Exploring the Physics of the Electric Arc Furnaces

Mohamad Al-Nasser[a], Abdellah Kharicha[a], Hadi Barati [a], Mehran Abdi [a], Menghuai Wu [b], Andreas Ludwig [b], Christian Redl [c], Harald Holzgruber [c], Anton Ishmurzin [d], Christoph Pichler [d], Gernot Hackl [d], Markus Gruber [d], Yong Tang [d]

a) Christian Doppler Laboratory for Metallurgical Applications of Magnetohydrodynamics

b) Chair for Modeling and Simulation of Metallurgical Processes, Department of Metallurgy, Montanuniversität,

c) INTECO melting and casting technologies GmbH,

d) RHI Magnesita, Department of Modelling and Simulation

Mohamad.al-nasser@unileoben.ac.at

Outline

- Introduction of EAF Model
- Single phase electric arc
- Arc impingement 3-phase flow
- Closing remarks

Outline

- Introduction of EAF Model
- Single phase electric arc
- Arc impingement 3-phase flow
- Closing remarks

Introduction of EAF Model

- The model presented aims to model the processes occurring inside electric arc furnace
- This model is capable of solving the flow, turbulence, thermal and electromagnetic field in **coupled** fashion.
- As the first step the model aims to optimize **DC-EAF** through 2D axisymmetric simulations
- The electromagnetic field is solved in the domain using the induction method
- The model accounts for **multiphase-flow** simulation and the interaction between air (plasma), slag and liquid metal

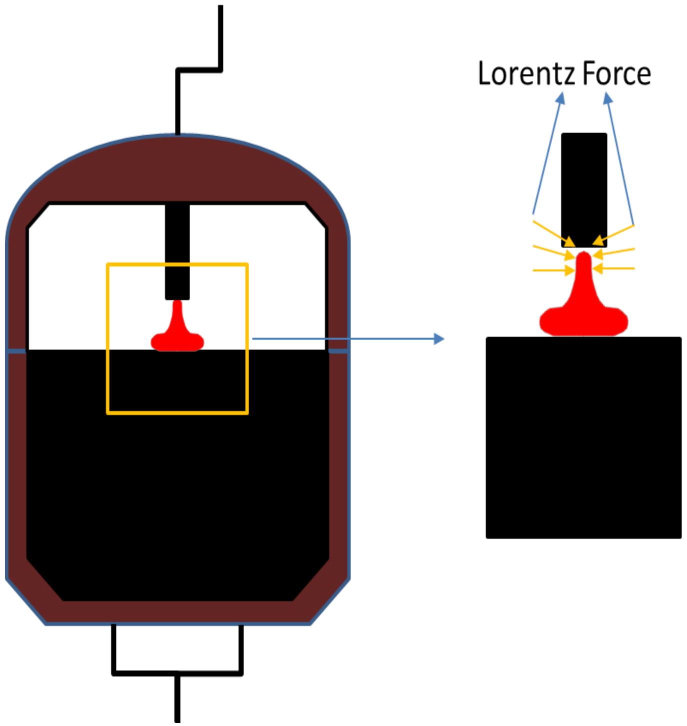


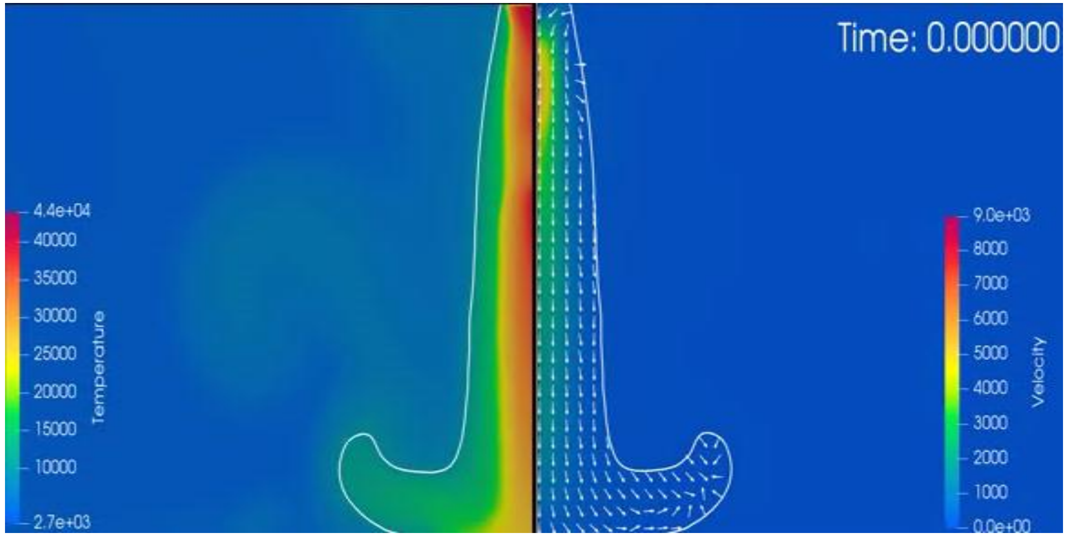
Figure 1: Simplified DC EAF schematic

Outline

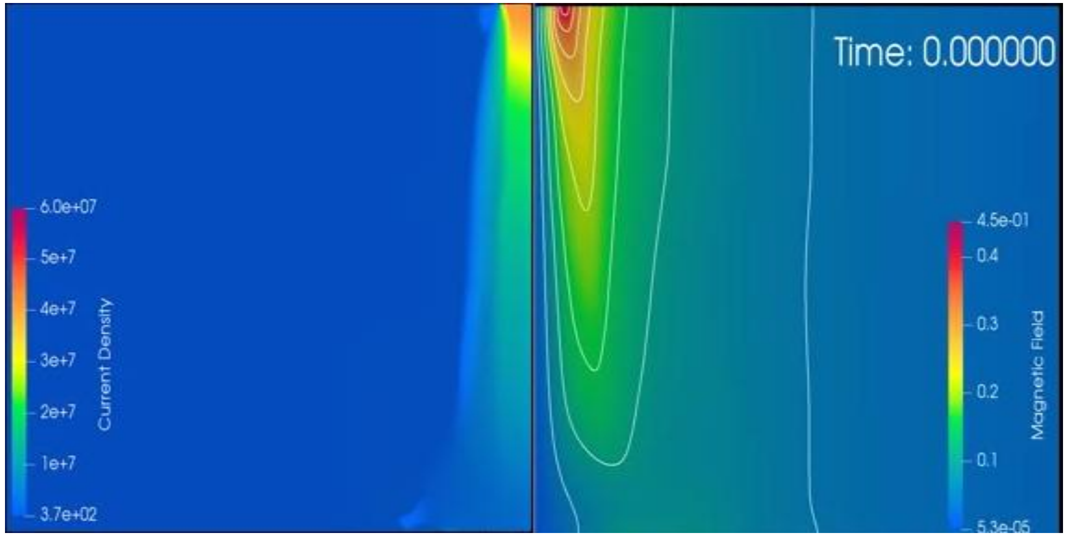
- Introduction of EAF Model
- Single phase electric arc
- Arc impingement 3-phase flow
- Closing remarks

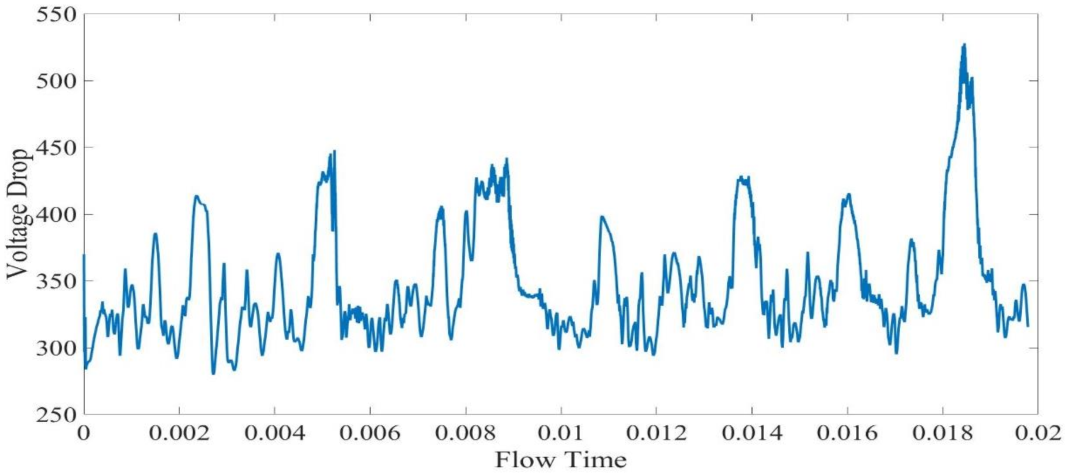
Incompressible model (single phase simulation)

Temperature Velocity

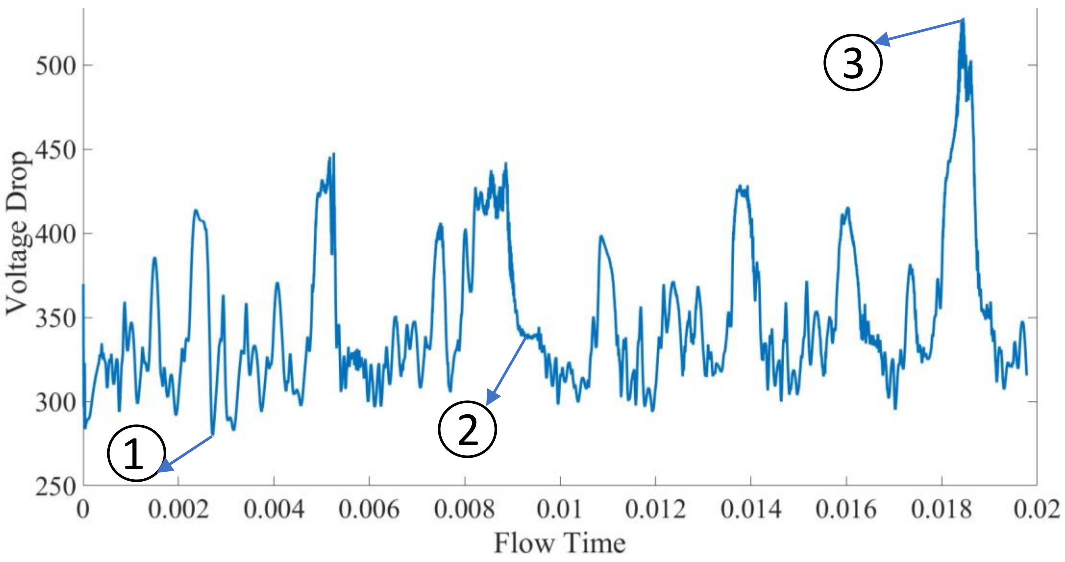


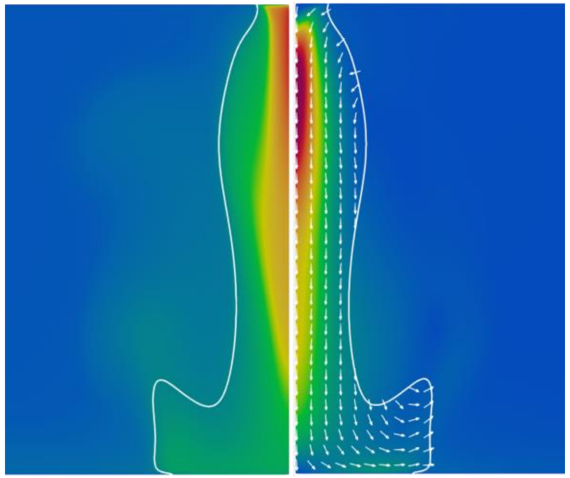
Current Magnetic field



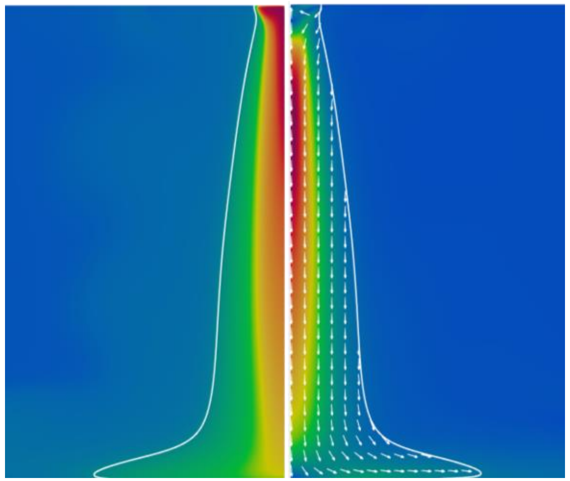


$$\Delta\phi = \frac{1}{I_0}\sum \frac{{J_z}^2 + {J_r}^2}{\sigma}\Delta V$$

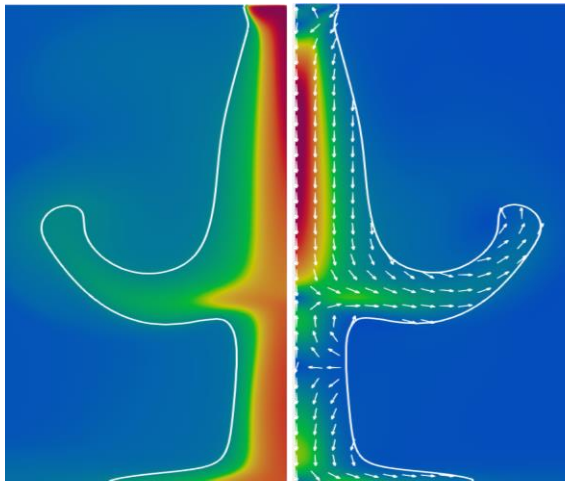




①

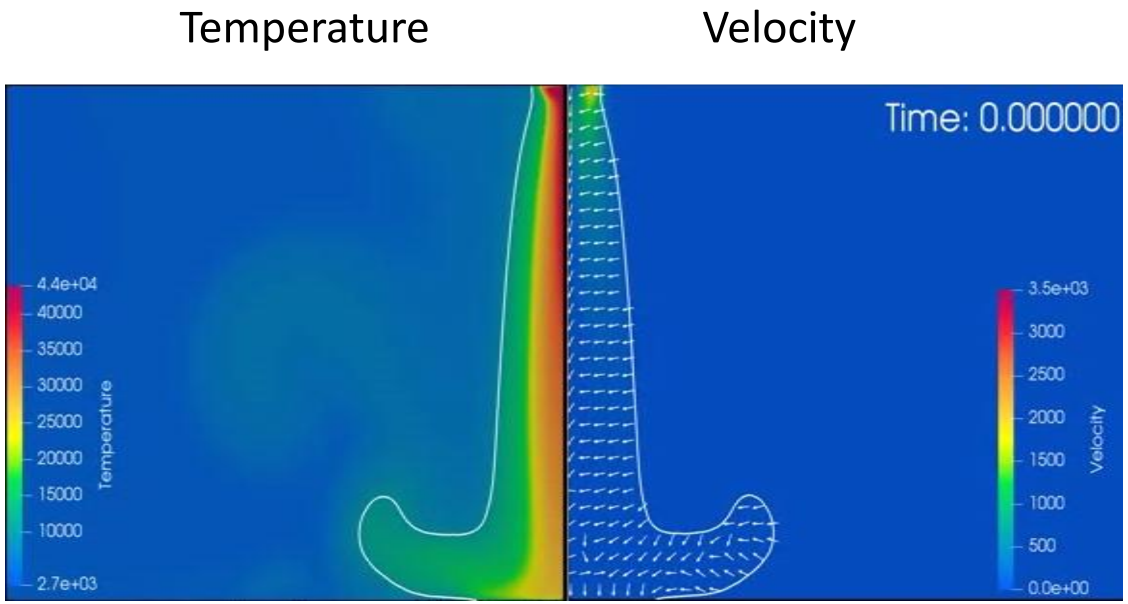


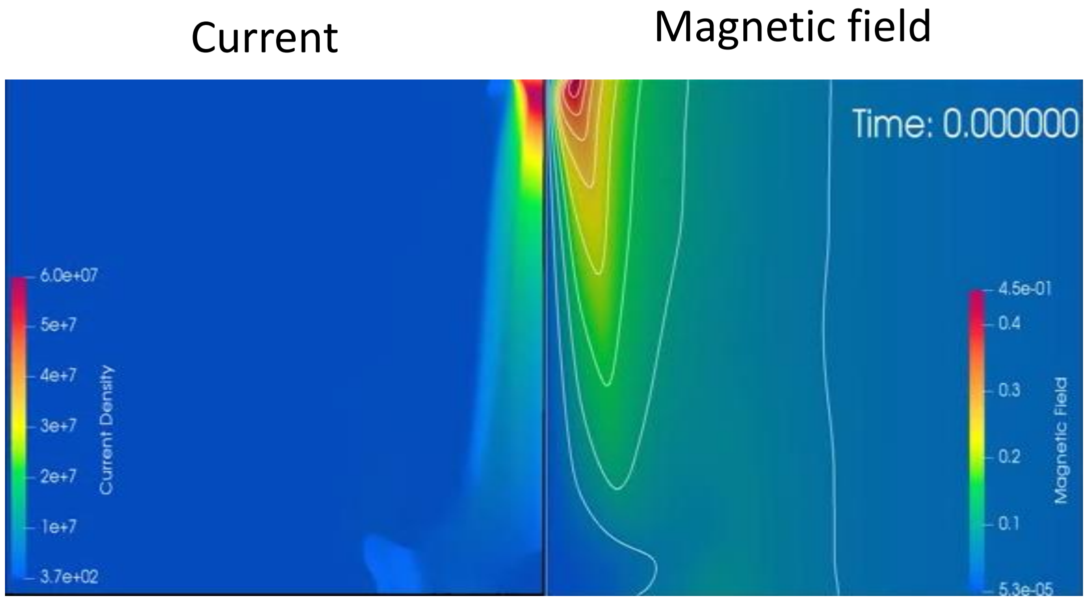
②



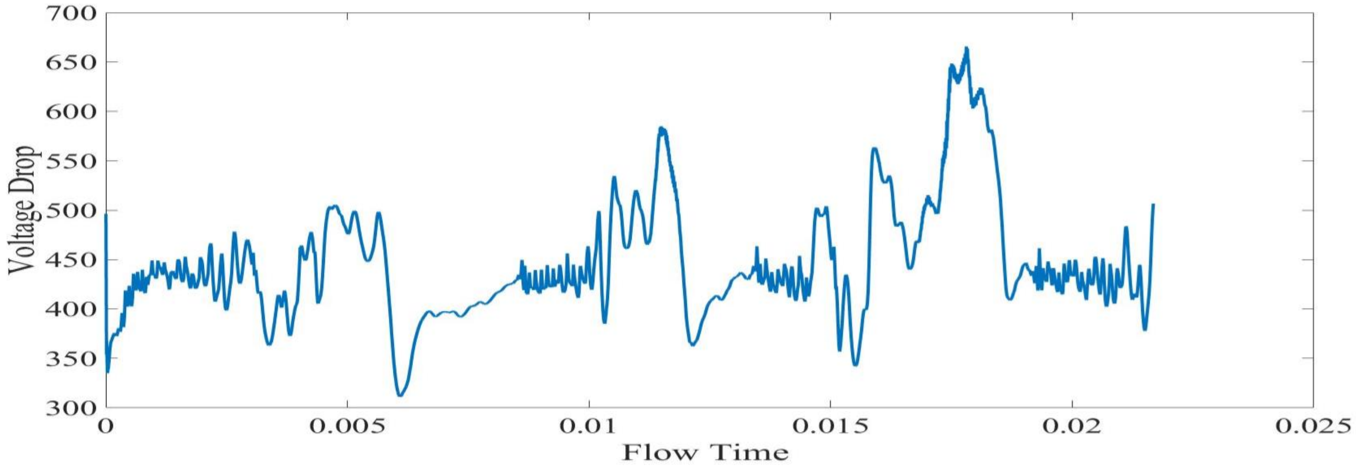
③

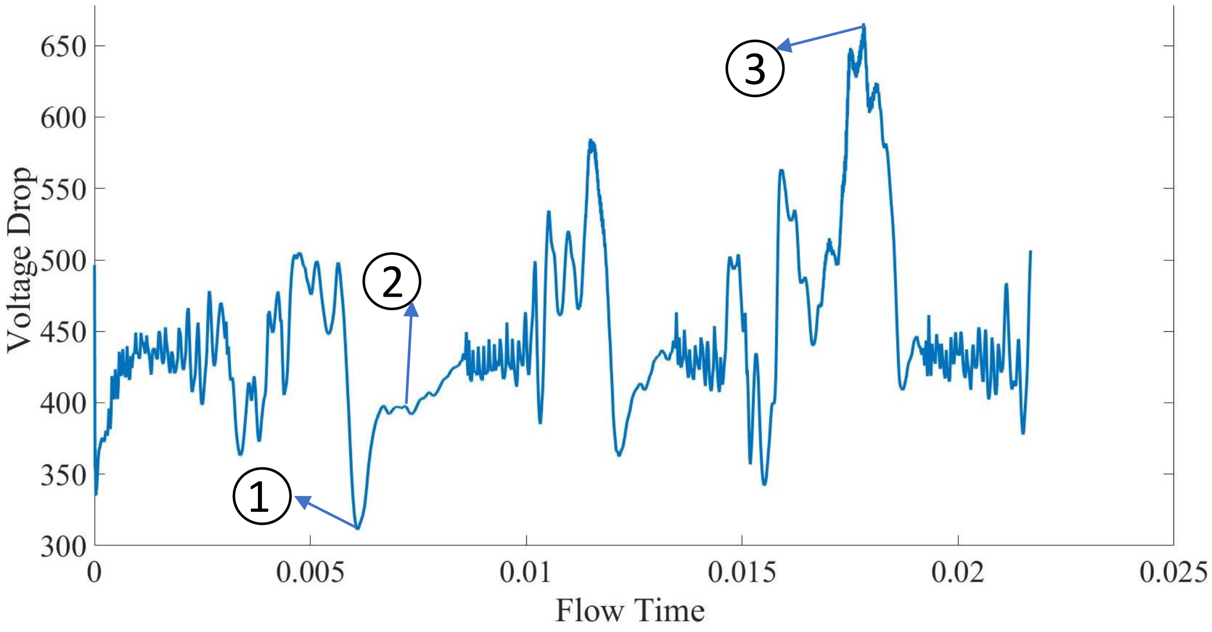
Compressible: Ideal Gas Model (single phase simulation)

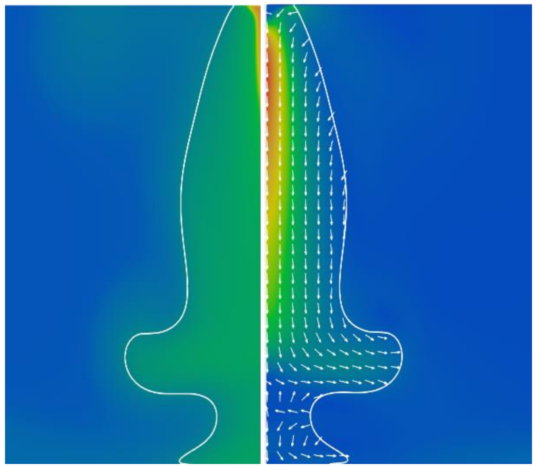




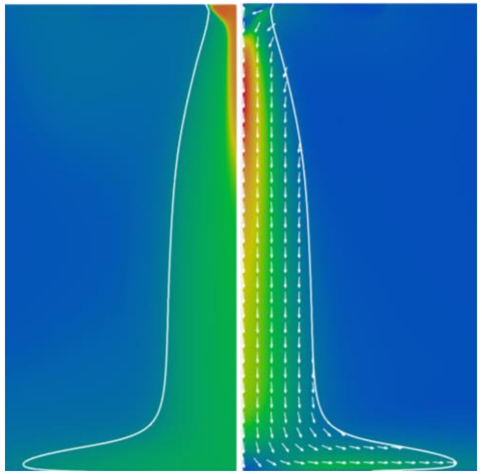
$$\Delta\phi = \frac{1}{I_0}\sum\frac{{J_z}^2 + {J_r}^2}{\sigma}\Delta V$$



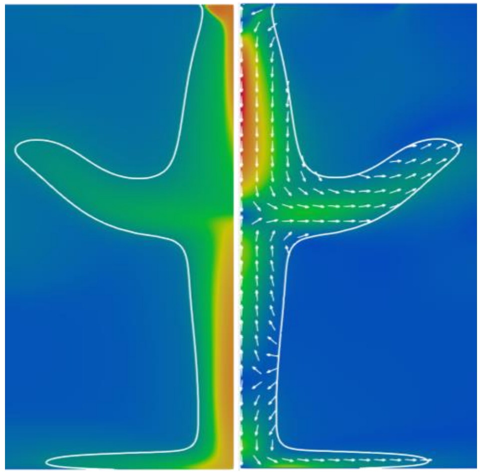

650
600
550
500
450
400
350
300
Voltage Drop
0
0.005
0.01
0.015
0.02
0.025
Flow Time
1
2
3



1



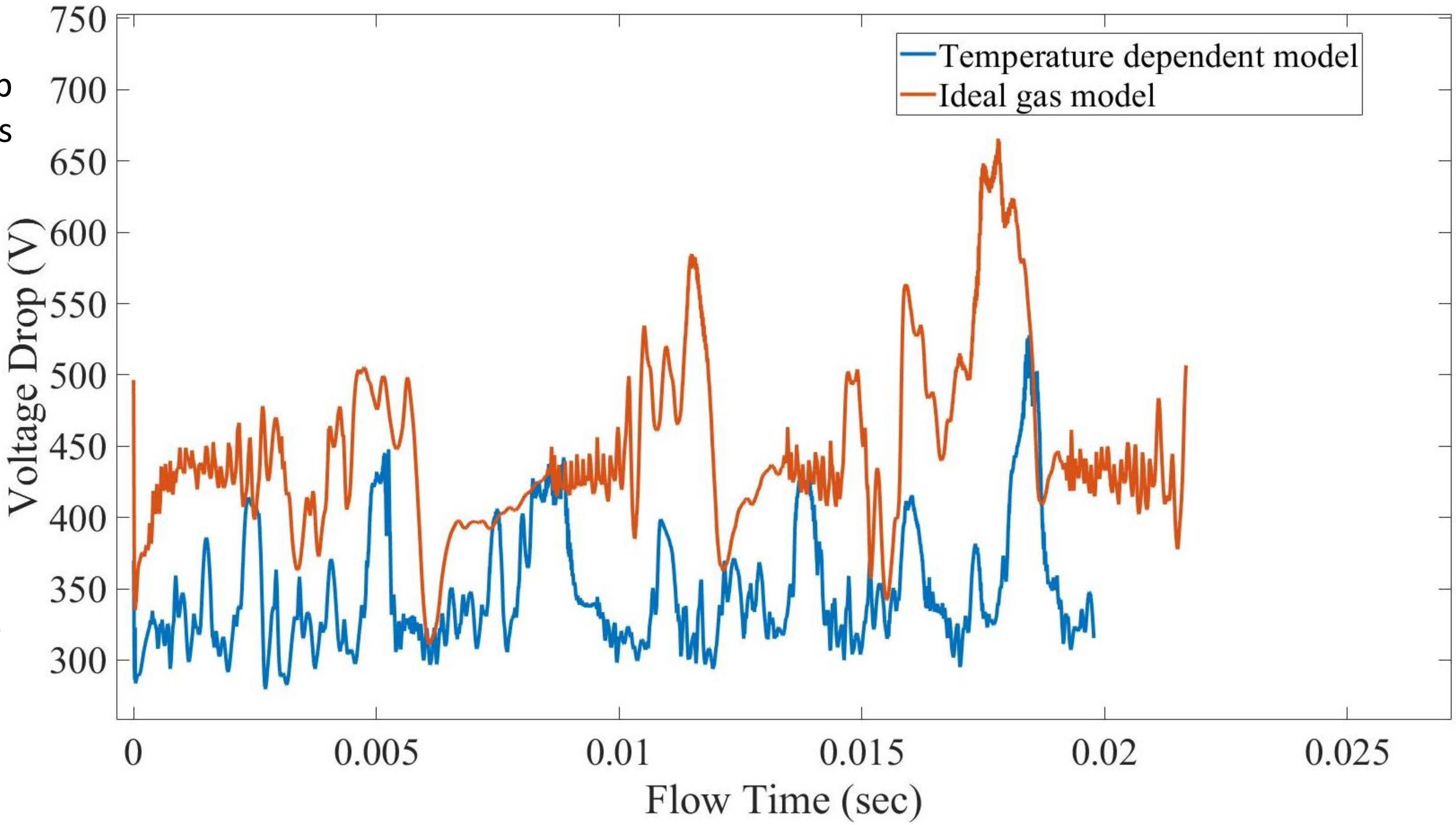
2



3

Comparison between Voltage Drop between compressible and incompressible flow

- The average voltage drop of incompressible flow is 320 V
- Compressible flow have a voltage drop of 430 V
- Difference is 110 V significant
- The compressible flow seems to have repetitive voltage drop pattern



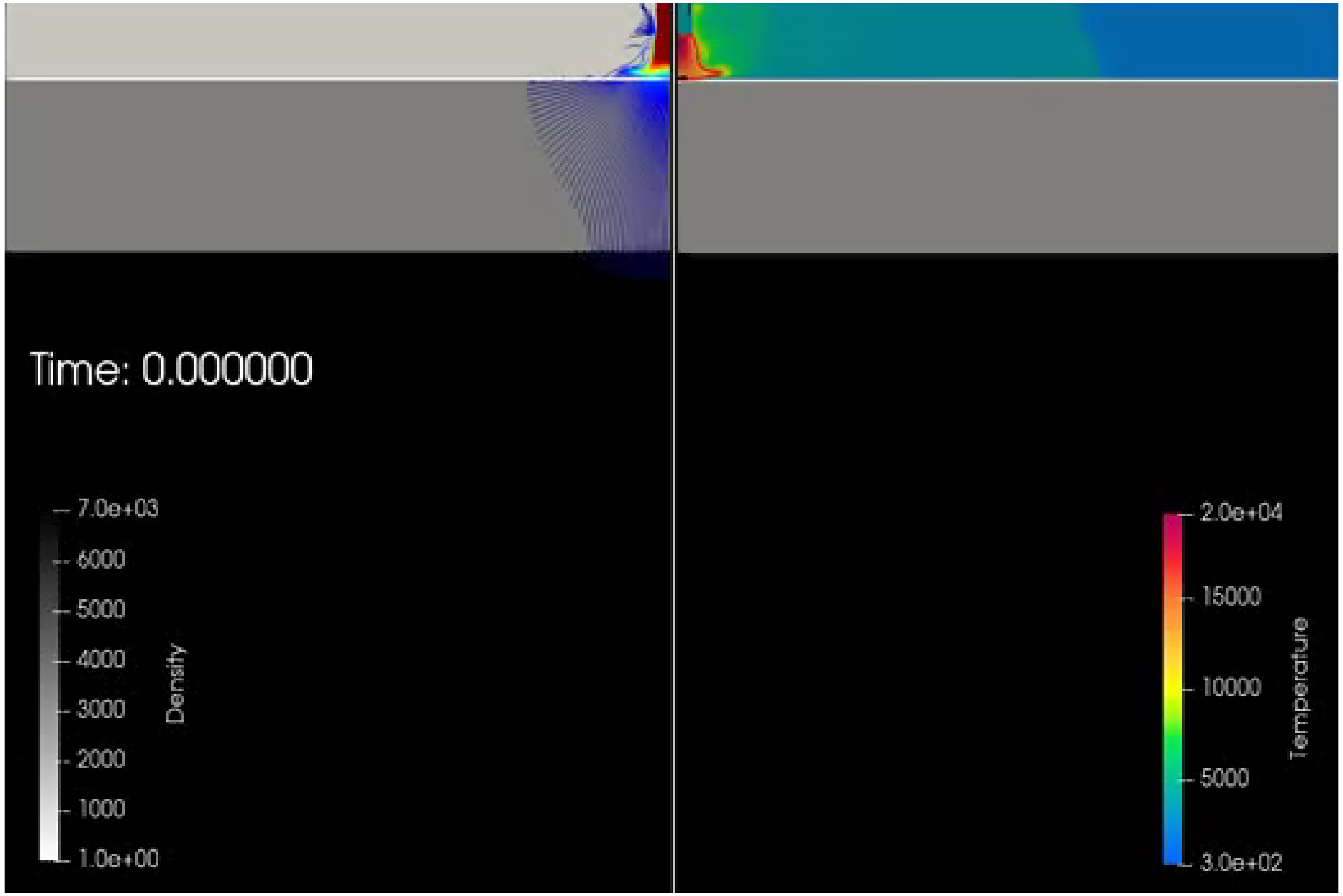
Outline

- Introduction of EAF Model
- Single phase electric arc
- Arc impingement 3-phase flow
- Closing remarks

10 kAmp Arc Impingement

I = 10 K amps

Arc Gap = 0.05 m



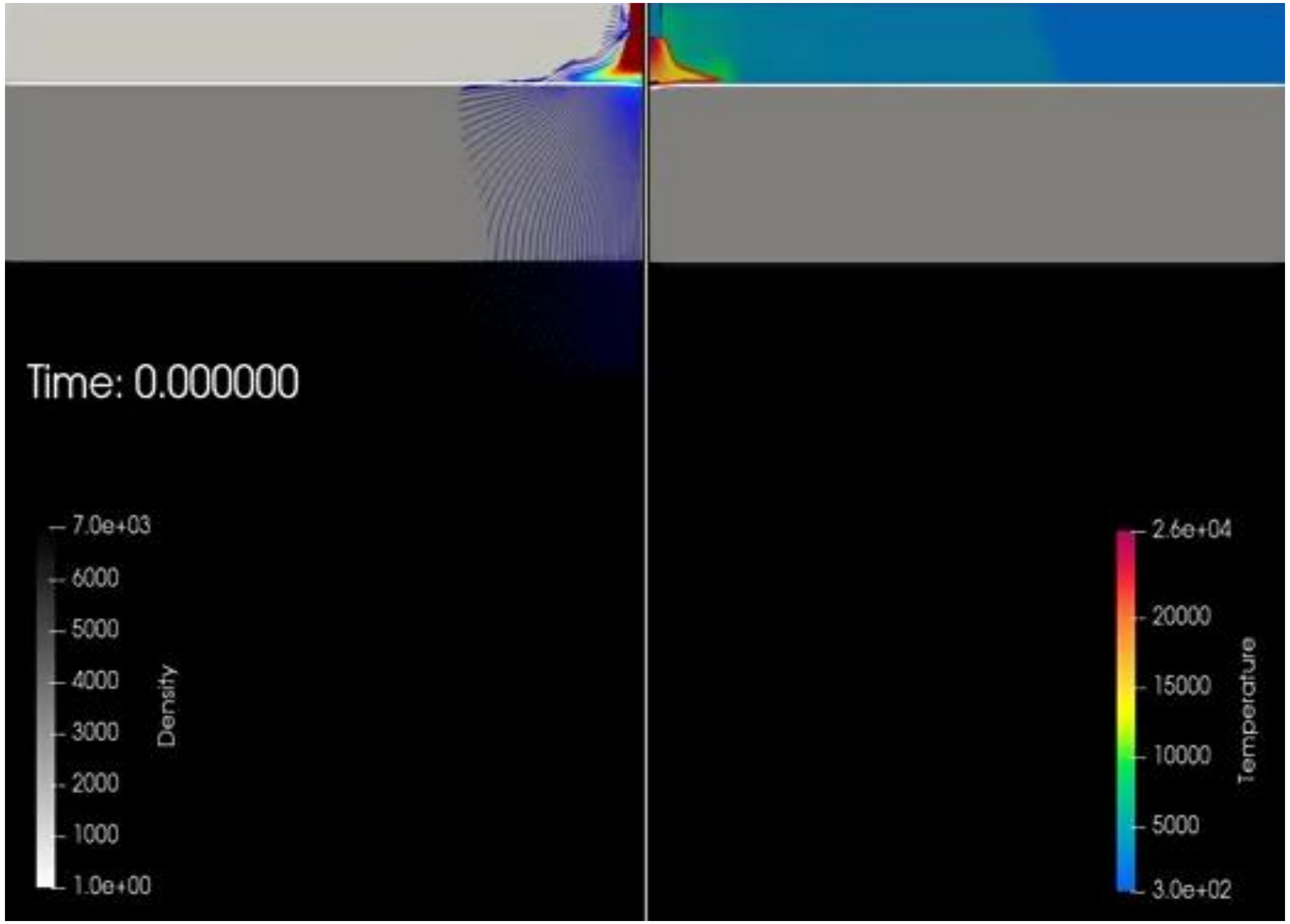
Arc Path

Temperature

20 kAmp Arc Impingement

I = 20 K amps

Arc Gap = 0.05 m



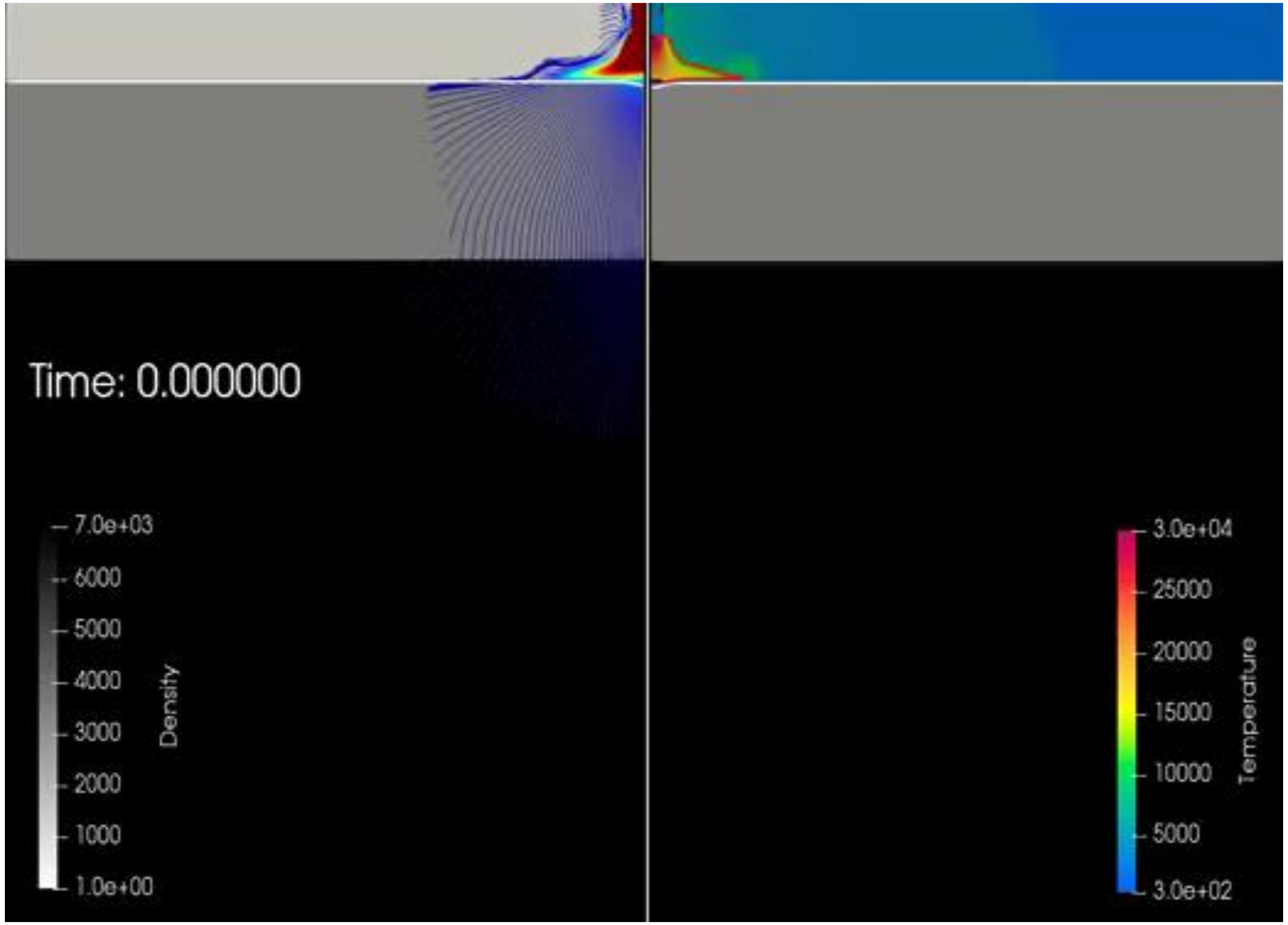
Arc Path

Temperature

30 kAmp Arc Impingement

I = 30 K amps

Arc Gap = 0.05 m



Arc Path Temperature

Outline

- Introduction of EAF Model
- Single phase electric arc
- Arc impingement 3-phase flow
- Closing remarks

Closing remark

Arc simulation

- Aerodynamic instabilities increases voltage drop significantly
- Accounting for compressibility damps the flow from 10 000 m/sec to 3 500 m/sec
- Compressibility upturns voltage drop along the arc from average of 320 volt to 430 volt

Arc impingement:

- Slag layer protects the liquid metal from getting direct exposure to high arc temperatures and being exposed to air directly
- 20 kA increases the mixing of slag and metal significantly
- Arc impingement depth exceeds 0.7 m for 20 kA and 30 kA

Appendix

Mathematical model

- In order to solve the flow, thermal and electromagnetic field these equations are solved :

  - Flow equations:

$$\frac{\partial \rho}{\partial t} + \nabla \rho.\mathbf{u} = 0$$

$$\frac{d\rho\mathbf{u}}{dt} = -\nabla p + \nabla.(\mu\nabla\mathbf{u}) + \frac{1}{\mu_0}(\mathbf{J}\times\mathbf{B}) + \rho g$$

  - Energy equation:

$$\frac{\partial}{\partial t}(\rho c_p T) + \nabla.(\rho c_p \mathbf{u} T) = \nabla.(k\nabla T) + J_{heat} + Q_{rad\ loss} \qquad (J_{Heat} = \frac{J^2}{\sigma})$$

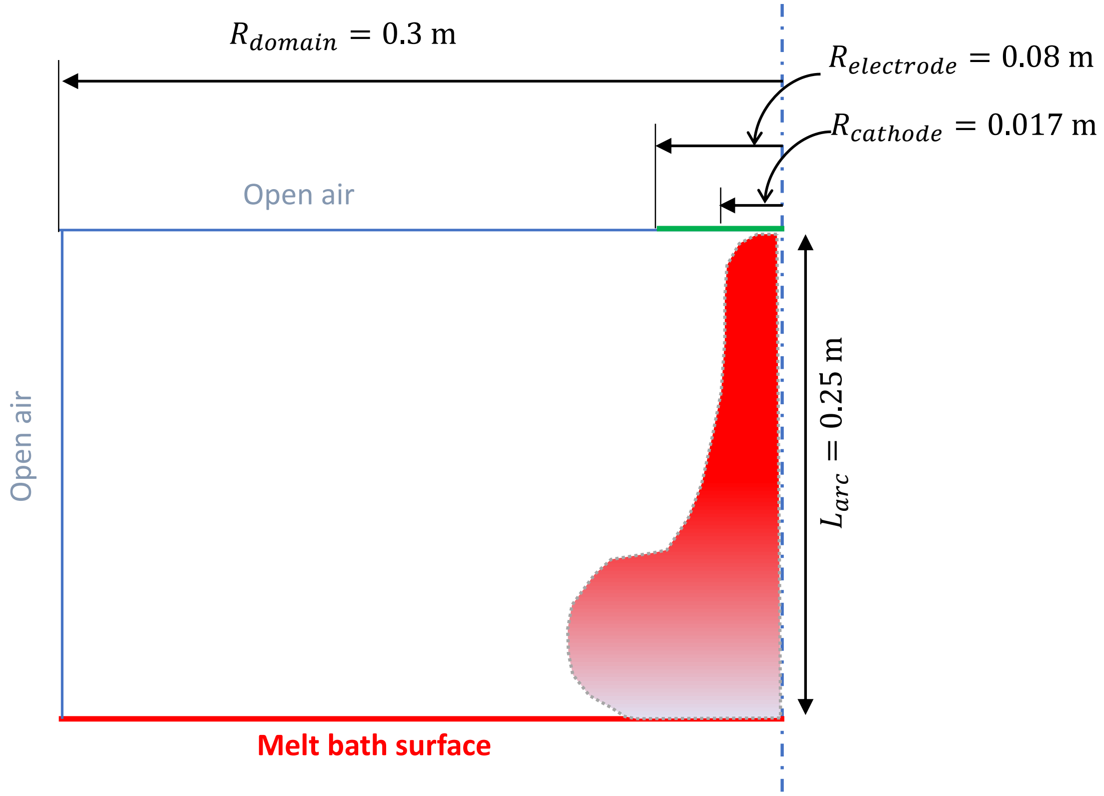
  - Induction Equation:

$$\frac{\partial B_\theta}{\partial t} + \nabla\cdot(\mathbf{u}B_\theta) = \nabla(\frac{1}{\sigma\mu_0}\nabla B_\theta) + \frac{\partial}{\partial r}(\frac{1}{r\sigma\mu_0})B_\theta - (\partial_z(u_\theta b_z) + \partial_r(u_\theta b_r))$$

- ρ density
- μ_0 magnetic permeability
- g gravitational accelaration
- c_p specific heat
- k thermal conductivity
- J_{heat} joul heating
- $Q_{rad\ loss}$ radiation loss
- σ electrical conductivity

Boundary conditions single phase electric arc

- The geometry is modeled in 2D axisymmetric domain
- The arc gap is taken to be 25 cm
- And the electrode radius is set to 8 mm
- We assume that we have a constant current density at the cathode spot which gives 1.7 cm for 40 kAmp



Boundary conditions single phase electric arc

Boundary conditions

I_0= 40 kA

$$B_\theta = \frac{I_0 \mu_0 r}{2\pi {R_c}^2}$$

T= 4000 K
No-slip wall

$$B_\theta = \frac{I_0 \mu_0}{2\pi r}$$

$$\frac{\partial h}{\partial z} = 0$$

P = 1 atm

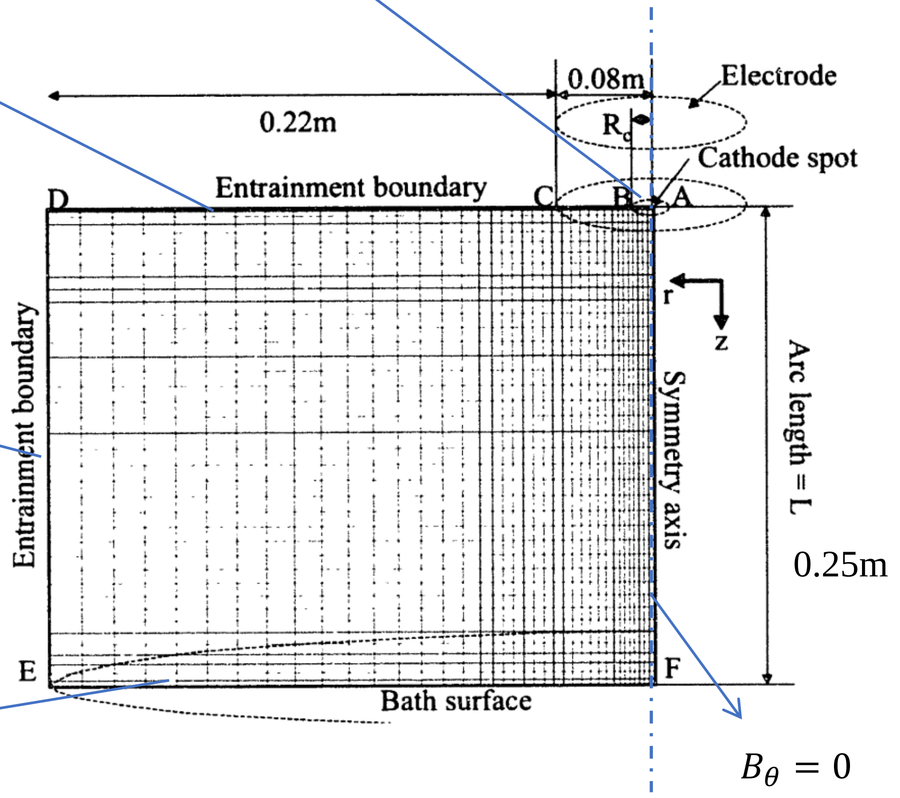
$$B_\theta = \frac{I_0 \mu_0}{2\pi r}$$

$$\frac{\partial h}{\partial r} = 0$$

P = 1 atm

$$\frac{\partial B_\theta}{\partial z} = 0$$

T= 1800 K
No-slip wall

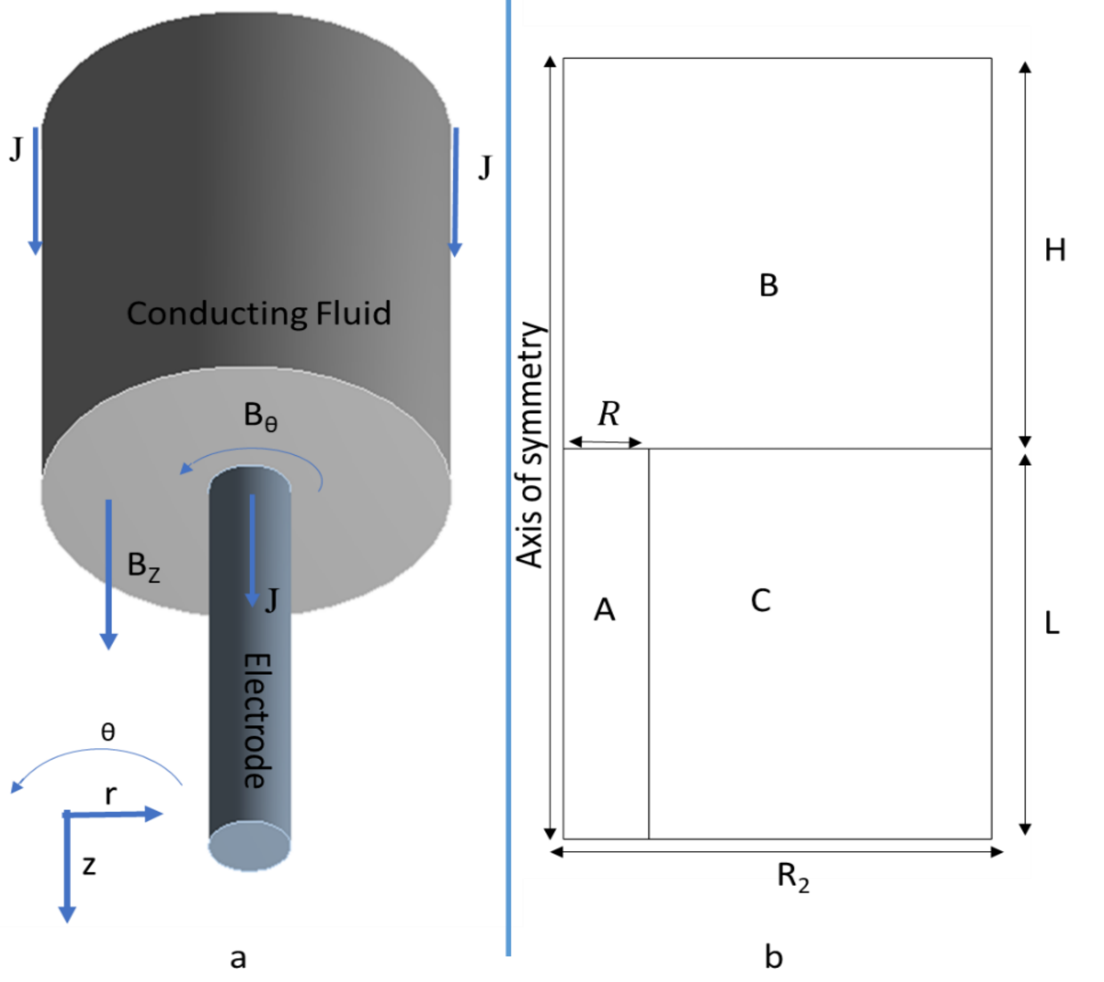


$B_\theta = 0$

Liquid metal simulation

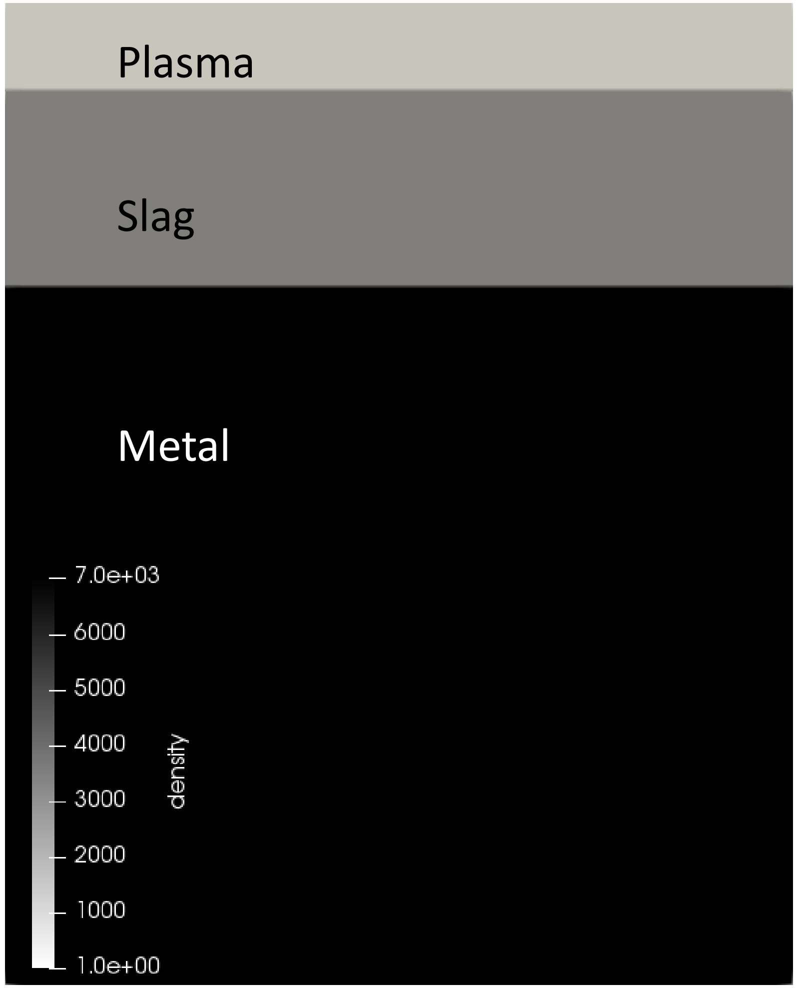
Geometry of the 2D axisymmetric space:

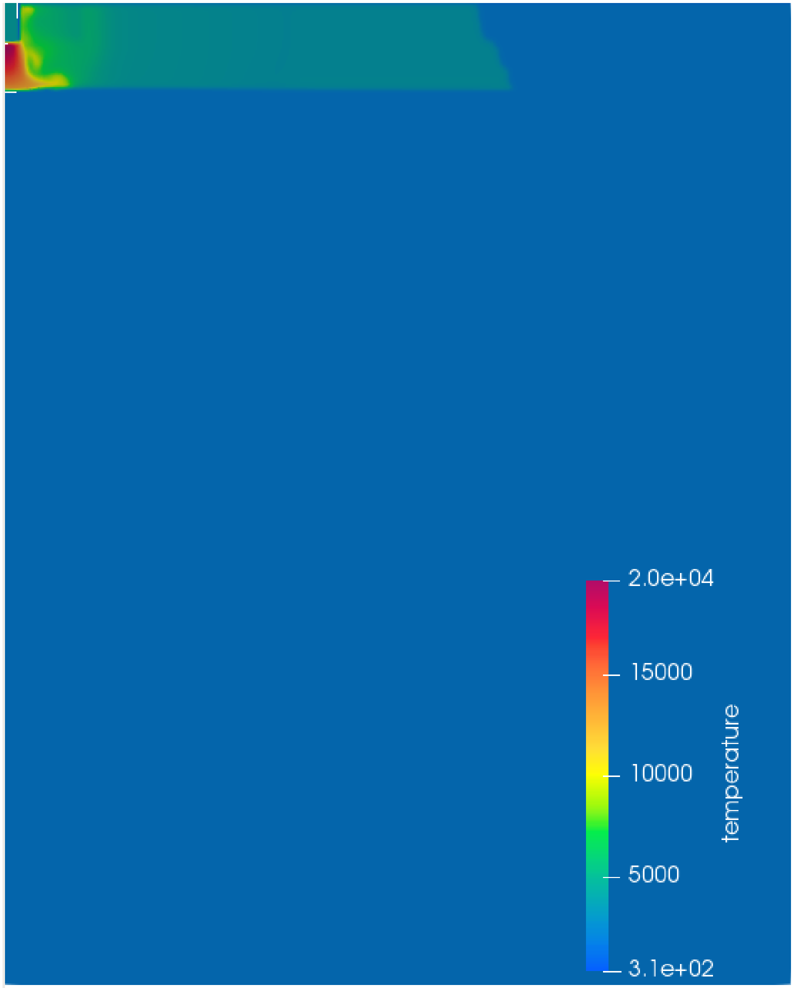
- A is the electrode,
- B is the conducting fluid zone,
- C is a non-conducting enclosure



Boundary conditions

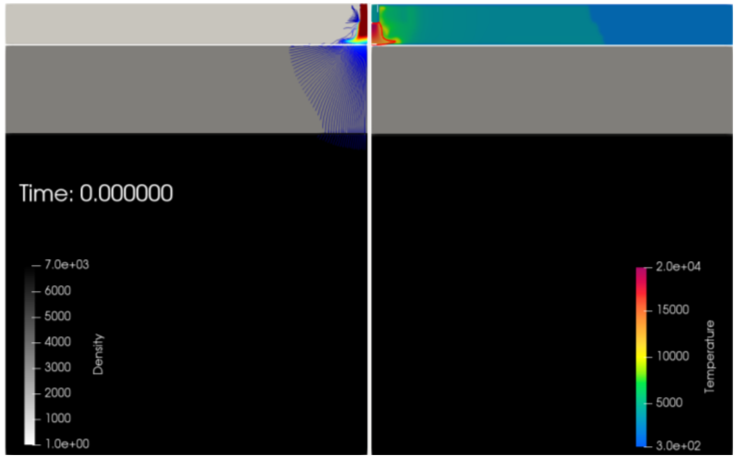
- 10 ,20, 30 KA
- Electrode R =8,12 ,15 mm
- Arc Gap = 0.05 m
- Metal depth = 0.73 m
- Slag depth = 0.2 m
- No external magnetic field
- Sides and bottom are adiabatic
- Top is cooled and have a temperature of 500 K



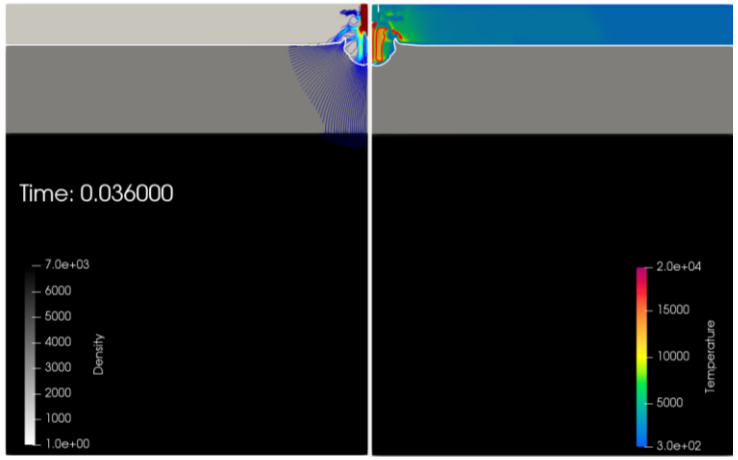


Arc Impingement

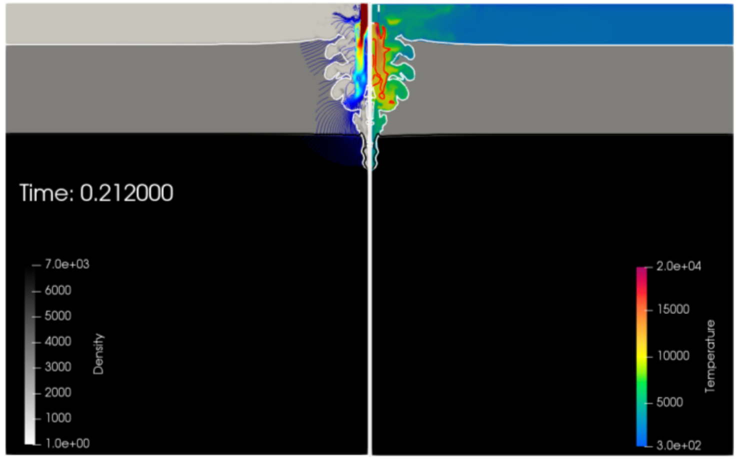
1



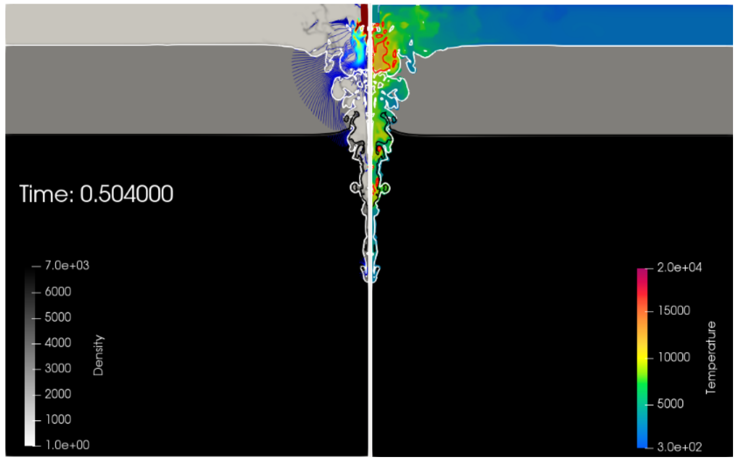
2



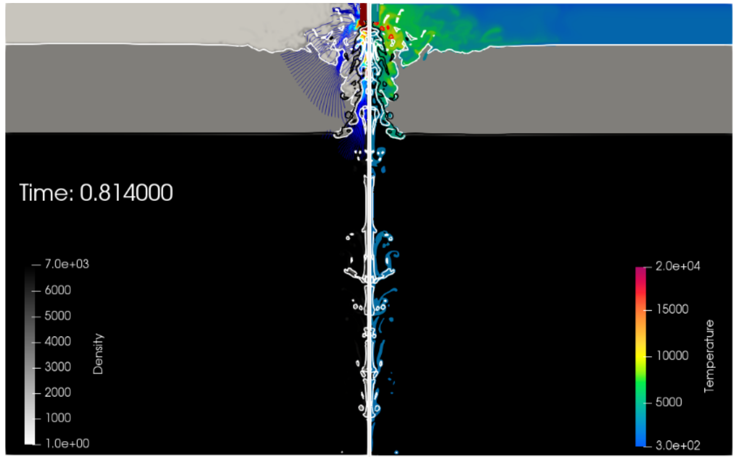
3



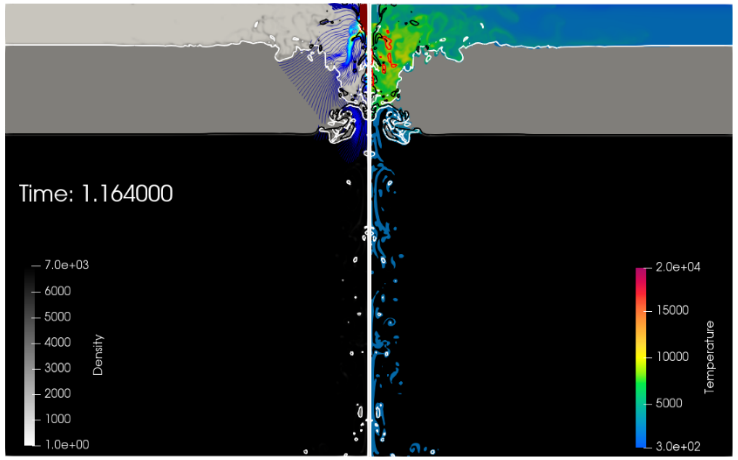
4



5

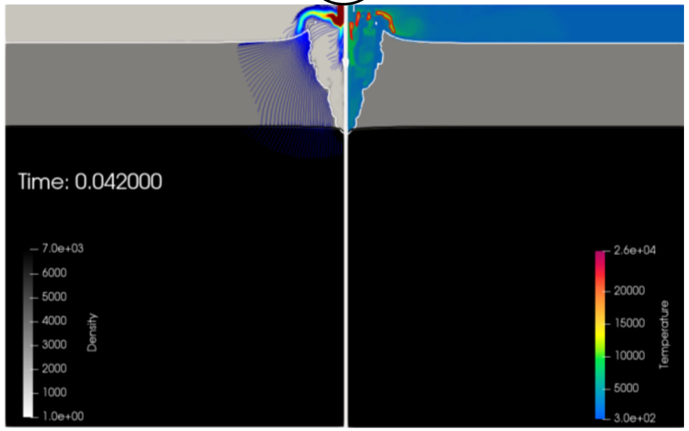


6

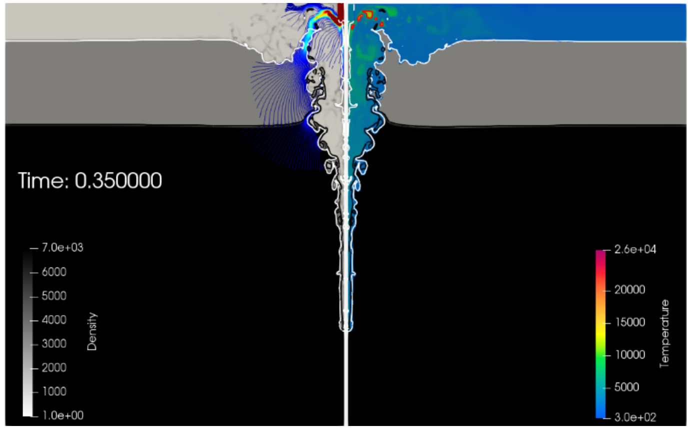


Arc Impingement

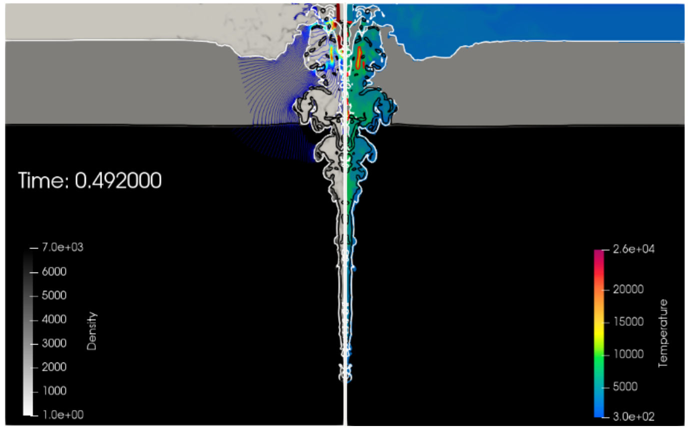
1



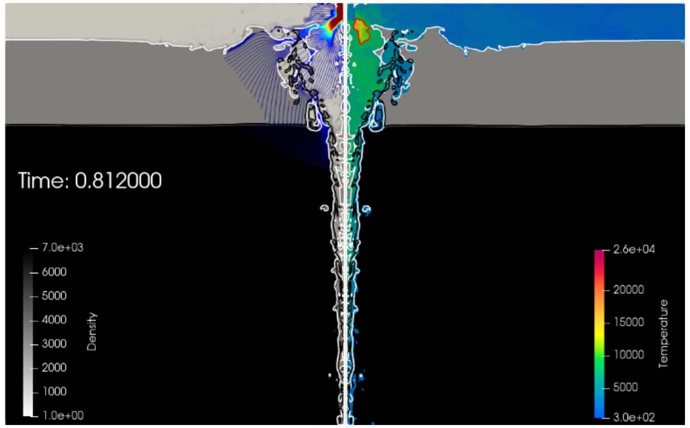
2



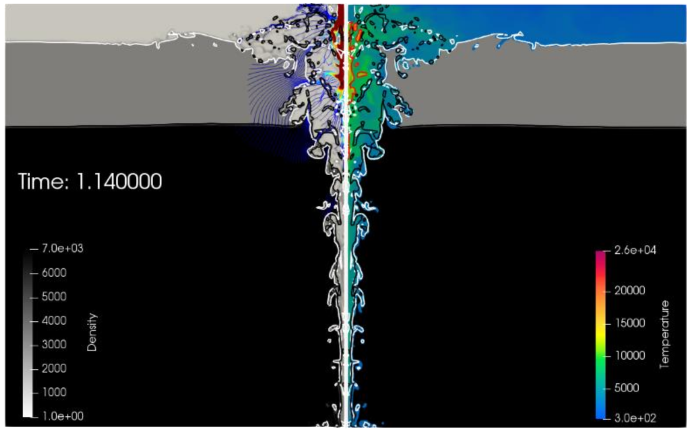
3



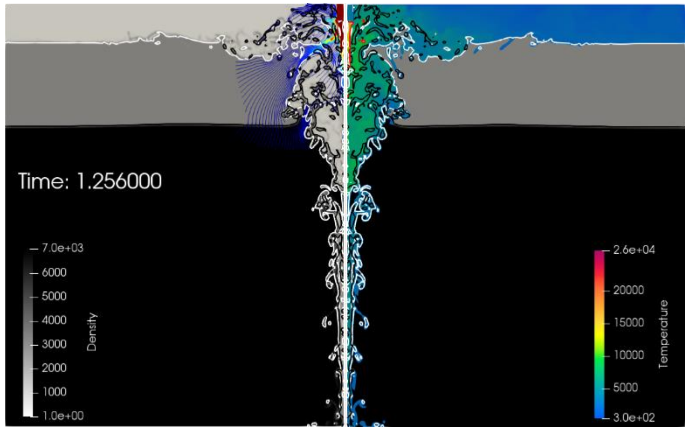
4



5

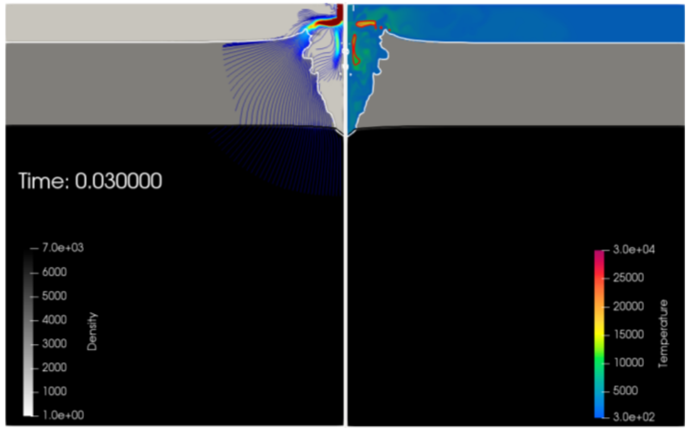


6

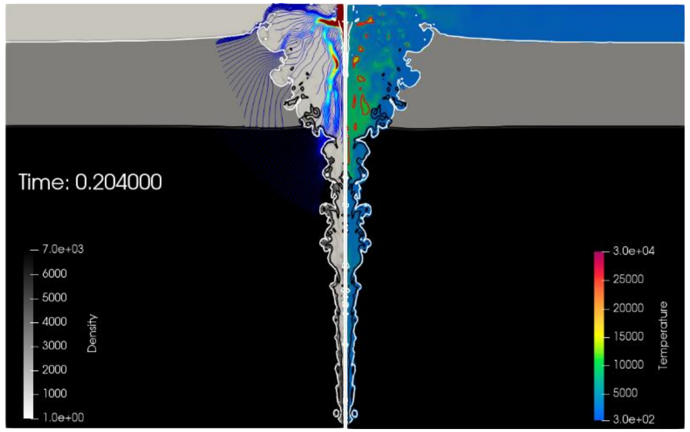


Arc Impingement

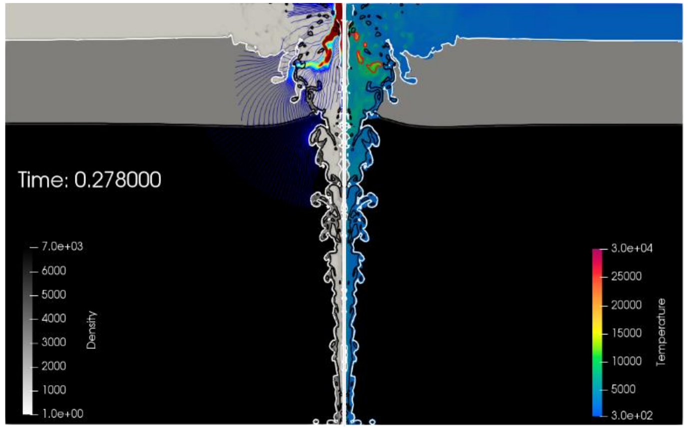
1



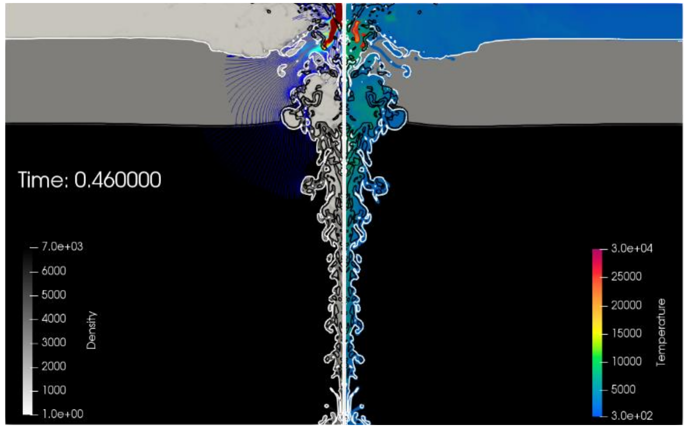
2



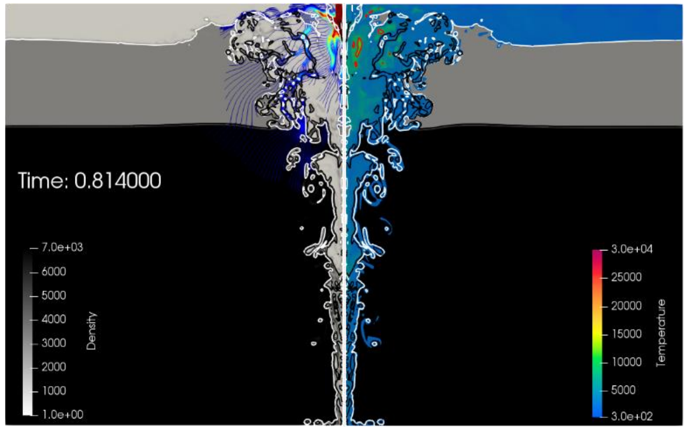
3



4



5



6