



## Physics with Industry workshop 2022

### Title: Removal of unwanted particles/bubbles in liquid steel by using an injected electric current

#### 1. Company information

Tata Steel Nederland is one of Europe's leading steel producers. The company supplies high-quality steel products to the most demanding markets, including construction, automotive, packaging and engineering. Tata Steel Nederland works with customers to develop new steel products that give them a competitive edge. Tata Steel Nederland has sites in the Netherlands, Belgium, Germany and elsewhere in Europe and is part of the Indian Tata Steel Group, one of the world's largest steel companies. Tata Steel Nederland recorded a turnover of 4.3 billion euros in the financial year ending 31 March, 2021. Tata Steel Nederland is working on producing steel with zero carbon emissions by 2050. It will do so by switching to producing steel by using hydrogen instead of coal.

#### 2. Problem

An integrated steel plant, like Tata Steel IJmuiden, turns iron ore into steel using multiple process steps. During these steps non-metallic inclusions or bubbles can enter the liquid steel. These particles (inclusions, bubbles) can turn into surface defects or mechanical failures of the final product which are unwanted by the customer. The current steelmaking process does contain steps where most particles are removed but not all. To increase the removal rate of particles one can think of applying electromagnetic fields that enable the redistribution of particles [1] in such a way that they can be removed from the liquid steel. Besides using coils to create a magnetic field inside the liquid metal one can also introduce an electric current into the melt via electrodes. The electric current creates a magnetic field which interacts with the applied current resulting in a Lorentz force that can drive a fluid flow. This is the so-called electrovortex [2] flow and can be described using magnetohydrodynamics (MHD [3]). Particles in the liquid melt experience different forces [4]: drag, buoyancy, lift, magnetophoresis [5]. The magnetophoresis force follows from the Lorentz force that creates a pressure difference in the liquid metal surrounding the particles resulting in a net force acting on the particle. Depending on intensity and frequency of the pulsed current injection the induced alternating Lorentz force could produce sound waves [6] that can disperse particles [7].

During the Physics with Industry workshop, we would like the following questions to be addressed:

1. What are the dominant forces acting on the particle depending on particle size/density and current setting?
2. Can you derive a theoretical analysis, without actually calculating the fluid flow and particle positions using Computational Fluid Dynamics (CFD), that determines the particle behaviour given a certain current setting?

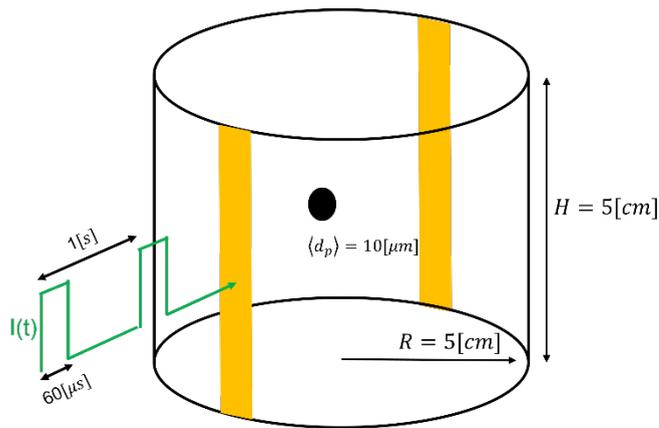


Figure 1 Cylindrical geometry of crucible equipped with electrodes and some characteristic values are indicated.

3. What are characteristic fluid velocities and time scales to remove particle given a certain treatment time, current setting, container length scale and particle size/density?
4. Can you identify some dimensionless numbers that can determine which physical mechanism drives particle migration?

Figure 1 gives an indication of the geometry and operating conditions in case of a small-scale experiment. Other operating conditions might be preferential, and the proposed analysis should be independent of these values. Such a simple geometry can help in carrying out a theoretical analysis. It is suggested to write down the relevant fluid flow and particle motion equations and determine the dominant terms. From there on, it is up to your creativity and ingenuity. You might end up with a small mathematical model that can be solved in Matlab.

In order to design industrial scale facilities that make use of electromagnetic fields to remove particles, one makes use of CFD simulations. The proposed theoretical analysis can help in determining which physical processes are dominant and should be included in the CFD model.

## References

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