Numerical simulation of Ar−x%CO_2 shielding gas and its effect on an electric welding arc

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- **Context / Motivation:**

  better understand the heat source

- **Aim:**

  develop a 3-dimensional simulation software
  for electric welding arc heat source

- **Software OpenFOAM-1.6.x**

  - open source CFD software
  - C++ library of object-oriented classes
    for implementing solvers for continuum mechanics

Contents

- Thermal fluid model (plasma core)
  - assumptions – governing equations
- Electromagnetic model (plasma core)
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- Magnetic field model : 3D or axi-symmetric ?
  - infinite rod test case
  - water cooled MIG welding test case
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  - comparison with experimental data
  - influence of shielding gas composition
  - influence of boundary conditions on anode and cathode
- Conclusions

Model: thermal fluid part

Main assumptions (plasma core):

- one-fluid model
- local thermal equilibrium
- mechanically incompressible and thermally expansible
- *steady flow*
- *laminar flow(assuming laminar shielding gas inlet)*

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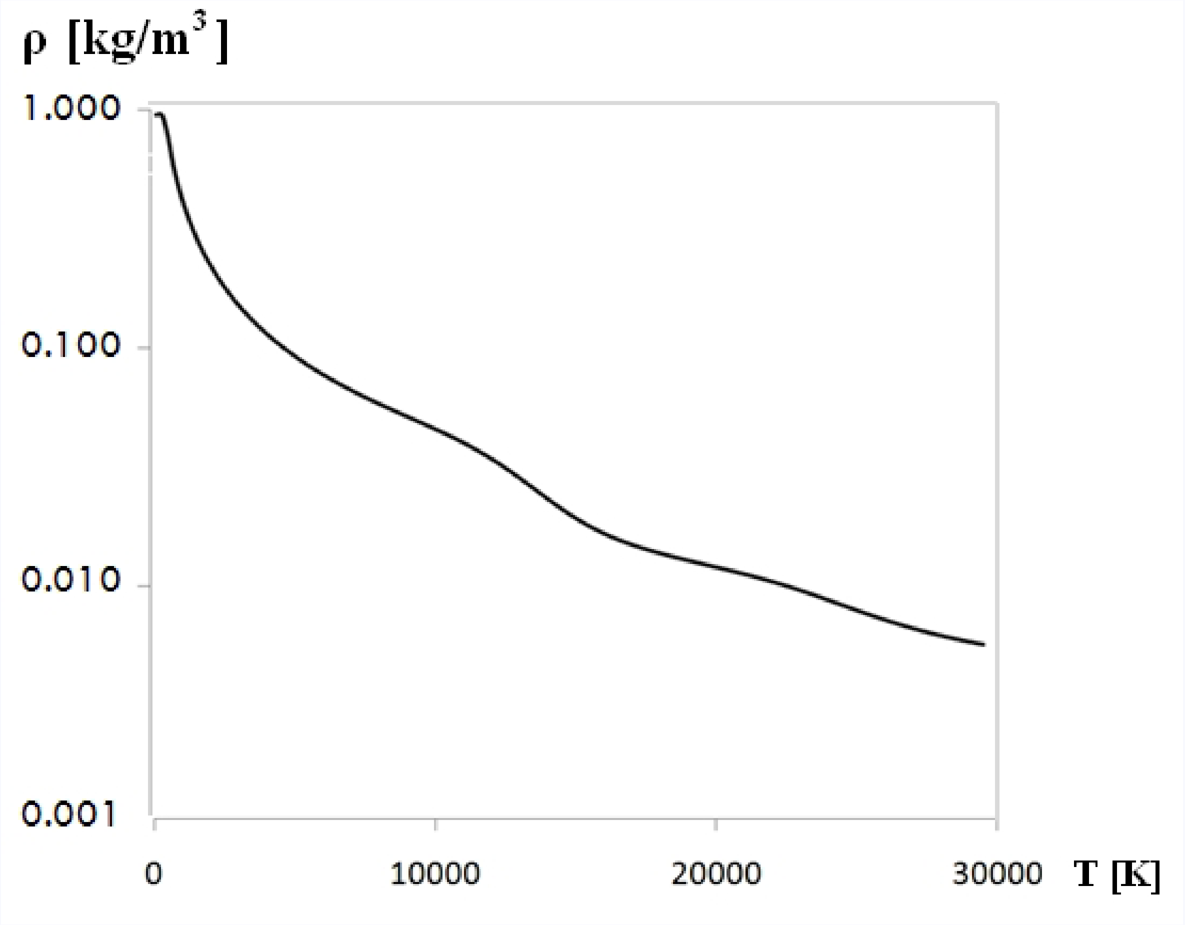

Argon plasma density as function of temperature.

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$$+ \nabla \cdot \left[\mu(T)\, \left(\nabla \vec{u} + (\nabla \vec{u})^T \right) - \frac{2}{3} \mu(T)\, \left(\nabla \cdot \vec{u} \right) I \right] = -\nabla P + \vec{J} \times \vec{B}$$

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Lorentz force

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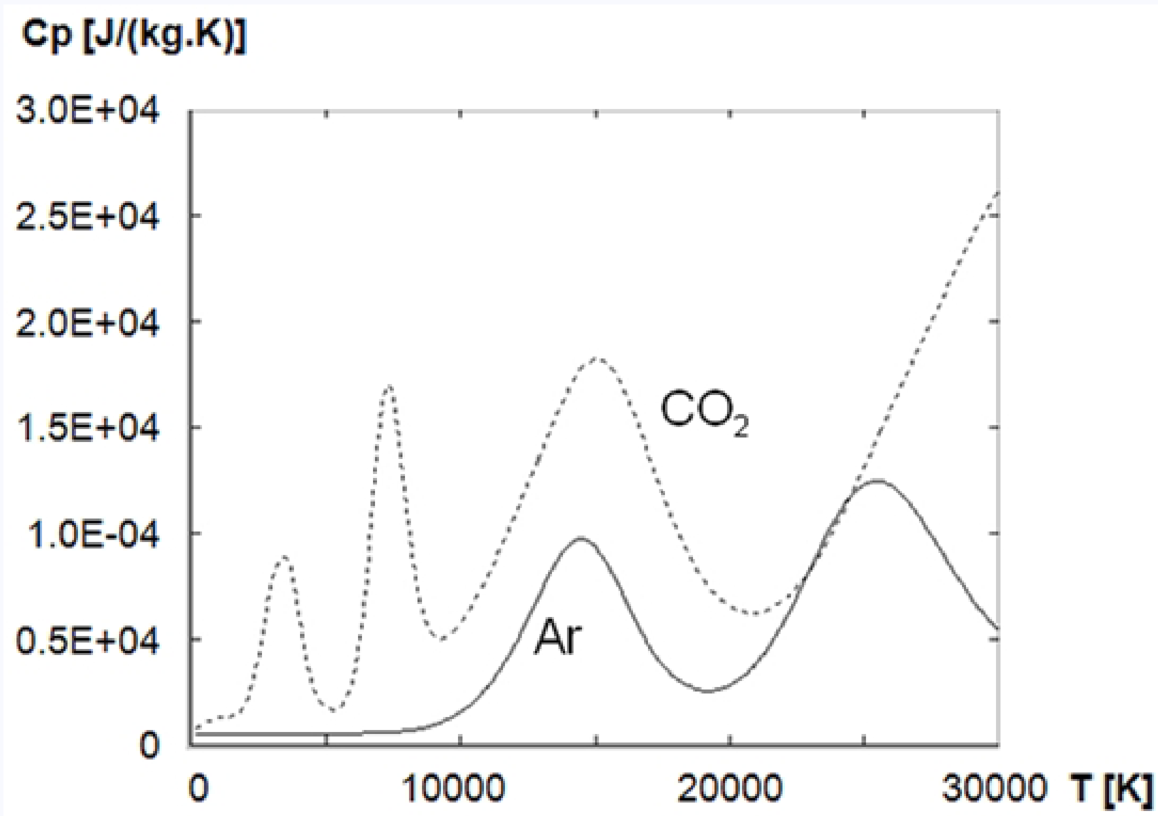

Specific heat as function of temperature
for Ar (solid line) and CO_2 (dotted line)

J. Aubreton, M. F. Elchinger

Model: electromagnetic part

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  $\mathrm{Re}_m << 1$ ⟹ $\vec{J}_{ind} = \sigma\, \vec{u} \times \vec{B} << \vec{J}_{cond}$
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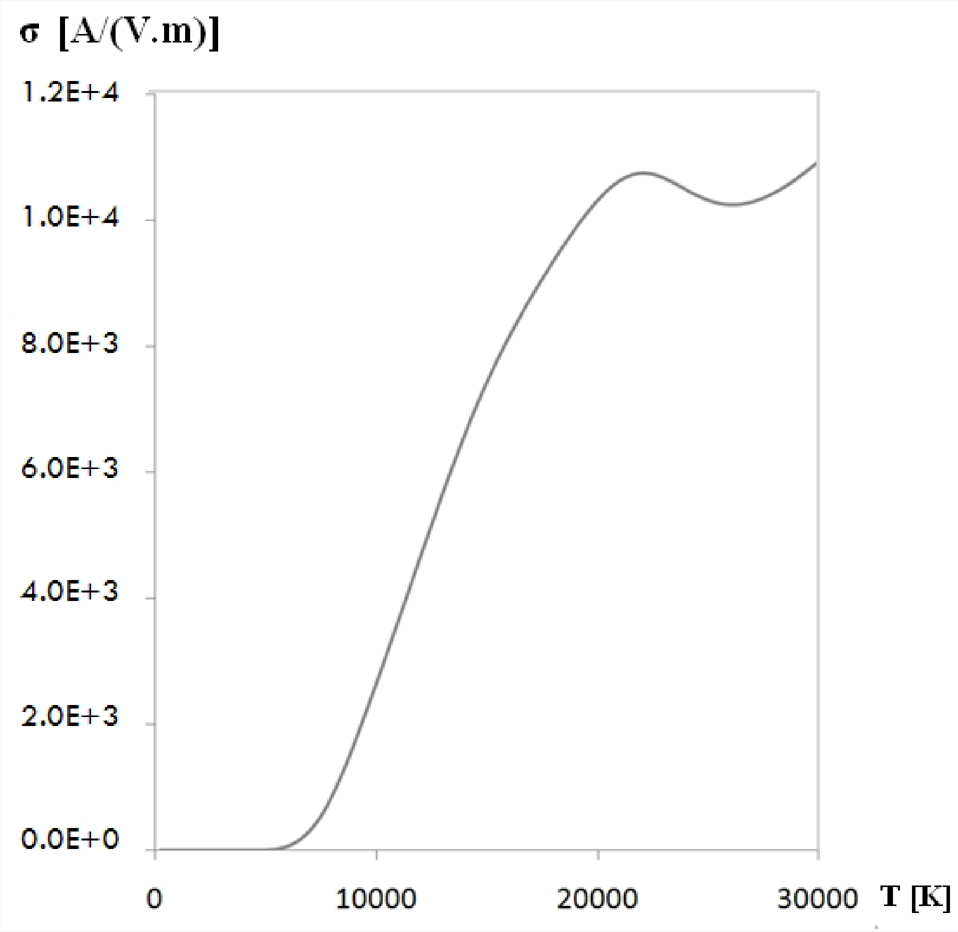

Argon plasma electric conductivity as function of temperature

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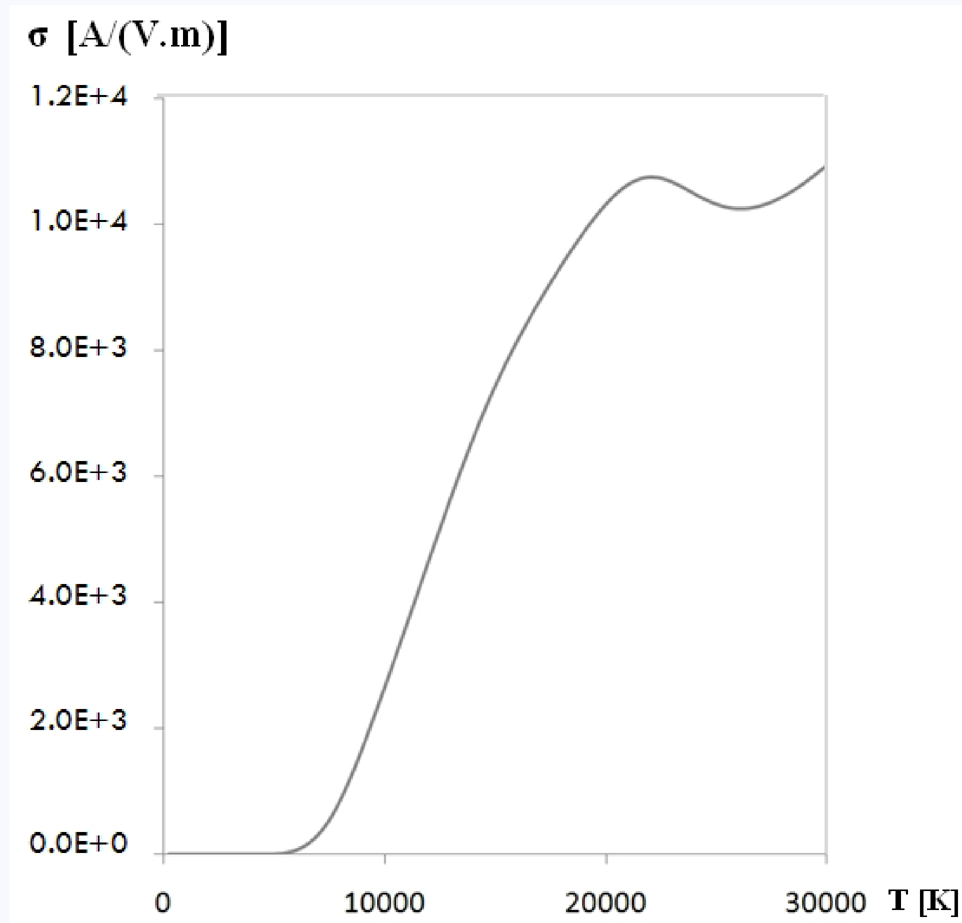

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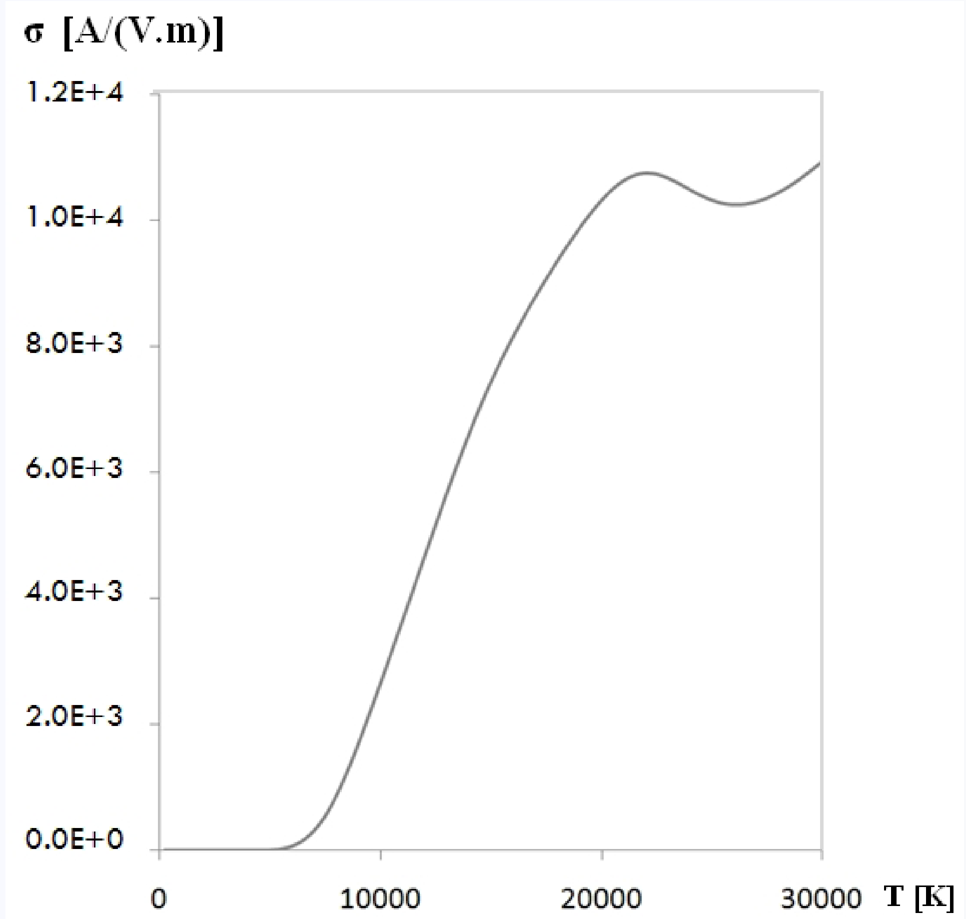

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for axi-symmetric configuration

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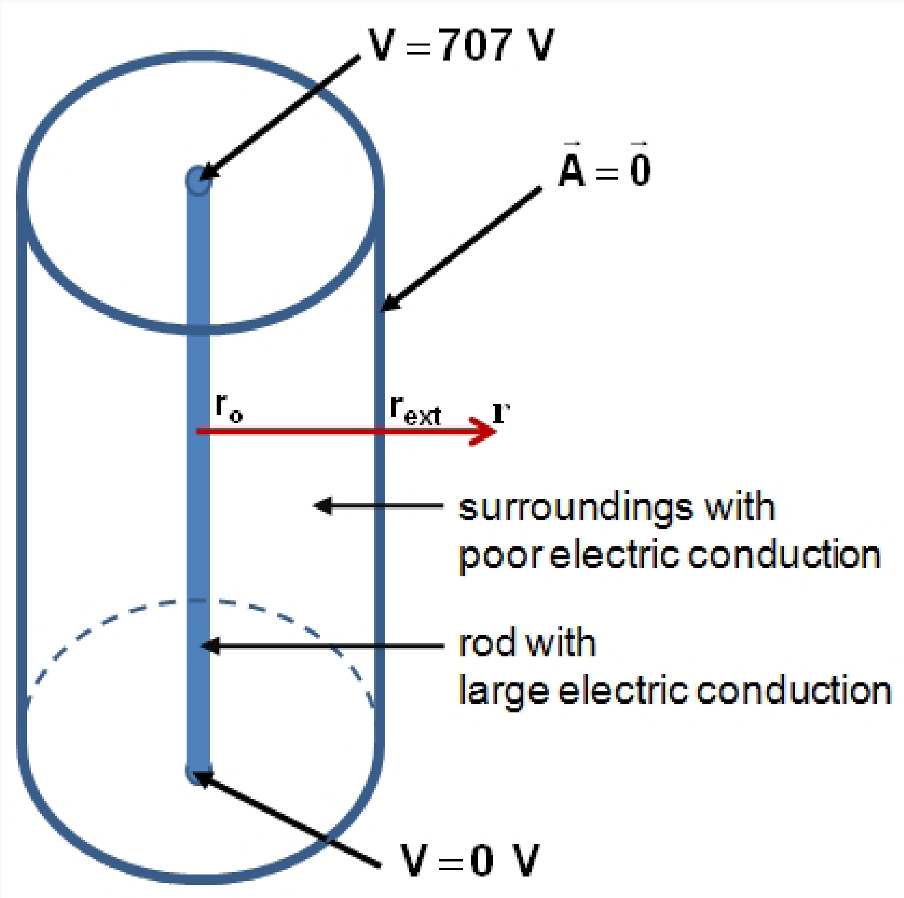
Test case: infinite conducting rod



$\sigma = 2700 A/(V.m)$

$\sigma = 10^{-5} A/(V.m)$

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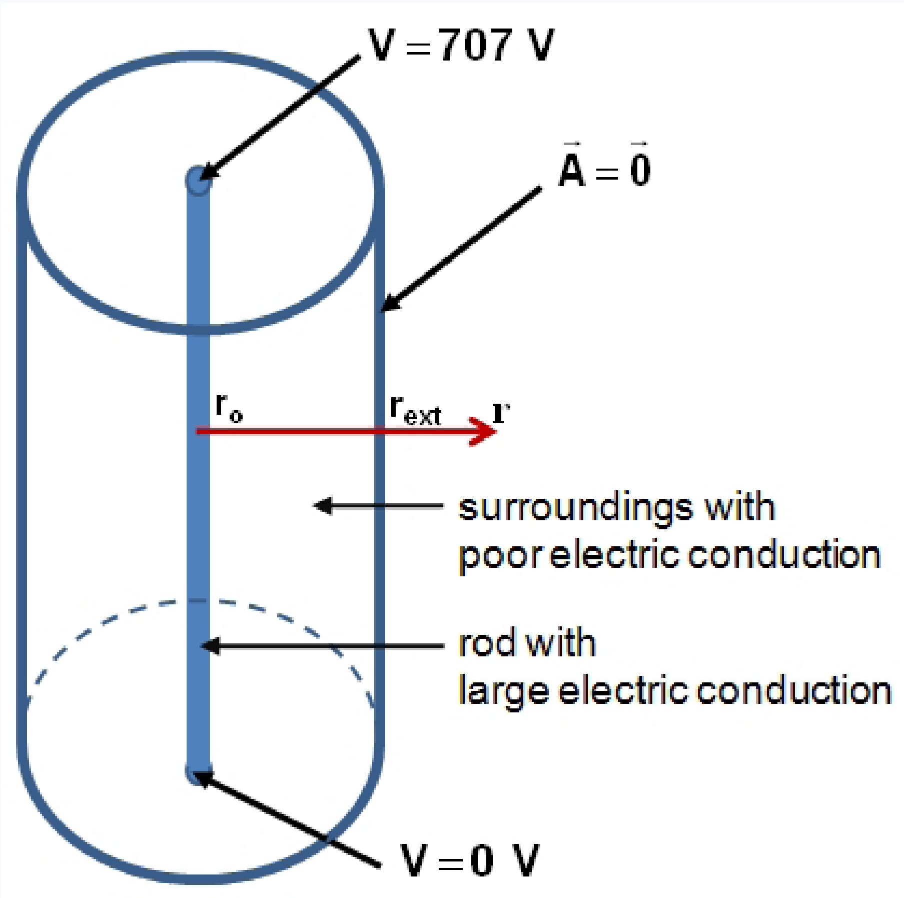

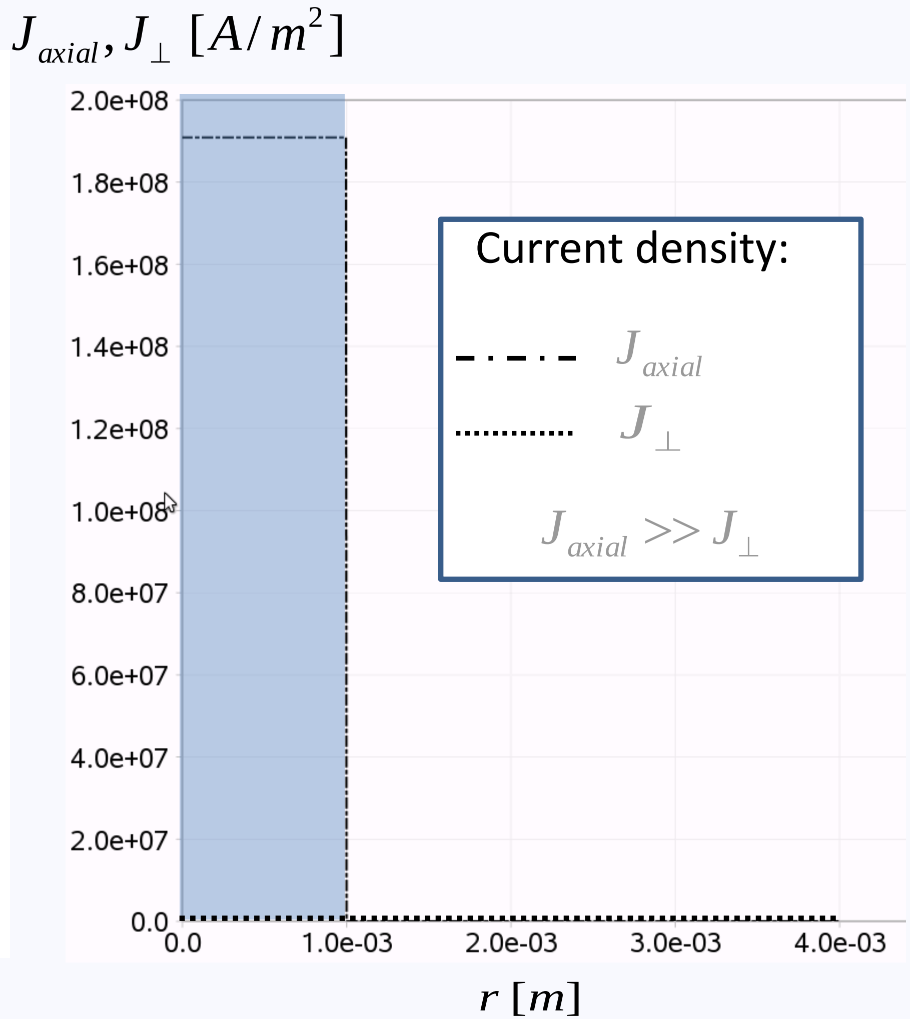

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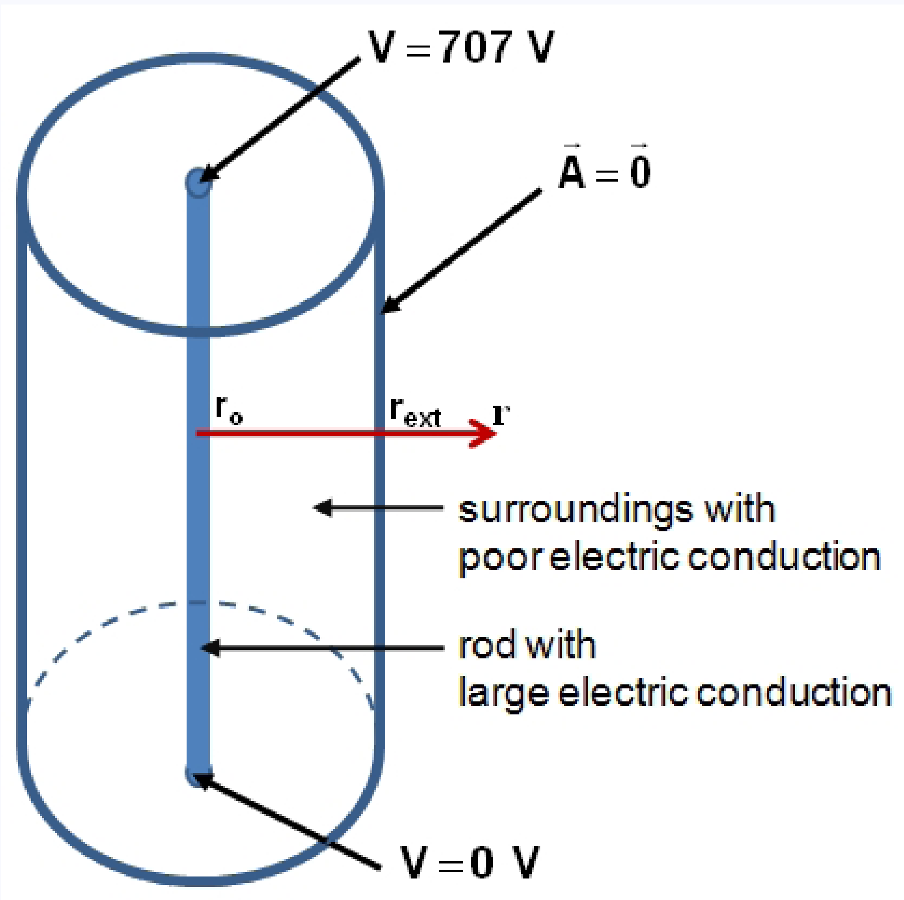

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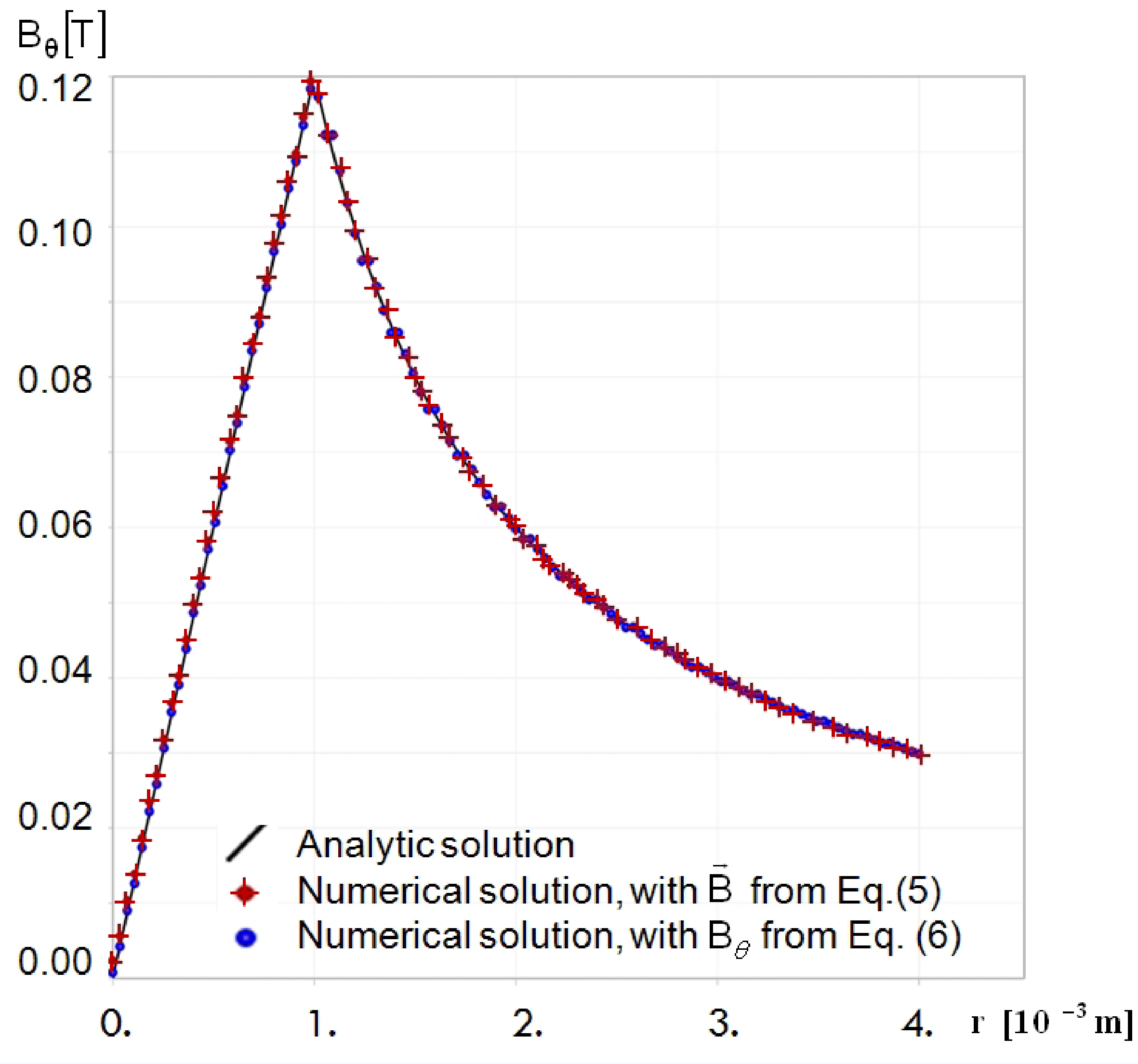
Analytic solution:

$$B_\theta(r) = \frac{\mu_o J_{axial}\, r}{2} \quad if \quad r < r_o$$

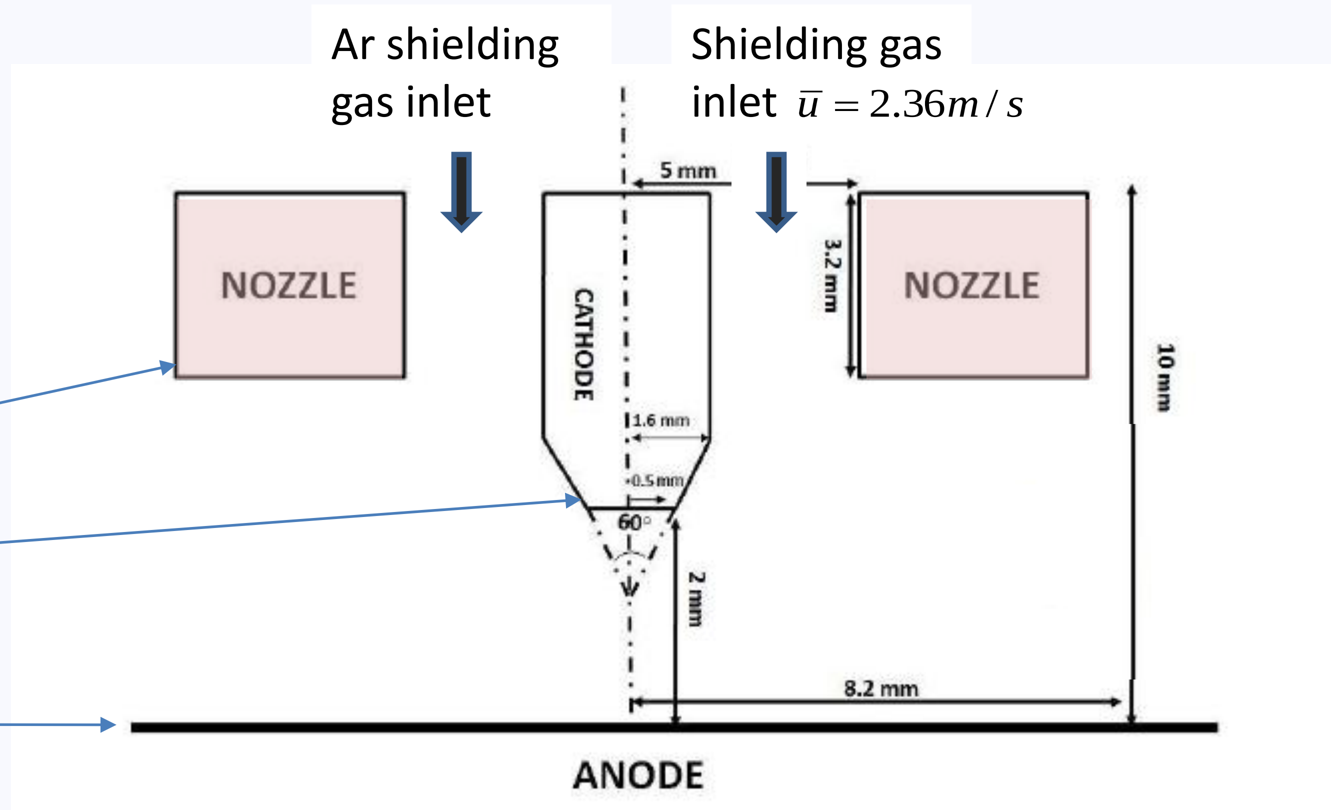
$$B_\theta(r) = \frac{\mu_o J_{axial}\, r_o^2}{2\, r} \quad if \quad r \geq r_o$$



Angular component of the magnetic field along the radial direction (r_0= 10^{-3}m)

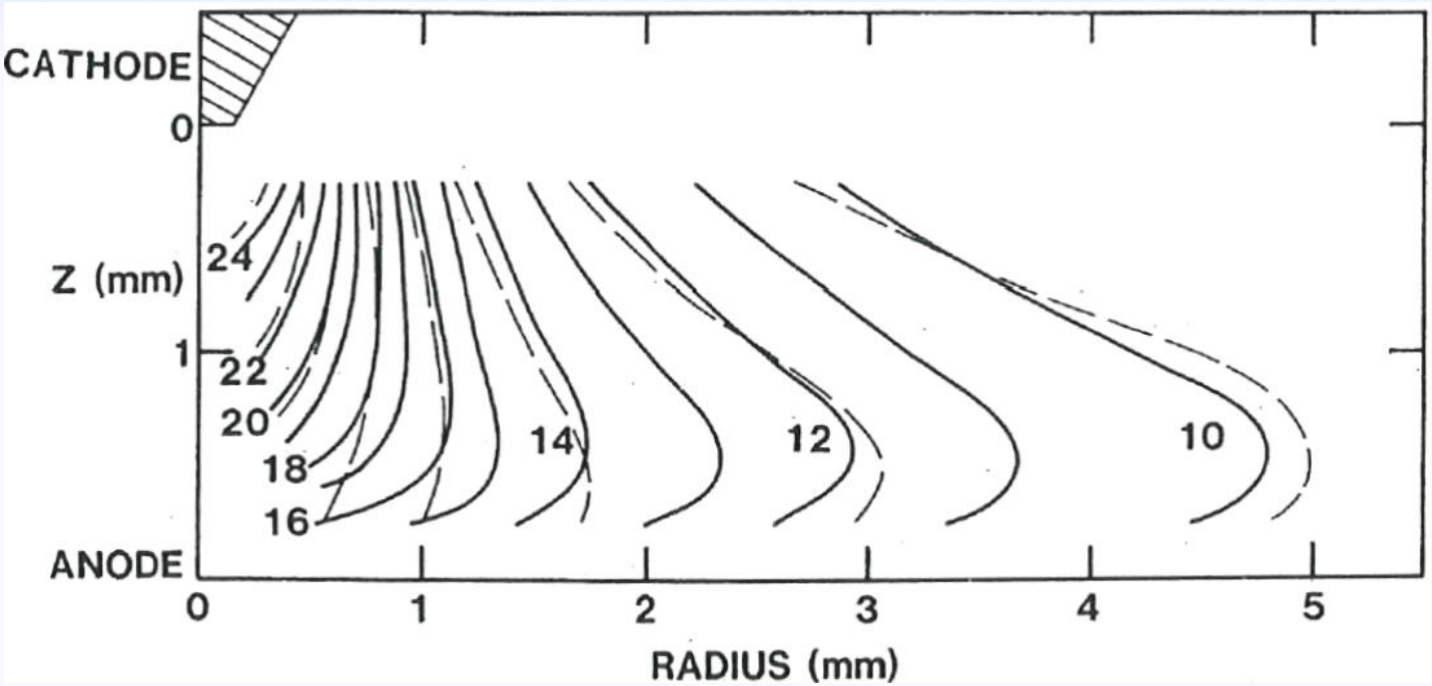
Test case: Metal Inert Gas welding

Applied current: I=200A



Picture of a MIG torch

Sketch of the cross section of a MIG torch



Measured temperature profile for
a current intensity 200 A and 2 mm long
arc.

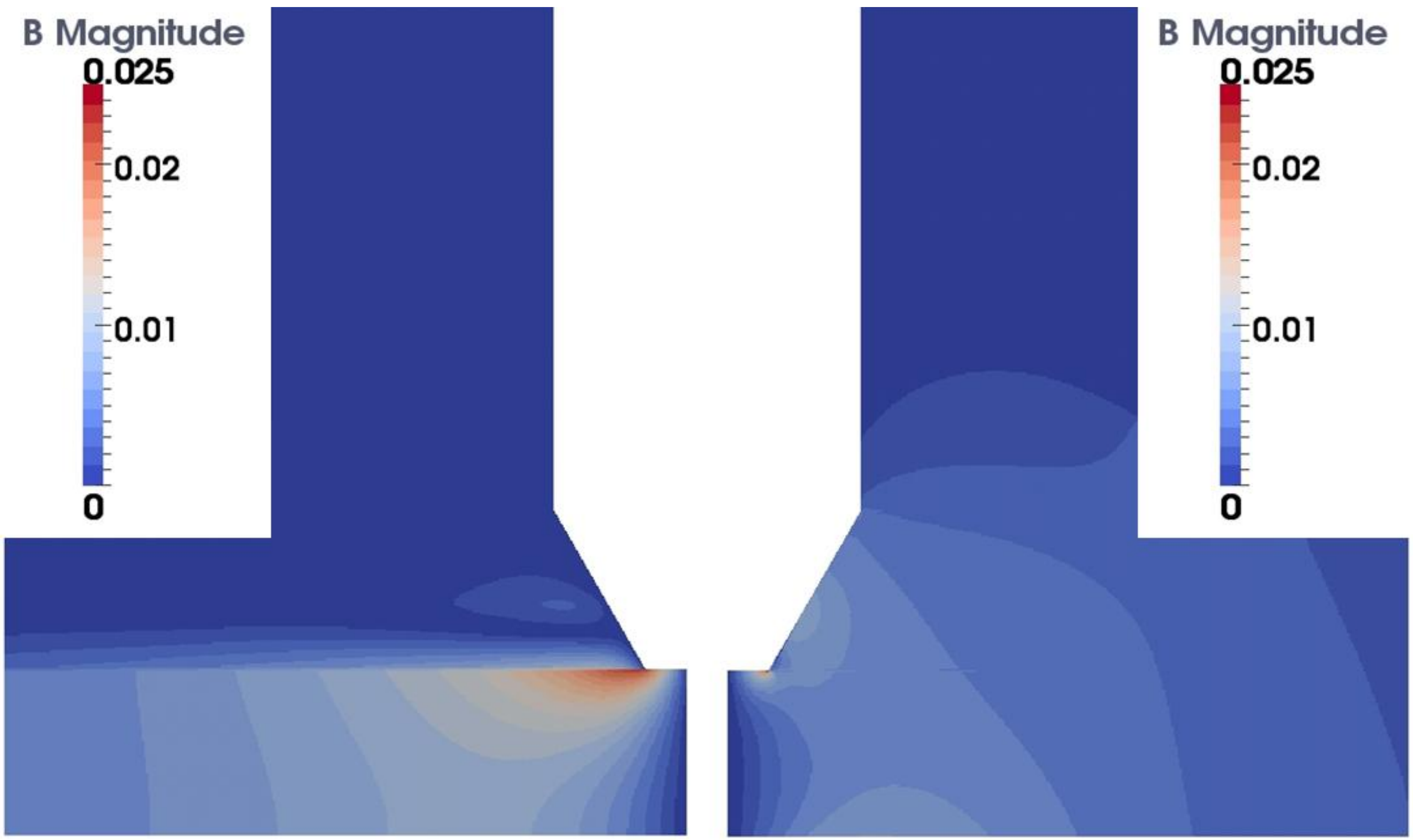
Figure from*: G.N. Haddad and A.J.D. Farmer (1985) .Temperature measurements in gas tungsten arcs, Welding J, **64**, pp. 339-342.*

Boundary conditions:

*M.C. Tsai, and Sindo Kou (1990). Heat transfer and fluid flow in welding arcs produced by sharpened and flat electrodes, Int. J. Heat Mass Transfer, **33**, pp. 2089-2098.*

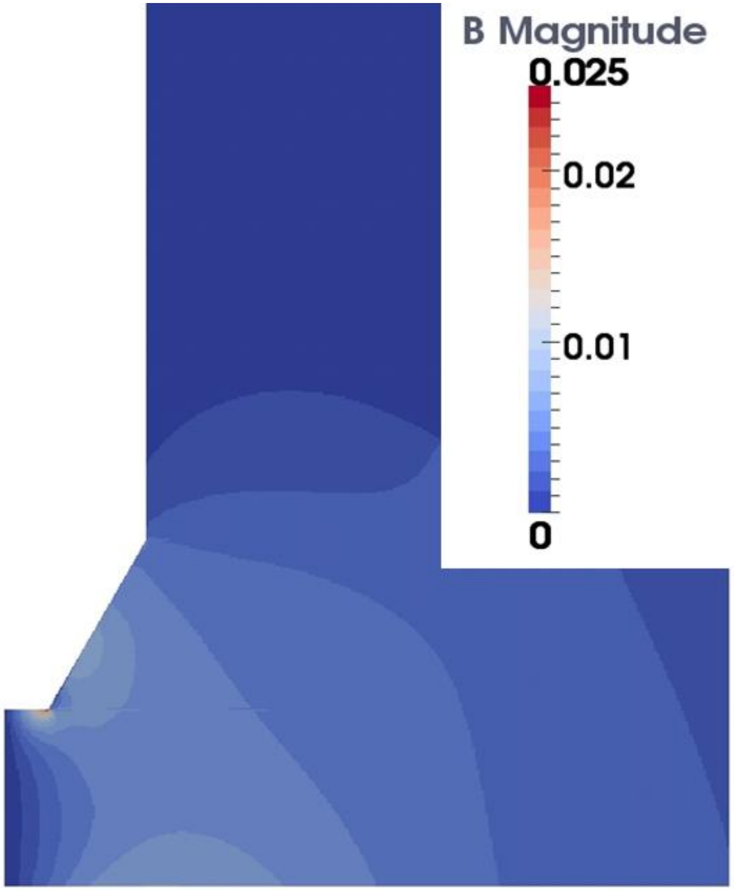
$$B_{\vartheta}(r) = \frac{\mu_0}{r} \int_0^r J_{axial}(l)\ l\ dl$$

$$\vec{B} = \nabla \times \vec{A}$$

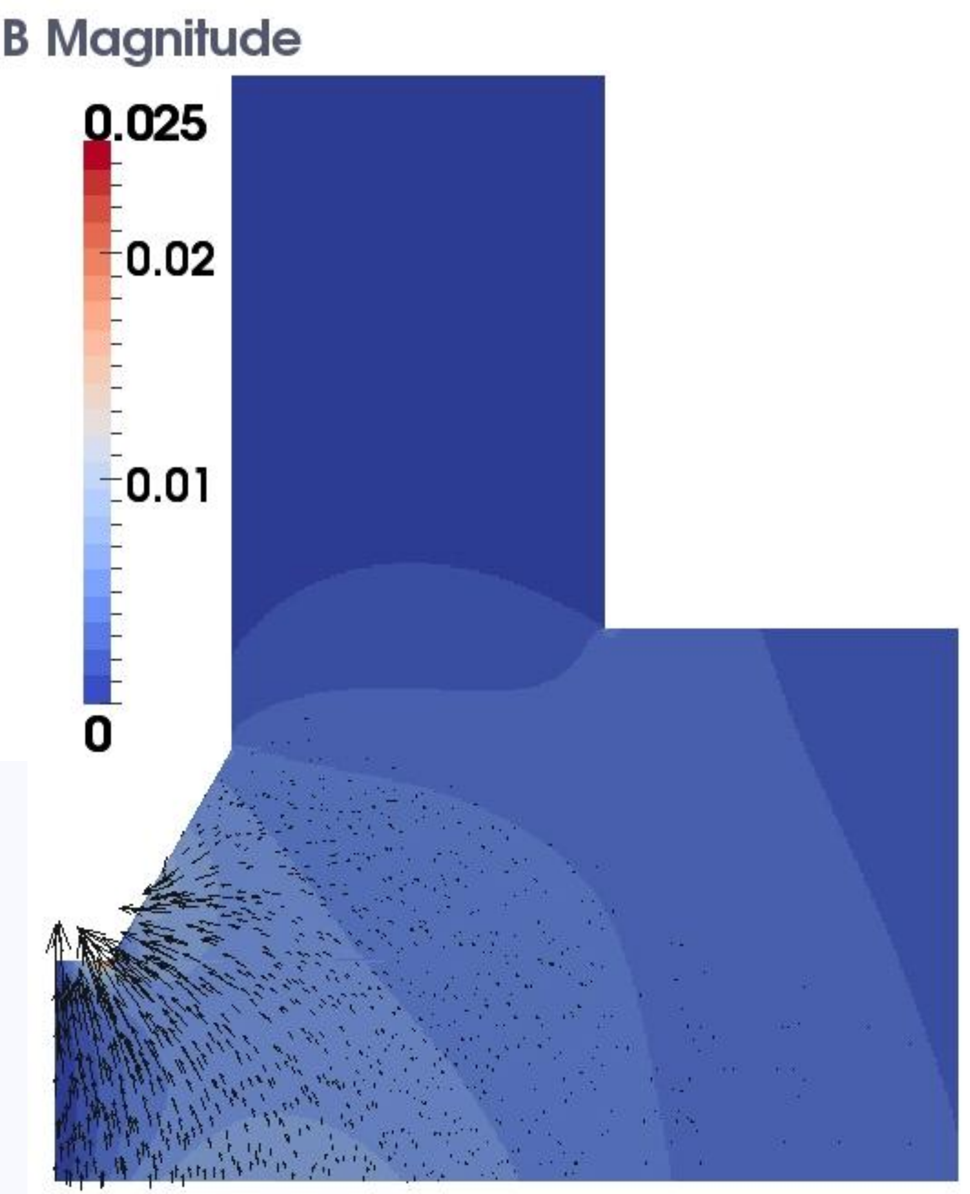


Magnetic field magnitude calculated with the axi-symmetric (left) and the three-dimensional (right)

$$\vec{B} = \nabla \times \vec{A}$$

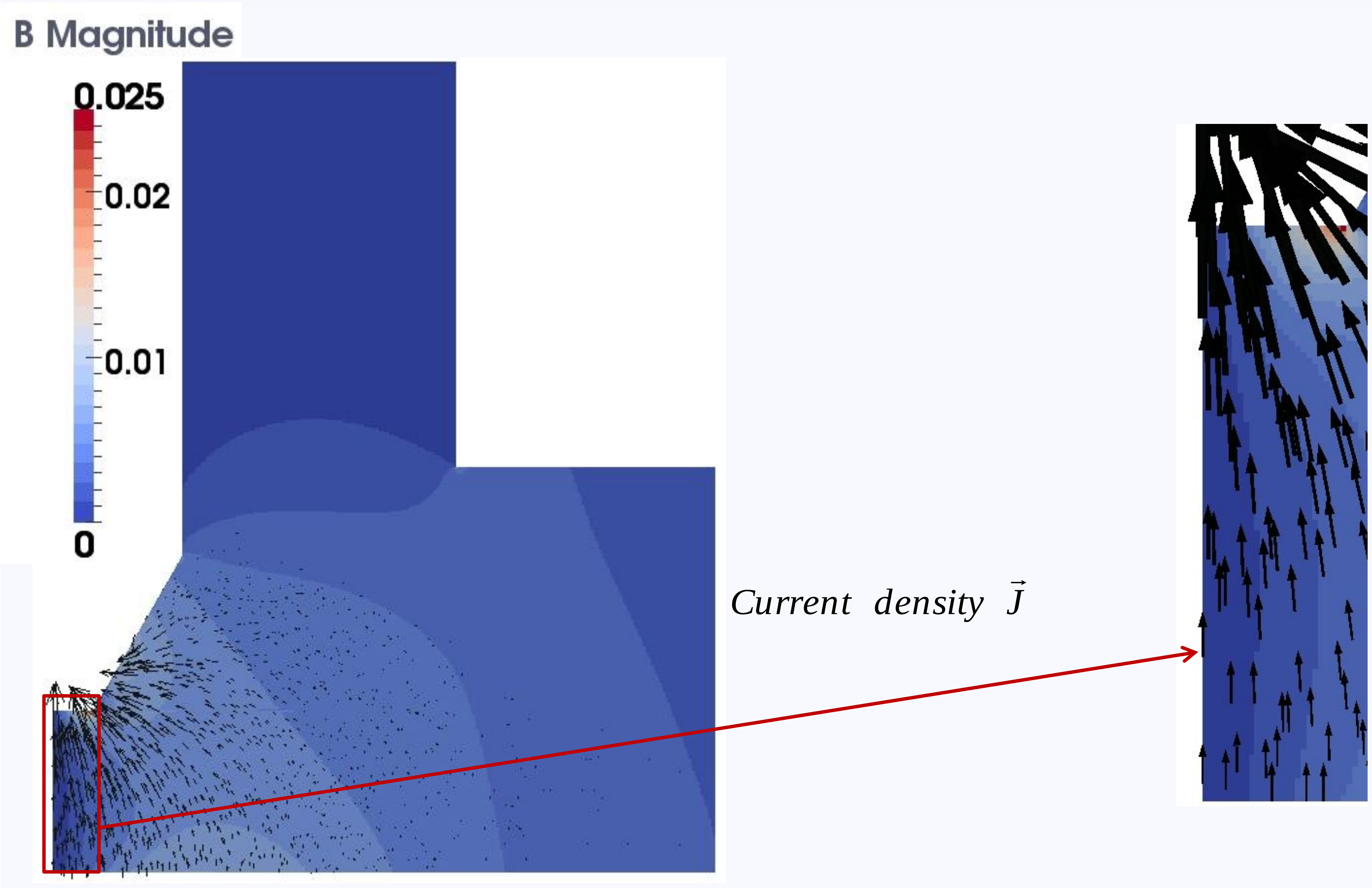


Magnetic field magnitude calculated with the three-



Current density $\vec{J}$

With: GAMG preconditioner, Fine mesh



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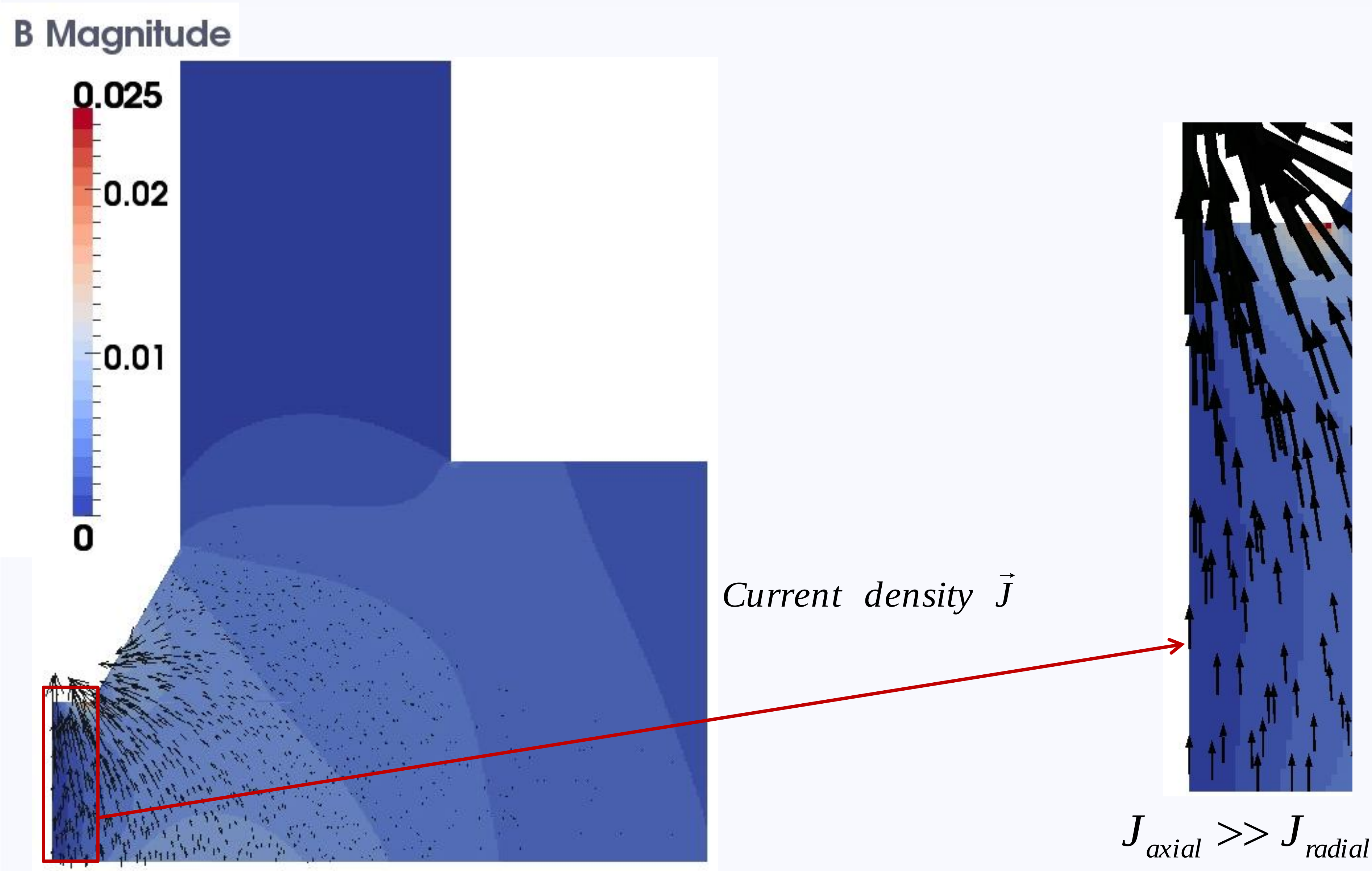

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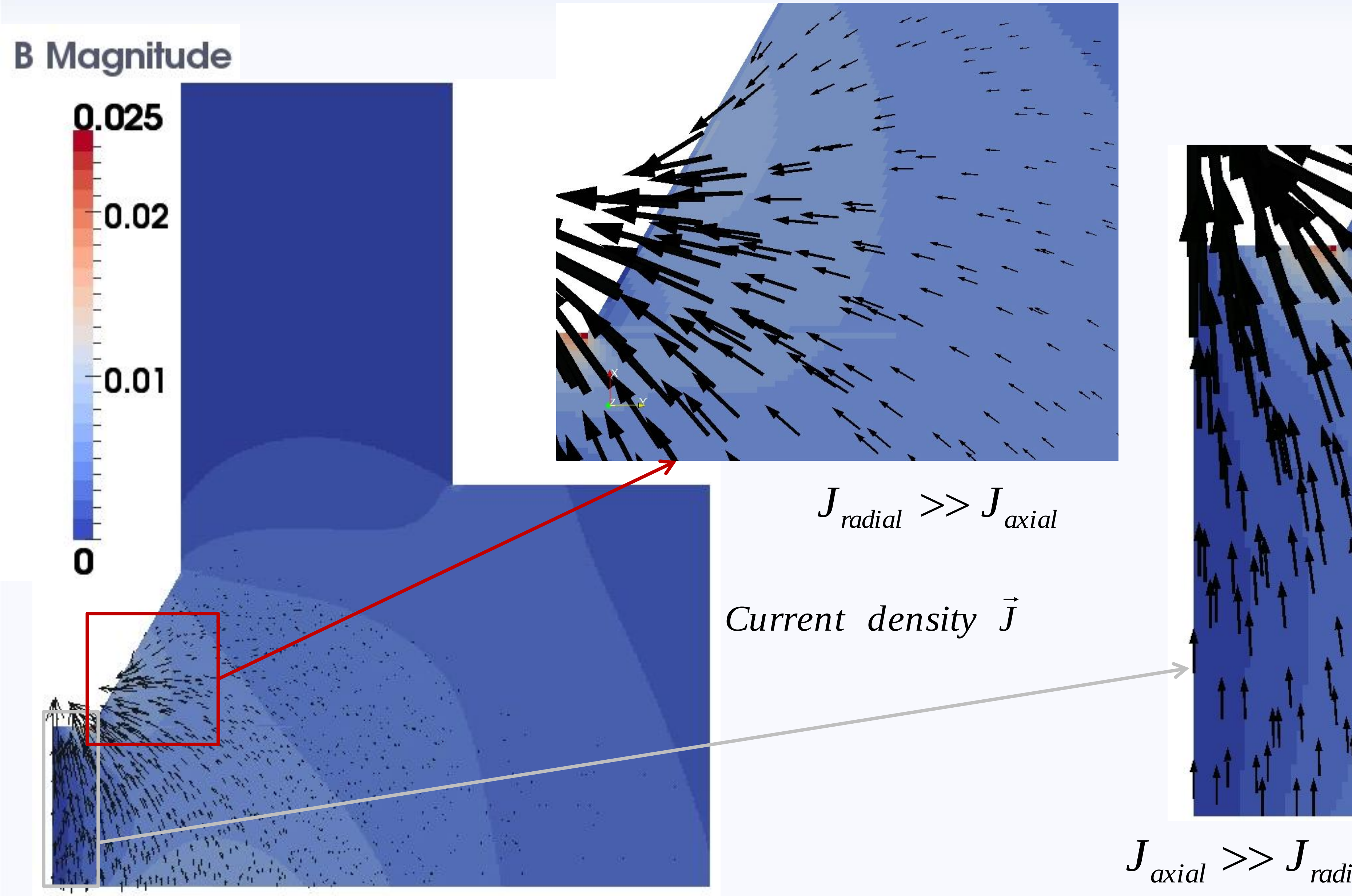

$J_{radial} >> J_{axial}$

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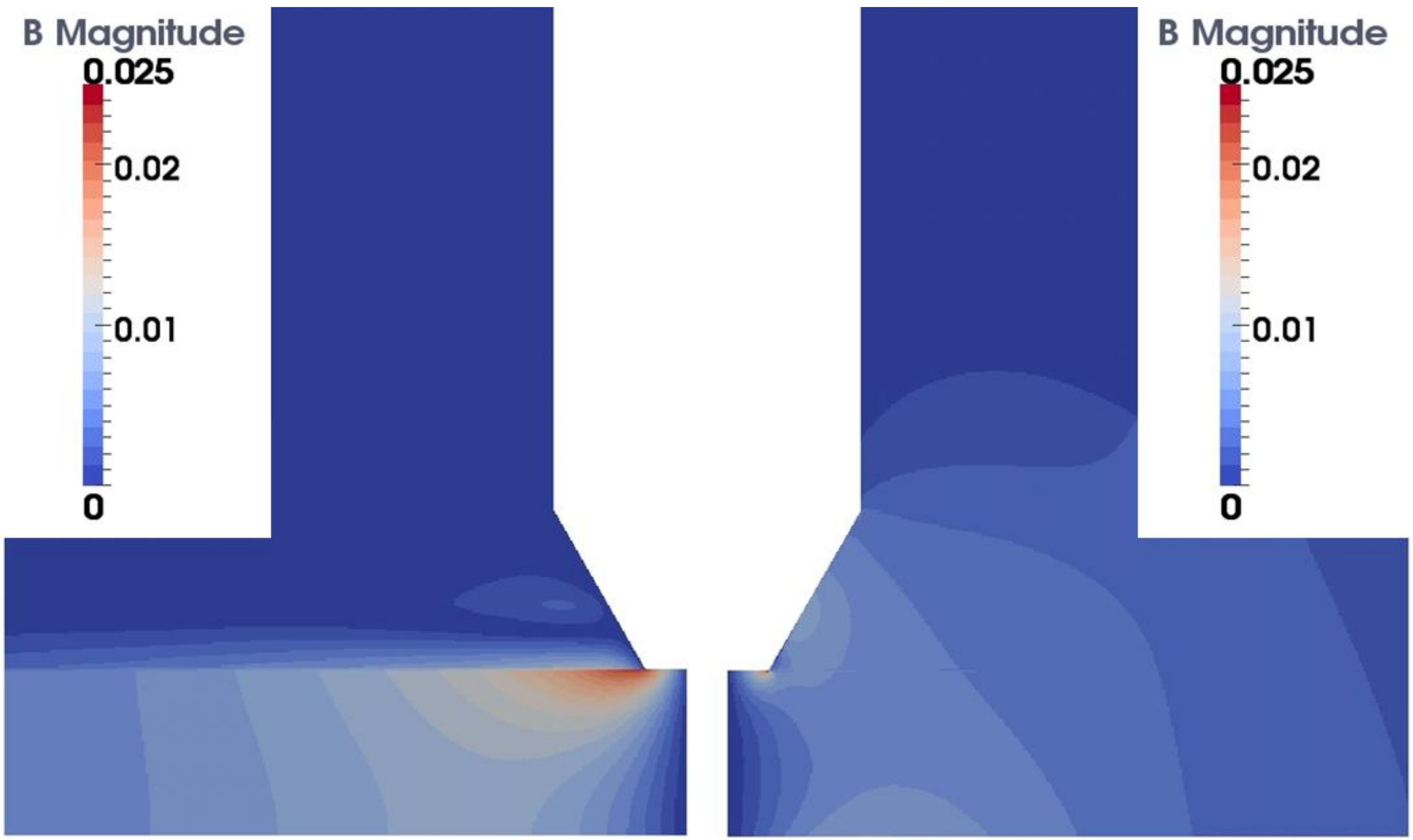

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for axi-symmetric configuration if $J_{axial} >> J_\perp$

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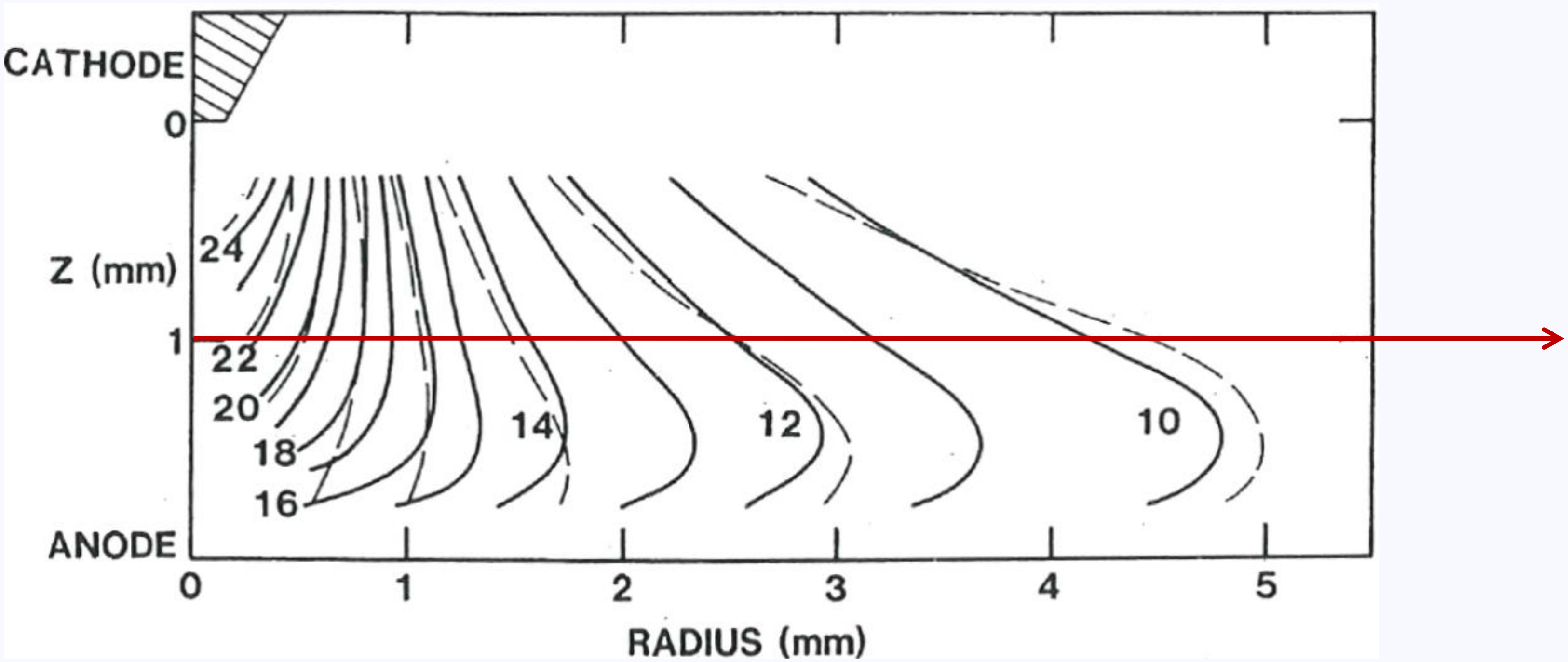

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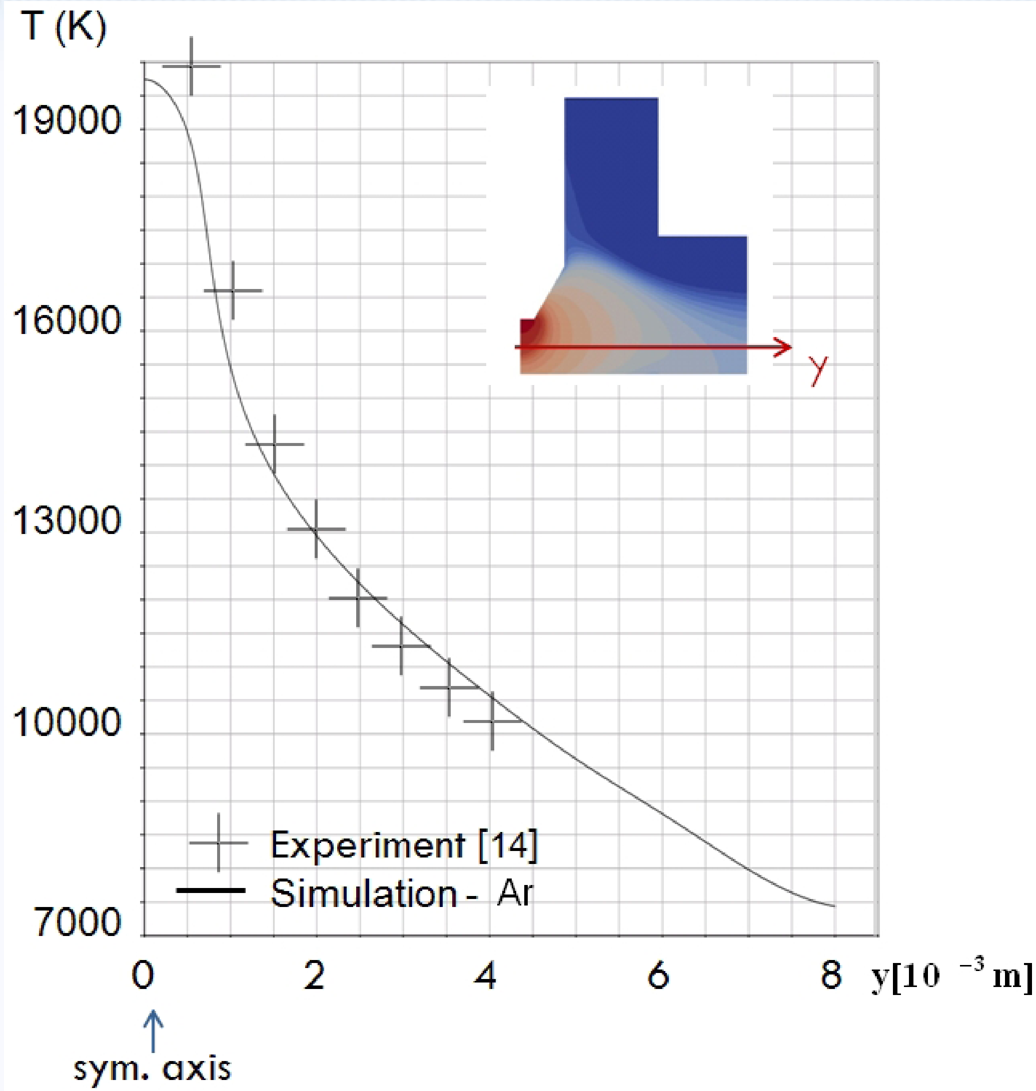

Temperature along the radial direction, 1 mm above the anode.

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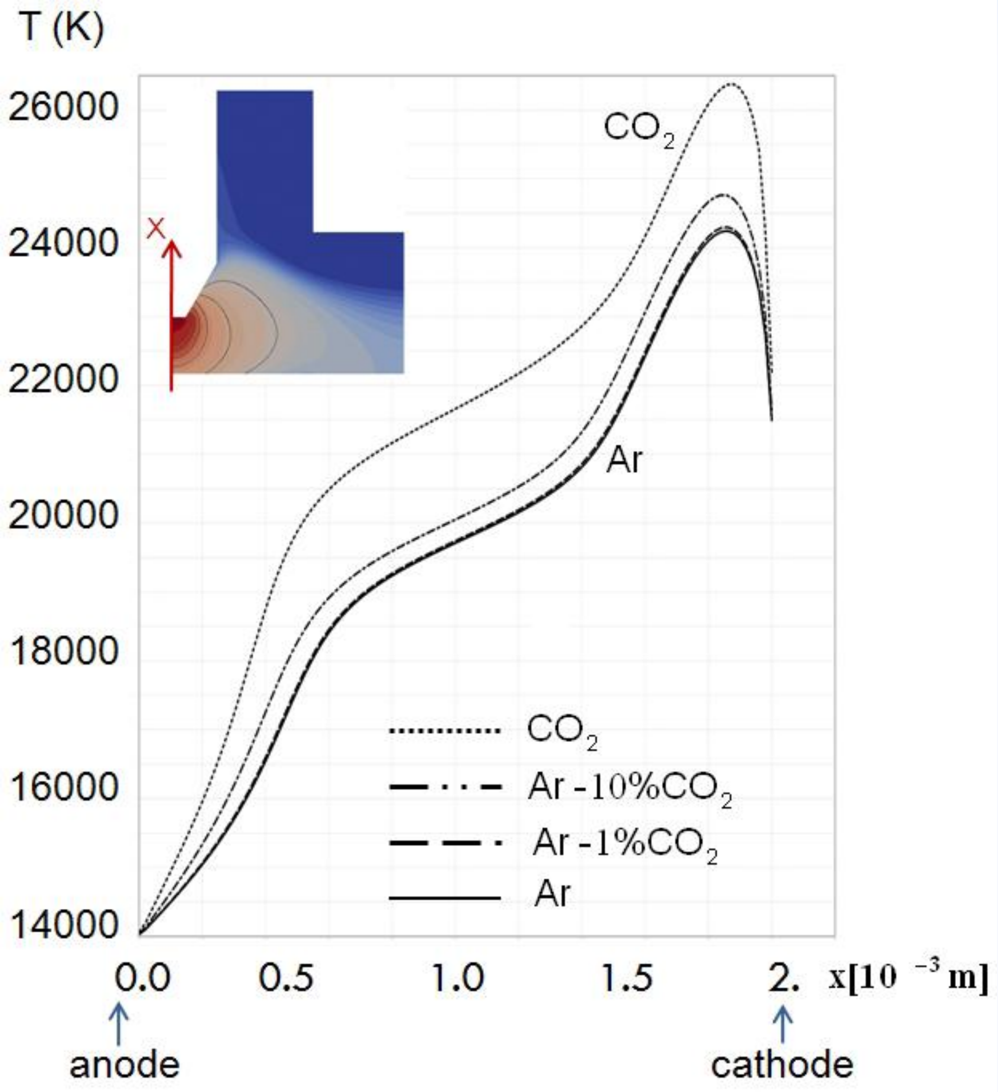
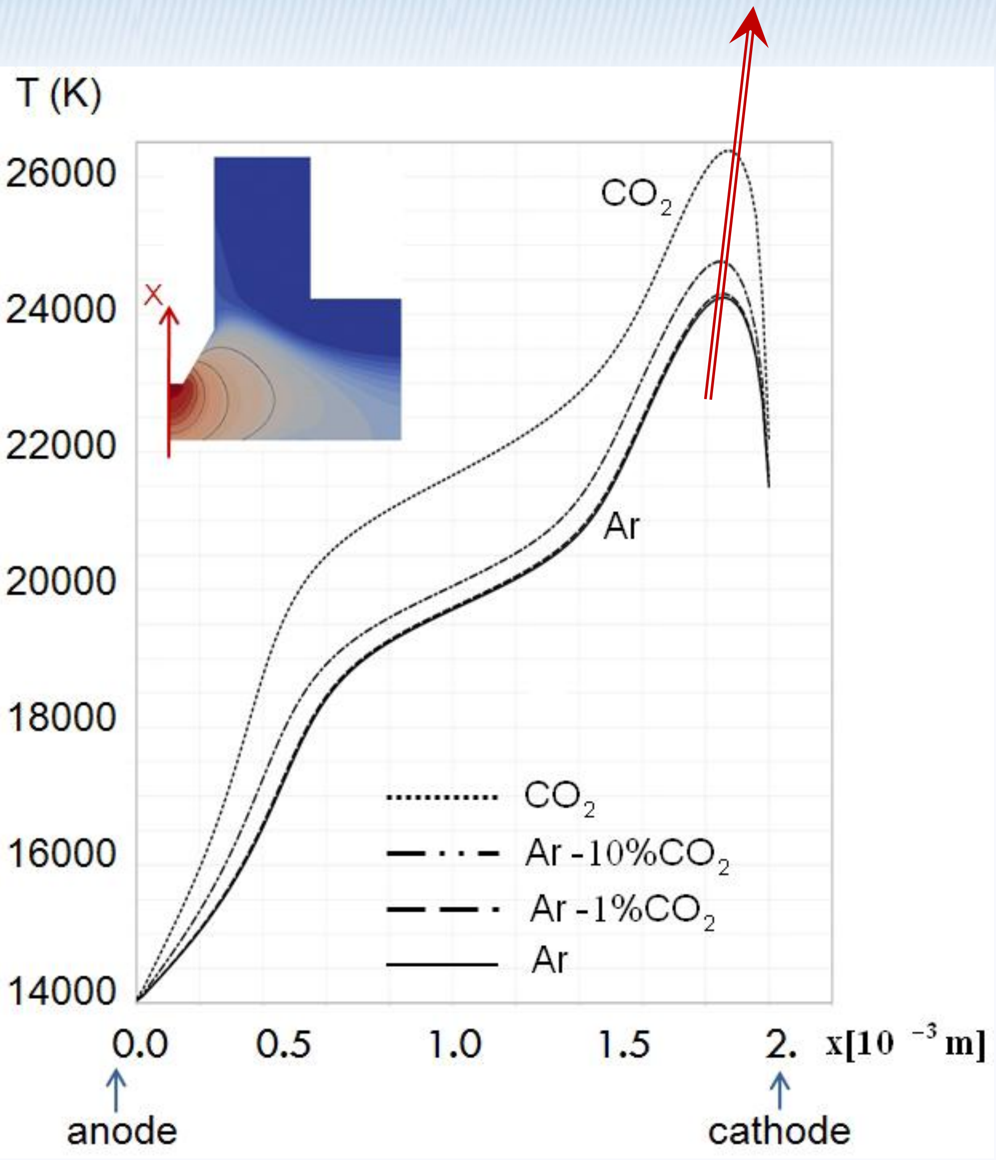


Temperature along the symmetry axis



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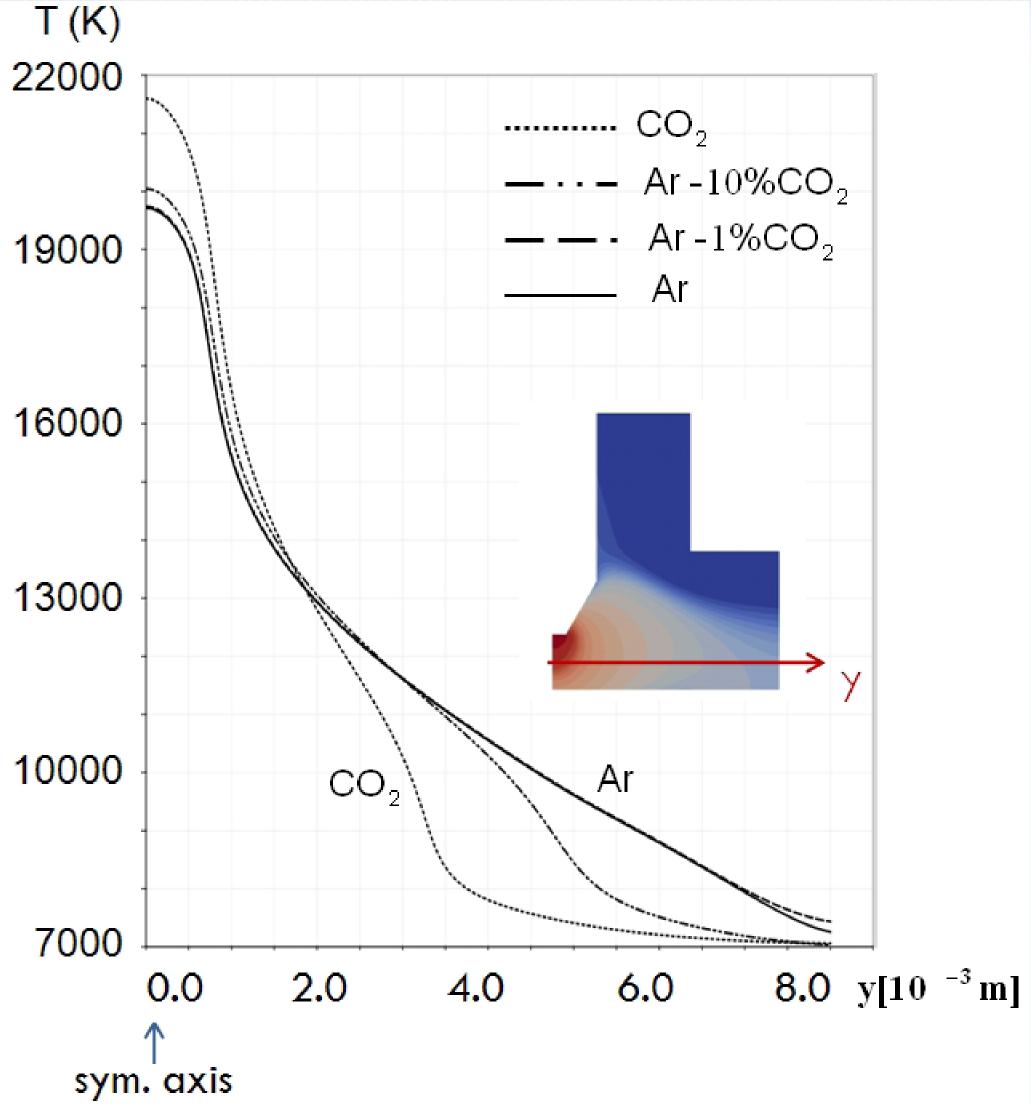
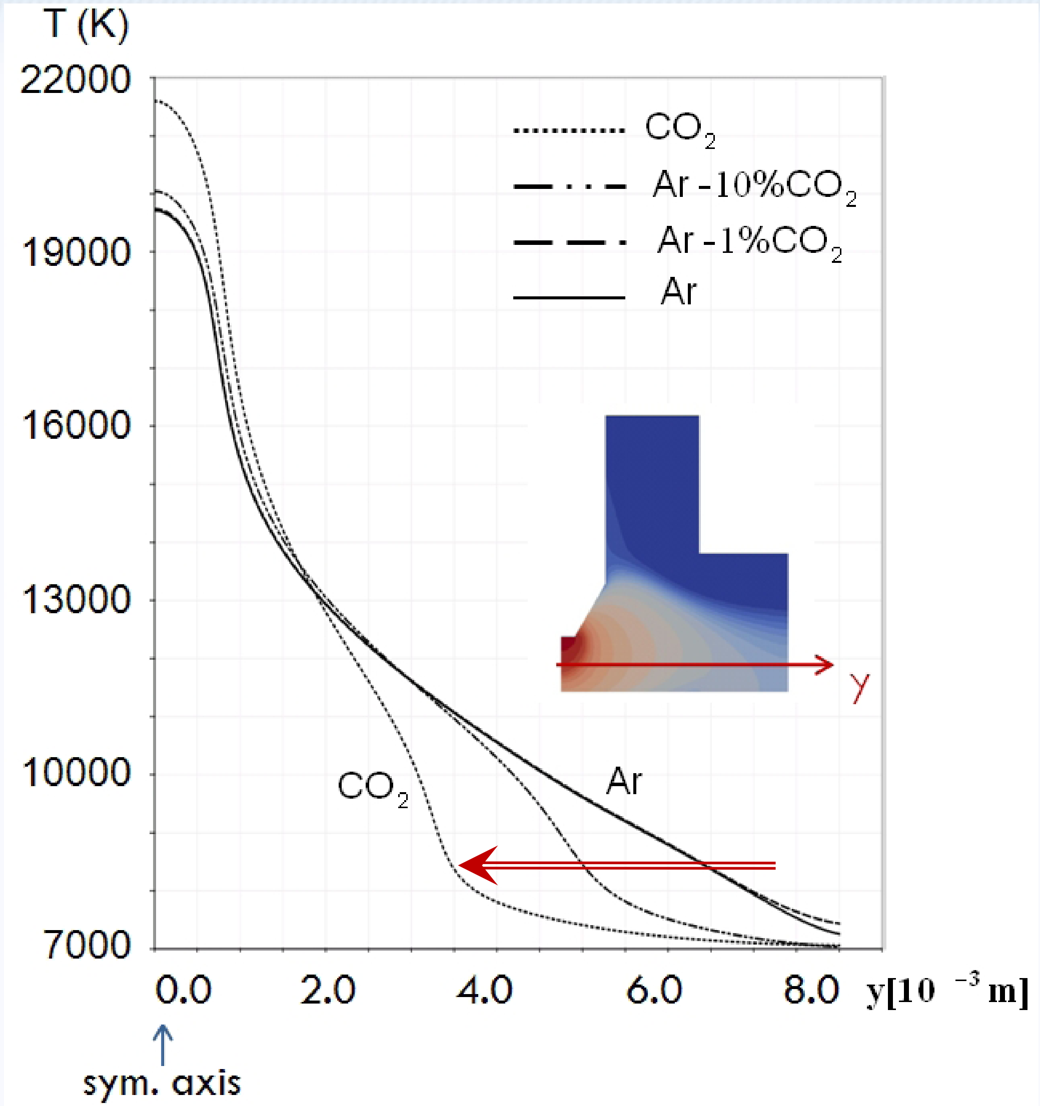


Temperature along the radial direction, 1 mm above the anode.



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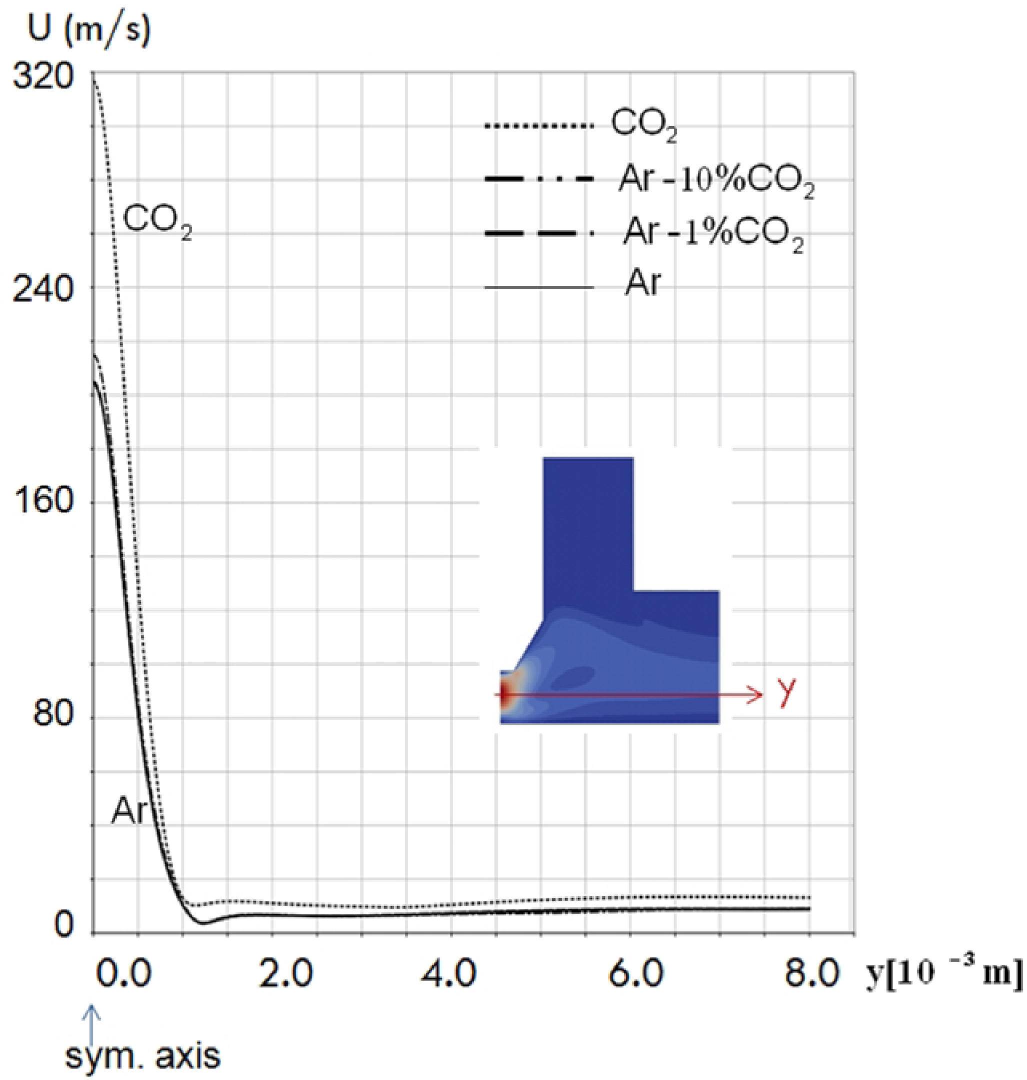
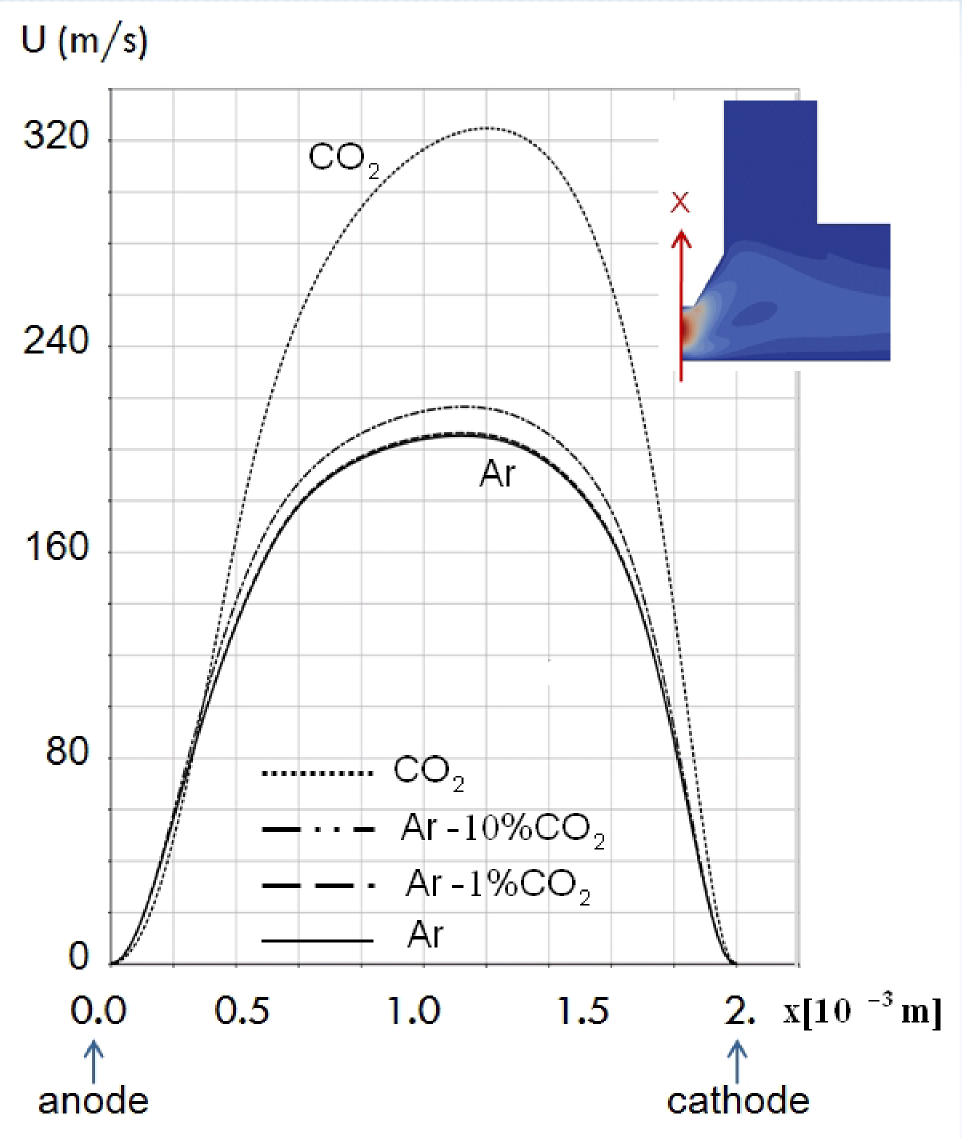
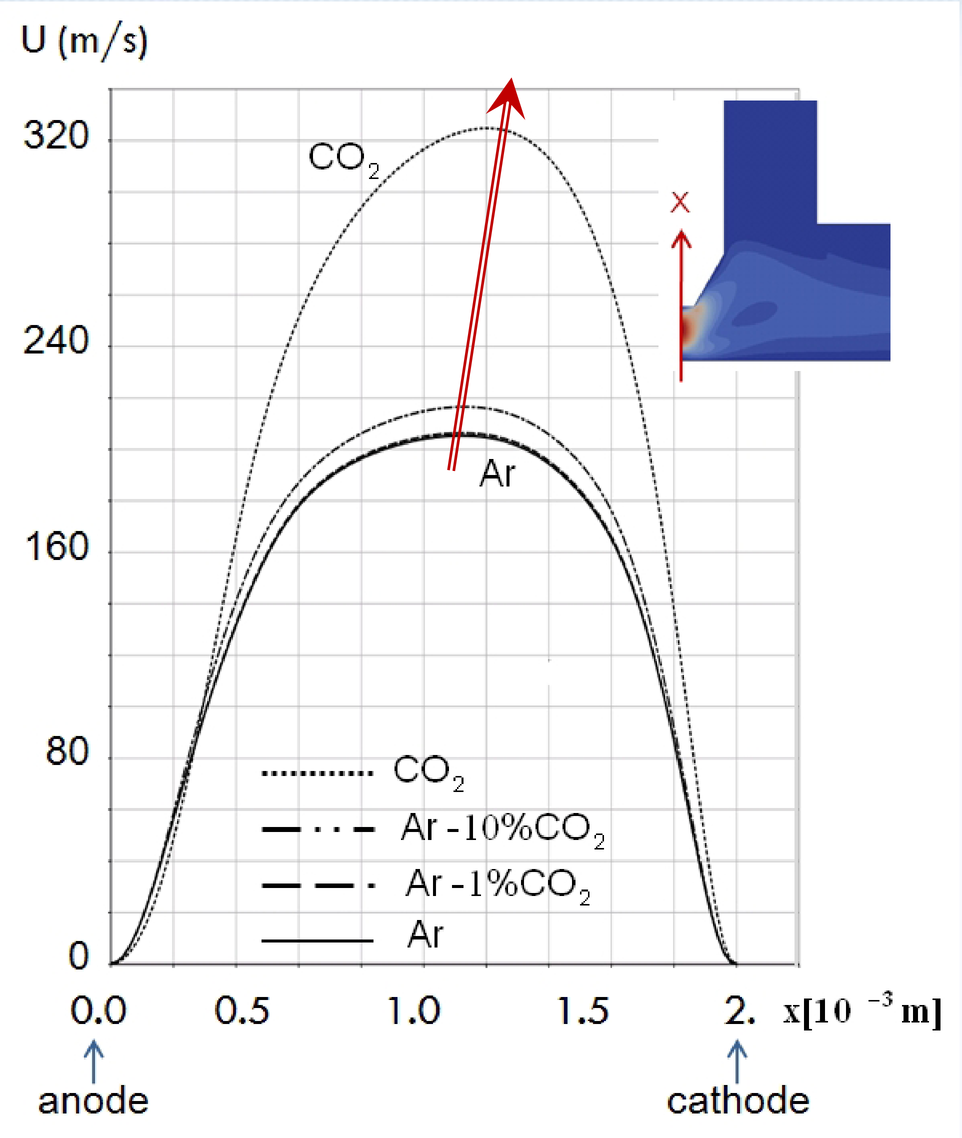


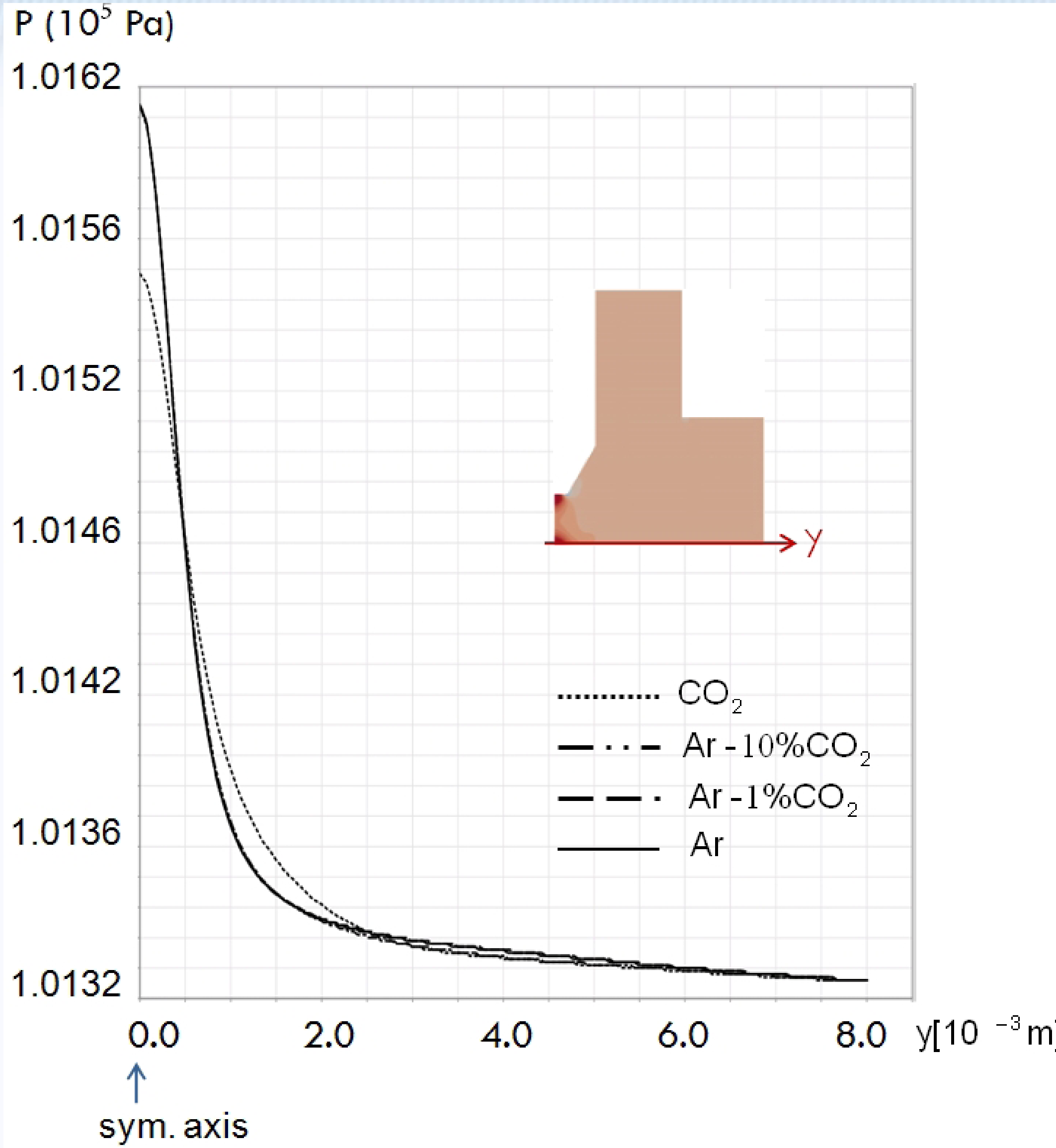
Velocity along the radial direction, 1 mm above the anode.



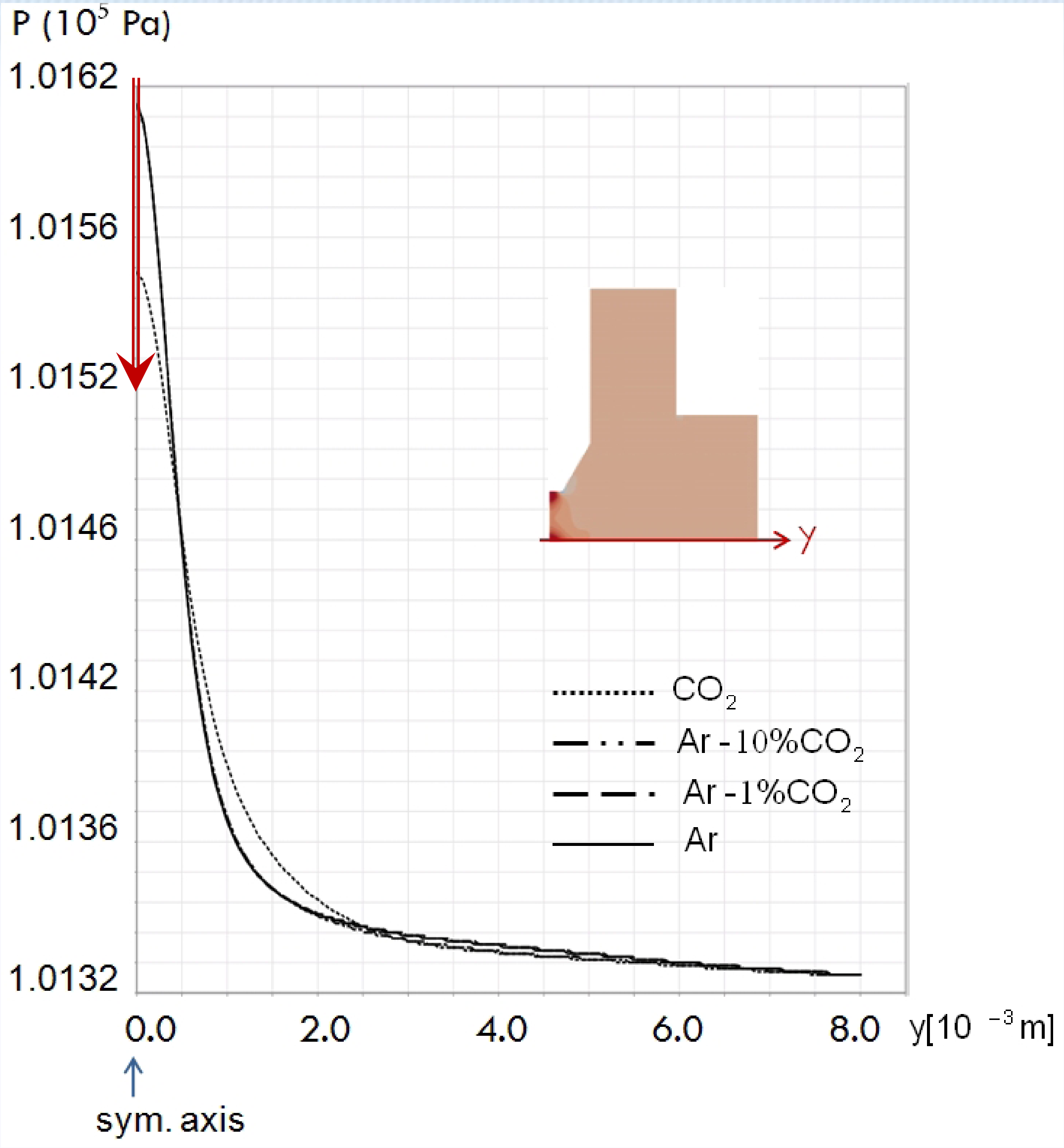
Velocity along the symmetry axis



Velocity along the symmetry axis



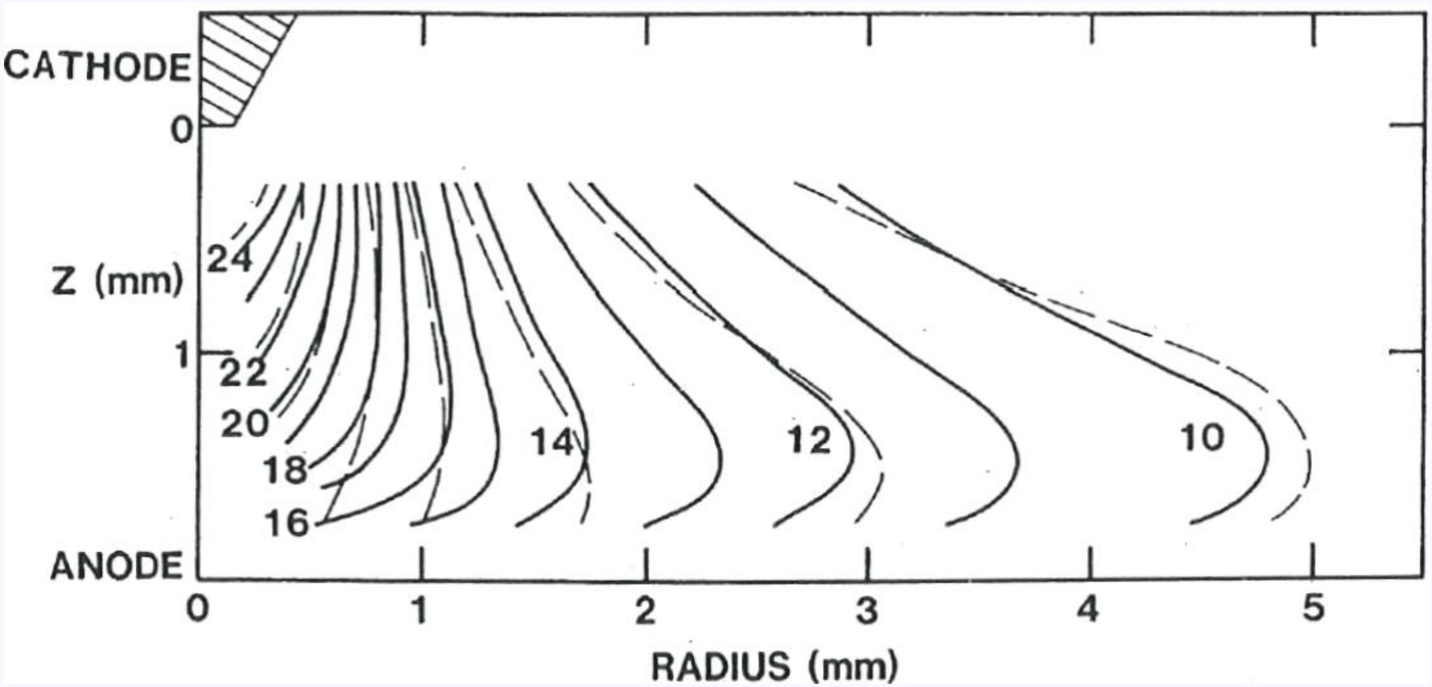
Pressure on the base metal, along the radial direction



Pressure on the base metal, along the radial direction

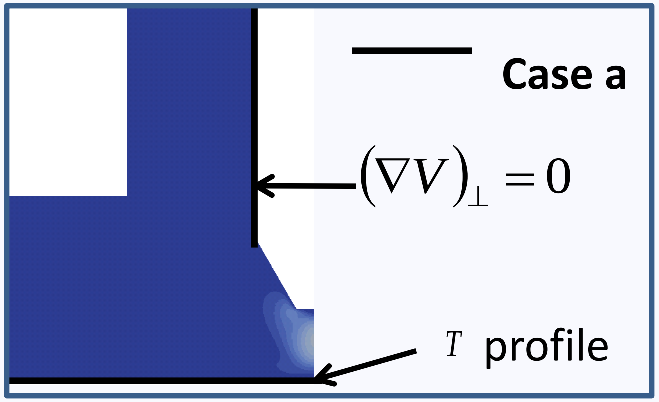
Contents

- Thermal fluid model (plasma core)
  - assumptions – governing equations
- Electromagnetic model (plasma core)
  - assumptions – governing equations
- Magnetic field model : 3D or axi-symmetric ?
  - infinite rod test case
  - water cooled MIG welding test case
- Water cooled MIG welding test case
  - comparison with experimental data
  - influence of shielding gas composition
  - influence of boundary conditions on anode and cathode
- Conclusions

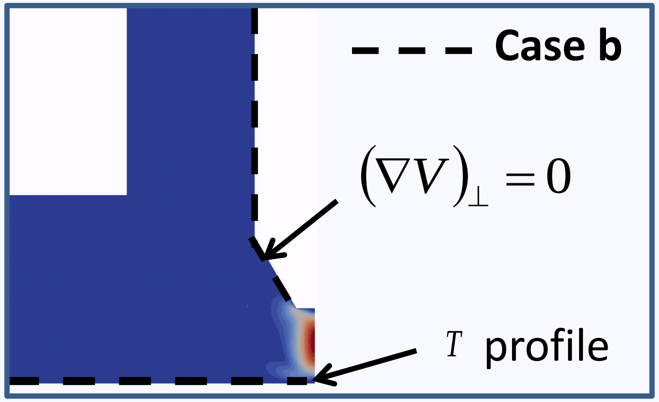


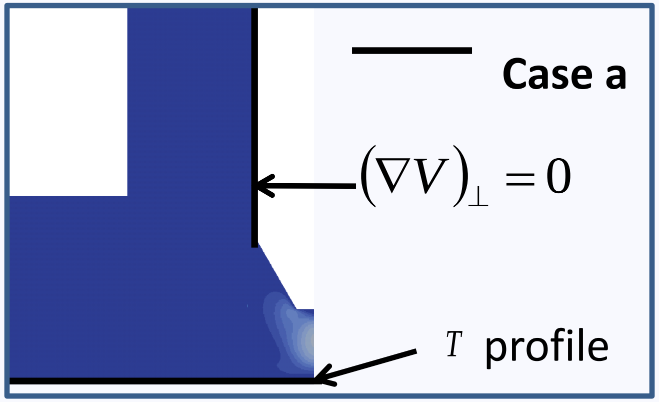
Measured temperature profile for a current intensity 200 A and 2 mm long arc.

Figure from: *G.N. Haddad and A.J.D. Farmer (1985). Temperature measurements in gas tungsten arcs, Welding J,* ***64****, pp. 339-342.*

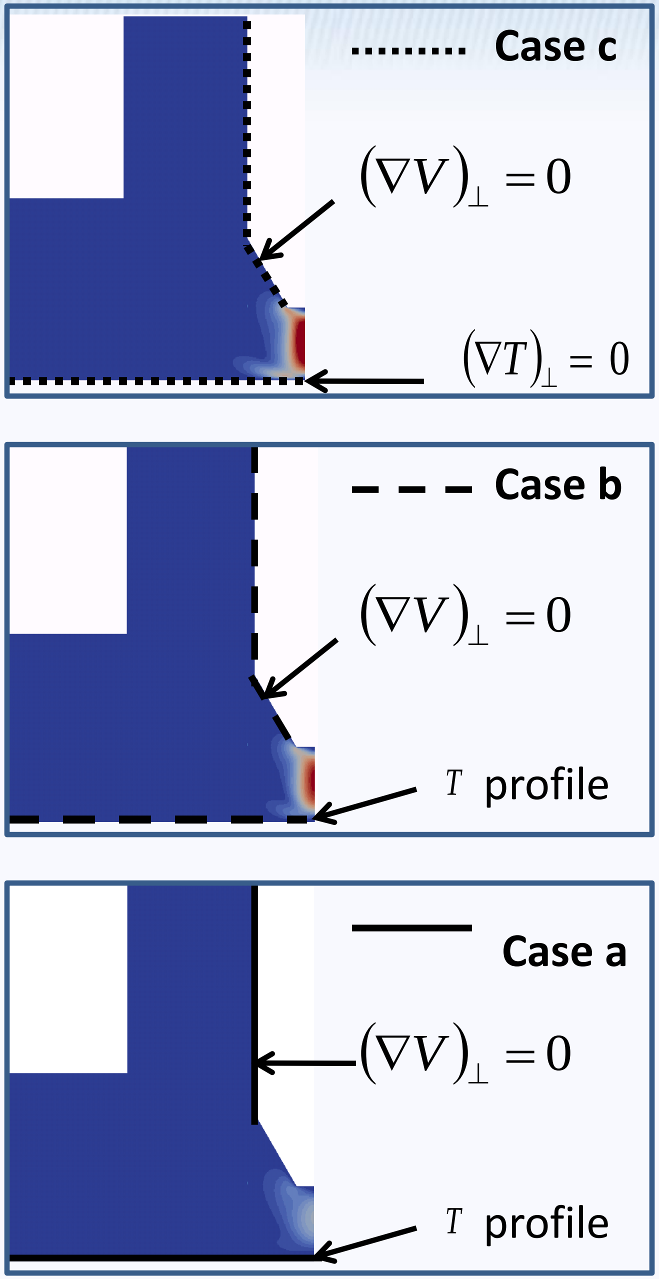


Influence of the anode and cathode boundary conditions

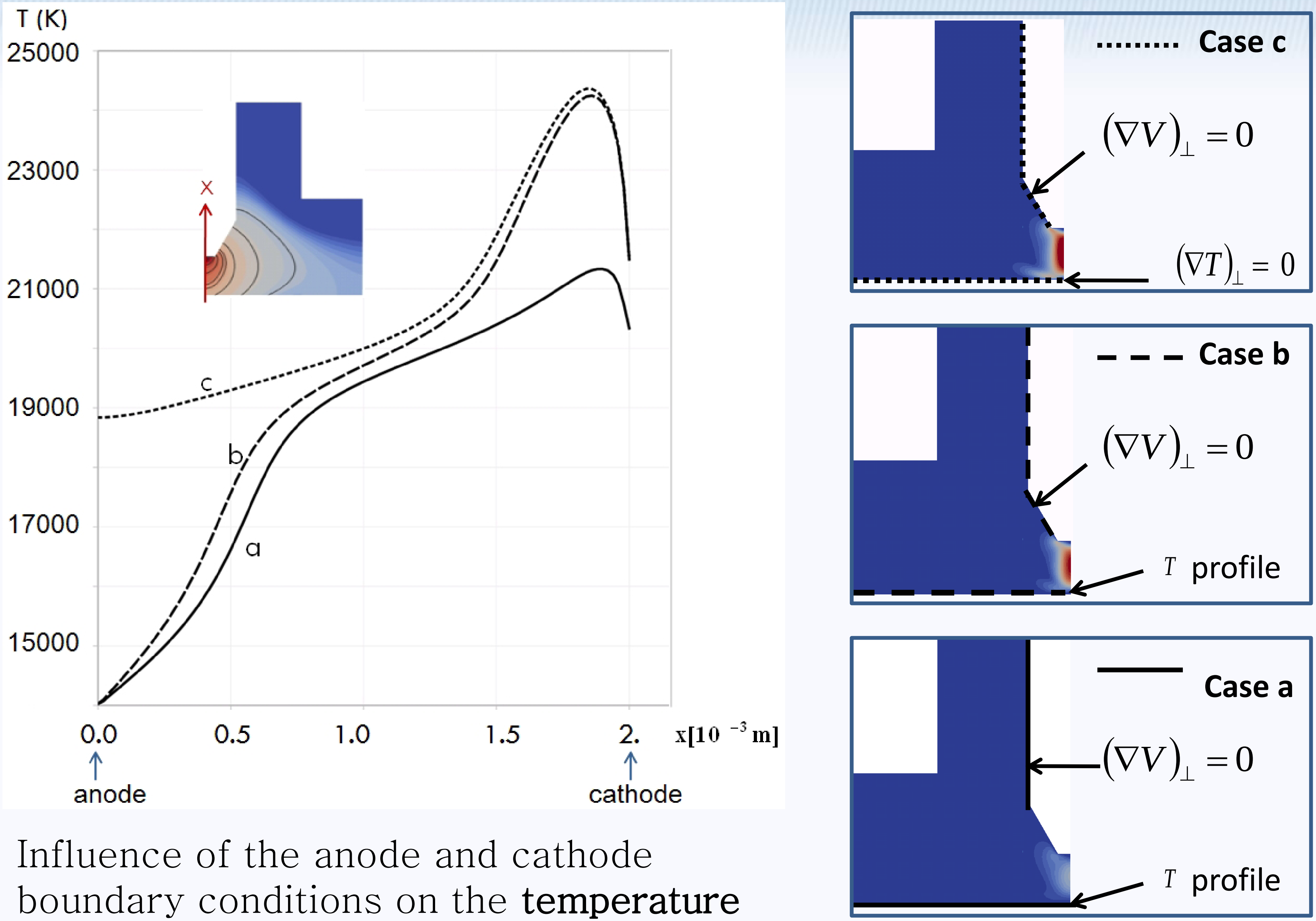




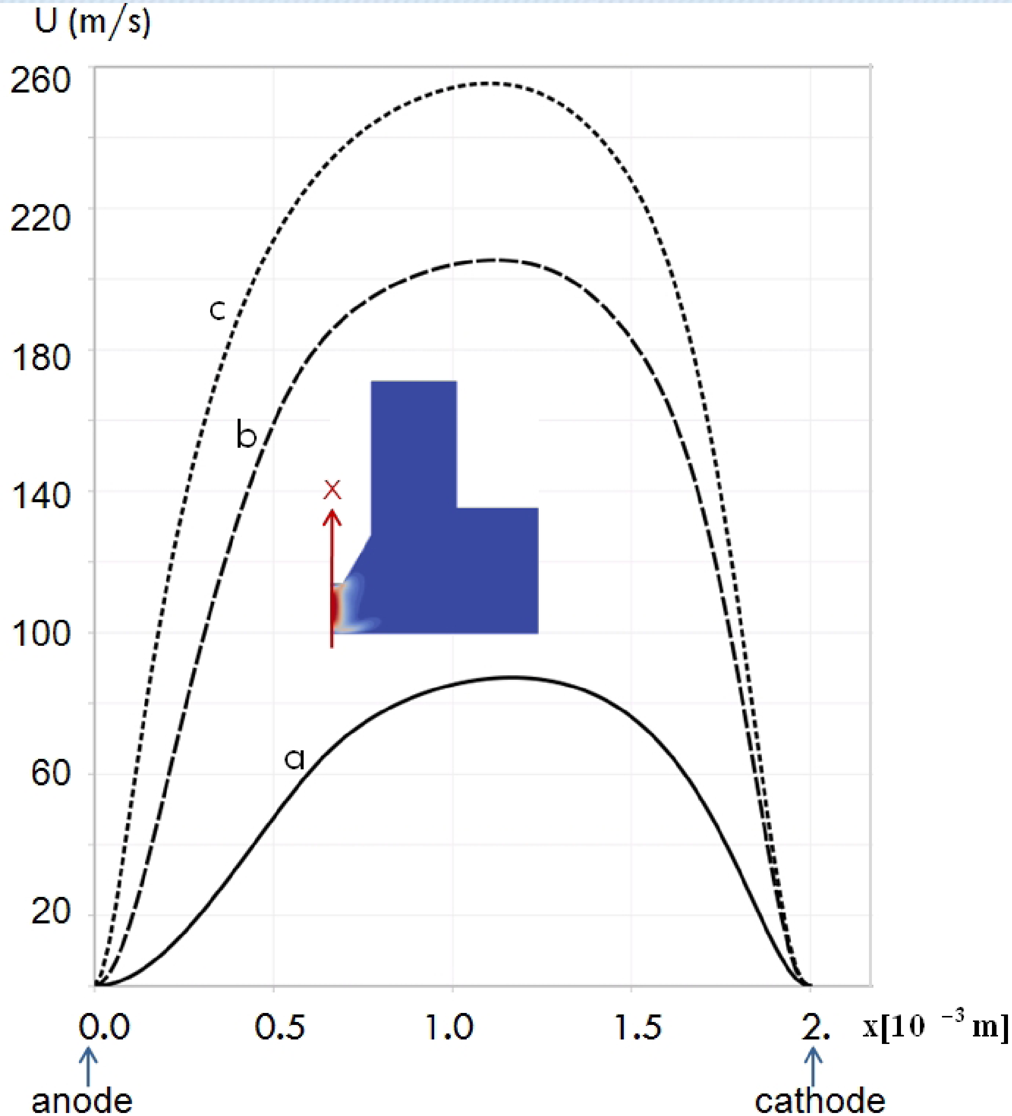
Influence of the anode and cathode boundary conditions

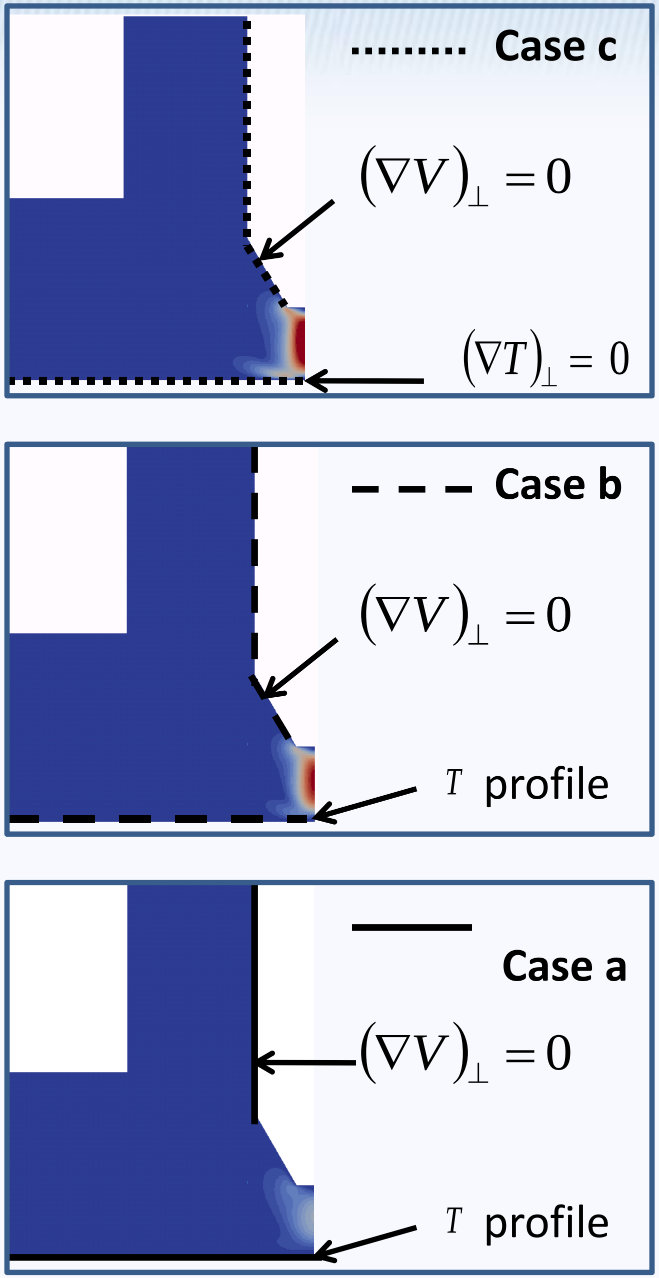


Influence of the anode and cathode boundary conditions

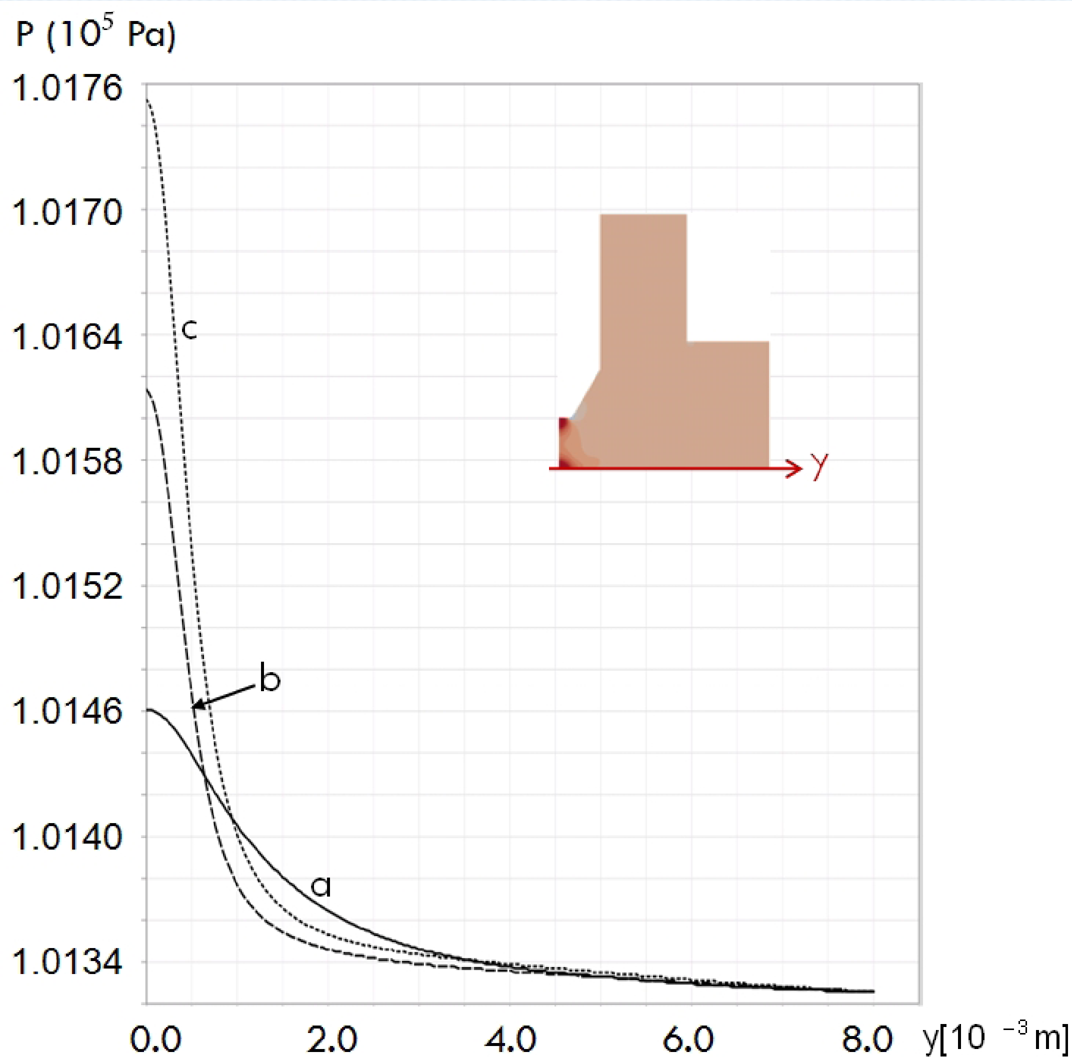


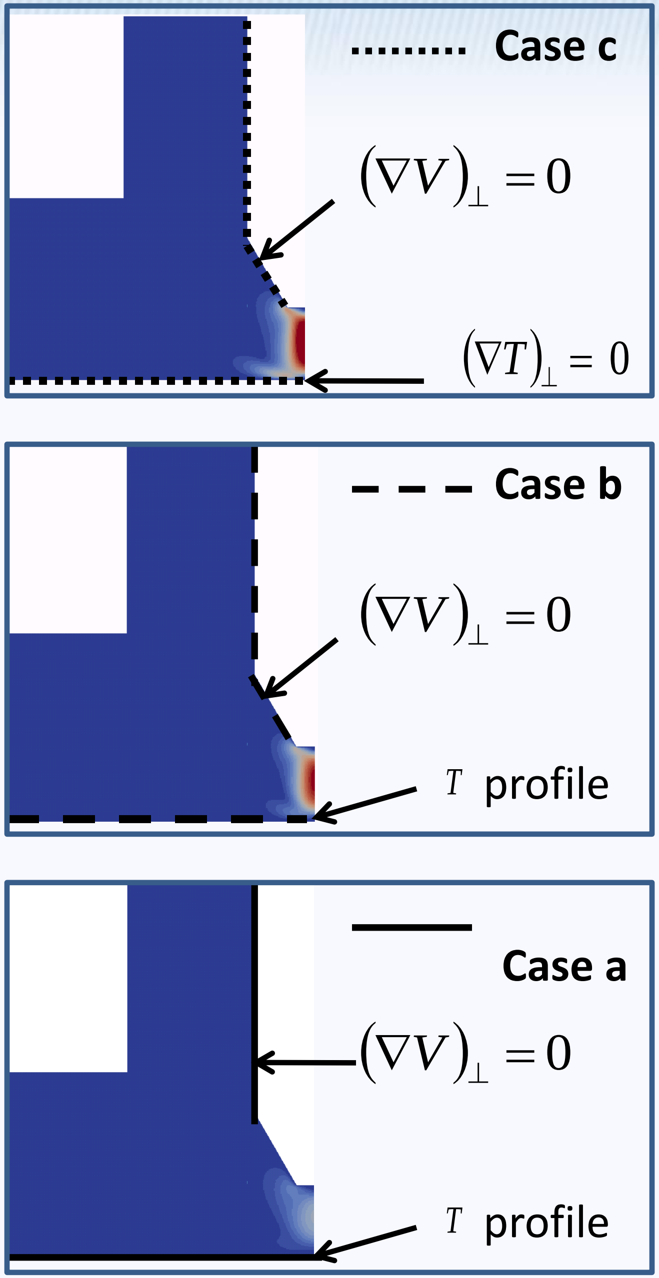
Influence of the anode and cathode boundary conditions on the **temperature** along the symmetry axis





Influence of the anode and cathode boundary conditions on the **velocity** along the symmetry axis





Influence of the anode and cathode boundary conditions on the **pressure** on the base metal

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- 3D thermal magneto-hydrodynamic model (plasma core)

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- Magnetic field model : 3D or axi-symmetric ?

  short arc derived from

- Water cooled MIG welding test case

  comparison with experimental data

  influence of shielding gas composition

  influence of boundary conditions on anode and cathode

  boundary conditions on anode and cathode

- Next step

  extend the model to electrode and base metal

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- Acknowledgements

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