Influence of EMS and EMBr in continuous casting

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Background

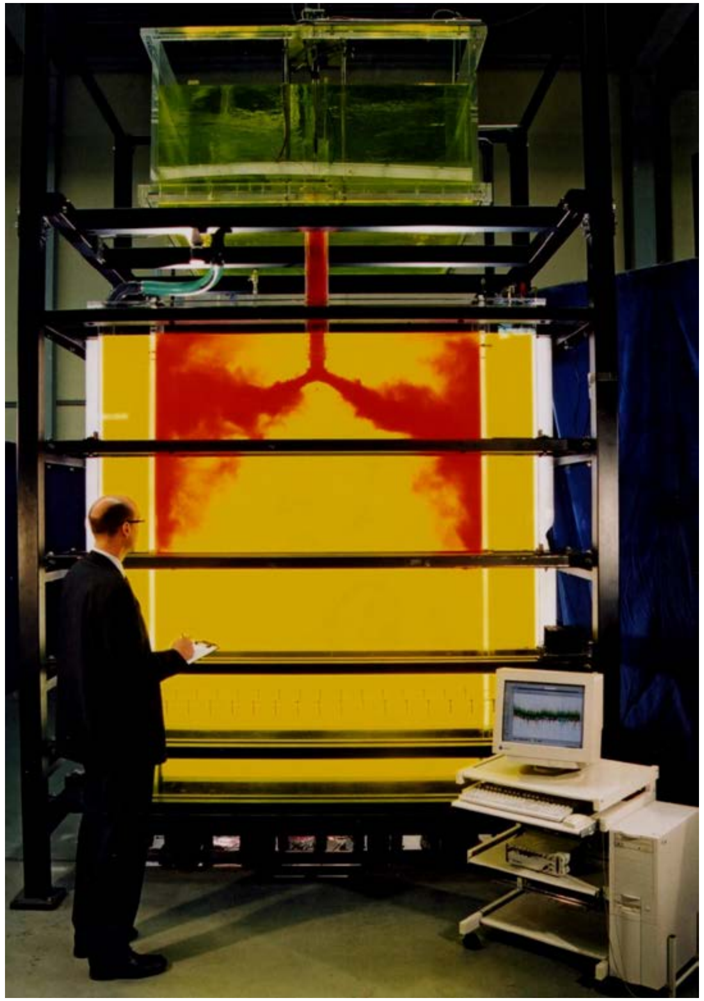
- For further improvement of as-cast product quality, electromagnetic forces, e.g. due to **electromagnetic braking (EMBr)** or **electromagnetic stirring (EMS)**, are applied in continuous casting moulds.
- An optimum utilisation of these techniques is limited by the fact that little is known about the influence of the acting forces on the physical processes.
- Direct assessment of the relevant processes, e.g. flow conditions, is very difficult or even impossible.
- Thus, simulation approaches became an important tool to obtain the necessary information.

Ways and Means

- Advanced numerical simulations concerning flow conditions in the mould were performed for variation of operational parameters including those of electromagnetic actuators.
- Verification of numerical results without electromagnetic forces were successfully performed via physical modelling.
- Extensive simulations were carried out for a thin slab and a billet casting mould equipped with EMBr or EMS, respectively, basing on operational input data.
- Results were presented concerning the influence of above mentioned operational parameters on process stability and product quality.

Physical Modelling

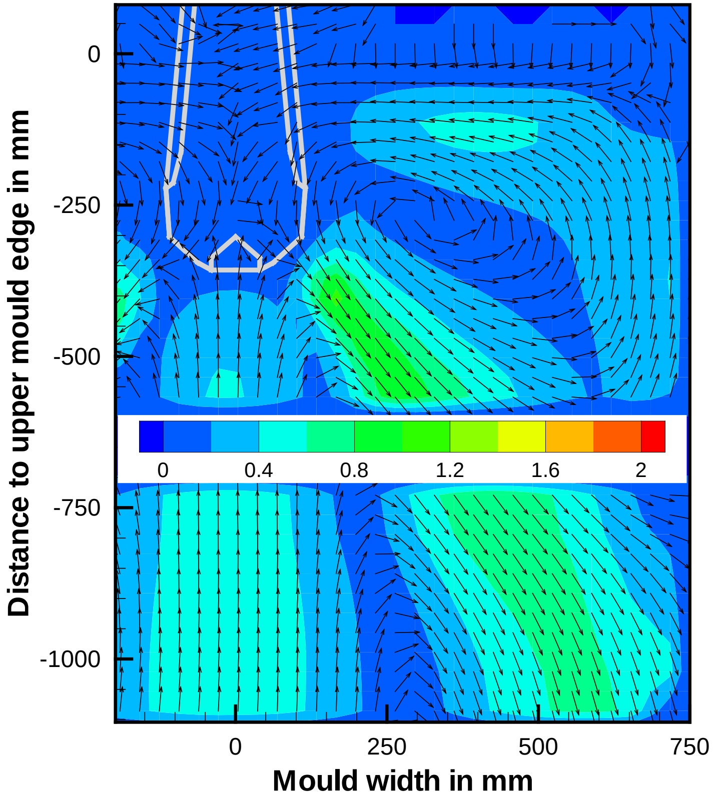
Validation of numerical simulation by physical modelling



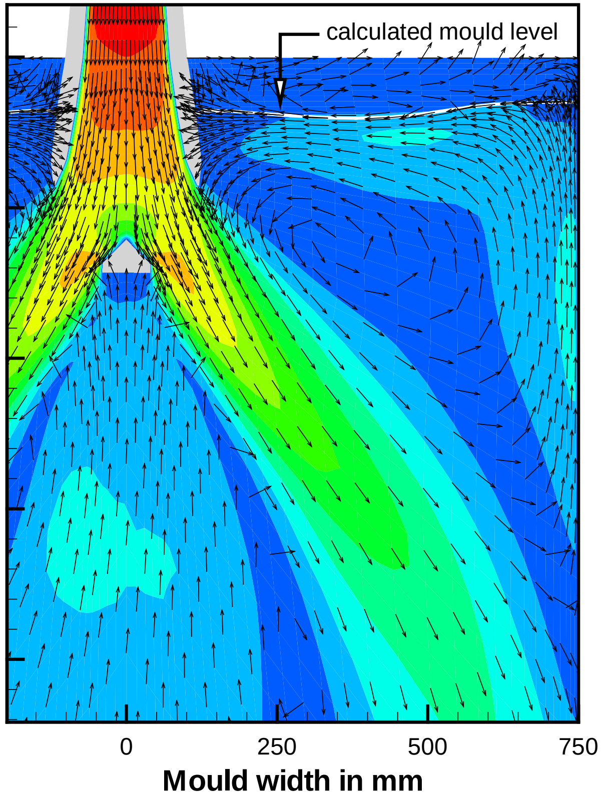
- Modular full scale mould models for simulations of flat and long product casters including tundish with regulation system (sliding gate or stopper rod) also gas injection possible
- Colour injection for flow visualisation and flow symmetry quantification
- Particle Image Velocimetry (PIV) to quantify time-dependent flow fields
- Ultrasonic sensors to quantify local time-dependent mould level behaviour

Physical and Numerical Modelling

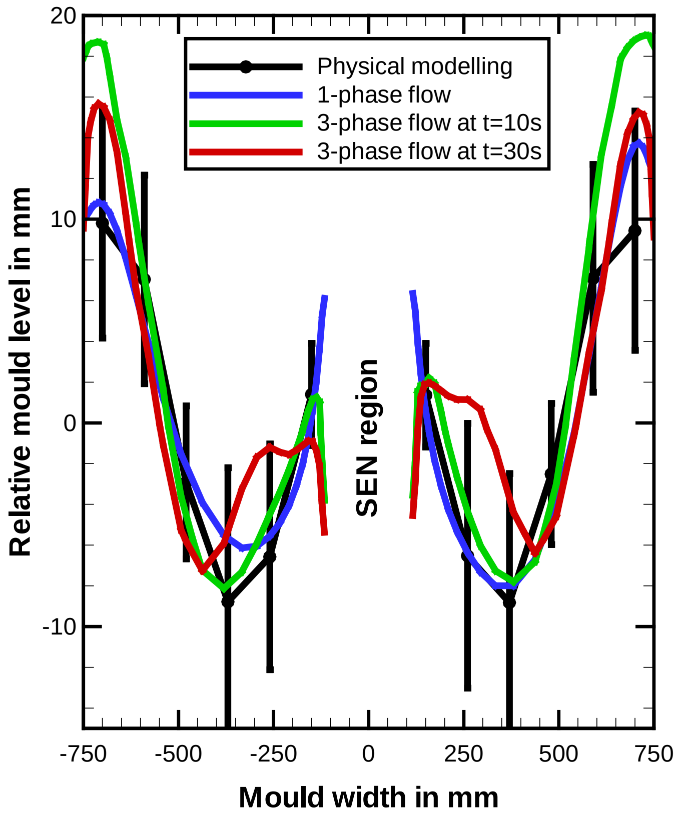
Validation of numerical results for casting velocity of 8m/min



PIV-Measurement



Numerical simulation

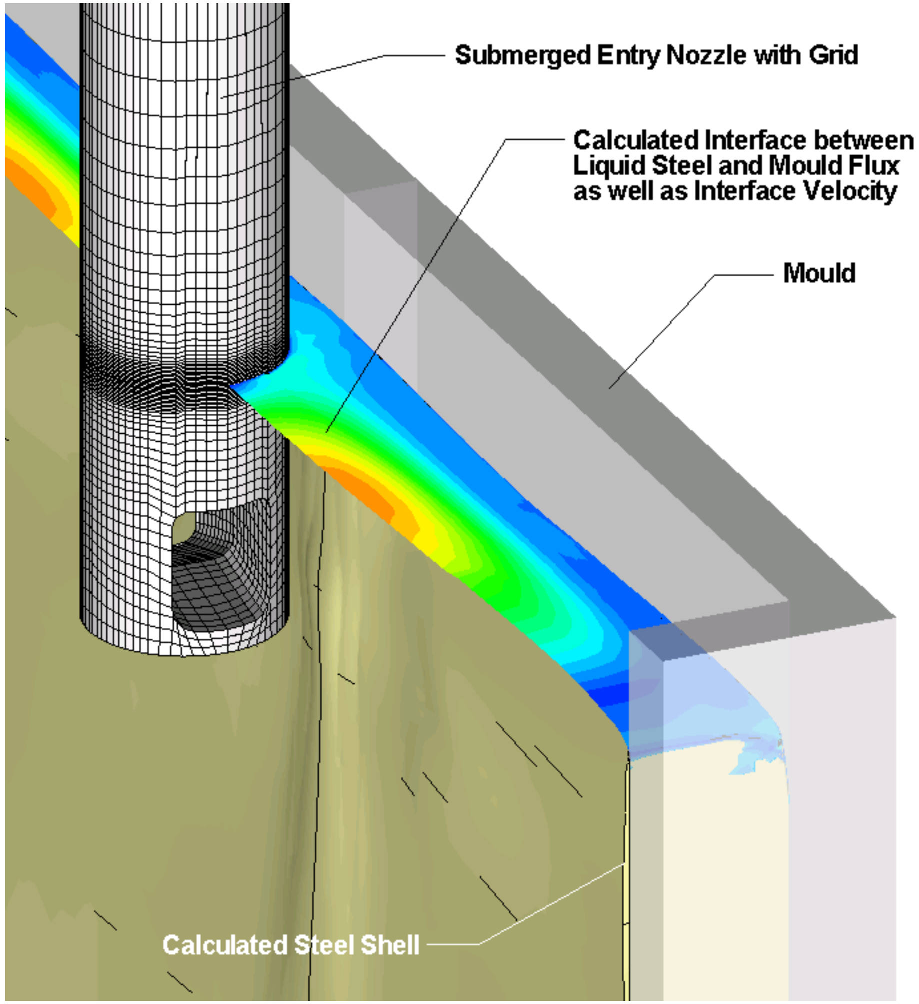


Comparison of results

SWERIM
sidenor
RINA
Materials Processing Institute
BFI

Numerical Modelling

Computational Fluid Dynamics (CFD) program Ansys/Fluent



- CFD code for 3D, turbulent and time-dependent flow
- Multiphase flow with several fluid layers and interfaces (e.g. liquid steel, mould flux, air)
- Dynamic behaviour of dispersed phases (gas bubbles and/or inclusions)
- Solidification
- Electromagnetic forces
- Simultaneous simulation of these phenomena

Numerical Modelling

Main equations used

$$\frac{\partial(\rho\vec{u})}{\partial t} + (\vec{u}\cdot\nabla)(\rho\vec{u}) = -\nabla p + \nabla(\eta\nabla\vec{u}) + \rho\vec{g} + \vec{F}$$

Conservation of momentum

$$\frac{\partial(\rho c_p T)}{\partial t} + (\vec{u}\cdot\nabla)(\rho c_p T) = \nabla(\lambda\nabla T) + Q_v + Q_i$$

Conservation of energy

$$\vec{j} = \sigma(\vec{E} + \vec{u}\times\vec{B})$$

Ohm's Law in a fluid flow field

$$\frac{\partial\vec{B}}{\partial t} + (\vec{u}\cdot\nabla)\vec{B} = \frac{1}{\mu\sigma}\nabla^2\vec{B} + (\vec{B}\cdot\nabla)\vec{u}$$

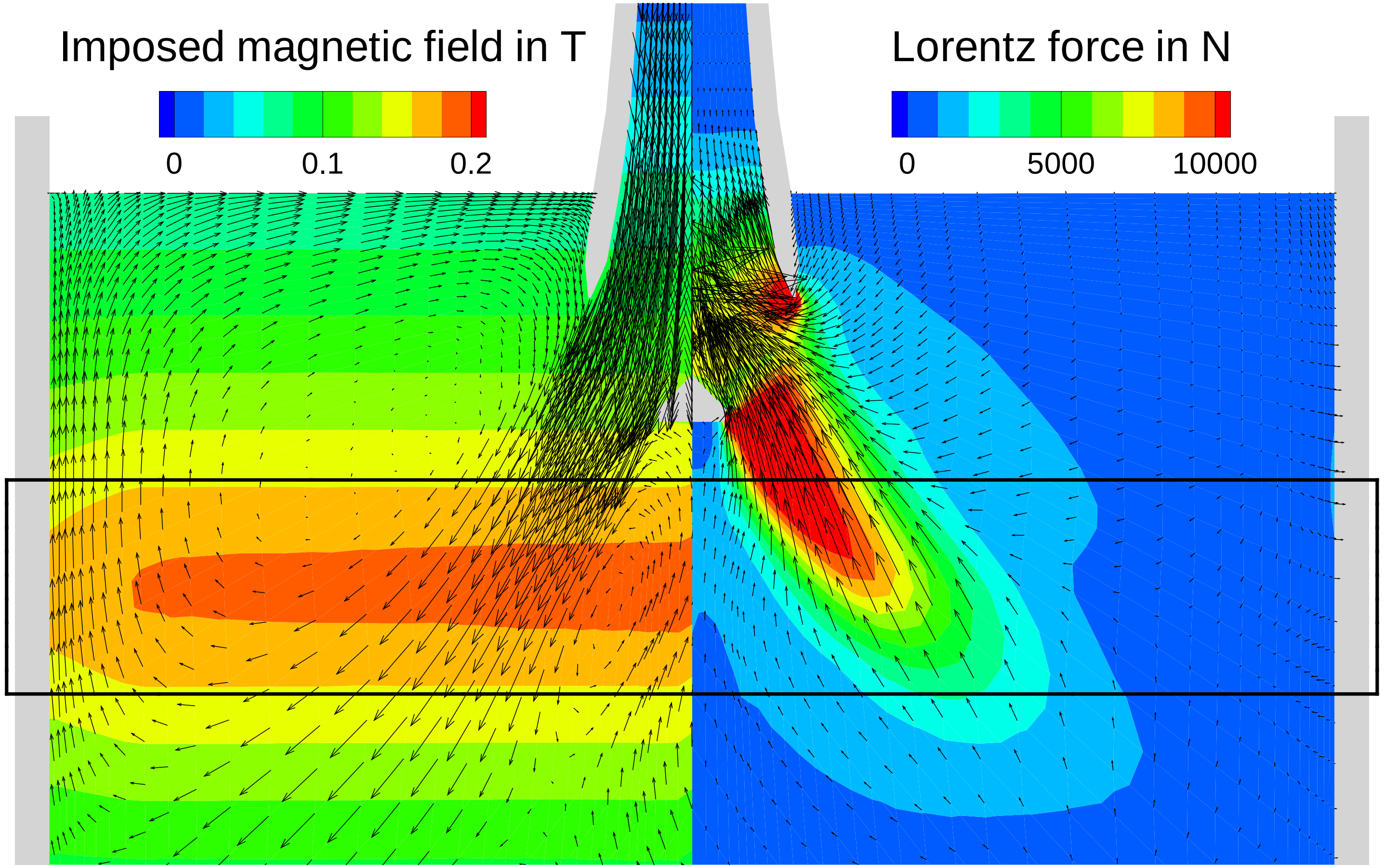
Transport equation for induction (Maxwell's Equation)

$$F_r = -\frac{1}{8}B_0^2\left(\omega - \frac{u_t}{r}\right)^2\sigma^2\mu r^3 \qquad F_t = \frac{1}{2}B_0^2\left(\omega - \frac{u_t}{r}\right)\sigma r$$

Stirring forces (rotational)

Results EMBr (Slab caster)

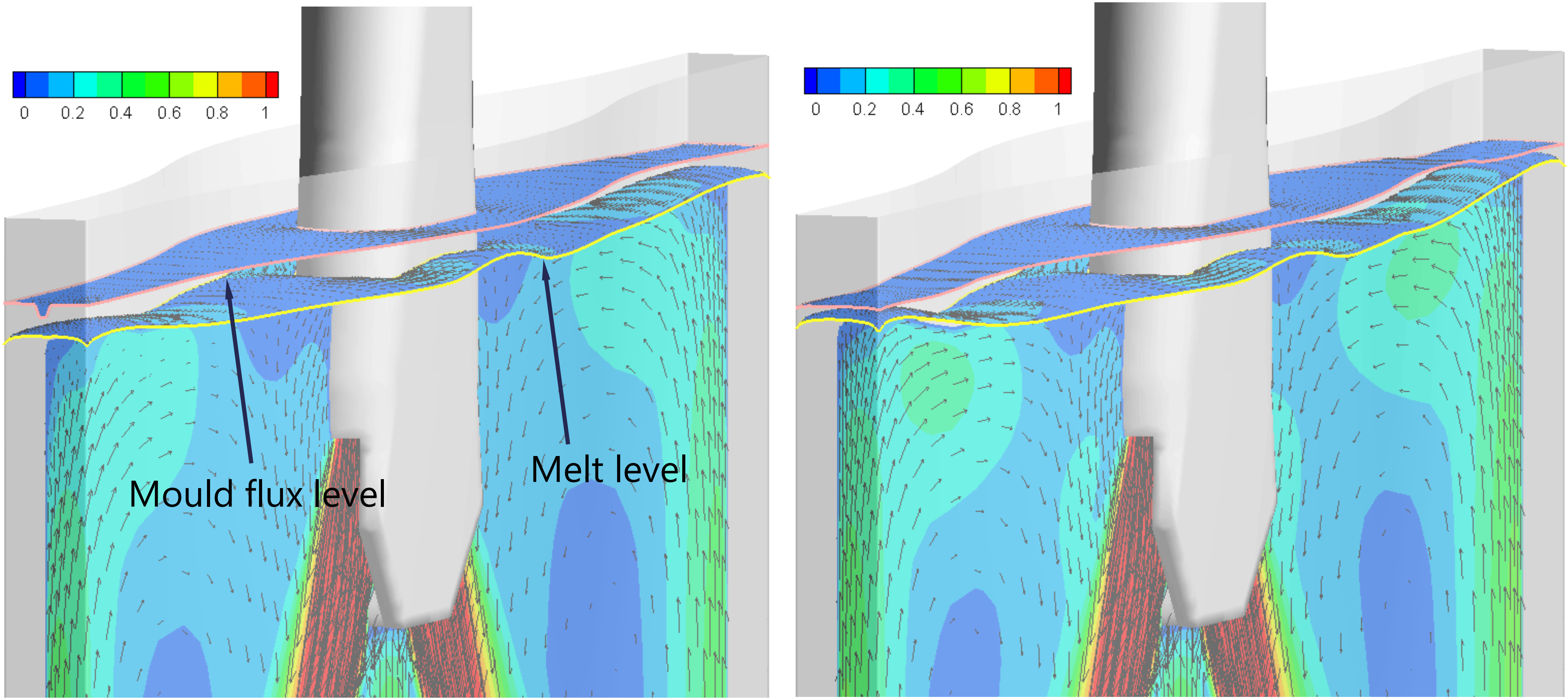
Numerically computed flow field and Lorentz force



Magnetic field **Calculated Lorentz force**

Results EMBr (Slab caster)

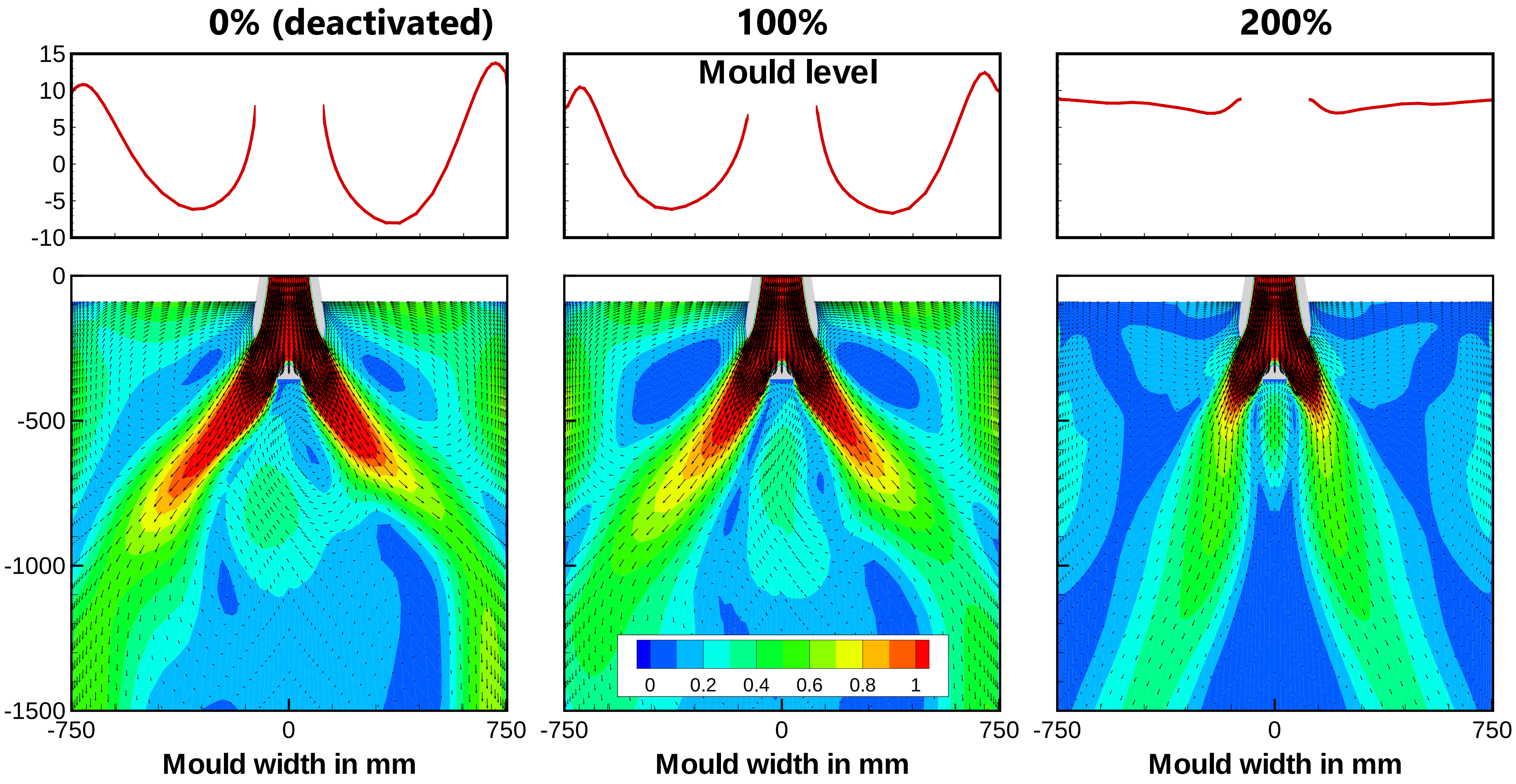
Numerically computed mould level behavior (Animation)



Without EMBr **With EMBr**

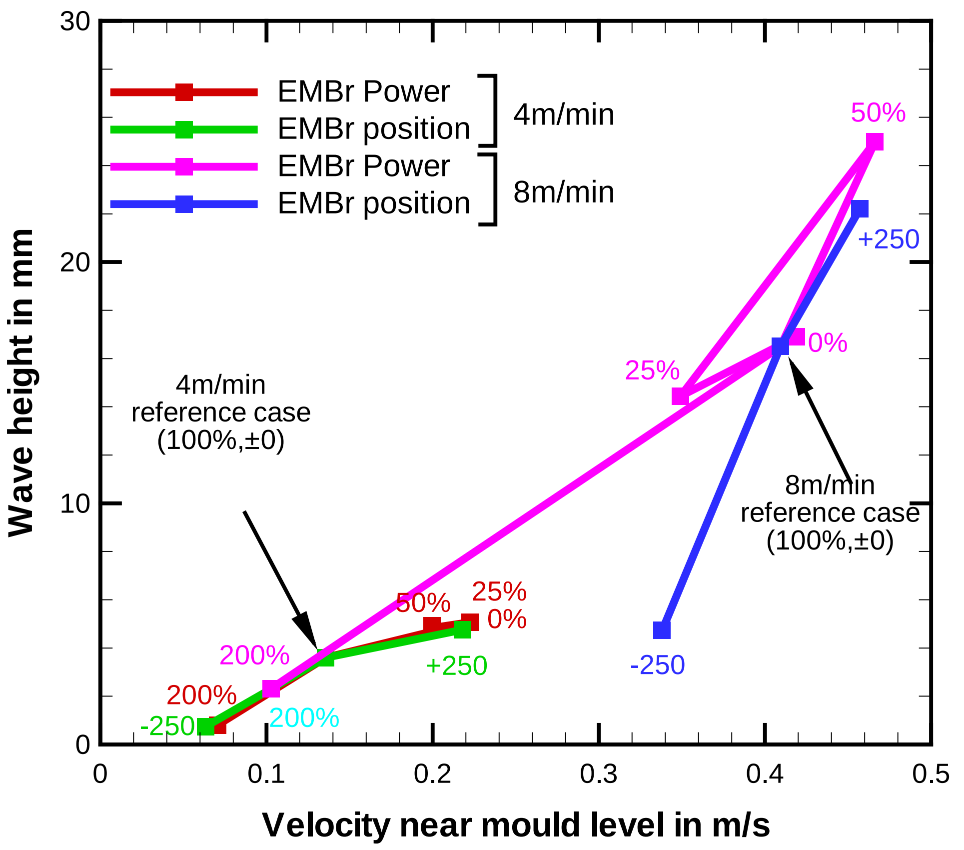
Results EMBr (Slab caster)

Influence of EMBr power

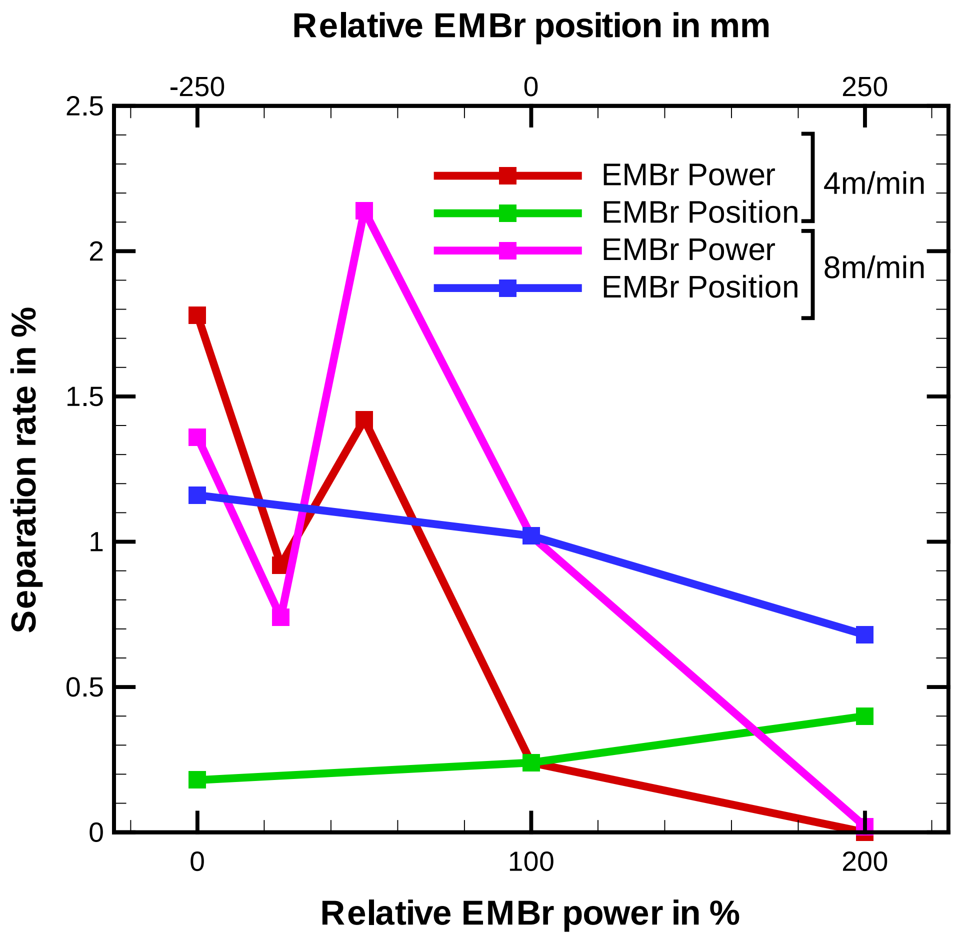


Results EMBr (Slab caster)

Influence of EMBr parameters



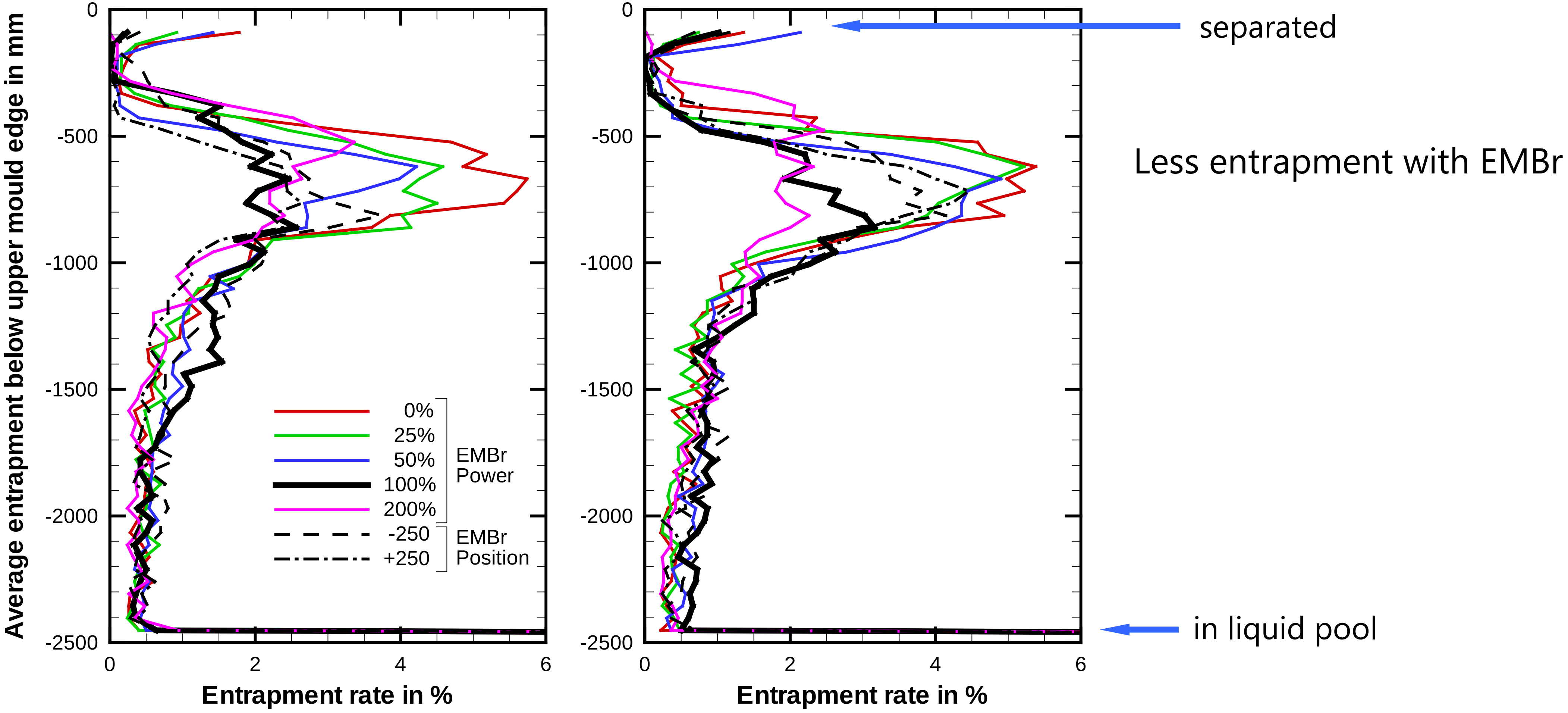
Mould level dynamics



Inclusion separation

Results EMBr (Slab caster)

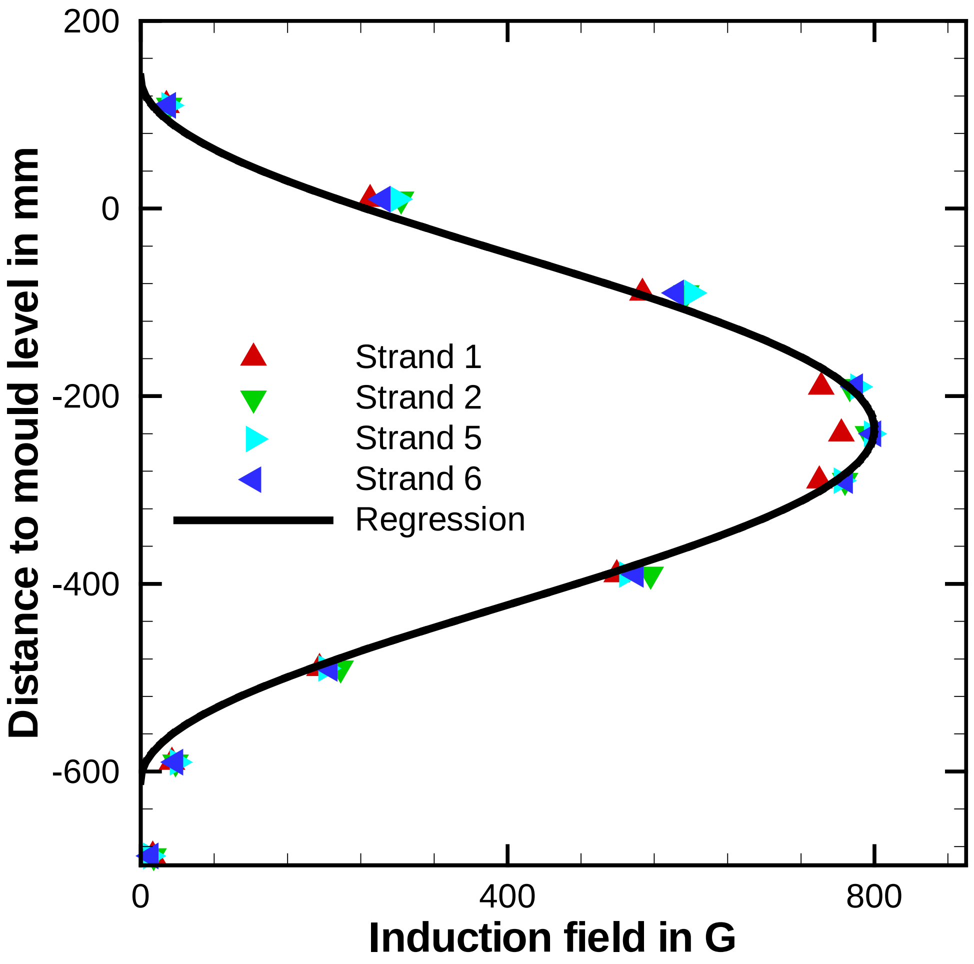
Numerically computed entrapment position

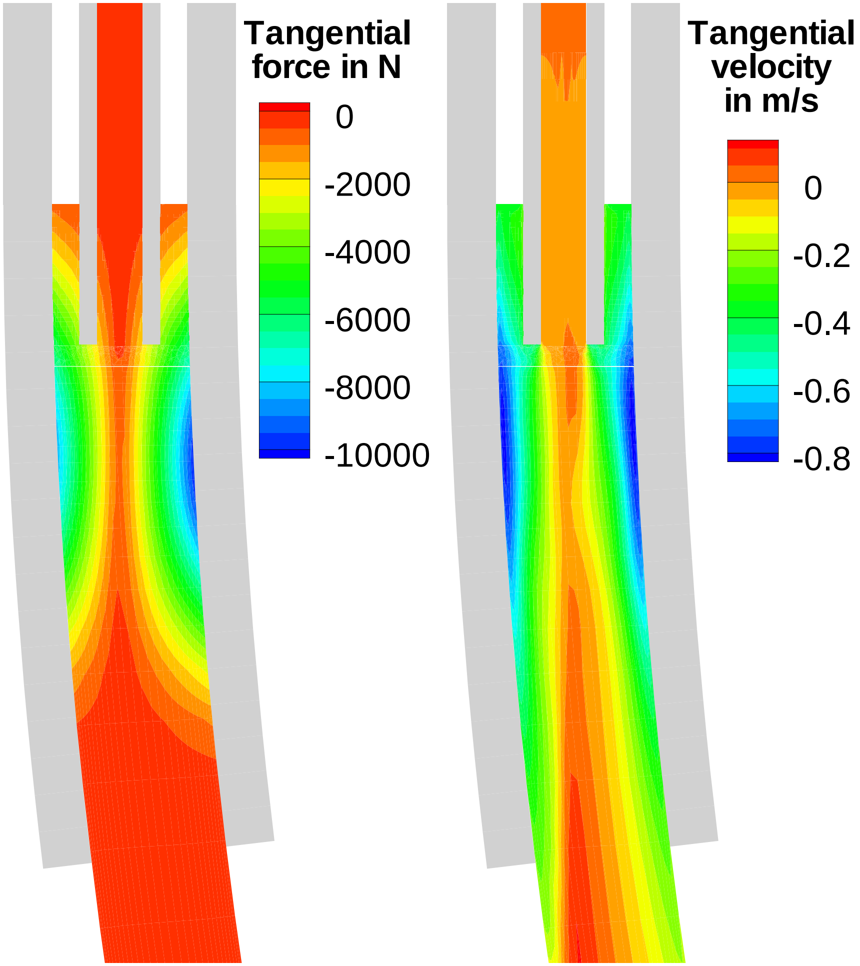


Casting velocity of 4 m/min **Casting velocity of 8 m/min**

Results EMS (Billet caster)

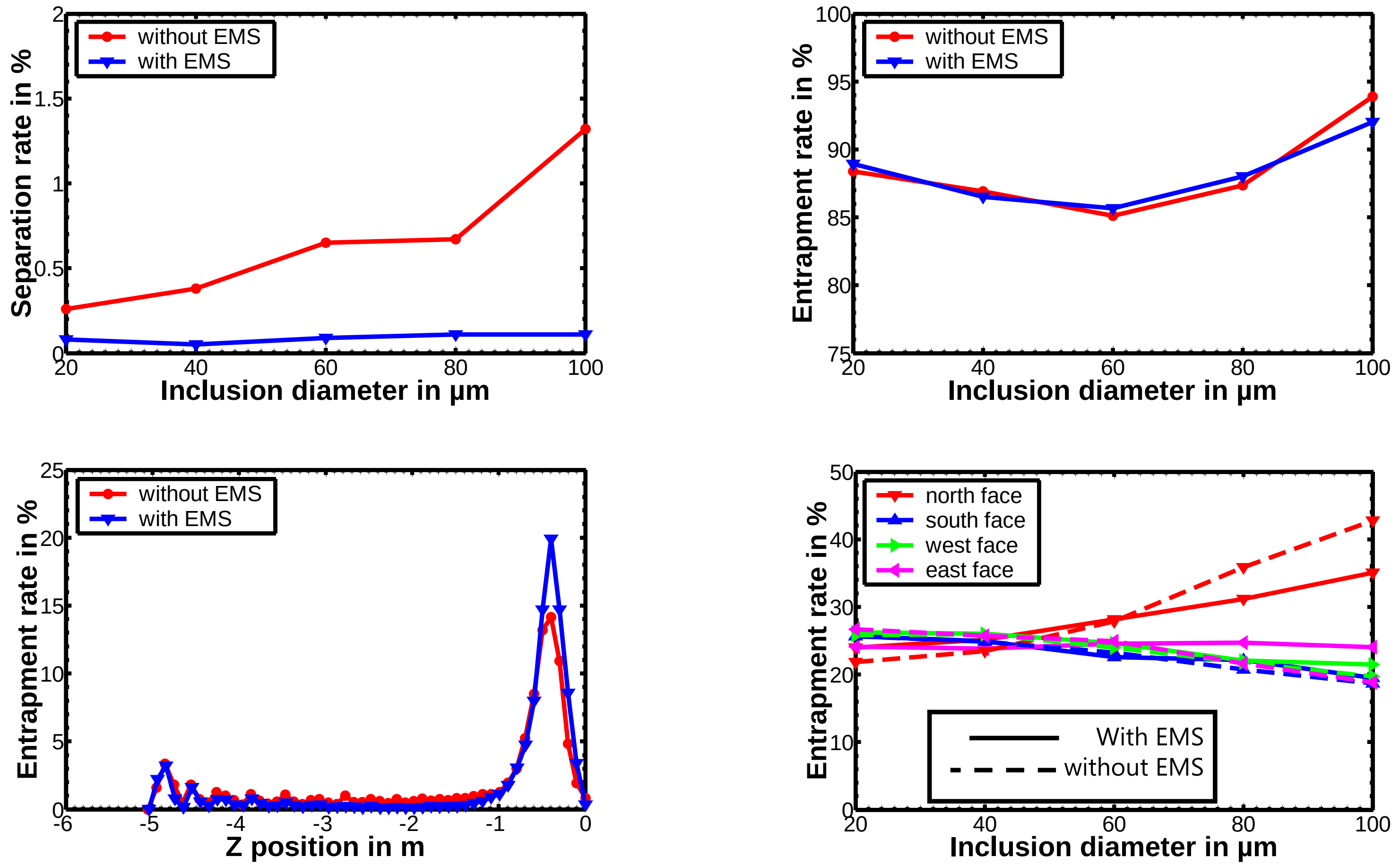
Measured magnetic field and computed forces and velocities





Results EMS (Billet caster)

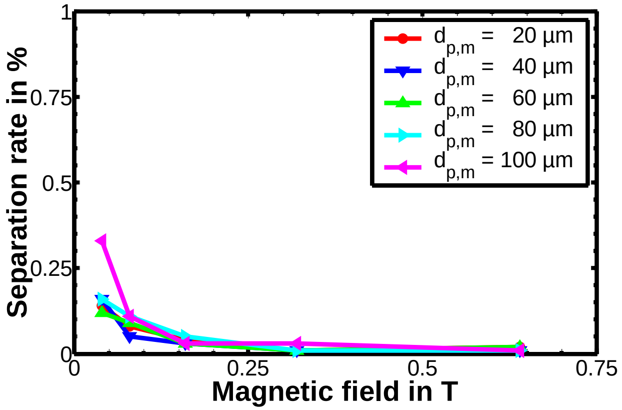
Numerically computed inclusion behaviour with and without EMS

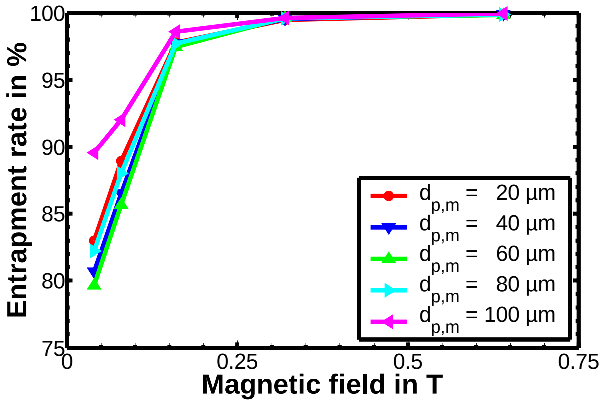


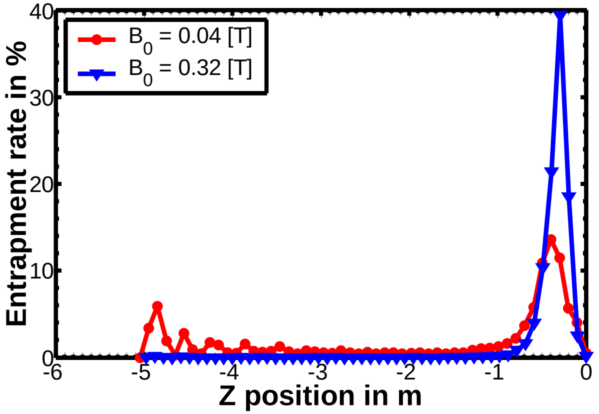
- Separation rate higher without EMS
- Entrapment rate similar with and without EMS
- Entrapment rate highest near mould level
- More uniform distribution of inclusions between the faces with EMS

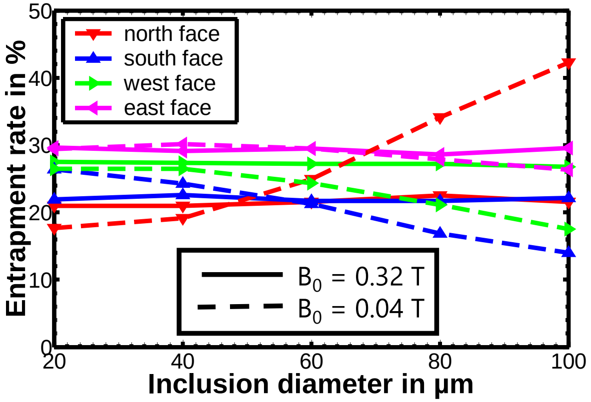
Results EMS (Billet caster)

Computed inclusion behaviour for varying magnetic field strength





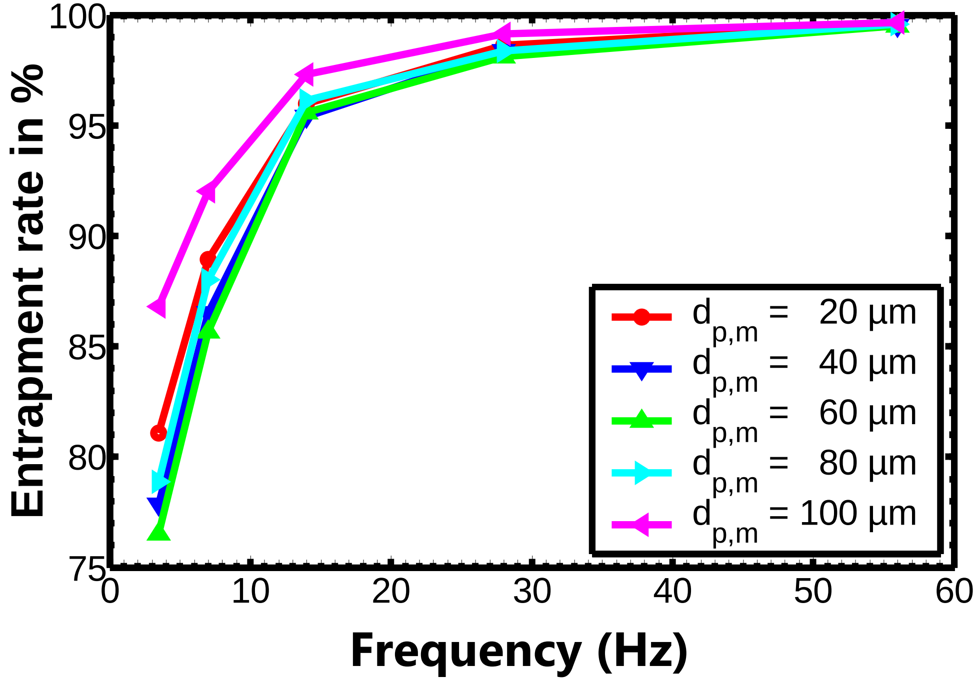


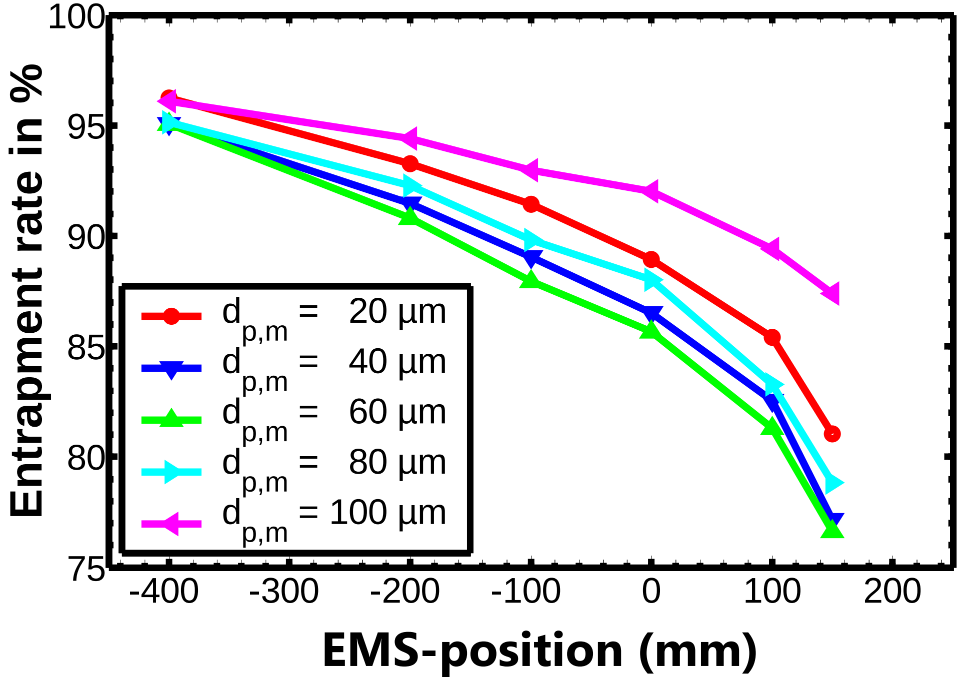


- Separation rate decreases with magnetic induction
- Entrapment rate increases with magnetic induction
- Entrapment rate increases especially near mould level with magnetic induction
- More uniform distribution of inclusions between the faces with high magnetic induction

Results EMS (Billet caster)

Computed inclusion behaviour for varying frequency and EMS-position





Conclusions EMBr

- Numerical computations can provide important information on physical processes concerning electromagnetic forces applied in continuous casting moulds.

- The influence of process parameters can be studied also taking into consideration extreme values of these parameters.

- A properly adjusted EMBr (position and power) can decrease near mould level flow velocities and level fluctuations and increase the separation rate.

Conclusions EMS

- The comparison of casting with and without EMS for the reference condition investigated shows that application of EMS is slightly decreasing separation rate but has no significant influence on inclusion entrapment.

- An EMS with a high magnetic field can decrease inclusion separation but increase inclusion entrapment.

- With a strong magnetic field it is possible to obtain a more even distribution of the inclusions entrapped in near the mould faces.

- Frequency and position of the EMS can influence inclusion entrapment significantly.

Outlook

- It is expected that due to the rapid development of soft- and hardware numerical simulation will become more important.
- The computation of more complex physical phenomena taking into consideration their simultaneous interaction will be possible more efficiently.
- Further work is envisaged concerning MHD effects with simultaneous solidification and structural dynamics.
- New and more detailed information is expected which will help to further optimise the continuous casting process.

Thank you for your attention!

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