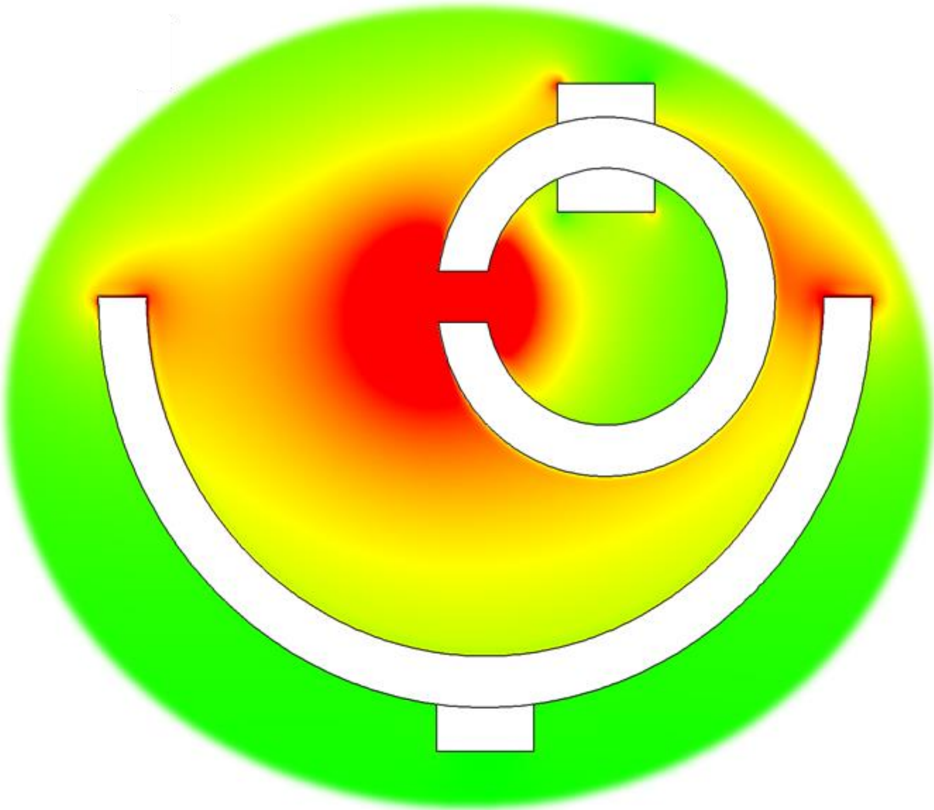
Electro-Chemical Etching & Deposition of a Super Alloy Using Tertiary Current Distribution Method



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OVERVIEW

- Introduction to Electrochemical Machining process
- Types
- Process involved & parameters
- Application & industries
- Model overview
- Model variables
- Physics- Electrochemical
- Physics- Electrode kinematics & parameters
- Mesh
- Results

INTRODUCTION-ELECTROCHEMICAL MACHINING

- Process of material removal by means of Electrochemical process (Electrochemistry).
- Unconventional machining process.

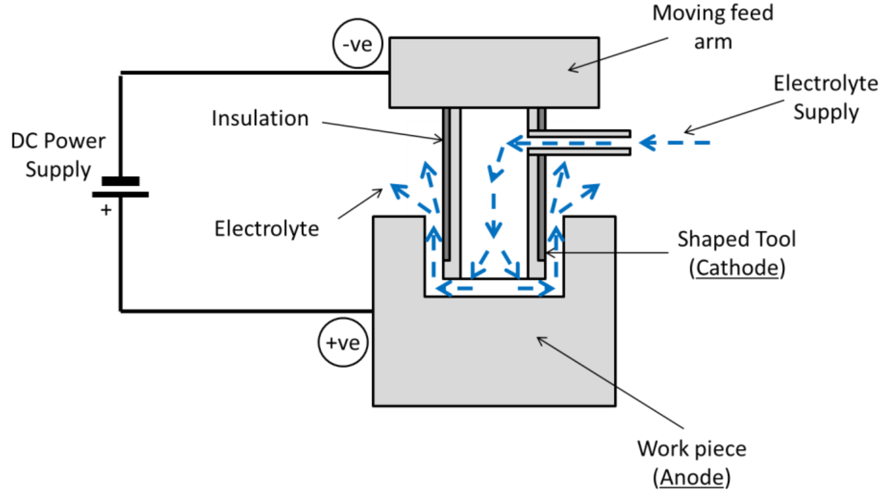
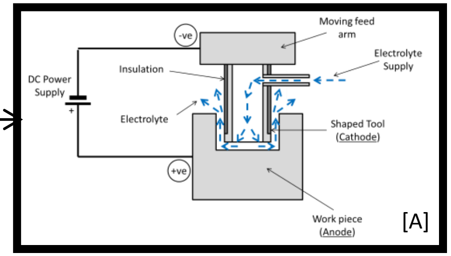


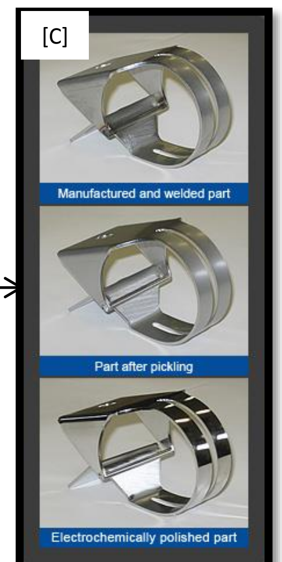
Image courtesy:
G.E. Benedict, Nontraditional Manufacturing Processes.

Advantages	Disadvantages
• Complex geometry	• Electrical conducting material only (Metal)
• Soft & Hard Material	• Complex system
• No contact and no residual stress	• Handling chemical sludge's
• Thin component	• Expensive setup
• No tool wear & use of a soft tools	

TYPES-ELECTROCHEMICAL PROCESSING

- Electrochemical machining
- Electrochemical Etching
- Electro polishing
- Electrochemical drilling





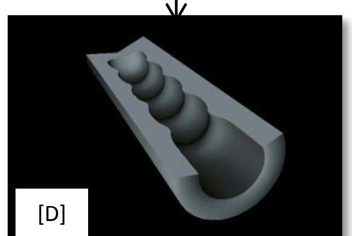


Image courtesy:
A .G.E. Benedict, Nontraditional Manufacturing Processes
B .Electro-chem etch, www.ecemmi.com
C. Hio-mex Killotuksen Ammattilainen
D. CASA Research project [http://www.win.tue.nl/casa/research/casaprojects/noot.htm]

PROCESS-ELECTROCHEMICAL PROCESSING

- Multiphysics process
- Coupled interaction between different physical and chemical phenomena.
- Describe very well in R. van Tijum & T. Pajak paper[2]

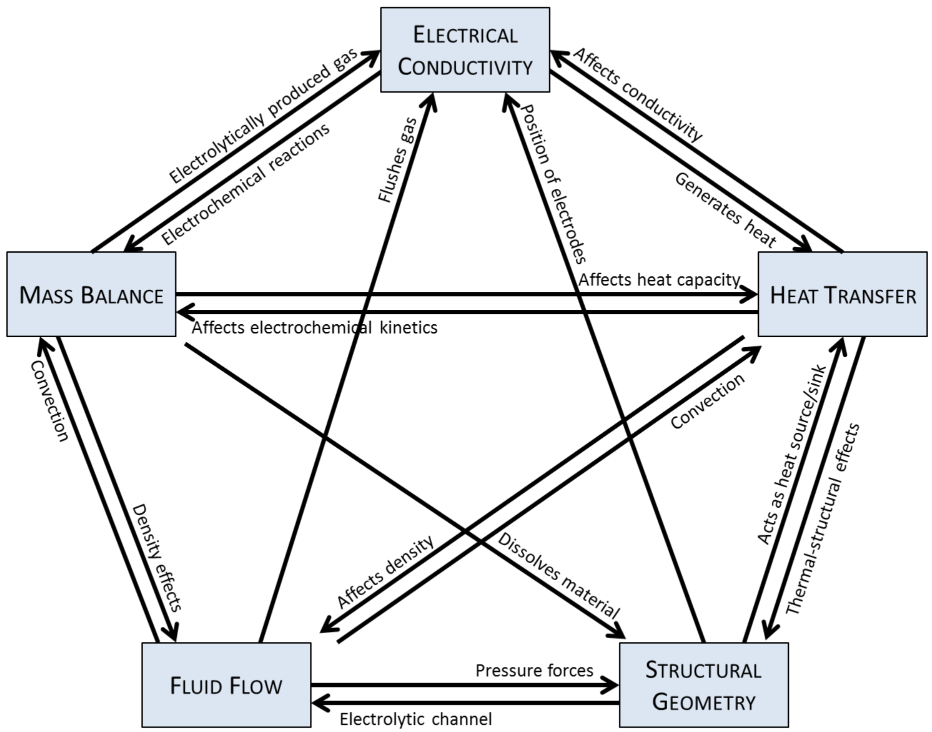


Image courtesy: R.van Tjium & T. Pajak paper[2]

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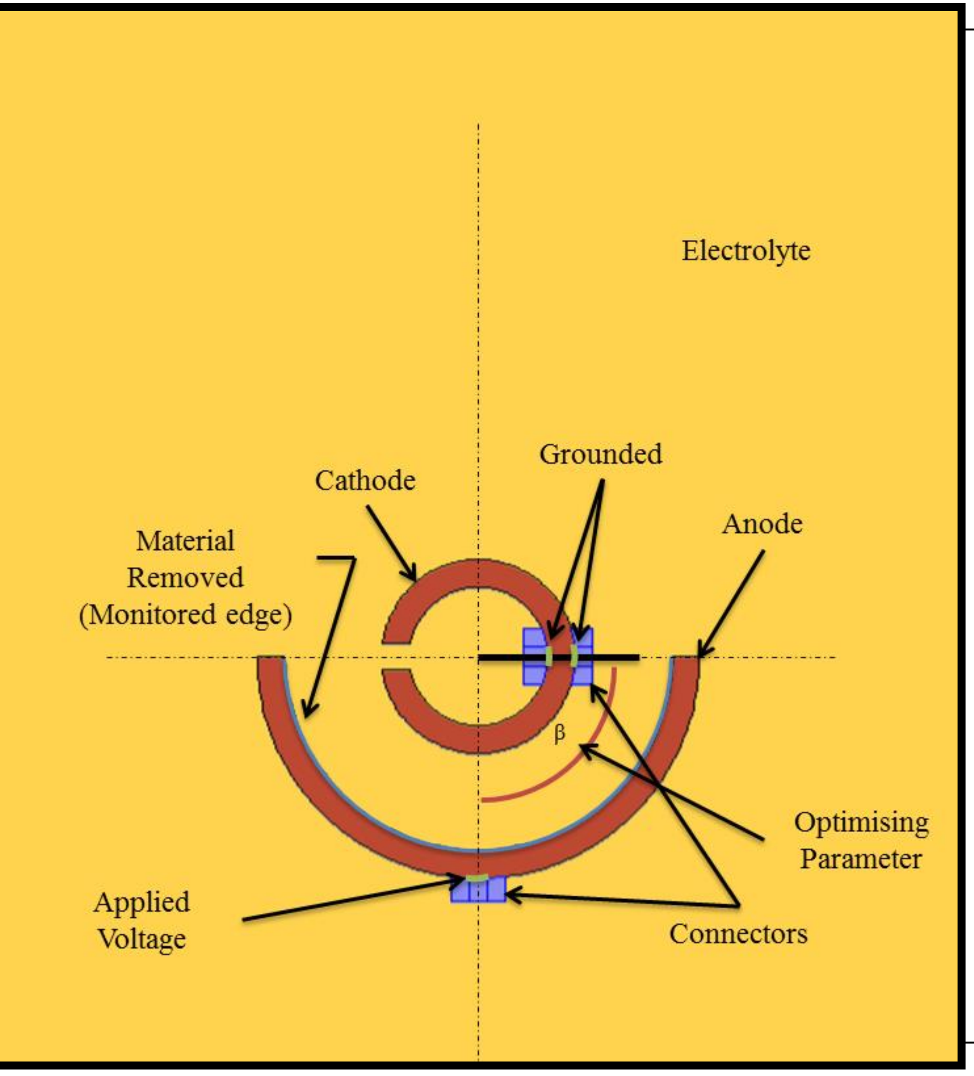
Application-Electrochemical Processing

1. Aviation
2. Automobile
3. Medical
4. Consumer Products
5. Manufacturing
6. Nuclear
7. Fashion

MODEL OVERVIEW-1 [ELECTROCHEMICAL ETCHING]



- Electrochemical Etching of inner surface on anode.
- Anode and cathode both are made of Waspaloy® super alloy.
- System is under static voltage control where anode is placed in close vicinity to cathode.
- Effects due to following factors mentioned below are not modelled:-
  - Effect of evaluation of H_2 gas on the surface of cathode.
  - Convective flux.
  - Effect of temperature on Electrochemical reaction.

Model Overview-2 [Electrochemical Etching]

Table 1: Elemental composition of Waspaloy® [3]

Element	Maximum percentage composition
Cr	21
Ni	51.58
Mo	5
Co	15
Al	1.6
Ti	3.25
B	0.01
C	0.1
Zr	0.08
Fe	2
Mn	0.1
Si	0.15
P	0.015
S	0.015
Cu	0.1

Material Used

- Electrolyte is dilute Sulphuric acid.
- Waspaloy® super alloy is used.
- For this particular study we will only consider 2 major material constituents from the table 1.
    - Chromium (29%)
    - Nickel(71%)

Study type

- Time-dependent analysis is required as cathode & anode boundaries move during deposition & dissolution

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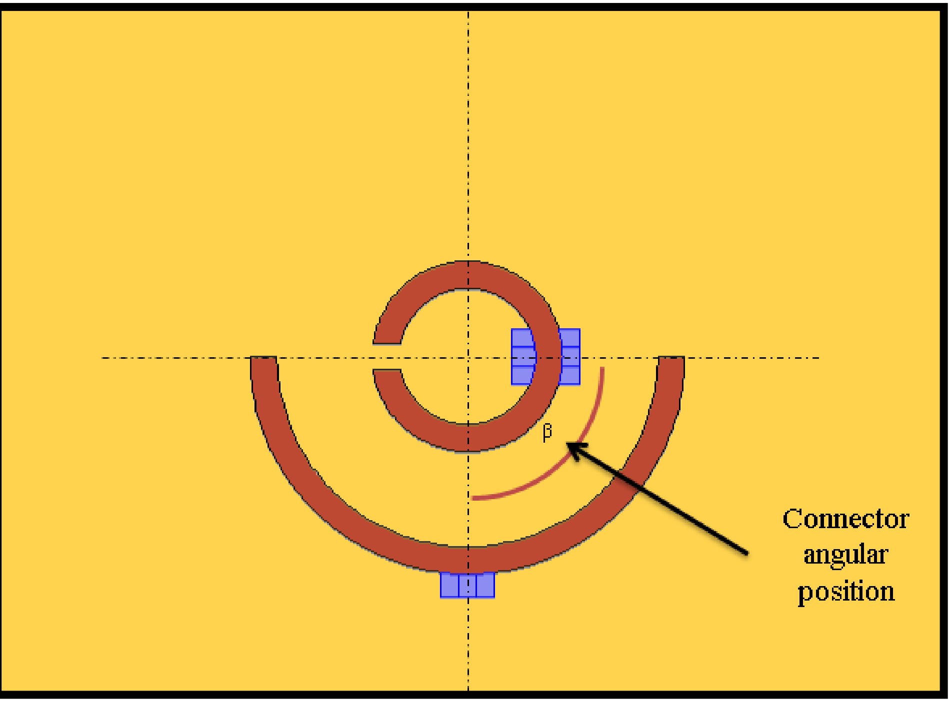
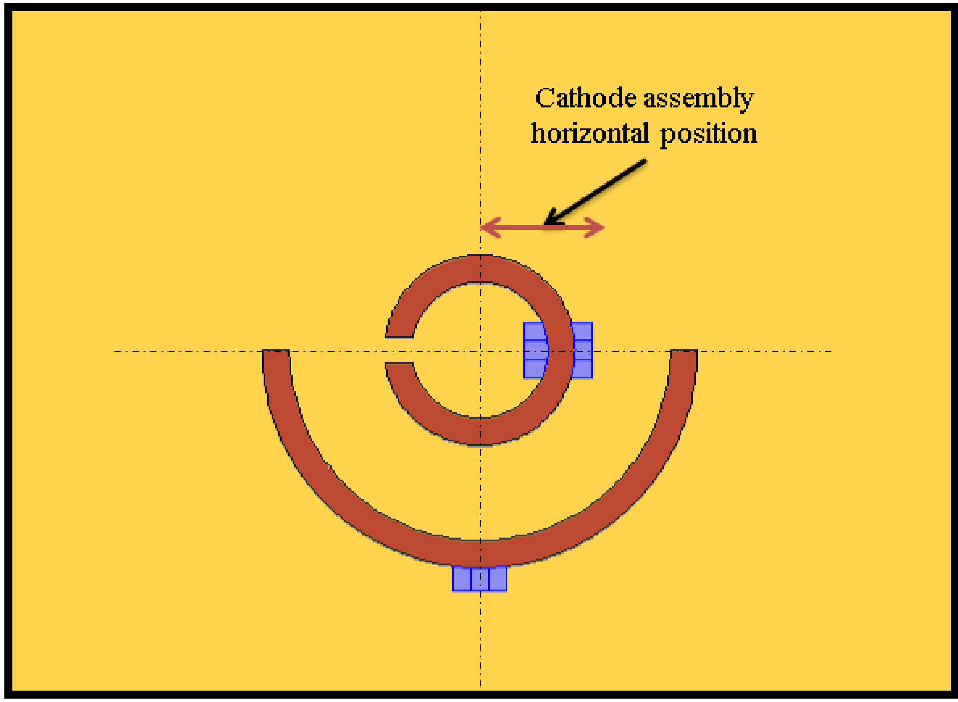
MODEL VARIABLE

Adjusted variables

- Connector angular position (β) &
- Cathode assembly horizontal position





Results Assessed

- Magnitude of material dissolution from anode

Physics-Electrochemistry 1

- Electrodeposition is modelled based on *Nernst-Planck* equation, which describes the current and potential distribution in an electrochemical cell taking into account the transport of charged species (ions) in the electrolyte through diffusion, migration, and convection.

- This physics interface further assumes that the *electroneutrality* condition is valid in electrolyte. Under these assumptions, the contributions to the transport of current in electrolyte are due to diffusion and migration of ions [4].

- The above are interfaced and coupled with the geometries and describe the effect of deposition of species on the participating boundaries of the electrodes. Ions are absorbed or removed from the surface and their effect during the deposition processes is modelled.

<u>Nernst-Planck equation</u>

The material balance equation for the i^{th} species in the electrolyte is given as:

$$\frac{\partial c_i}{\partial t} + \nabla \cdot (-D_i \nabla c_i - z_i u_i F c_i \nabla \emptyset_i + c_i \boldsymbol{U}) = R_{i, tot}$$

Where,

PHYSICS-ELECTROCHEMISTRY 2

….continued from previous slide

c_i	Concentration in the electrolyte of i^{th} species (mol·m^{-3}),
D_i	Diffusion coefficient of i^{th} species (m^2/s),
z_i	Ionic charge of i^{th} species,
u_i	Ionic Mobility of i^{th} species (m^2·s^{-1}·J^{-1}·mol^{-1}),
F	Faraday's constant (A·s·mol^{-1}),
$\emptyset_i$	Electric Potential (V)

Current density in the electrolyte is calculated as follows:

$$i_i = F\sum_{i=1}^{n} z_i\left(-D_i \nabla c_i - z_i u_i F c_i \nabla \emptyset_i\right)$$

The last unknown variable for the given set of species is calculated based on *Electroneutrality* condition. As stated below:

$$\sum_i z_i c_i = 0$$

PHYSICS-ELECTRODE KINETICS

Electrode kinetics used in the model, which define the local charge transfer current density based on concentration of the various species involved in reaction on the electrode surface. These are described by the following:

$$i_{loc} = i_o(C_R e^{(\frac{\alpha_a F\eta}{RT})} - C_o e^{(\frac{\alpha_c F\eta}{RT})}),$$

Where,

i_o	Exchange current density of the species;
α_a	Anodic transfer coefficient ;
α_c	Cathodic transfer coefficient;
C_R	Reduced species expression ;
C_o	Oxidized species expression ;
R	Universal Gas constant;
T	Operating Temperature ;
F	Faraday constant;
η	($E-E_{eq}$); activation overpotential;
E_{eq}	Equilibrium (REDOX) potential for the given species;

Where, the following chemical reactions takes place at the anode and cathodes, respectively:

Anode

$Cr = Cr^{2+} + 2e^-$

$Ni = Ni^{2+} + 2e^-$

Cathode

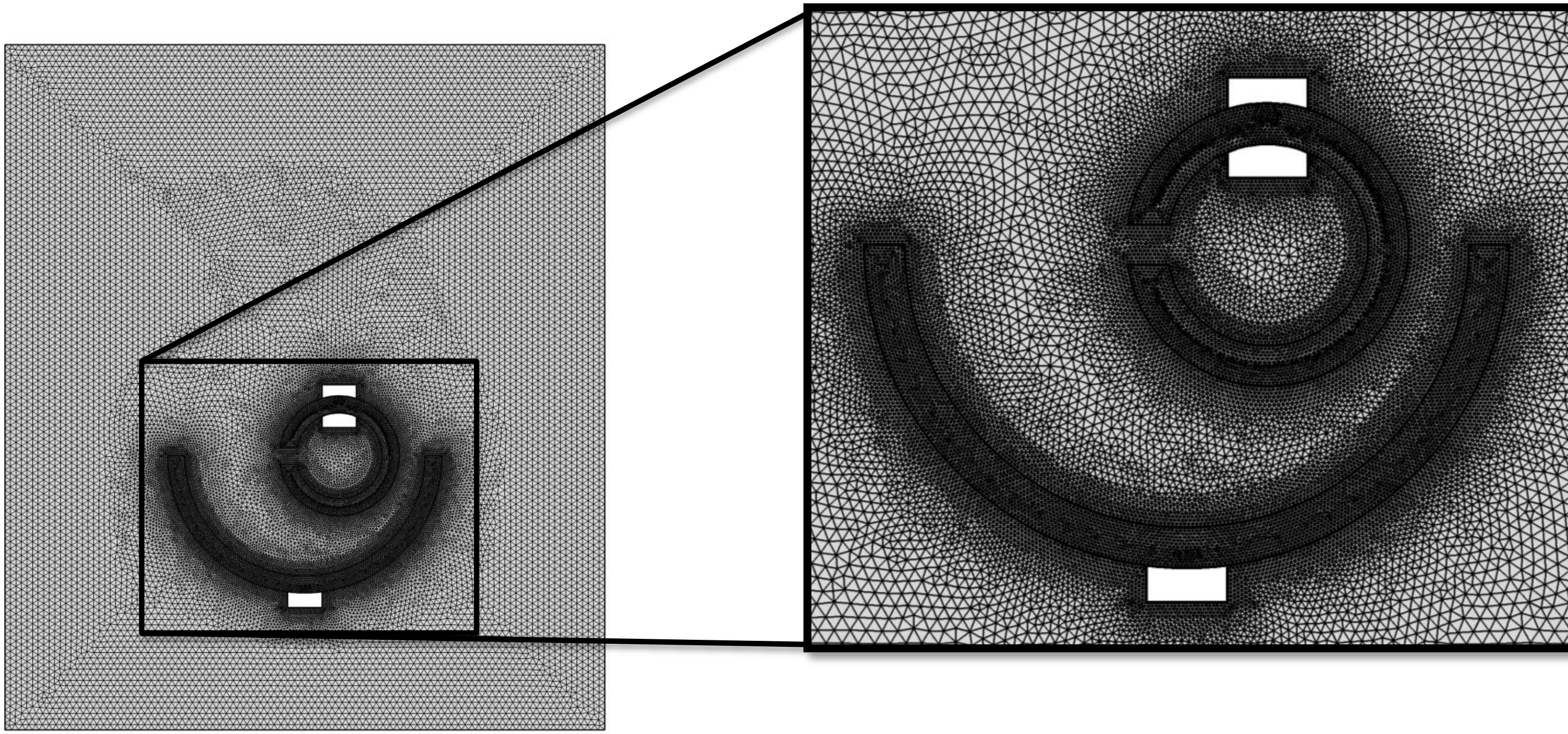
$Cr^{2+} + 2e^- = Cr$

$Ni^{2+} + 2e^- = Ni$

In the model subject to the study, three species were considered participating in the electrochemical reactions are:-

1. Ni^{2+}
2. Cr^{2+}
3. So_4^{2-}

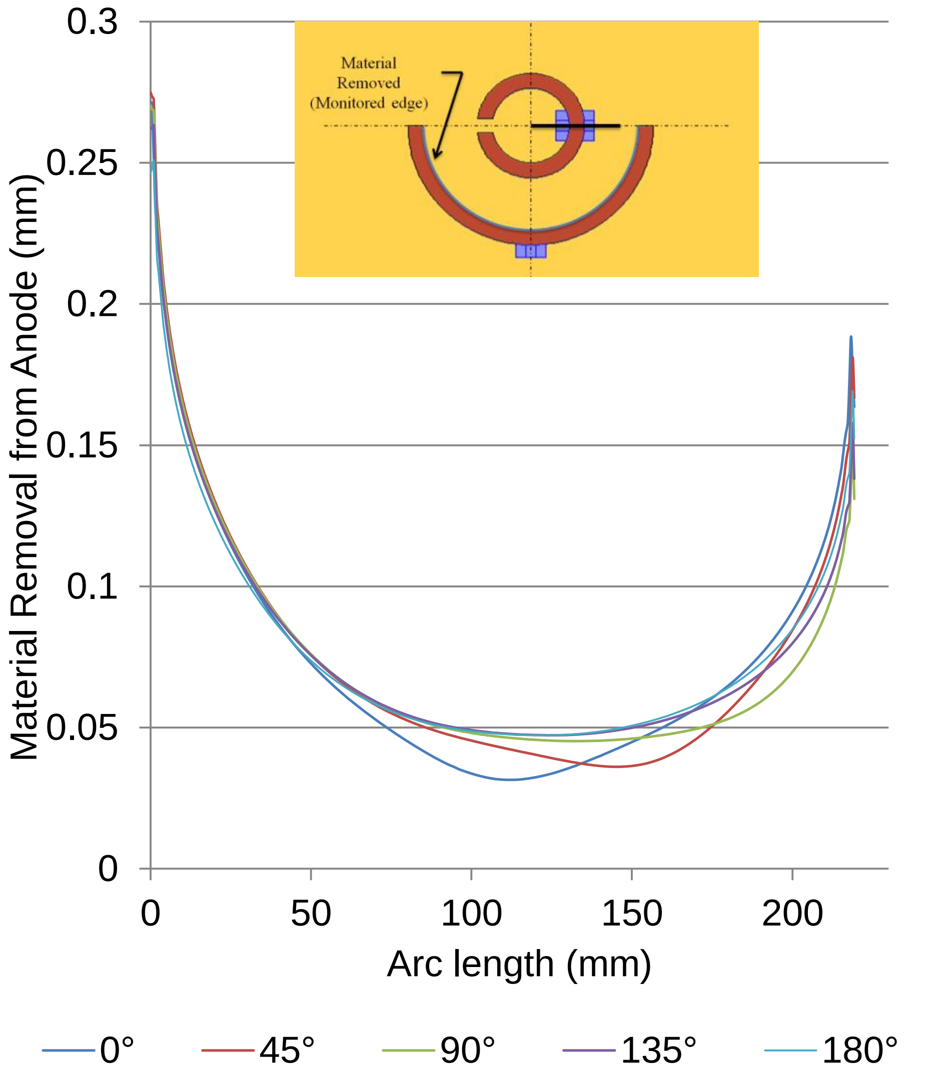
Mesh



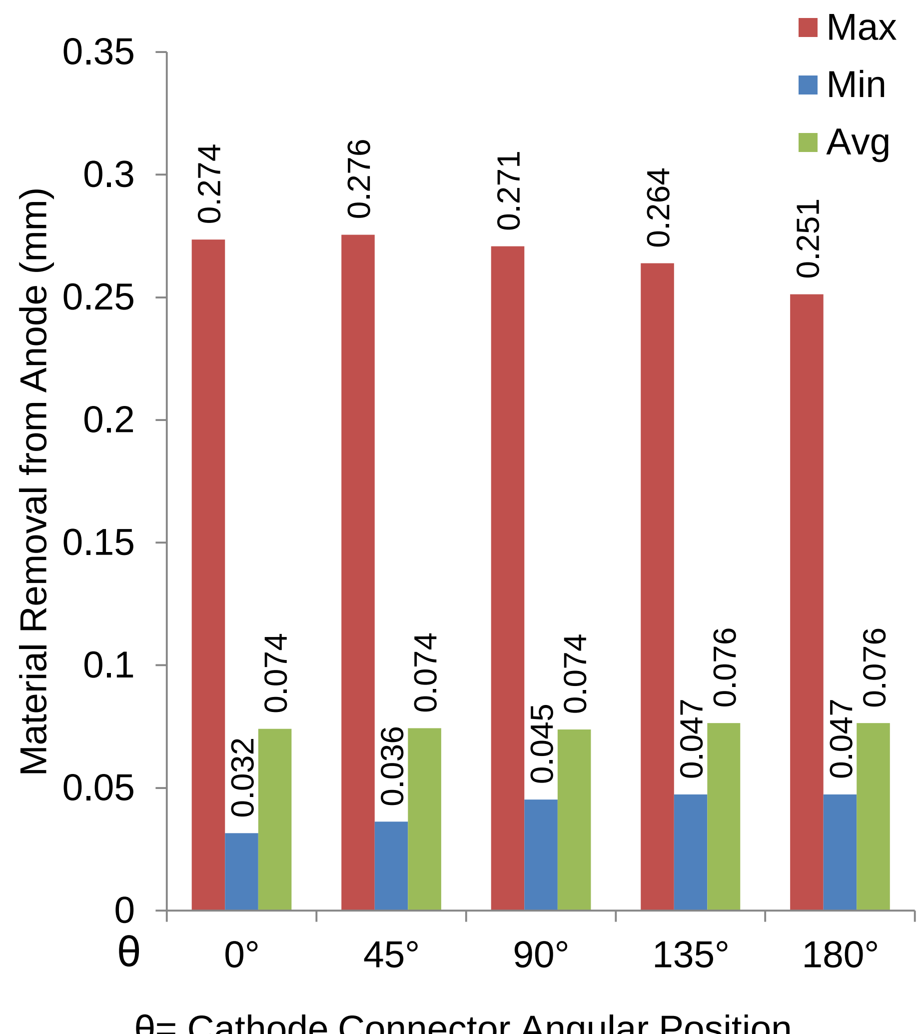
Parameters	Number
Triangular elements	54648
Minimum element quality	0.7492
Average element quality	0.9789

Results- At Different Connector Positions

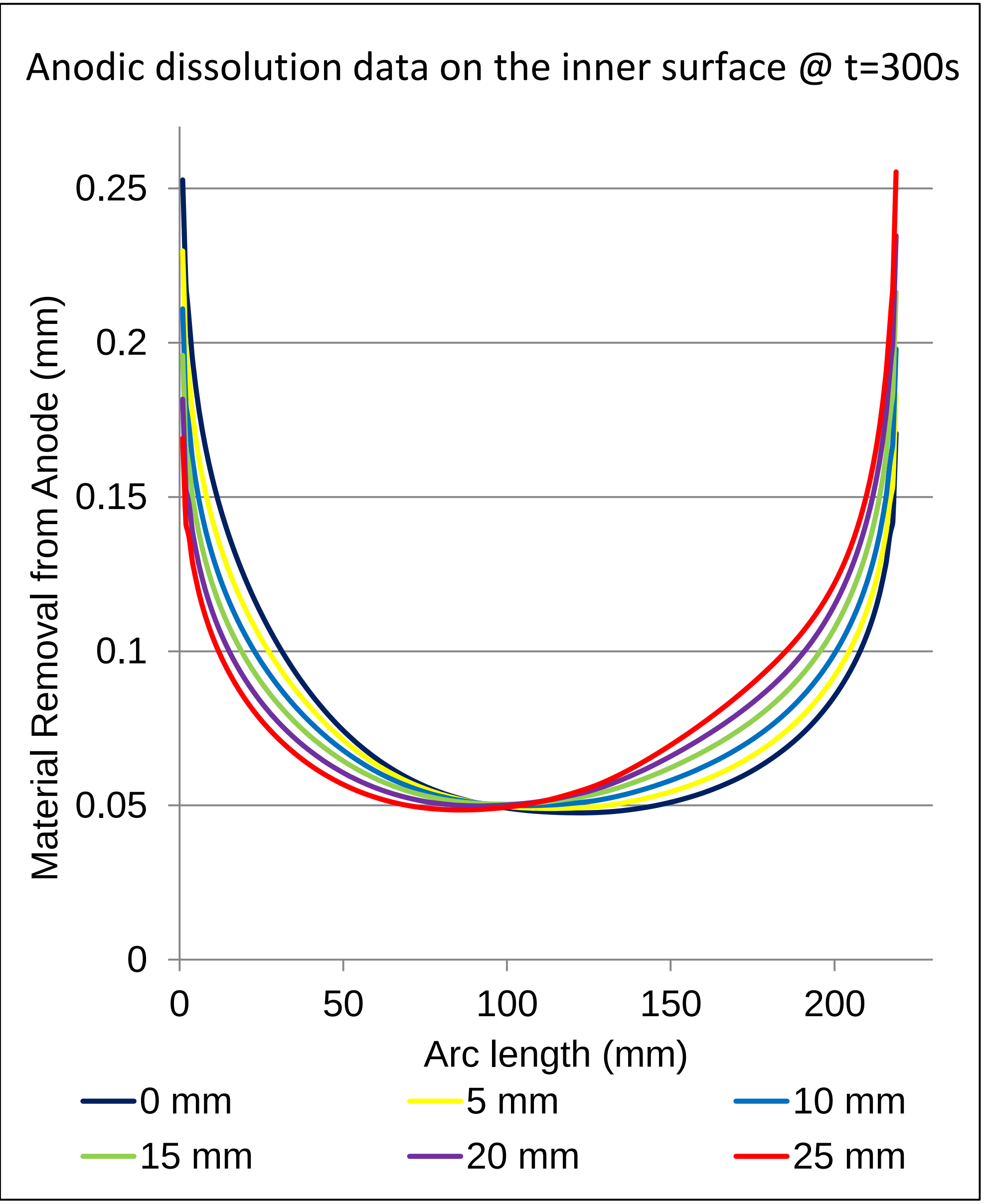
Anodic dissolution data on the inner surface @ t=300s

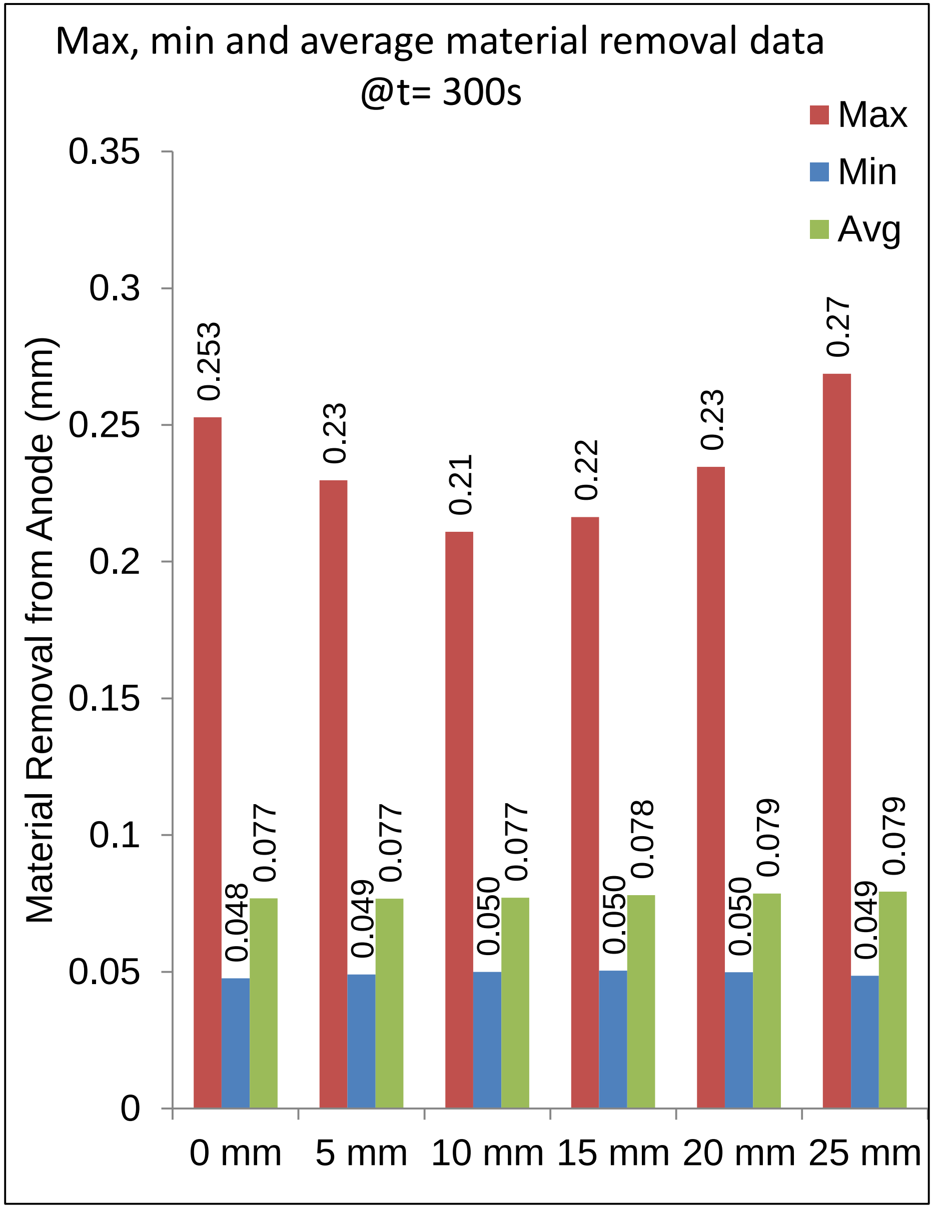


Max, min and average material removal data @t= 300s



RESULTS- AT DIFFERENT CATHODE POSITION

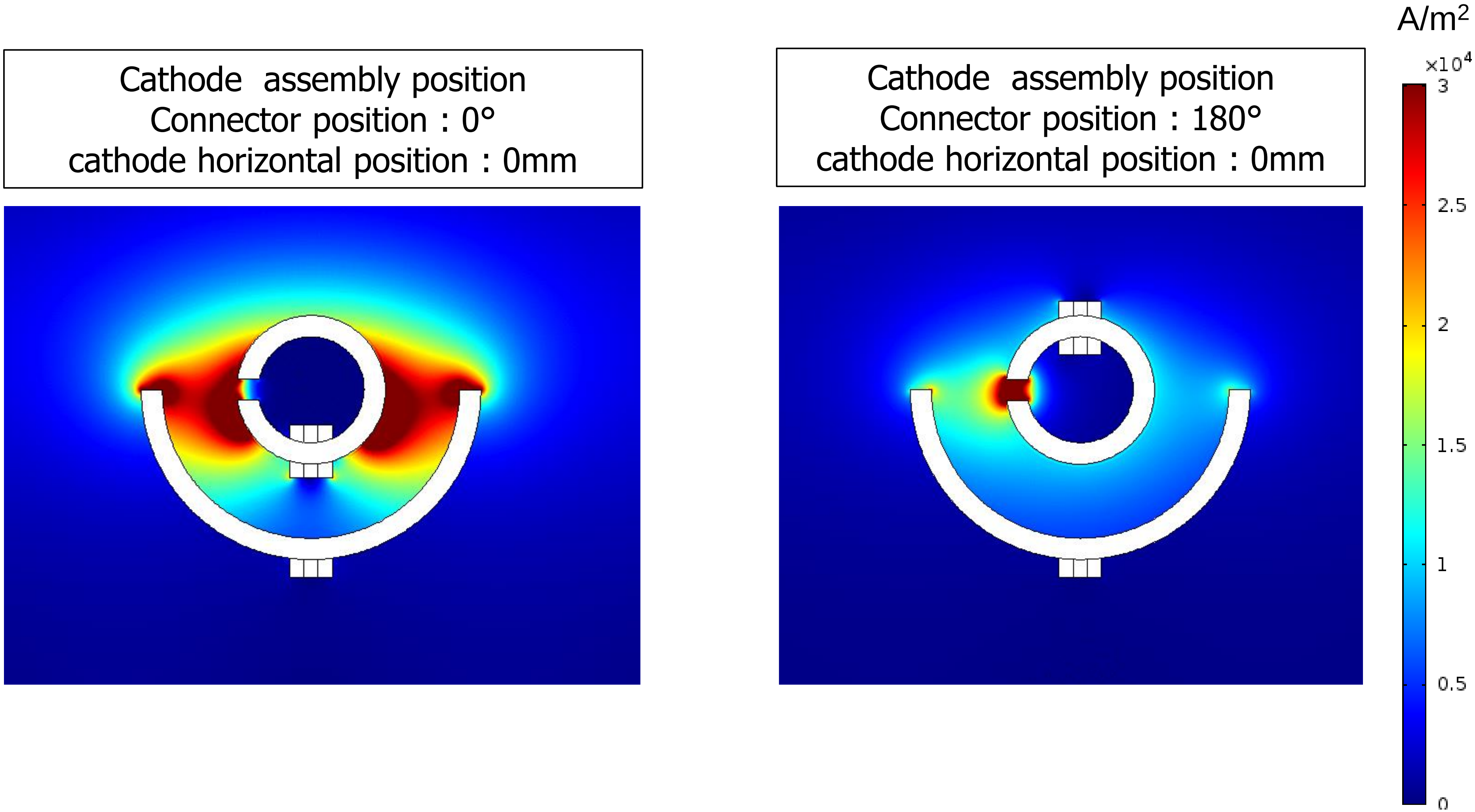




RESULTS- ELECTROLYTE CURRENT DENSITY

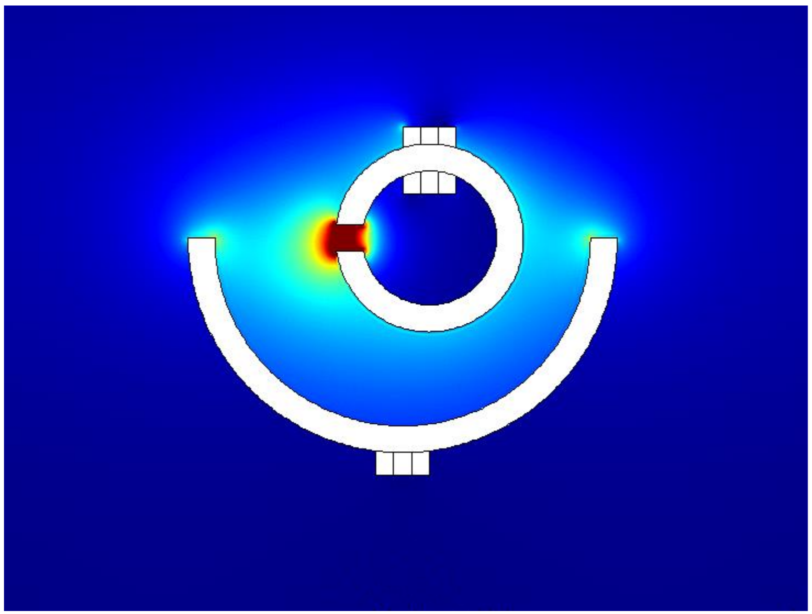
Cathode assembly position
Connector position : 0°
cathode horizontal position : 0mm

Cathode assembly position
Connector position : 180°
cathode horizontal position : 0mm

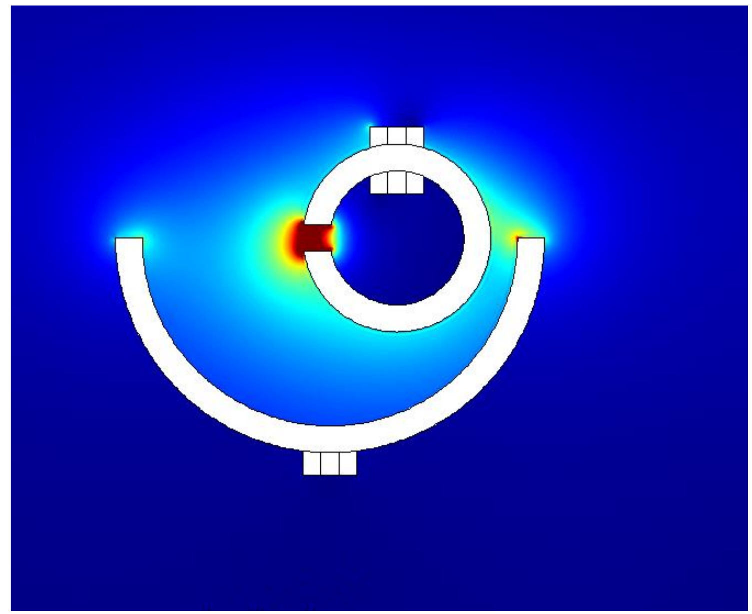


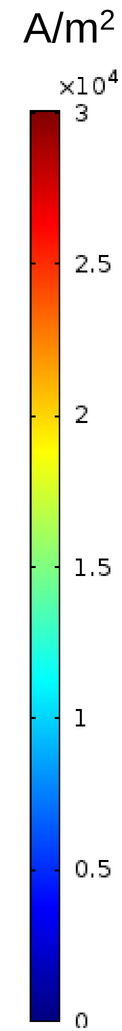
Results- Electrolyte current density

Cathode assembly position
Connector position : 180°
cathode horizontal position : 10mm



Cathode assembly position
Connector position : 180°
cathode horizontal position : 25mm





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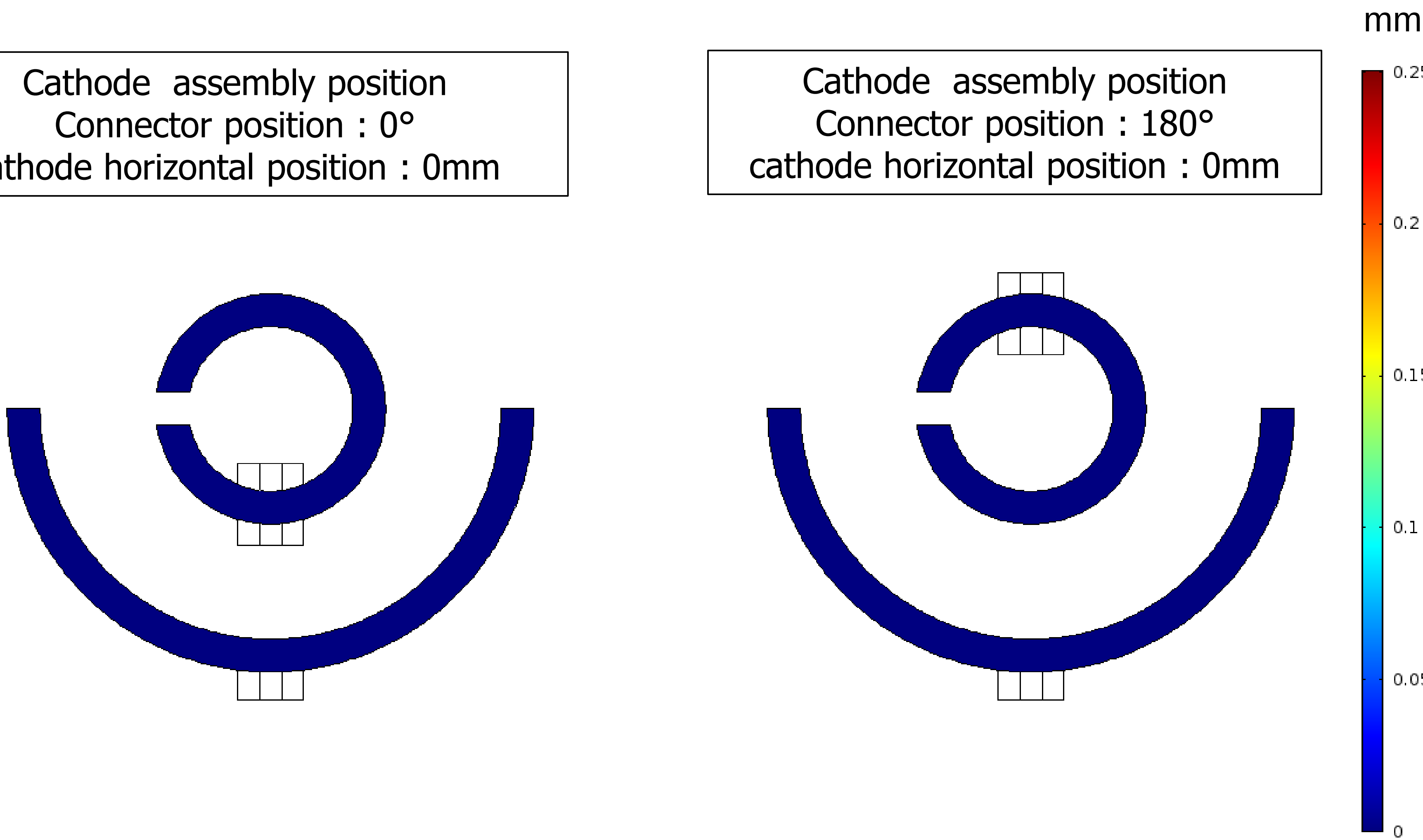
Results- Material removal

Cathode assembly position
Connector position : 0°
cathode horizontal position : 0mm

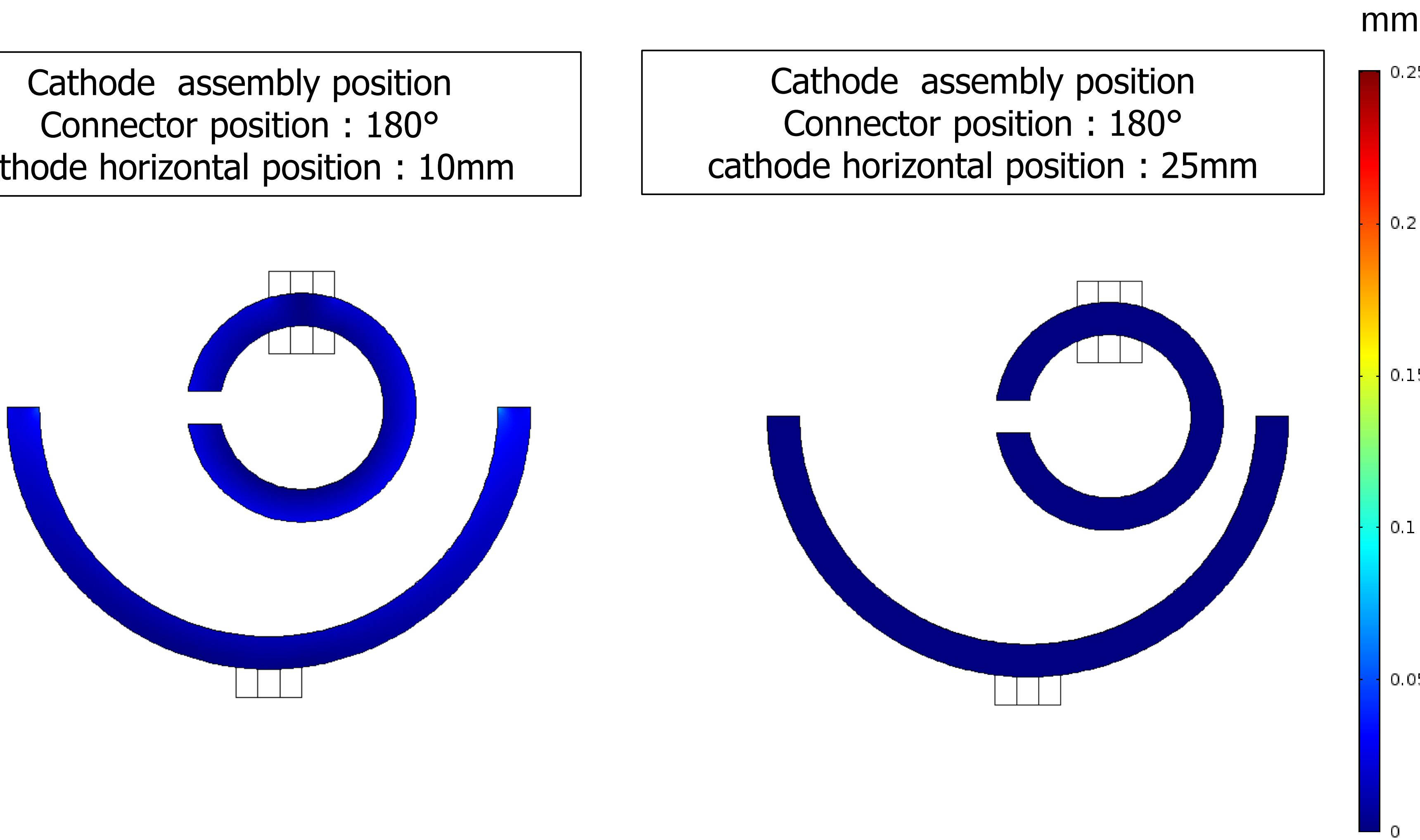
Cathode assembly position
Connector position : 180°
cathode horizontal position : 0mm



RESULTS- MATERIAL REMOVAL

Cathode assembly position
Connector position : 180°
cathode horizontal position : 10mm

Cathode assembly position
Connector position : 180°
cathode horizontal position : 25mm



Conclusion & Discussion

Conclusion

- In the current paper we discussed about modelling of Electrochemical material removal process of an super alloy by considering materials major constituents using tertiary current distribution method in COMSOL
- Conducting such type of simulation can help to understand the effect of change in process parameters (variables) on the system.

Future Work

- Addition of fluid flow effect (CFD) and mixing of electrolyte of varying concentrations.
- Effect of temperature on the Electrochemical reactions.
- Modelling the effect of H2 gas evolution at cathode using bubble flow module.

Reference

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5. Gleb Mamantov, H.W Jenkins, D.L. Manning, Exchange Current measurements on the Nickel-Nickel(II) Couple in molten Fluorides

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8. http://ocw.mit.edu/courses/chemical-engineering/10-626-electrochemical-energy-systems-spring-2011/lecture-notes/MIT10_626S11_lec13.pdf

Thank You

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