Electrical Scale-Up of Metallurgical Processes

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Abstract

The problem under investigation is electrical scale-up of a metallurgical process where the slag is heavier than the metal. The process is powered by resistive heating in the slag and the current is fed through horizontal electrodes, typically AC three-phase controlled. A measure of how deeply the current penetrates the conductor is called skin depth or skin effect, and is a function of frequency, electrical conductivity and relative magnetic permeability of the conducting material in question. This effect is observed as frequency increases which makes the current mainly flow along the surface of the conductor. A non-dimensional analysis has been performed on Maxwell's equations to investigate how the skin depth is affected related to scale-up of the physical dimensions of the process geometry. The results show than a notable scale-up factor to be considered is (δ/L)^2, where the skin depth is denoted δ and L is the length of the appropriate physical dimension (length, width, height or a diameter).

Two simulation studies were performed in COMSOL Multiphysics® to verify the theoretical findings. The geometry utilized in the first simulation study was in 2D as depicted in Figure 1. The green circle denotes the cross section of the cylindrical tank containing the slag and the three electrodes, which are horizontally equiangular, are in black. Moreover, the tank was assumed to be enveloped by an artificial cylinder of air in order to perform suitable FEM numerical computations. The geometry was parameterized to easily investigate different dimensions of the geometry. The simulations were performed utilizing time harmonic A-V formulated eddy current model. The input to the model was given as normal current density homogenously distributed over the cross section of the electrodes. The frequency and physical dimensions of the geometry were changed according to the scale-up analysis, yielding simulation results supporting the theoretical findings. Figure 2 shows a plot of the current density norm over the geometry for 50 Hz current input, which was part of this study. Note that care should be taken when performing these kinds of simulations in 2D as the electrodes, which usually are cylindrical, now are considered as infinite plates. The magnetic field due to an infinite plate is proportional to current density and independent of the distance between the plates. This effect causes the difference in current distributions on each side of the electrodes as can be seen in Figure 2, and is dominant for lower frequencies.

Next, a full 3D model was implemented as depicted in Figure 3. The two top layers (alloy and gas phase) were removed and it was assumed that the top boundary layer to be a perfect

conductor i.e. with zero electric potential boundary condition. This is a reasonable approximation as most metals have much higher conductivity in liquid metal phase compared with the slag. A similar study as in the 2D case was performed yielding similar results, further supporting our findings.

Figures used in the abstract

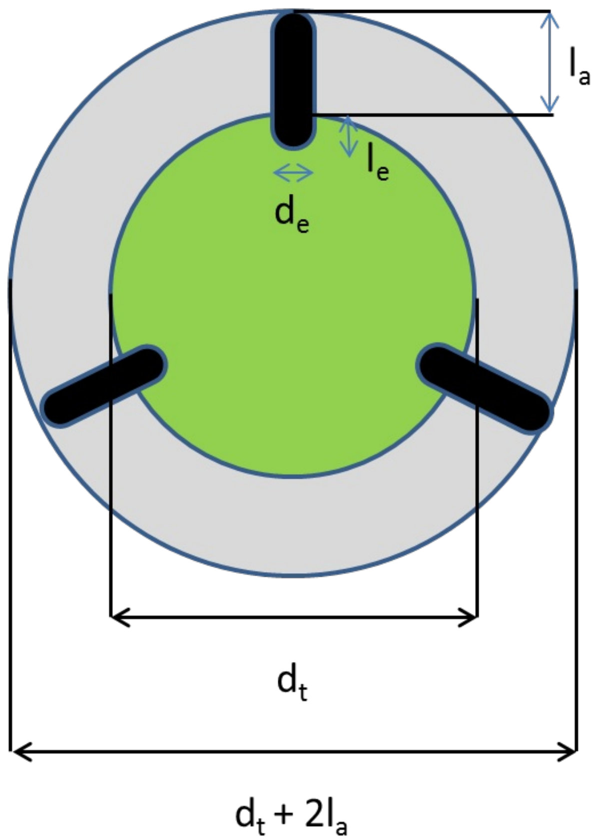

Figure 1: Top view of the process geometry, for the 2D simulations.

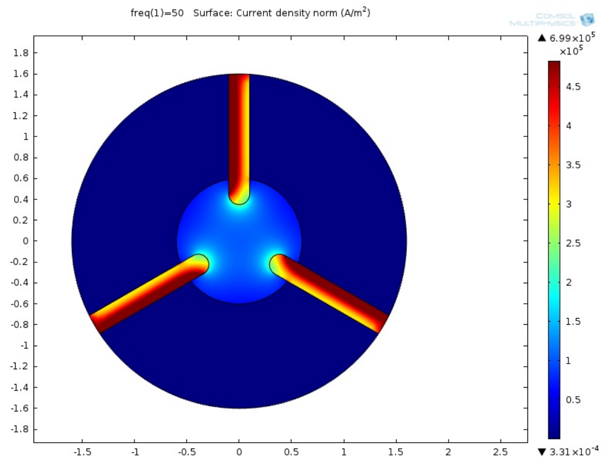

Figure 2: Plot of current density norm from 2D simulation at 50 Hz current input.

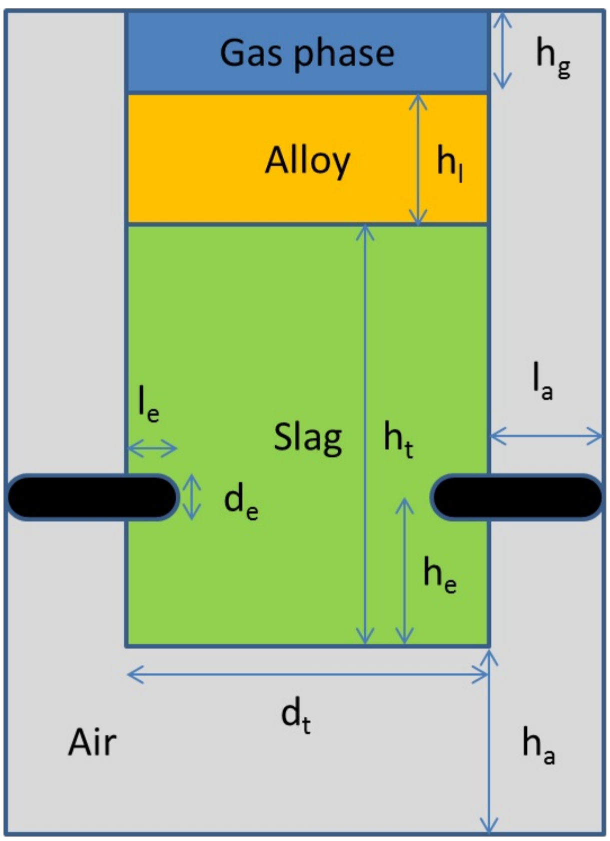

Figure 3: Side view of the process geometry.