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Thesis outline

Study on Remote Elemental Analysis System for Aqueous Solutions using Sonoluminescence

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This dissertation focuses on a study on a qualitative remote elements analysis system using a well-known ultrasonic phenomenon, namely sonoluminescence (SL), which emits light with specific wavelengths depending on the elements of the targeted aqueous solutions. The study's basis is that after the TEPCO's Fukushima nuclear power plant accident, the contaminated water remains one of the crucial problems. The harsh condition inside the reactor complicates the challenges; among the existing quantitative elemental analysis that requires sample transportation outside the reactor, a complementary remote elemental analysis is required. The dissertation aims to study the remote elemental analysis using SL. The dissertation consists of 5 chapters, as summarized below.

Chapter 1, "Introduction."

As stated above, post-TEPCO's Fukushima accident, contaminated water remains one of the crucial problems. Some elemental analysis methods have been proposed to tackle the problem. However, the high radiation conditions inside the reactor become the primary concern. For this, remote analysis is required. Moreover, an application of *in-situ* analysis could accelerate obtaining the elemental information inside the reactor by remote analysis. Ultrasound is known to have high radiation durability as it had been used in the three-mile island post-accident investigation, and the size of the ultrasonic transducer is suitable for remote *in-situ* analysis. Therefore, this dissertation aims to clarify the feasibility of the remote elemental analysis system for aqueous solutions using sonoluminescence. The study aims for qualitative analysis; the quantitative results presented in this dissertation are used to understand the phenomenon better. As a fundamental investigation process, SL emissions in ideal closed conditions are investigated from SL's viewpoint for the use

for elemental analysis. Moreover, for remote analysis, the system's mobility and versatility in various situations such as an open situation and the existence of a flow are required. SL analysis with the mobile system using an external transducer in an open condition is conducted. The versatility of the system in the presence of flow is examined. Furthermore, an analysis using the developed spectroscopic system in aqueous solutions is carried out based on the previous findings, and the feasibility of the remote elemental analysis system for aqueous solutions using sonoluminescence was clarified.

Chapter 2, "Sonoluminescence Characteristics in Closed Condition into the Use for Elemental Analysis"

This chapter explains the essential characteristics of SL for its uses in elemental analysis. The SL is known to undergo high- and low-pressure phases due to ultrasonic sonication in the liquid corresponding to the ultrasonic wave. The pressure changes lead to bubbles' formation, expansion, and collapse. The presence of argon in the solution presumably led to plasma formation and light emission. In this study, the experiment was conducted using a bath-type ultrasonic transducer for analyzing various elements. Photographs of each element were taken in dark environments using a still camera with a long exposure technique. An image analysis algorithm was developed, mainly for color categorizing the experiment results. The image categorization algorithm was developed based on HSV (hue-saturation-value) color scheme. The main reason for choosing the analysis based on this characteristic among other color schemes is that HSV only has one color dimension, and the value directly represents the intensity of each color. The SL intensity analysis was based on normalizing the total number of values of corresponding H. The image taken allowed 2-dimensional observations of SL behavior. The chapter mainly focuses on parameters affecting SL, such as power, frequency, concentration, and argon gas treatment. The chapter contains demonstrations of SL showing the standing wave pattern under ultrasound sonication. Further test on the relation between solution concentration and SL intensity, proportional relation was obtained. Also, the parametric study showed that the SL intensity increases with the increase of ultrasonic frequency and power, and the continuous injection of argon gas extended the detection limit. Furthermore, for elemental analysis, SL shows specific colors for each element, confirming the feasibility of qualitative elemental analysis.

Chapter 3, "Sonoluminescence Characteristics in Open Condition with Mobile System using an External Transducer"

Although the SL shows the potential for use as elemental analysis in the previous chapter, the relatively big bath-type transducer is impractical. Therefore, this chapter aims to fulfill one of the requirements to enable remote analysis: mobile ultrasonic transmission to produce SL. The study mainly focuses on analyzing the performance by constructing a mobile ultrasonic transmitter system using an external transducer. The experimental setup consisted of 2 main systems, an ultrasound transmission to produce SL and a light analysis system. The former consists of a single Langevin transducer, function generator, and power amplifier, while the latter mainly uses a still camera with a long exposure technique and image analysis algorithm, as explained in chapter 2. This chapter studied the open environment effect, the direct solution contact, and the containers' size. The results show that SL characteristics generated in this condition with the parameter changes are similar to those in the closed system. The study on the container size effect reveals the intensity decreased with the increase of the distance between source and wall due to the reduction of the system's source and wall surface pressure. Finally, the visualization of SL of various elements using an external transducer was confirmed. Further comparison with the closed system reported that the standing wave was still observed in the presence of the wall, and the color obtained was the same. However, slightly higher uncertainties such as intensity and color distribution were observed compared with the closed system. Furthermore, the existence of flow inside the reactor is inevitable; therefore, the versatility test of the SL behavior with the presence of flow is investigated. Photograph results showed a broadening of SL emissions points due to the flow of the solutions. An investigation of the SL bubbles' formation, expansion, and collapse process on the flow was conducted with an ultrasonic velocity profiler (UVP). The result showed that disturbances in the flow were observed with the SL operation. SL power, flow rate, and distance between the SL and UVP system highly affect the flow disruption. The optimum flow rate and SL power combination were also evaluated, and it can be concluded that the operating area of the current setup is in laminar and transitional flow conditions.

Chapter 4, "Evaluation of Remote Elemental Analysis System for Aqueous Solutions using Sonoluminescence"

This chapter aims to clarify the feasibility of the remote elemental analysis system for aqueous solutions using sonoluminescence. The remote ultrasound transmission using an external transducer and light analysis using optical lenses and optical emission spectrometer were combined. The SL spectrum analysis system was performed based on the standard principle of an optical emission spectrum analysis to analyze the chemical components of the solution. The focusing optical system consists of convex lenses, a multimode optical fiber bundle, and a Czerny-Turner spectrometer. The experiment was preceded by aligning the optical fiber and lenses. The analysis of various elements showed that the peaks are in good agreement with the wavelength presented in the reference. Also, light transmission using optical fiber fulfills one of the requirements of remote analysis, which is to analyze the SL emission remotely. Further study on the limit of detection of the current setup is approximately 7 g/l with an average yield of approximately 8%. Although the limit of detection is relatively high, the findings in this dissertation satisfied the purpose of the dissertation and fall under the specified scope of the study. This being said, the feasibility of the qualitative remote elemental analysis system for aqueous solutions using sonoluminescence was clarified.

Chapter 5. "Conclusions"

Overall achievements of the dissertation and conclusions from each chapter were summarized. The summary includes the results, limitations, and recommendations for possible improvements. The recommendations such as limit of detection, quantitative analysis, and presence of high-density particles were added to the dissertation. Although some improvements are recommended for more extensive analysis, the feasibility of the remote elemental analysis system for aqueous solutions using sonoluminescence was clarified.