K1-MET

Competence Center for Excellent Technologies in Advanced Metallurgical and Environmental Process Development

Main Location	Linz, Upper Austria
Other Locations	Leoben, Styria
Key topic	K1-MET has its focus on the modeling and simulation of metallurgical processes, including metallurgical raw materials and refractories with the goal of an optimal process control with respect to product quality, zero waste and the minimization of energy and raw materials.

Title

Influence of Marangoni convection on refractory wear

Success Story short version

Convective flow driven by interfacial tension gradients is thought to accelerate refractory wear at three phase contacts. From theoretical considerations corrosive mass transfer caused by this so called Marangoni convection can be estimated. Attempts to simulate the effect of Marangoni convection on refractory/slag mass transfer during a finger test were successful and are promising for industrial applications.

Success Story long version

Objectives

The determination of measures for refractory wear reduction necessitates knowledge and understanding of wear mechanisms and wear dominating influencing factors. The objective of this work is to evaluate the relevance of Marangoni flow with regard to refractory corrosion. Quantification of wear and weighting of the essential influencing parameters are aimed.

Approach

To investigate a possibly impact of Marangoni flow on refractory corrosion computational fluid dynamics calculations are performed. Due to the service conditions at refractory applications direct observation and even measurements are hindered or are not possible. The simulation approach allows to evaluate the prevailing conditions in dependence of various process parameters. Marangoni convection in the vicinity of three phase contacts refractory/slag/liquid steel or refractory/slag/air is caused by interfacial tension gradients due to concentration and/or temperature differences within the fluid. Therefore a multi-phase model including surface tension effects is required. To account for refractory corrosion a species transport model for diffusion of the dissolving refractory component into the slag is used. With the help of an user defined function concentration-dependent surface tension is defined. From time dependent simulation results corrosive mass transfer coefficients can be calculated for cases with and without consideration of Marangoni flow as well as for different process parameters. Thus conditions under which Marangoni convection contributes essential to refractory corrosion can be identified.

Results and Economic Impact

First attempts to simulate the effect of Marangoni convection on refractory/slag mass transfer were done for a laboratory test analyzing the slagging resistance of refractories, the so called finger test. The cylindrical refractory test sample is immersed into a cup filled with slag and is rotated to model bath movement like occurring in industrial application. Different rotational speeds can be applied to achieve more or less intense slag movement. Simulations were performed using an axisymmetrical model of the test assembly. Fig.1 shows resultant dimensionless mass transfer coefficients (Sherwood numbers Sh) as well as Marangoni numbers Ma for cases including Marangoni effect in dependence on Reynolds number Re for calculations with three different slags. The slags differ in their initial concentration of dissolving species. From slag A to C initial species concentration increases, so concentration difference to the saturation limit of the slag, that is driving the corrosion, decreases. For Sh and Re rod diameter is used as significant length and for Re circumferential velocity of the rod is used. Ma is calculated from surface tension difference, boundary layer thickness - calculated from resultant mass transfer coefficient – diffusion coefficient and slag viscosity. Obviously at higher Reynolds numbers associated to higher rotational speeds a higher mass transfer occurs. In case of slag A and B beneath a certain Re number higher Sh numbers for the calculations including Marangoni effect (dotted line) than in the cases without Marangoni flow (solid line) can be detected. For slag A the "critical" Re number under which Marangoni impact is obvious is about 71 corresponding to a rotational speed of 200 rpm. At 200 rpm no significant difference between the calculations with and without surface tension effects can be detected, consequently the impact of Marangoni convection is overwhelmed by the higher forced convection in this case. For slag C no significant impact of Marangoni flow is found indicating an insufficient difference in surface tension due to its already initially high species concentration.

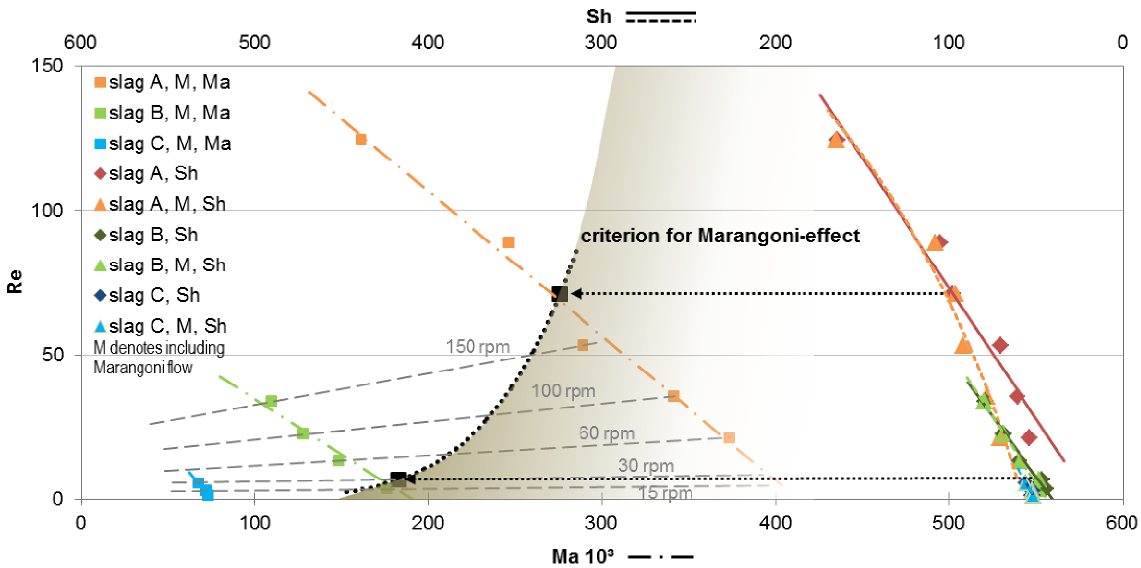

Fig.1: Sherwood and Marangoni numbers in dependence of Reynolds number resulting from simulations of the finger test for three different slags A – C.

The investigation shows that Marangoni flow contributes essentially to refractory wear if two conditions are fulfilled:

- Reynolds number is sufficiently low corresponding to a non-dominant forced convection
- Marangoni number is sufficient which means a sufficient driving force for Marangoni flow.

Using a theoretical consideration gives a mass transfer coefficient for a static finger test of about $4.16 \cdot 10^{-6}$ m/s. Mass transfer coefficients calculated by simulation are in the magnitude of 10^{-6} m/s as well although a forced convection exists additionally. This deviation can be explained by several assumptions made for the theoretical calculation.
This work shows that modeling and simulation can be used successfully as a tool to investigate effects where direct observations are impossible. The used approach for modeling surface tension effects gives reasonable results and is

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promising for industrial applications although further efforts have to be done to cope with the computationally costly calculations in case of large geometries.

Next Steps

Future work deals with the application of the modeling approach for industrial applications. The consideration of surface tension effects requires a high mesh resolution at phase contacts as well as specified solver settings. In combination with the necessary multi-phase approach including species transport and the time-dependent character of such simulations this results in computationally expensive time consuming calculations especially for large geometries. Thus following steps are planed:

- Identifying an appropriate modeling procedure for industrial applications.
  First attempt is using a sub-model of lower size comprising only the three phase contact areas with sufficient high mesh resolution for applying the model approach already used. Boundary conditions for the sub-model result from simulations of the whole aggregate that do not include surface tension effects and can be performed on a coarser mesh. A coupling of the two models may be done.
- Testing and adopting the modeling approach.
- Simulation of industrial used aggregates considering different process conditions.
- Deduction of measures for wear reduction from investigation results.

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