# Some Investigations into the Dynamic Mass Transfer at the Slag–Metal Interface Using Sulfur: Concept of Interfacial Velocity

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In the current work, dynamic studies of mass transfer of sulfur from the gas phase to the metal phase of pure iron through $CaO$-$SiO_2$-$Al_2O_3$-$FeO$ quaternary slag were carried out. X-ray videos were taken that were later processed to identify the oscillation of the metal drop occurring during the mass transfer. It was observed that the metal drop had hybrid oscillations. Each of these oscillations could be identified as composed of a symmetric and an asymmetric element, which was attributed to the changes in the shape of the droplet. The latter (asymmetric part) could be identified by the deviation of the left and right contact angles from the stable configuration. The symmetric oscillations were traced to the surface movement of sulfur at the interface, which created an instantaneous area change at the slag–metal interface. This area change was due to the combined effect of Marangoni flow and interface dilatation. The velocity of sulfur at the interface was calculated from the area change and had a maximum order of magnitude as $10^{-4}$ m/s. It was also observed that the interfacial velocity increased with increase in temperature.

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## I. INTRODUCTION

NUMEROUS investigations have been carried out on surface phenomena, especially surface tension and surface energies pertaining to both slag and metal/alloy systems.[1–5] Interfacial phenomena studies mainly focusing on Marangoni forces and interfacial tensions have also been dealt with extensively.[6–10] The potential drive for this extensive research is the importance of interfacial reactions in metallurgical process occurring during metal refining, degasification process, and slag entrapment. However, some issues with respect to the interfacial properties need to be addressed, *viz.* interfacial viscosities (both shear and dilatational). Currently, there has been no accurate measurement of these properties, although extensive studies have been carried out in colloidal systems. To the knowledge of the current authors, the only experiments to measure the surface shear viscosity were conducted by Popel *et al.*[11] and Hara *et al.*[12] using an oscillating method and rotating plate viscometer, respectively. The authors obtained different viscosity values as a function of immersion depth. However, because the interface is of only few atomic layers thick, the values obtained would strictly not represent the surface property but would be closer to the bulk values. To study these properties, it is highly essential to focus on dynamic interfacial phenomena as these properties involve changes in flow rates and interfacial areas.

The current work takes inspiration from the earlier works wherein it was reported that during intense mass transfer between two phases, low apparent interfacial tension resulted.[13–15] In these works, iron containing higher oxygen content was introduced into a slag–iron system that was maintained already at equilibrium at a lower oxygen level. A sharp decrease in the interfacial tension was observed caused by the surface-active oxygen and, consequently, was dependent on the oxygen content in the liquid iron. This difference later decreased but was stabilized at a lower interfacial tension. However, because the mass transfer involved a solid–solid interface, the question arises regarding the precision of the values obtained.

Another work along around which the concept of the present article revolves is that of Jakobsson *et al.*[16] In this work, mass transfer of sulfur from gaseous phase to a metal drop through an alumina-saturated $CaO$-$SiO_2$-$Al_2O_3$-$FeO$ slag to the metal sample (sulfurization process) was envisaged. In this work, the source of sulfur would be a gas. In this way, the errors involved by mixing and other similar phenomena were reduced. It was observed using an X-ray source that, under dynamic conditions, the drop shape changed because of the sulfur movement along the interface and into the bulk of the drop. The property "interfacial velocity" using sulfur

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