MONDRAGON UNIBERTSITATEA

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NUMERICAL MODELING OF COLD CRUCIBLE INDUCTION MELTING

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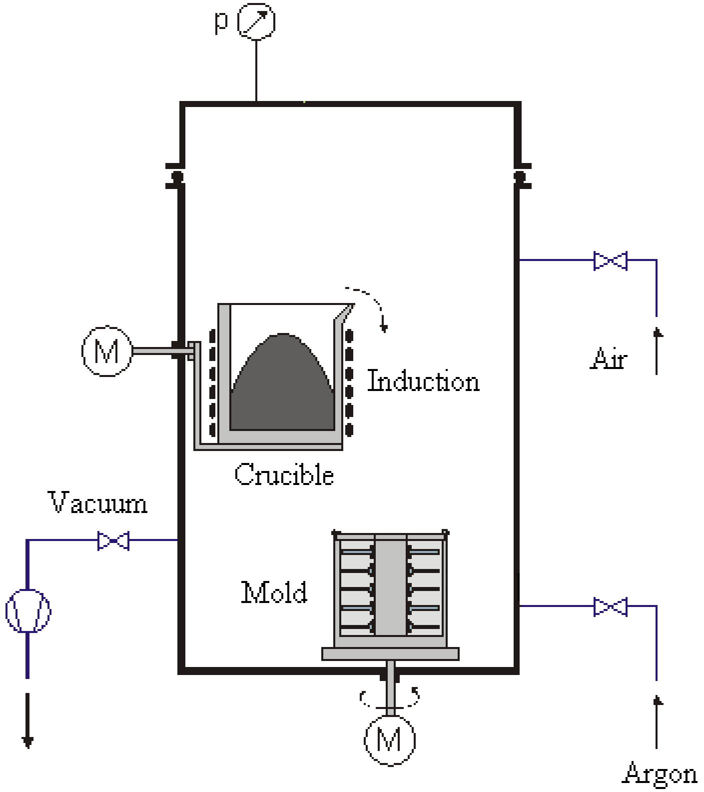
OVERVIEW

- Introduction
- Numerical model
  - Geometry
  - Main features of the model
  - Governing equations
- Numerical results
- Conclusions

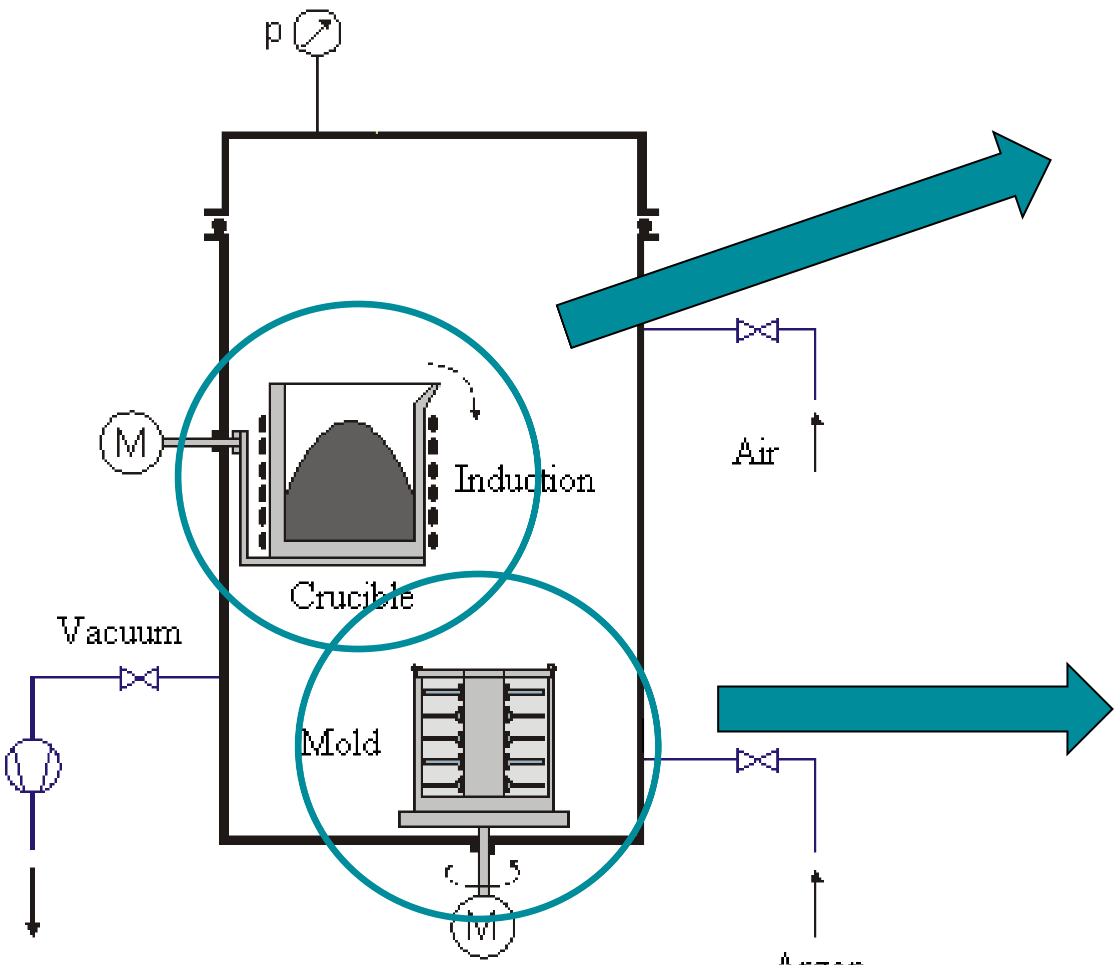
■ COLD CRUCIBLE INDUCTION MELTING

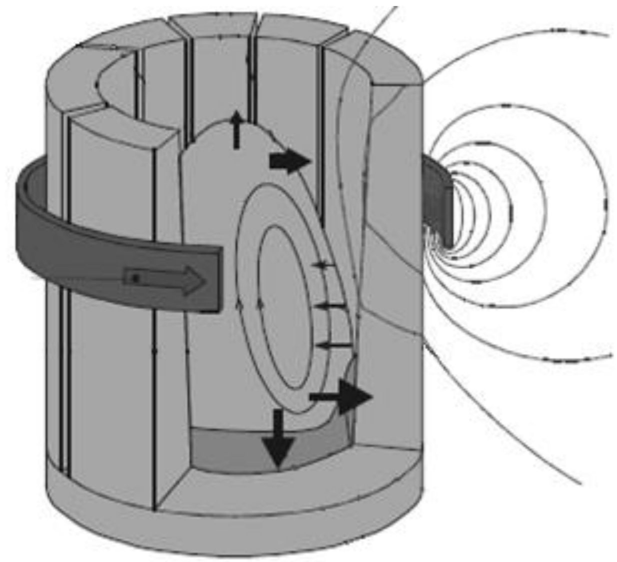
An innovative process to melt HIGH TEMPERATURE REACTIVE MATERIALS where the casting and the melting is made in vacuum (or in a controlled atmosphere) and a water cooled segmented cooper crucible is used instead of a typical ceramic crucible.

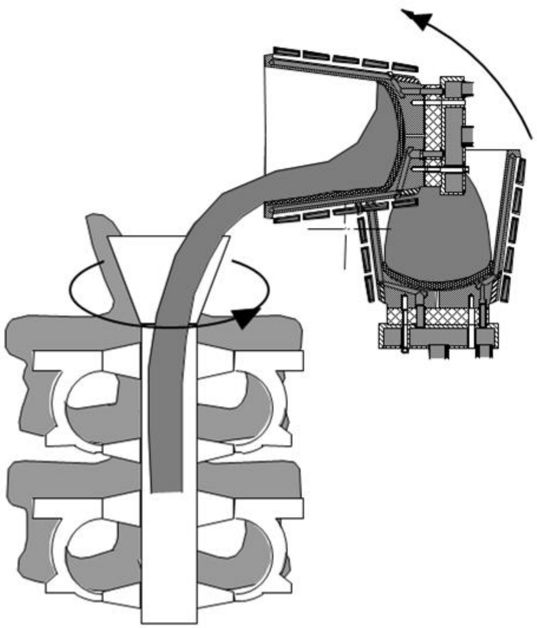


PROCESS DESCRIPTION

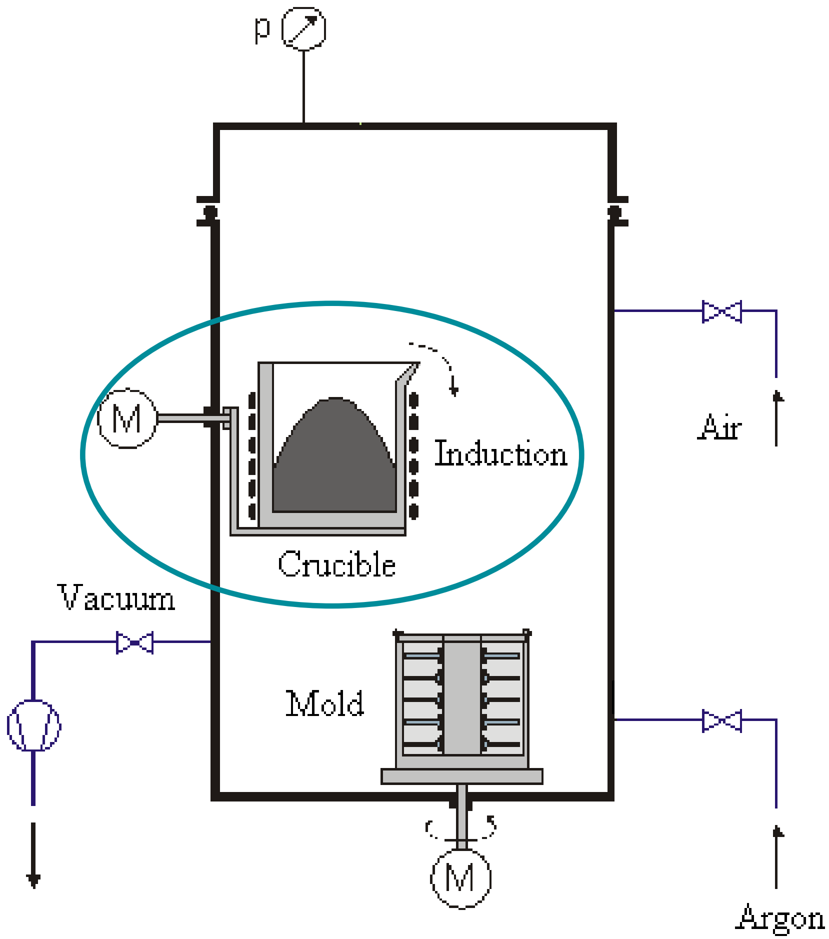
- Melting and casting

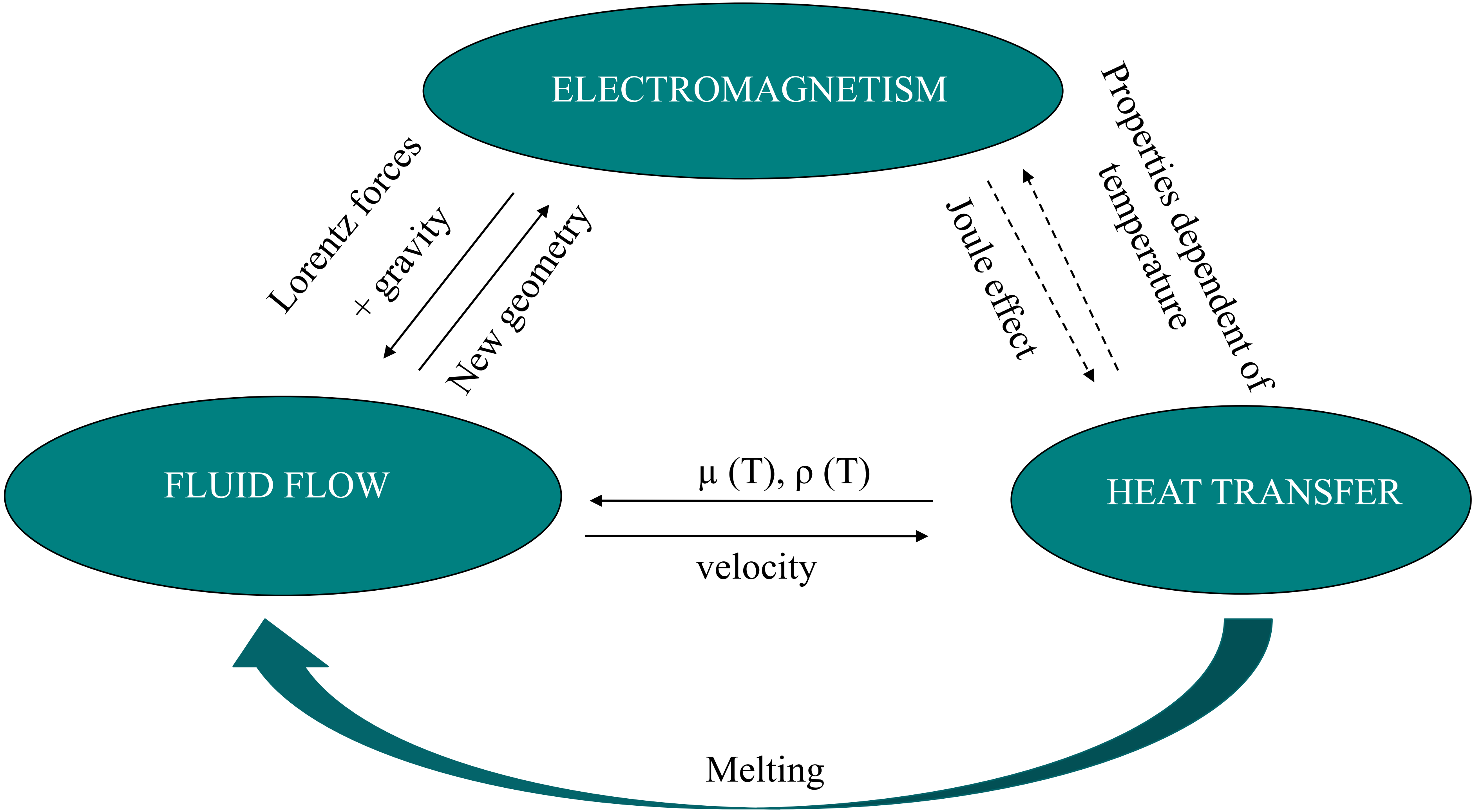




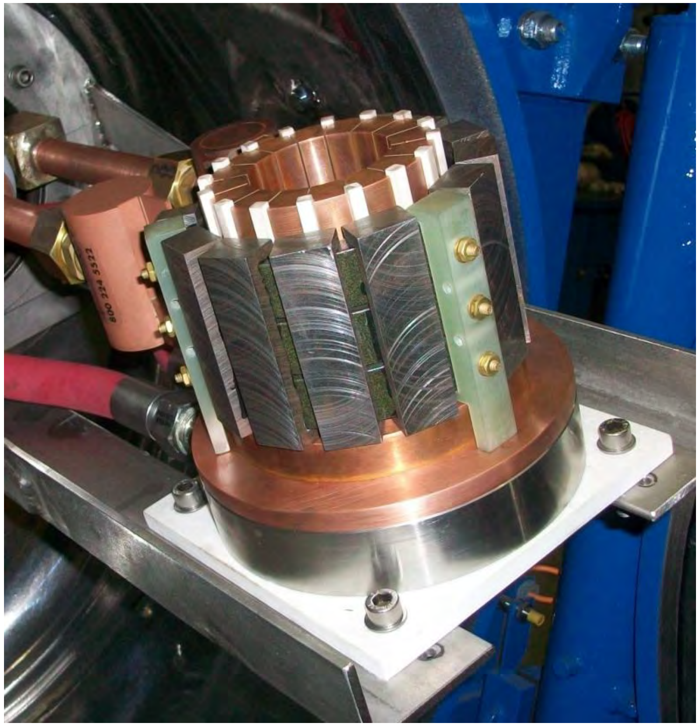


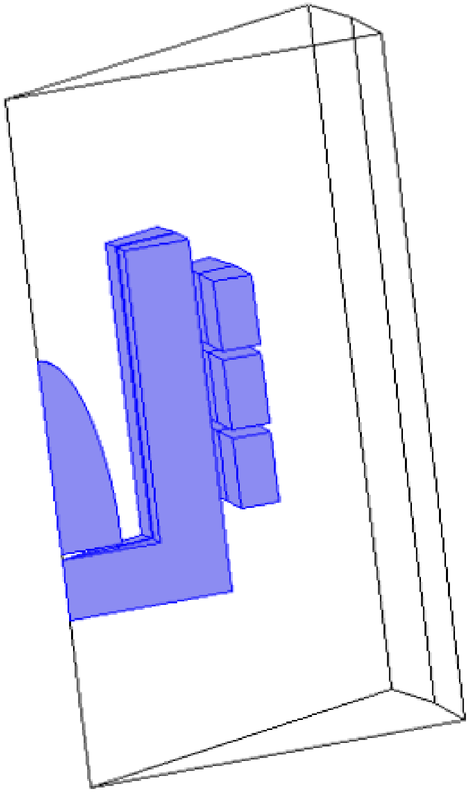
- Numerical modeling of the step 1 of the process (melting)




ELECTROMAGNETISM
Lorentz forces
+ gravity
New geometry
Joule effect
Properties dependent of
temperature
FLUID FLOW
μ (T), ρ (T)
velocity
HEAT TRANSFER
Melting

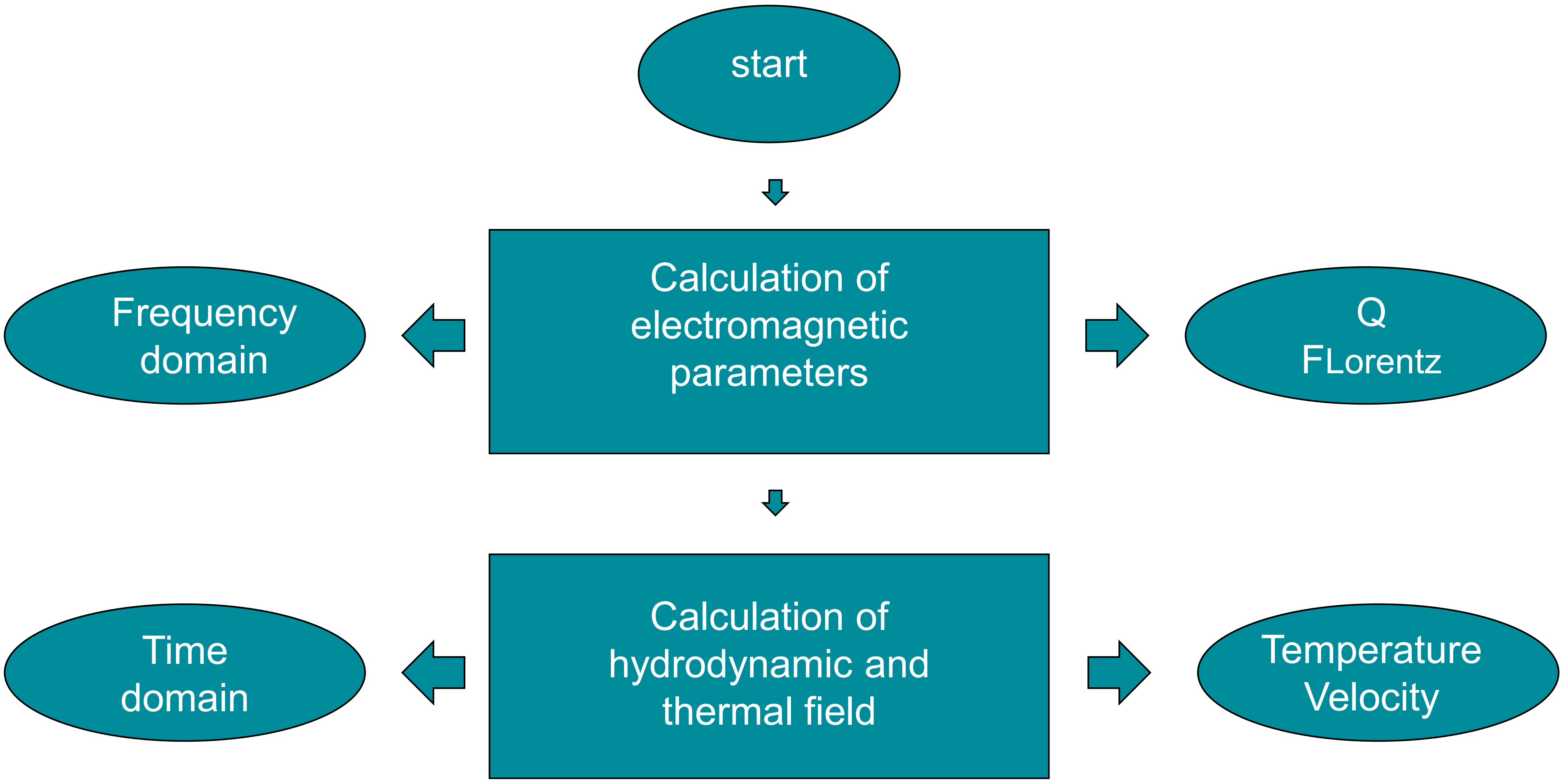
Geometry





- The modeled crucible has the same dimensions as the crucible of the CCIM installation at the University of Mondragon, which is able to melt 1kg. of titanium.
- Periodicity: sixteenth part

- Main features of the model



Linear problem

1) Electromagnetic fields (Maxwell's equations) (frequency domain)

$$(j\omega\sigma - \omega^2 \varepsilon_0 \varepsilon_r)A + \nabla \times (\mu_0^{-1} \mu_r^{-1} B) = J_e$$

- Air, crucible, charge and coil
- Magnetic insulation (in outer boundaries)
- Skin depth 3.4 mm (boundary layer)

Linear problem

1) Thermal field (Poisson equation) (time domain)

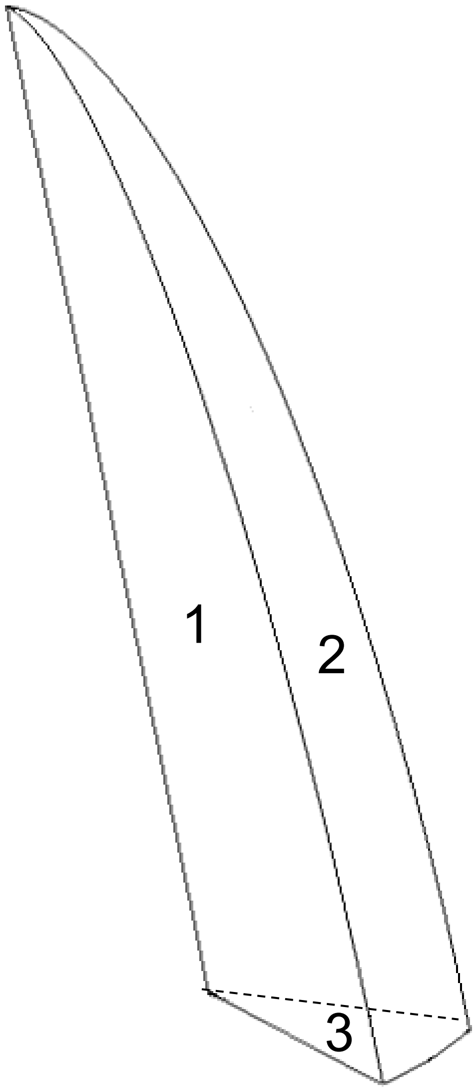
$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p v \cdot \nabla T = \nabla \cdot (k \nabla T) + Q$$

- Boundary condition

1.- Periodic heat condition

2.- Radiation condition

3.- Temperature condition of 400ºC



Non-Linear problem (time domain)

1) Fluid flow phenomena (Navier Stokes)

$$\rho\frac{\partial v}{\partial t}+\rho v\cdot\nabla v=-\nabla p+\nabla\cdot\left[\mu\left(\nabla v+\left(\nabla v\right)^{T}\right)\right]+F$$

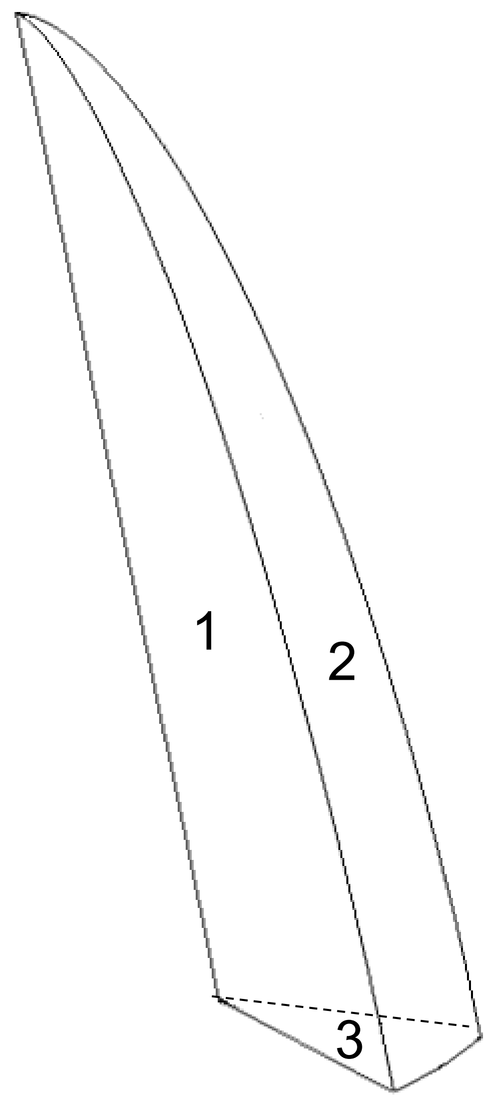
$$\nabla\cdot\left(\rho v\right)=0$$

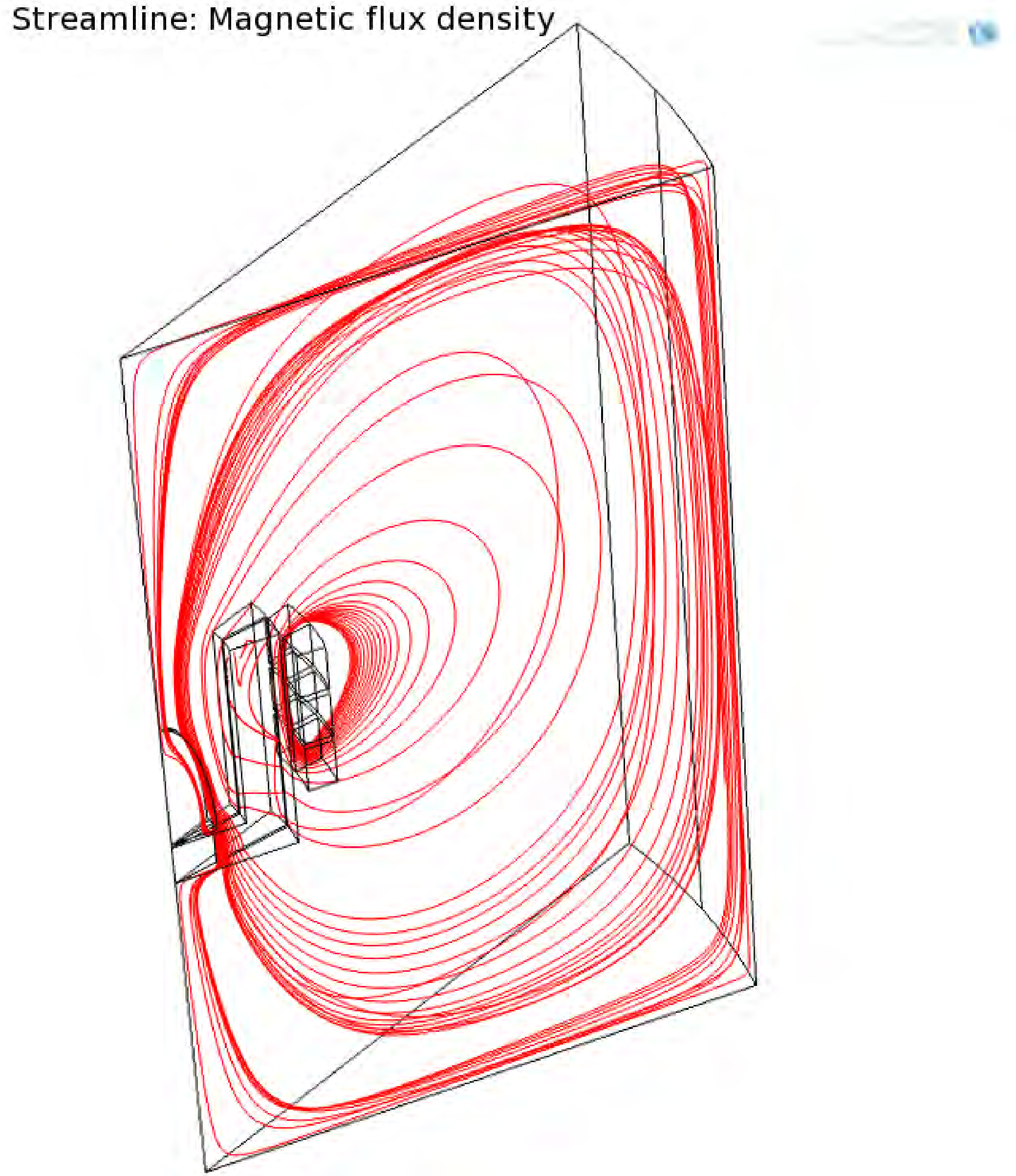
- Boundary condition

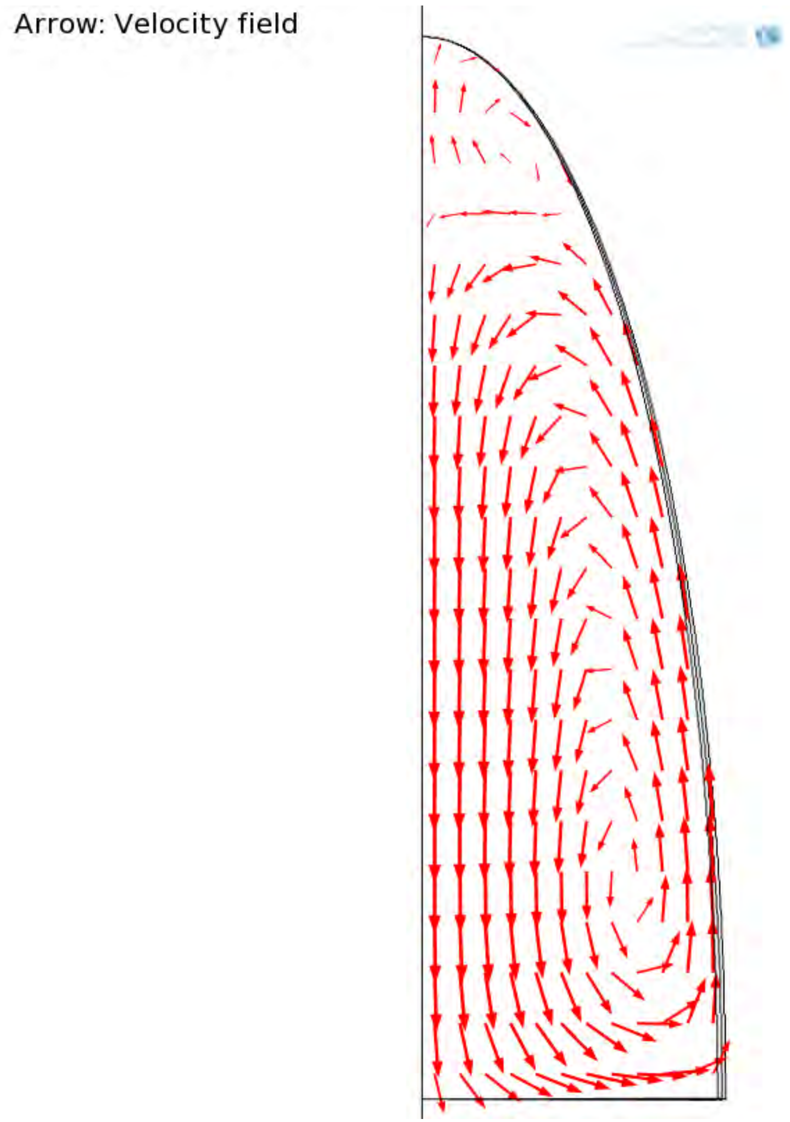
1.- Periodic flow condition

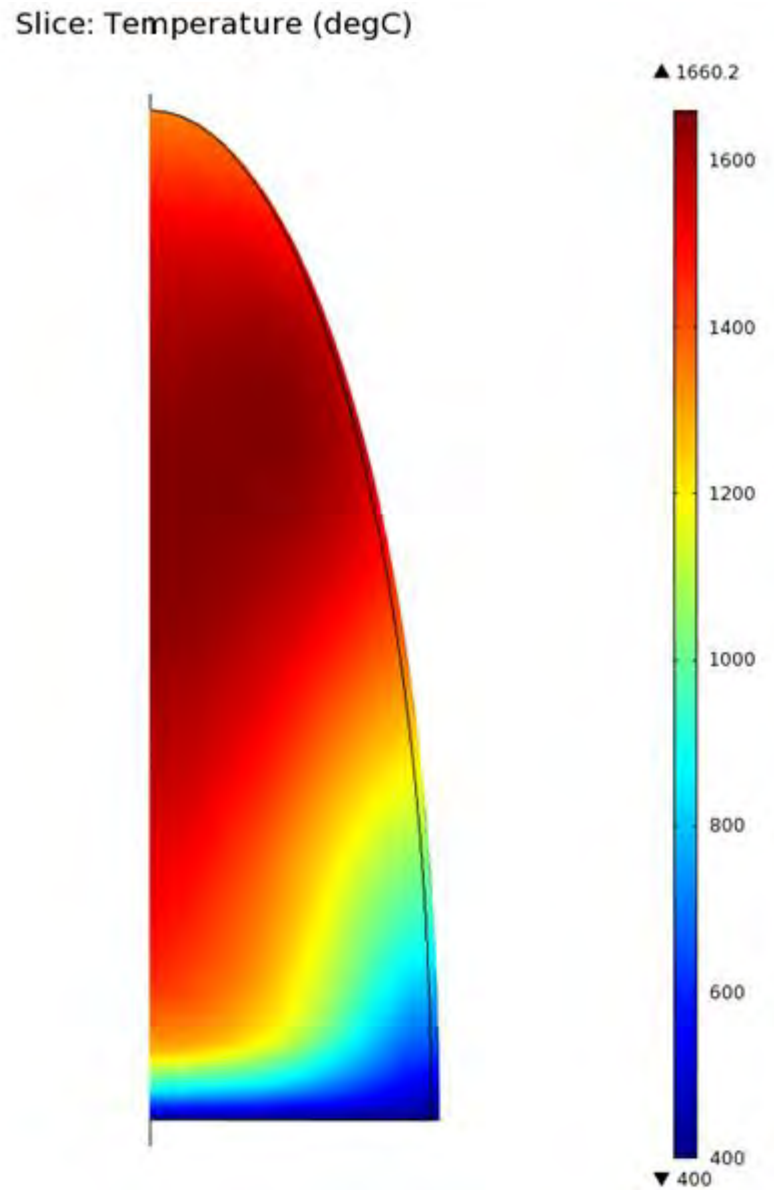
2.- Slip condition

3.- Slip condition




Streamline: Magnetic flux density


Arrow: Velocity field


Slice: Temperature (degC)
▲ 1660.2
1600
1400
1200
1000
800
600
400
▼ 400

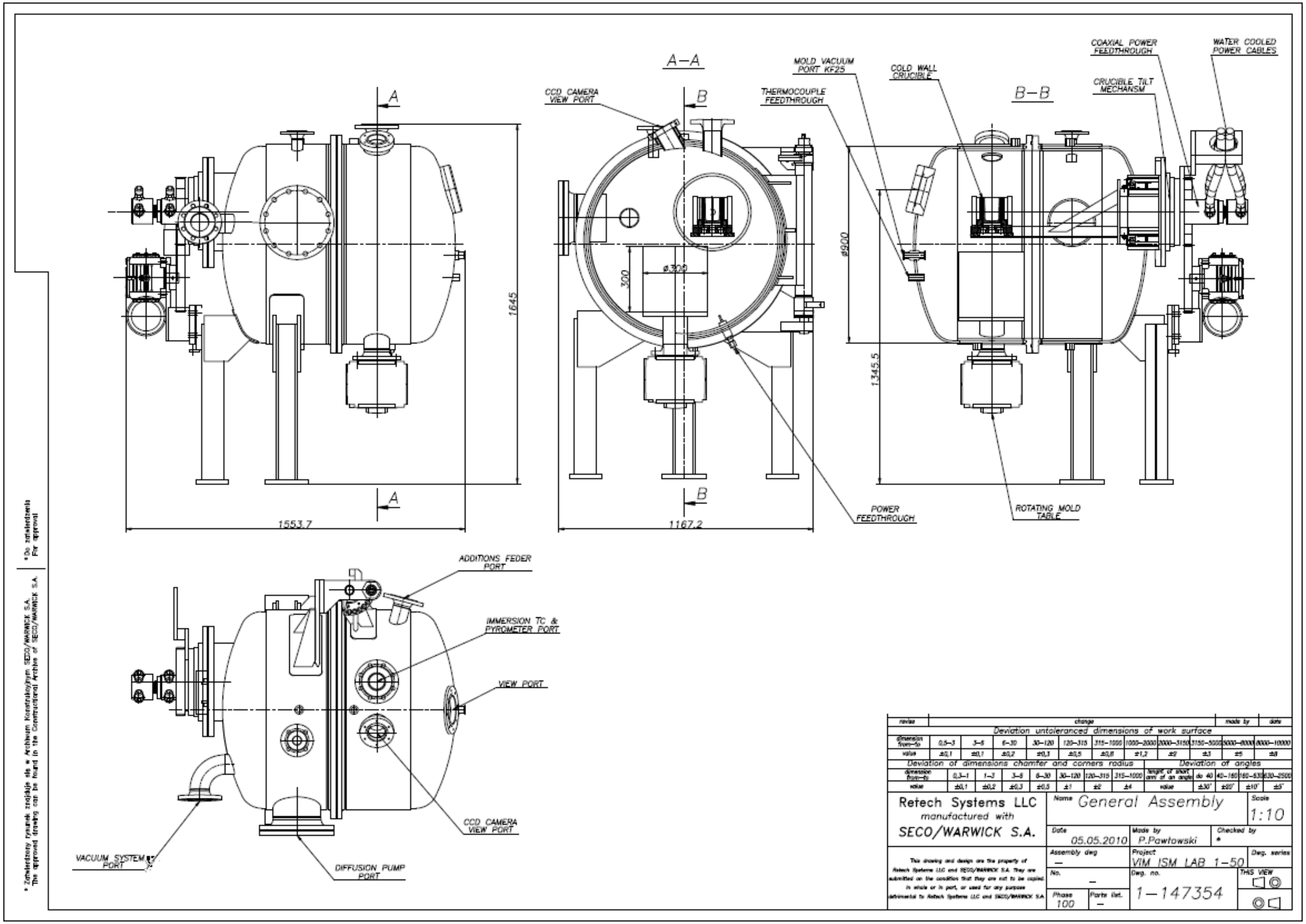
- Conclusions
  - Preliminary numerical model
  - Good agreement
  - Strong coupling
  - Geometry movement

NUMERICAL MODELING OF COLD CRUCIBLE INDUCTION MELTING

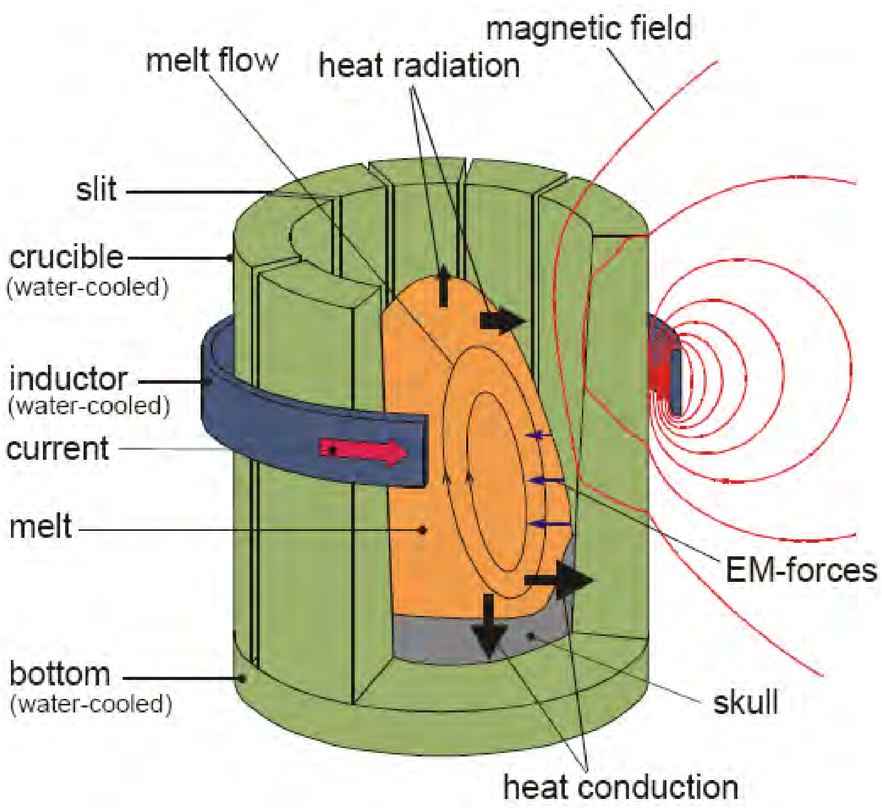
Thanks for your attention

- Questions
  - Induction heating: strong coupling 4e-4 for "Time dependent and constraint the solver time stepping”. 1 sec; 102.12ºC; 10sec, 101.9 ºC
    - ***Time dependent current density***

- The installation of Mondragon University



- First step of the process: Physical principles



- Ampere's Law.
- Faraday's Law.
- Importance of slits.
- Joule effect.
- Phase change → solid-liquid.
- Lorentz forces.
- Liquid movement → temperature homogenization.

- Process steps

1) Melting:

The magnetic field supplied by the induction coil passes through the crucible segments and the induced currents heat and melt the metal charge (joule effect). As the titanium alloy melts, it solidifies against the wall, forming a thin skin or “skull” on the surface. Titanium has a low thermal conductivity, so the skull insulates the molten metal from the cooling effect of the crucible. Moreover, the effective power input is so high that the molten metal is partially levitated, which further reduces heat exchange between the liquid metal and the skull.

2) Casting:

The molten metal is tilted in order to pour its content into a ceramic mould. As the conventional SiO_2 refractory investment casting cause big reactions among metal and ceramic, it is important to consider mold materials containing MgO, Al_2O_3, ZrO_2, Y_2O_3 and CaO in order to minimize these reactions.

- Advantage:
  - No contamination of the charge
- Disadvantage:
  - Poor efficiency
  - Poor overheating

ner diameter is 65 mm, and its height 105 mm. The crucible has 16 sectors and the slits are

- Parameters

POWER	FREQUENCY	CRICIBLE DESIGN	FILLING LEVEL	COIL DESIGN	ATMOSPHERE TIPE / PRESSURE PARTIAL

Optimization of process parameters: Power supply, frequency, coil design, crucible design,...

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Physical experiments + Numerical Modelling