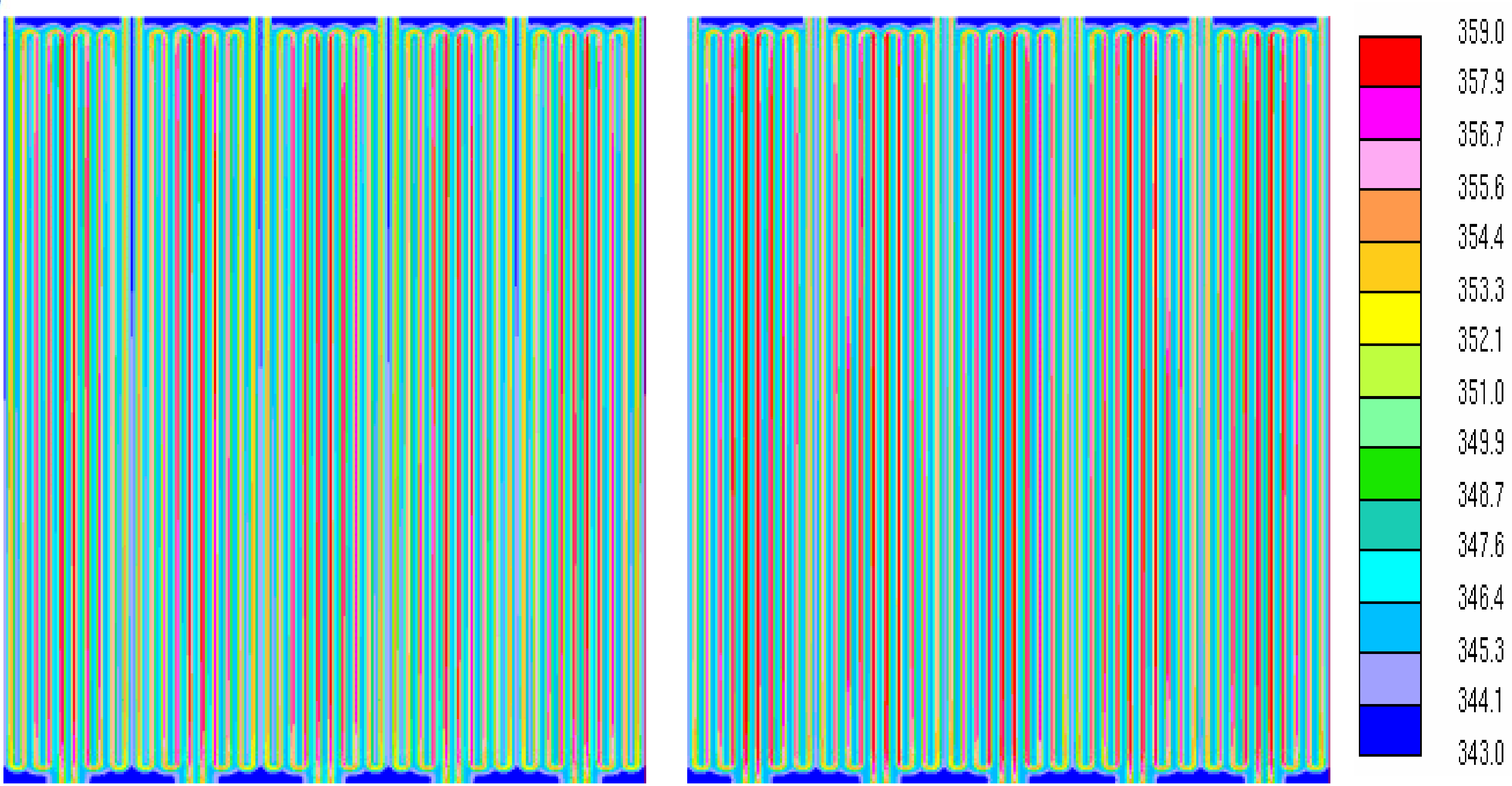
Liquid water fraction distribution on cathode MEA surface at I_{avg} of 0.6 mA/cm^2 between Normal case and Cathode by-pass case



Normal case
CW_{avg} = 0.02, Vcell = 0.59V

Cathode by-pass case
CW_{avg} = 0.008, Vcell = 0.57V

Temperature (K) distribution on anode MEA surface at I_{avg} of 0.6 mA/cm^2 between Normal case and Cathode by-pass case



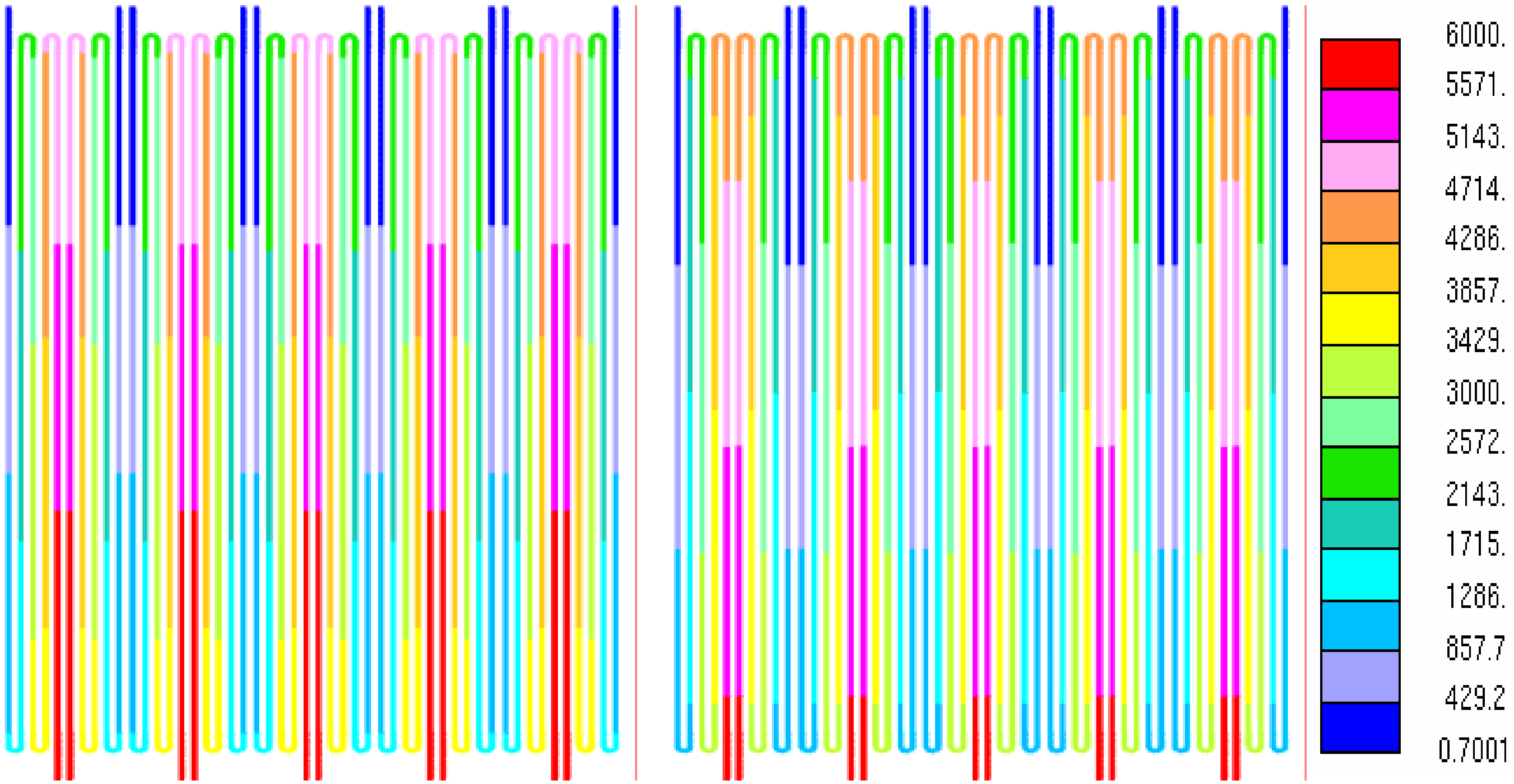
Normal case

T_{avg} = 349, Vcell = 0.59V

Cathode by-pass case

T_{avg} = 349, Vcell = 0.57V

Relative Pressure (Pa) distribution on anode flow channel at I_{avg} of 0.6 mA/cm^2 between Normal case and Cathode by-pass case



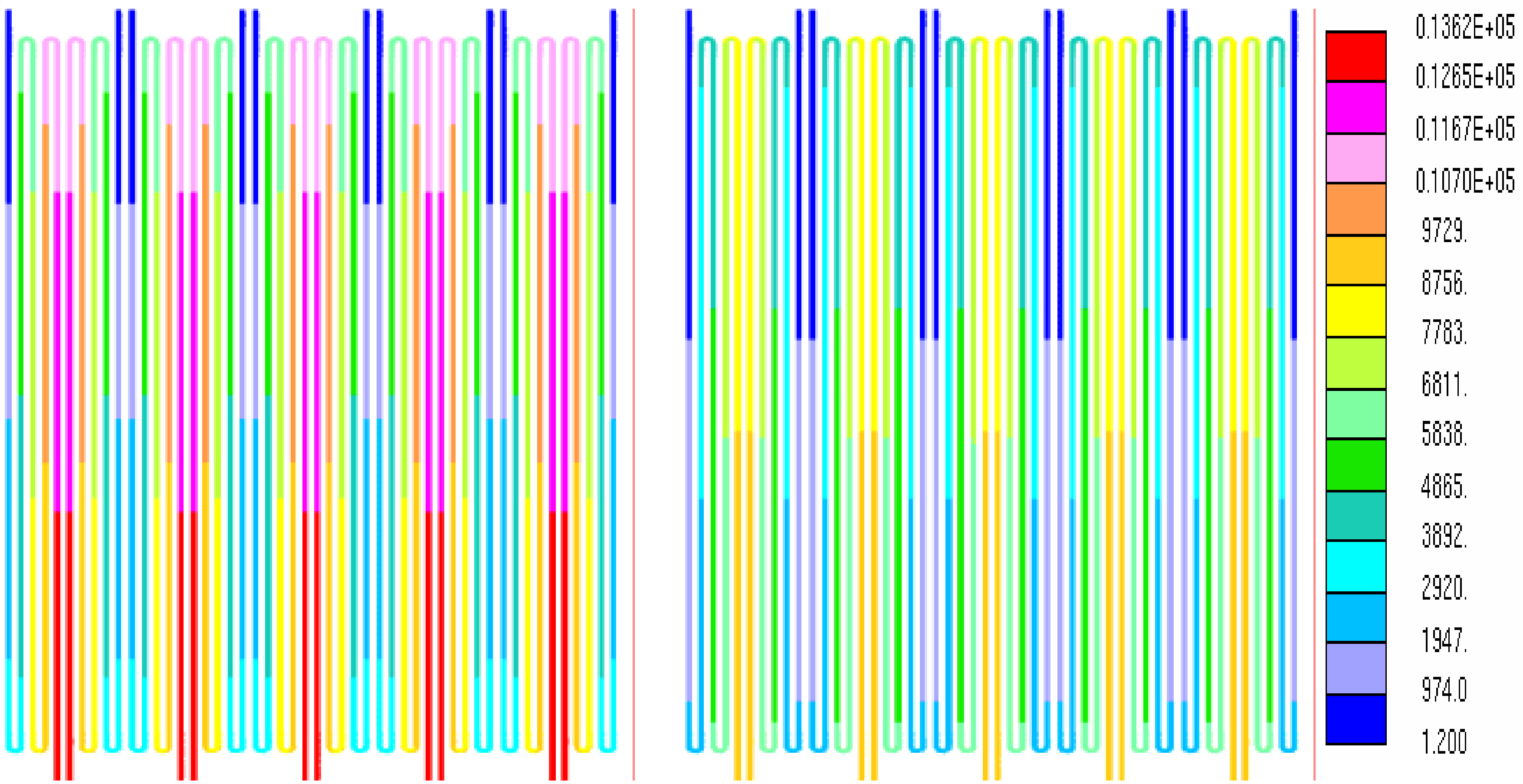
Normal case

ΔP = 6079 Pa, Vcell = 0.59V

Cathode by-pass case

ΔP = 5760 Pa, Vcell = 0.57V

Relative Pressure (Pa) distribution on cathode flow channel at I_{avg} of 0.6 mA/cm^2 between Normal case and Cathode by-pass case



Normal case

ΔP = 13618 Pa, Vcell = 0.59V

Cathode by-pass case

ΔP = 9632 Pa, Vcell = 0.57V

Summary

- Using similar membrane parameters, results were obtained for a well hydrated and dry membrane conditions.
- Polarization data for the two cells were similar, but distributions of electrochemical variables were different
  - Membrane Water Content and thus Membrane Conductivity were lower in the dry case
  - Cathode Overpotential was lower for the dry case due to the very low concentration of liquid water

Conclusions

- The performance of the dry cell is lower, but not significantly lower
- The decrease in Cathode Overpotential in the dry case nearly compensated for the lower Membrane Conductivity
- The lower pressure drop in the cathode bypass case makes the flow-field better suited for automotive applications

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