Title	Control of Concentration Boundary Layer Development by Time-Varying Electromagnetic Force Imposition near Solid-Liquid Interface [an abstract of dissertation and a summary of dissertation review]
Author(s)	XU, Guangye
Citation	北海道大学. 博士(工学) 甲第15347号
Issue Date	2023-03-23
Doc URL	http://hdl.handle.net/2115/89488
Rights(URL)	https://creativecommons.org/licenses/by/4.0/
Type	theses (doctoral - abstract and summary of review)
Additional Information	There are other files related to this item in HUSCAP. Check the above URL.
File Information	XU_Guangye_abstract.pdf (論文内容の要旨)

学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　博士（工学）　氏名　XU Guangye

学 位 論 文 題 名

Control of Concentration Boundary Layer Development by Time-Varying Electromagnetic Force Imposition near Solid-Liquid Interface
(固液界面近傍への振動電磁気力の印加による濃度境界層の制御)

For solid-liquid chemical reactions, the mass transfer in a concentration boundary layer formed near the solid-liquid interface is often the rate-determining step. The mass transfer in it depends on diffusion and convection. The former positively relates to the diffusion coefficient and the concentration gradient. The diffusion coefficient control is difficult because it is one of the physical properties. Increasing the concentration gradient is an effective way to enhance the mass transfer. Convection increases the concentration gradient because it decreases the concentration boundary layer thickness by introducing the liquid with the initial concentration from the bulk region to the adjacent region of the solid-liquid interface. Therefore, a flow excitation in the bulk region has been used as traditional methods to enhance the mass transfer.

By exciting the flow in the bulk region, a velocity boundary layer forms near the solid-liquid interface because the velocity at the solid-liquid interface should be 0. The concentration boundary layer is usually thinner than the velocity boundary layer. The flow in the concentration boundary layer must be weak and it reduces the efficiency of enhancing the mass transfer. Thus, a strong force imposition in the bulk region is required. This degrades product qualities. The involvement of slags into a liquid metal in a refining process of the metallurgical industry and the void formation in the deposition layer in an electroplating process of the surface treatment industry due to the strong force imposition in the bulk region have been reported.

A new method was proposed to avoid these problems, which directly excited the flow in the concentration boundary layer by imposing an electromagnetic force. Because the force is induced by superimposing an electrical current and a magnetic field, this method is a powerful candidate for enhancing the mass transfer in industrial processes, such as the refining process in the metallurgical industry and the electroplating process in the surface treatment industry.

Regarding the newly proposed method, a Cu^{2+} aqueous solution system was used to visualize the time-variation of the concentration boundary layer. The results found that the concentration boundary layer development was suppressed by imposing the electromagnetic force without a time-varying component compared to that by imposing only the current at a point above the solid-liquid interface. The concentration boundary layer development was further suppressed at the same position by imposing a time-varying electromagnetic force. These results proved that the time-varying electromagnetic force imposition might be a promising method to enhance the mass transfer. However, because the solid-liquid interface in industrial processes is usually a plane, the result evaluated at one point is not enough to optimize the condition for enhancing the solid-liquid chemical reaction, and the clarification of whether the concentration boundary layer development could be suppressed or not in a plane above the whole solid-liquid interface by imposing the electromagnetic force is required. Therefore, the objectives of this dissertation are: (1) To study the concentration boundary layer development in a plane above the whole solid-liquid interface under the electromagnetic force imposition; (2) To optimize the condition of the solid-liquid chemical reaction enhancement by controlling the operating parameters of the electromagnetic force; (3) To study the mechanism of the time-varying electromagnetic force on suppressing the concentration boundary layer development.

The outline of this dissertation is as follows:

Chapter 1 describes the problem statement and the objectives of this dissertation.

The objective of chapter 2 is to investigate the concentration boundary layer development in a plane above the whole solid-liquid interface by evaluating the time variation of the solute concentration. By imposing only the current, the solute concentration increased with time, because of the dissolution of the solid into the liquid. In addition, the non-uniform solute concentration distribution with higher solute concentration near the side parts than that near the middle part was observed, because of the current concentration near the side parts. By imposing the electromagnetic force without the time-varying component, the increase of the solute concentration was suppressed. This means that the concentration boundary layer development was suppressed, because of the excitation of a macro-scale flow in the whole vessel. The high solute concentration was observed near the side parts of the solid-liquid interface because of the formation of stagnant zones near the side parts. In addition, the concentration boundary layer development was further suppressed by imposing the time-varying electromagnetic force, and the solute concentration uniformly distributed in the measurement plane. These were because of the enhancement of the macro-scale flow development and the excitation of a micro-scale flow near the solid-liquid interface.

The objective of chapter 3 is to optimize the condition for enhancing the solid-liquid chemical reaction by studying the effect of the time-varying electromagnetic force frequency on the concentration boundary layer development. The results showed that the development of the concentration boundary layer was suppressed by decreasing the time-varying electromagnetic force frequency because of the enhancements of the macro-scale flow development and the micro-scale flow development.

The objective of chapter 4 is to investigate the mechanism of the time-varying electromagnetic force imposition on suppressing the concentration boundary layer development by studying the reason for the micro-scale flow excitation. The micro-scale flow was excited due to the non-uniform electromagnetic force distribution near the solid-liquid interface caused by the non-uniform solute concentration distribution and the positive relationship between the solute concentration and the electrical conductivity. By imposing the time-varying electromagnetic force, the non-uniform solute concentration distribution was enhanced. Therefore, the micro-scale flow development was enhanced. Decreasing the time-varying electromagnetic force frequency or increasing the time-varying electromagnetic force amplitude further enhanced the micro-scale flow development.

Chapter 5 is the general conclusions of this dissertation.

Overall, the results of this dissertation prove that the imposition of the time-varying electromagnetic force is a promising way to enhance the solid-liquid chemical reaction. Compared to that by imposing the electromagnetic force without the time-varying component, the flow development is enhanced in both the macro-scale and the micro-scale. In addition, the flow can be controlled by controlling operating parameters. Therefore, the control of concentration boundary layer development by controlling operating parameters of the time-varying electromagnetic force is expected. These results are useful to optimize the condition of solid-liquid chemical reaction enhancement in industrial processes.