I-1. PROJECT RESEARCHES

Project 1

PR1

Development of Neutron Imaging Application

Y. Saito

Institute for Integrated Radiation and Nuclear Science, Kyoto University

OBJECTIVES and ALLOTED RESEARCH SUBJECT: Neutron imaging provides valuable information which cannot be obtained from an optical or X-ray imaging. The purpose of this project is to develop the imaging method itself and the experimental environment for expanding the application area of neutron imaging. The allotted research subjects are as follows:

ARS-1: Measurements of Boiling Two-Phase Flow Dynamics in a Heated Tube (D. Ito et al.)
ARS-2: Void Fraction of Silicon-oil Flow with Microbubbles in Horizontal Tube (H. Asano et al.)
ARS-3: Adaptation of Neutron Radiography for the Evaluation of Two-phase Flow (H. Umekawa et al.)
ARS-4: Observation of Condensation on a Single Flat Tube (R. Matsumoto et al.)
ARS-5: An integrated neutron radiography-based observation of spalling behavior in concrete containing ground granulated blast furnace slag (M. Kanematsu et al.)
ARS-6: Visualization of the Reactant Solution Distribution in a Mixer of a Super-critical Hydrothermal Flow-Type Reactor Using Gd3+ Ion Solution as a Tracer (S. Takami et al.)
ARS-7: Visualization of Root Water Uptake in Organic Substrates through Three-Dimensional Root Reconstruction from Cylindrical Panoramic Imaging (U. Matsushima et al.)
ARS-8: In-situ Observation of Lithium Migration in Solid Electrolyte by Using Neutron Radiography (S. Takai et al.)
ARS-9: Measurement of coolant distribution in a flat laminate vapor chamber utilizing neutron radiograpy (K. Mizuta et al.) (not performed)

MAIN RESULTS AND THE CONTENTS OF THIS REPORT:
ARS-1 performed visualization of boiling two-phase flow by high-speed imaging. A stainless-steel tube with an inner diameter of 7mm was electrically heated and the boiling two-phase flow was observed in the tube by high-speed neutron imaging at 1,000 fps.
ARS-2 applied to neutron imaging to void fraction measurements of silicone oil/gas two-phase flow to investigate the effect of void distribution on the heat transfer characteristics. From measurement results, at flow rate of 1.0 l/min, the bubbles appeared to flow more in the upper region due to buoyancy, but at 2.0 l/min, they were observed to be homogeneously dispersed.
ARS-4 evaluates the condensation on a single flat tube. In this experiment, dropwise condensation was observed by neutron imaging, and as the droplets grew and coalesced, increasing in size, their downward motion due to gravity was observed.
ARS-5 investigates the integrated neutron radiography-based observation of spalling behavior in concrete containing ground granulated blast furnace slag.
ARS-6 visualized the reactant solution distribution in a mixer of a supercritical hydrothermal flow-type reactor using Gd^{3+} Ion solution as a tracer.
ARS-7 combined a three-dimensional (3D) root surface model reconstructed from cylindrical panoramic photographs with neutron D_2O absorption images, enabling non-destructive correlation of root position with water uptake in organic substrates.
ARS-8 applied the electric field to the model cell to observe the lithium migration in the solid electrolyte through neutron imaging.
ARS-9 intended to investigate the coolant distributions in a flat vapor chamber by using neutron radiography, however, the experiments were not performed in this year.

PR1-1

Measurements of Boiling Two-Phase Flow Dynamics in a Heated Tube

D. Ito[1], T. Ami[2], N. Odaira[1], Y. Saito[1] and H. Umekawa[2]

[1] *Institute for Integrated Radiation and Nuclear Science, Kyoto University*
[2] *Kansai University*

INTRODUCTION: Neutron radiography (NRG) is a powerful technique for visualizing multi-phase flow phenomena. It has been widely applied to thermal-hydraulic studies, including boiling two-phase flows and void fraction measurements. In addition to steady boiling flows, NRG is especially useful for investigating highly transient phenomena such as reflooding during emergency cooling processes. Reflooding is a key process in nuclear reactor safety, where cooling water re-enters a heated channel and quenches the overheated surface. The complex interaction between liquid penetration, vapor generation, and quenching front propagation remains not fully understood due to limited visualization techniques in opaque structures. The objective of this study is to visualize and quantify the reflooding process in a heated tube using high-speed neutron imaging.

EXPERIMENTS: Neutron imaging experiments were conducted at the B-4 facility of Kyoto University Research Reactor (KUR). A high-speed imaging system consisting of an optical image intensifier coupled with a high-speed camera was used to capture neutron transmission images at 1000 fps. A stainless-steel tube with an inner diameter of 7 mm was used as the test section. The tube was electrically heated by Joule heating using a DC power supply. After reaching a high-temperature condition, cooling water was injected into the test section to initiate the reflooding process.

RESULTS: The instantaneous neutron transmission images during the reflooding process are shown in Fig. 1. At the onset of water injection, a sharp decrease in void fraction is observed near the inlet, indicating the penetration of the liquid front. The liquid front propagates upward along the tube, accompanied by complex vapor-liquid interactions. Behind the quenching front, intermittent vapor generation and condensation behavior are observed. The high-speed NRG successfully captured these rapid transient behaviors, demonstrating its capability to visualize reflooding phenomena inside opaque metallic channels. These results indicate that high-speed neutron imaging is an effective tool for investigating the detailed mechanisms of reflooding, including liquid front dynamics and transient vapor structures.

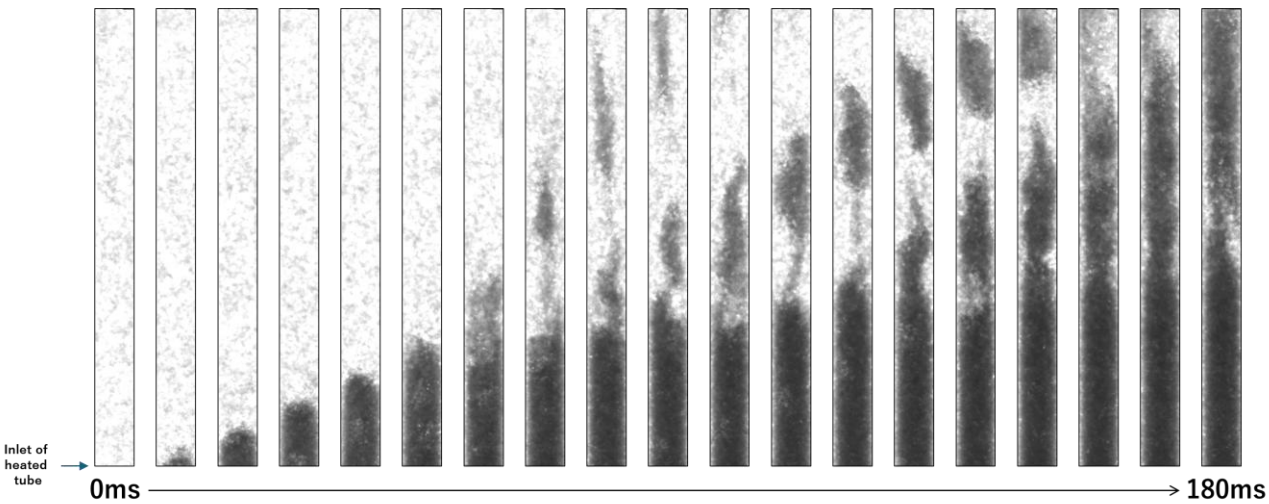

Fig.1. Instantaneous neutron transmission images during the reflooding process.

Void Fraction of Silicon-oil Flow with Microbubbles in Horizontal Tube

H. Asano[1], H. Murakawa[1], K. Sugimoto[1], S. Yoshimori[1], N. Yoshida[1], K. Nakagawa[1], G. Akiyoshi[1], E.S. Dzramado[2], J. Inukai[2], N. Odaira[3], D. Ito[3] and Y. Saito[3]

[1]*Graduate School of Engineering, Kobe University*
[2]*Hydrogen and Fuel Cell Nanomaterials Center, University of Yamanashi*
[3]*Institute for Integrated Radiation and Nuclear Science, Kyoto University*

INTRODUCTION: A method to reduce frictional resistance by adding microbubbles to the lubricating oil in automotive cooling systems is under investigation. In our previous research, we measured the heat transfer coefficient and pressure loss in horizontal pipe flow and found that no significant effect on pressure loss was observed in the laminar flow region. However, the results showed that adding microbubbles at a gas volumetric flow rate ratio above a certain threshold improved the heat transfer coefficient. The measurement results of the channel cross-sectional average void fraction by using an electrostatic capacitance sensor showed that, at low gas volumetric flow rate ratio, the void fraction was lower than the gas volumetric flow rate ratio; however, at high gas volumetric flow rate ratios where an increase in heat transfer coefficient was observed, the void fraction became higher than the gas volumetric flow rate ratio. This is considered to be because bubbles flowed not only along the center of the tube but also along the tube wall, where the liquid velocity is lower. Therefore, to clarify the distribution of microbubbles in the channel, visualization experiments using neutron radiography were conducted.

EXPERIMENTS: Silicone oil was used at 36℃. Dry air from an air cylinder was injected upstream of the test section, and microbubbles were generated by the strong shear forces produced by rotational stirring. The bubble diameter measured in preliminary experiments was approximately 90 μm, based on the Sauter mean diameter. A stainless-steel tube with an inner diameter of 3 mm and a wall thickness of 0.5 mm was used to visualize the flow within the horizontal tube. The temperature of the silicone oil was set to 36°C to match the dynamic viscosity coefficient (8.07 mm²/s) of the lubricating oil at 80°C in the actual equipment.

RESULTS: Brightness distribution perpendicular to the tube axis is shown in Fig. 1. The right side of the horizontal axis represents the top of the pipe. These are average values over a 260-pixel (4.42 mm) section along the axis. No changes in the brightness distribution were observed at a gas volumetric flow rate ratio of 10% or less for 1.0 *l*/min, or at 12% or less for 2.0 *l*/min, respectively. The reason is that silicone oil has a high gas absorption capacity, and the pressure in the measuring section was higher at the higher flow rate. At a flow rate of 1.0 *l*/min, the bubbles appeared to flow more in the upper region due to buoyancy, but at 2.0 *l*/min, they were observed to be homogeneously dispersed. However, in this experiment, the presence or absence of bubbles near the tube wall could not be confirmed.

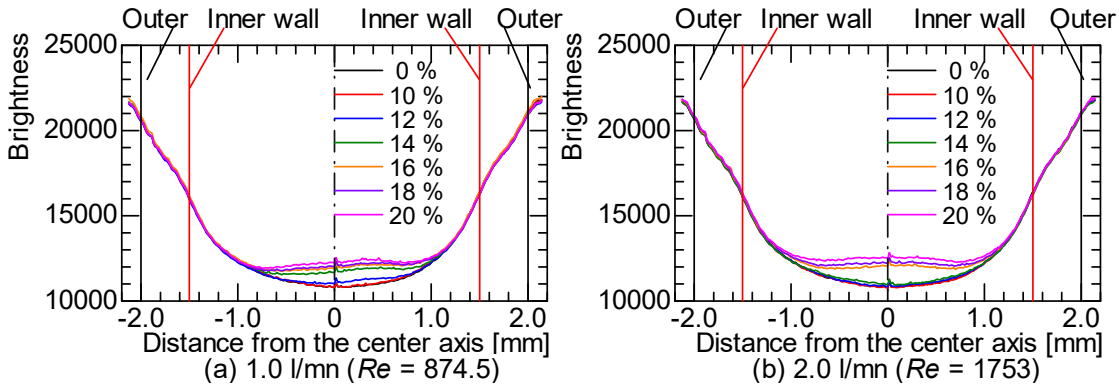

Fig. 1 Brightness distribution perpendicular to the tube axis.

PR1-3

Adaptation of Neutron Radiography for the Evaluation of Two-phase Flow

H. Umekawa[1], K. Nakamura [1], N. Matsuda [1], A. Nanno [1], D. Ito[2], N.Odaira[2] and Y. Saito[2]

[1] *Department of Mechanical Engineering, Kansai University.*
[2] *Institute for Integrated Radiation and Nuclear Science, Kyoto University.*

INTRODUCTION: Rapid cooling of high-temperature and high-heat-flux materials is a key issue in several industrial fields, such as nuclear power plants, electronic devices and metal processing. In these applications, a detailed understanding of film boiling is required. For effective rapid quenching, continuous supply of cooling liquid, and the continuous removal of generated vapor should be achieved. In this study, to clarify the fundamental characteristics of these phenomena, the quenching of bottom-closed heated pipe was visualized using thermal neutron radiography.

EXPERIMENTS: In this investigation, the three kinds of bottom-closed tubes with inner diameters of 4mm, 6mm and 8mm were heated to a predetermined temperature (800 deg.C), after which water was injected from the top of the tube. During the quenching process, wall temperatures were recorded, and internal flow behavior was dynamically visualized using neutron radiography.

RESULTS: Figure 1 shows the visualization results during the quenching process. These figures correspond to the sequential images around the quenching time indicated by thermocouple (TC1). In these figures, especially at the bottom re-gion of 6mm and 8mm tubes, inverted annular flow regime can be observed clearly. Figure 2 is time-strip image whole quenching process. In this figure, quench front line can be evaluated, and these lines show good agreement with the estimation by temperature trend. Moreover, occurrence of flooding can be ob-served near the bottom region of 6mm and 8mm tubes.

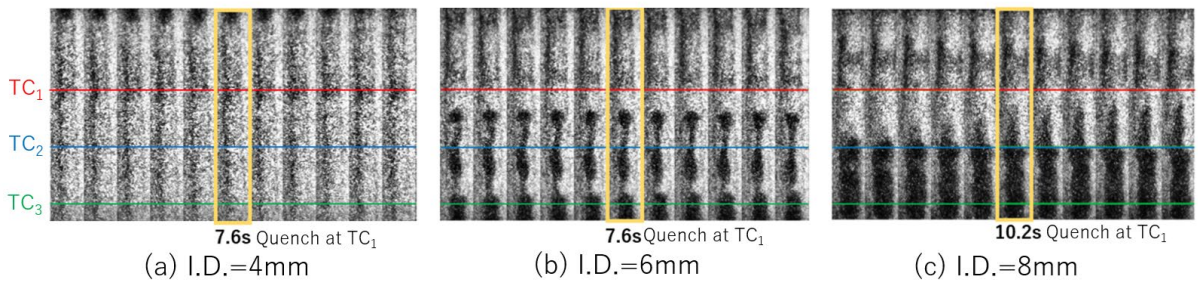

Fig.1 Sequential Images of Quenching Phenomena around TC1 (1000fps).

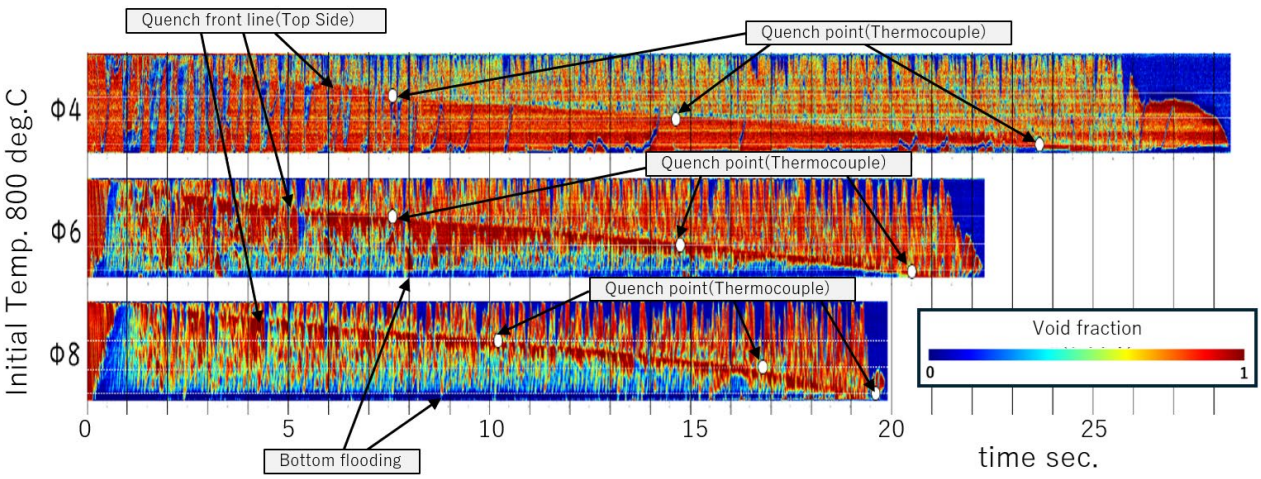

Fig.2 Time-strip Image of Quenching Phenomena.

PR1-4

Observation of Condensation on a Single Flat Tube

K Ikawa [1], R. Matsumoto [1], N. Fujikawa [1], Q. Chu [1], Y. Saito[2] D. Ito[2] and N. Odaira[2]

Graduate School of Science and Engineering, Kansai University
[1]Faculty of Engineering Science, Kansai University
[2]Institute for Integrated Radiation and Nuclear Science, Kyoto University

INTRODUCTION: The development of heat exchangers employing aluminum flat tubes for outdoor units of heat-pump air conditioners has been progressing. Although aluminum has a lower thermal conductivity than copper, which has traditionally been used as a heat-exchanger material, its light weight and ease of forming allow for the miniaturization of refrigerant flow channels. Reducing the channel diameter increases the heat-transfer surface area and decreases the required refrigerant charge.

Because aluminum is hydrophilic, condensation occurs when exchanging heat with ambient air, leading to filmwise condensation in which a continuous liquid film forms on the surface. When filmwise condensation develops on the heat-exchanger surface, the liquid film introduces additional thermal resistance and reduces the heat-transfer coefficient. Moreover, partial blockage of the airflow path by the condensate disturbs the air stream and increases pressure loss, ultimately degrading the heat-exchange performance. In general, heat exchangers employ fins to secure sufficient heat-transfer area; however, the complex fin geometry makes it difficult to analyze condensation behavior as a simple phenomenon.

Therefore, in this study, condensation experiments are conducted on a single flat tube as a fundamental investigation, with the objective of measuring the condensation distribution and liquid-film thickness.

EXPERIMENTS AND RESULTS: A single flat tube with a width of 18.6 mm and a thickness of 2 mm was vertically installed, and a refrigerant at 0 °C was circulated inside the flat tube to cool its surface temperature. An experiment was then performed with humidified ambient air to form a condensate film on the tube surface. The experiment was conducted for approximately 40 minutes, during which the behavior of the liquid film was observed.

The condensate water distribution image after 40 minutes obtained by neutron radiography is shown in Fig. 1. Because the amount of moisture supplied to the air was small, filmwise condensation did not occur. Instead, dropwise condensation was observed, and as the droplets grew and coalesced, increasing in size, their downward motion due to gravity was observed. This periodic coalescence resulted in intermittent downward flow within the liquid film, as confirmed during the observations.

The behavior of condensate can be observed using neutron radiography.

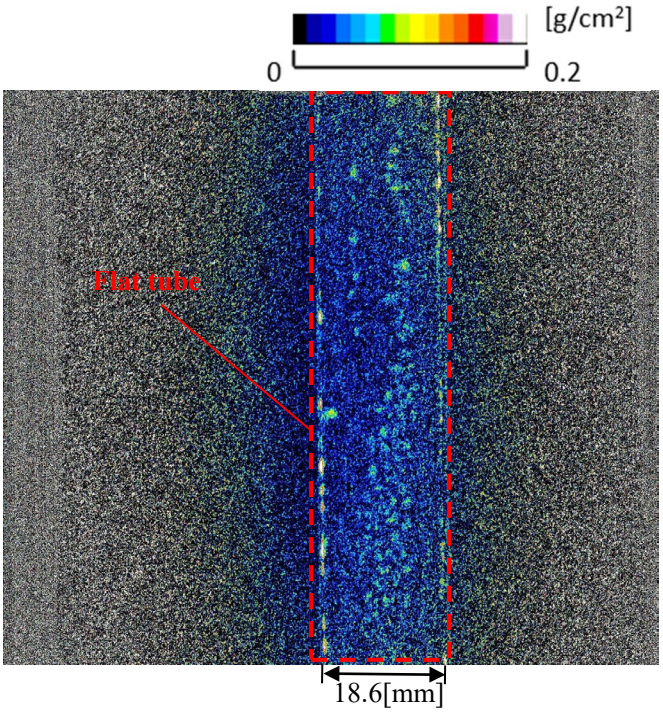

Fig.1 Condensate water distribution on a flat tube.

PR1-5

An integrated neutron radiography-based observation of spalling behavior in concrete containing ground granulated blast furnace slag

A. Toyoshima[1], M. Kanematsu[1], Y. Nishio[2], J. Kim[1], N. Odaira[3], D. Ito[3] and Y. Saito[3]

[1]*Department of Architecture, Tokyo University of Science*
[2]*Building Research Institute*
[3]*Institute for Integrated Radiation and Nuclear Science, Kyoto University*

INTRODUCTION: Understanding moisture behavior in concrete during fire exposure is essential for elucidating the spalling mechanism [1]. In this study, heating experiments were conducted on concrete containing ground granulated blast furnace slag using neutron radiography for integrated observation. The influence of the admixture on spalling was investigated based on temperature, pressure, and moisture conditions within the concrete.

EXPERIMENTS: Concrete specimens (70×100×30 mm) with a water-to-binder ratio (W/B) of 22% are prepared. Two mix conditions were considered: one using ordinary Portland cement (N) and the other in which 40% of the binder was replaced with ground granulated blast furnace slag (BB). Temperatures and internal pressures were measured at the positions shown in Fig.1. The specimens were heated from the bottom surface using a quartz heater. Neutron radiography was performed at B-4 port of KUR.

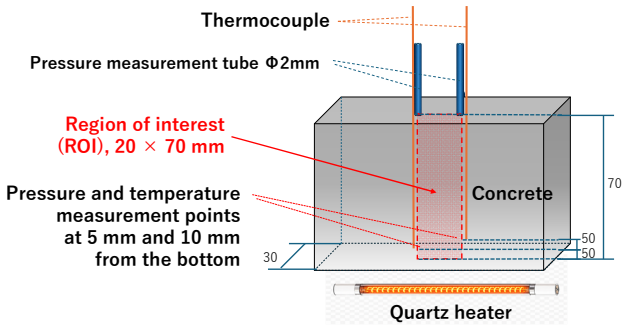

Fig. 1 Outline of concrete specimen

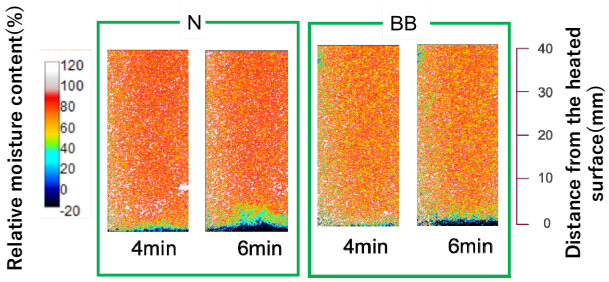

Fig. 2 change in relative moisture content

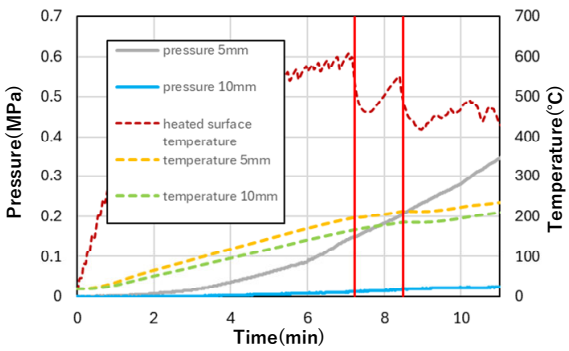

Fig. 3 Relationship between pressure and temperature in concrete under heating (BB)

RESULTS: Fig. 2 and Fig. 3 show the results of the heating experiment. Fig. 2 presents the temporal change in relative moisture content obtained by neutron radiography, while Fig. 3 shows the temporal changes in temperature and pressure in the BB specimen. The relative moisture content shown in Fig.2, expressed per unit paste, was determined using separately prepared calibration specimens, following Ref. [2]. As shown in Fig. 2, a difference in drying rate, which is considered to influence spalling behavior, was observed between N and BB. In addition, the moisture distribution could be tracked over time from the relative moisture content images. As shown in Fig. 3, in the BB specimen, pressure increased at a position 5 mm from the heated surface, whereas no significant increase was observed at 10 mm. Further detailed measurements and analyses are required to elucidate the fundamental mechanisms of spalling.

REFERENCES: [1] JCI-TC-154A (2017). “Committee Reports:” [2]Kanematsu, M. et al.:Evaluation of moisture migration during the water absorption process in cracked concrete using neutron radiography, Cement Science and Concrete Technology, Vol. 62, pp. 175–182, 2008.

PR1-6

Visualization of the Reactant Solution Distribution in a Mixer of a Supercritical Hydrothermal Flow-Type Reactor Using Gd^{3+} Ion Solution as a Tracer

T. Kurono[1], S. Takami[1], Y. Azami[2], T. Saito[2], M. Kubo[2], K. Sugimoto[3], N. Odaira[4], D. Ito[4], and Y. Saito[4]

[1] *Graduate School of Engineering, Nagoya University*
[2] *Graduate School of Engineering, Tohoku University*
[3] *Graduate School of Engineering, Kobe University*
[4] *Institute for Integrated Radiation and Nuclear Science, Kyoto University*

INTRODUCTION: Supercritical hydrothermal synthesis is a method for producing metal oxide nanoparticles in supercritical water. In flow-type reactors, the aqueous metal ion solution is instantaneously heated by mixing with a stream of heated water in a mixer. Previous studies have shown the density distribution of water in the mixer, which reflects the temperature distribution there. In this study, we attempted to visualize the distribution of the reactant solution by using Gd^{3+} ions as a tracer in neutron radiography.

EXPERIMENTS: The measurements were carried out at the B4 port of the Kyoto University Reactor (KUR). The experimental setup was similar to that used in previous studies.[1–4] In this study, a 0.01 mol/L Gd^{3+} ion solution was delivered using a high-pressure pump and mixed with supercritical water in a mixer. Neutron radiography images were continuously acquired with an exposure time of 30 s. A neutron radiography image of the mixer filled with air was also acquired and subtracted from the neutron radiography images obtained during operation.

RESULTS: Fig. 1 shows neutron radiography images of a mixer in a flow-type supercritical hydrothermal reactor. The Gd^{3+} ion solution reached the mixer 6 min after the start of $Gd(NO_3)_3$ supply. The images indicated that the darker region, corresponding to the presence of Gd ions, was located in the lower part of the side tube. The image at 6 and 10 min further showed that the dark region was present on the right side of the vertical tube. These behaviors were consistent with the water density distribution reported in previous studies. Therefore, the density profile mainly resulted from mixing between supercritical water and room-temperature water, rather than from heat conduction through the inner wall of the mixer. These images also revealed the progression of plugging in the mixer during hydrothermal synthesis.

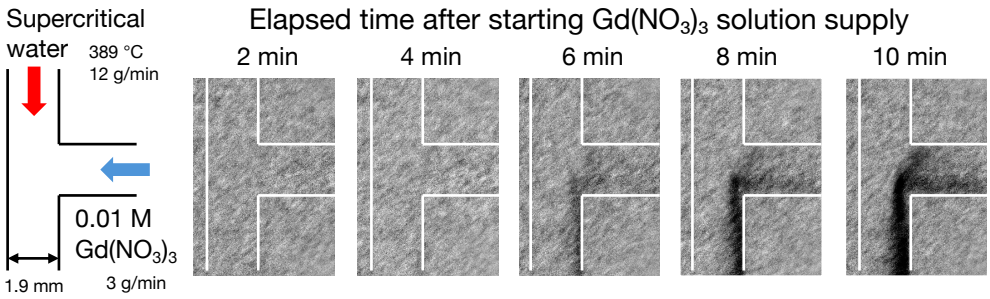

Fig. 1. Neutron radiography images of a mixer in supercritical hydrothermal reactor during Gd^{3+} solution supply.

REFERENCES:

[1] K. Sugioka *et al.*, AIChE J., **60** (2014) 1168-1175.
[2] S. Takami *et al.*, Phys. Proc., **69** (2015) 564-569.
[3] R. Sasaki *et al.*, J. Phys.: Conf. Ser. **2605** (2023) 012029.
[4] K. Sato *et al.*, Chem. React. Eng., **8** (2023) 1449-1456.

Visualization of Root Water Uptake in Organic Substrates through Three-Dimensional Root Reconstruction from Cylindrical Panoramic Imaging

U. Matsushima[1], N. Odaira[2], D. Ito[2] and Y. Saito[2]

[1] *Iwate University*
[2] *Institute for Integrated Radiation and Nuclear Science, Kyoto University*

INTRODUCTION: Non-destructive observation of root systems in organic substrates is essential for understanding plant water uptake. Neutron imaging visualizes water distribution with high hydrogen sensitivity, and a deuterium oxide (D_2O) tracer enables selective imaging of root-mediated water uptake. However, the low contrast between roots and organic substrates hinders accurate root localization in neutron images. To address this limitation, we combine a three-dimensional (3D) root surface model reconstructed from cylindrical panoramic photographs with neutron D_2O absorption images, enabling non-destructive correlation of root position with water uptake in organic substrates.
EXPERIMENTS: Komatsuna (*Brassica rapa* var. *perviridis* 'Wakami') was grown in quartz glass tubes (22 mm i.d., 120 mm high) filled with a rice-hull/soil substrate (3:1 v/v; $n = 10$). Each tube was rotated on a motorized stage and photographed using a digital camera. Panoramic unrolled images were synthesized through slit-scan compositing, and root regions were extracted using a Frangi vesselness filter, then back-projected onto a cylinder to generate a 3D root surface model. Virtual transmission images were subsequently produced from this model by parallel projection. Neutron imaging was conducted at the E2 beamline of the Kyoto University Research Reactor, and a relative transmittance map was computed from the ratio of images acquired before and after D_2O supply. A geometric correction that maximized the overlap between root regions and D_2O-absorbing regions was then applied.
RESULTS: Panoramic unrolling of the rotated glass tubes (Fig. 1a, b) enabled registration of detected root regions onto the cylindrical surface (Fig. 1c), from which virtual transmission images were generated (Fig. 1d). Overlaying the neutron D_2O absorption map (Fig. 1e) revealed a systematic vertical shift of $+88 \pm 12$ px and a scale factor of 1.15 ± 0.05 between the two modalities; geometric correction subsequently aligned the root regions (green) with the D_2O-absorbing regions (white) effectively (Fig. 1f). However, grid-based correlation yielded only a weak positive correlation coefficient ($r \approx 0.1$, $n = 10$), constrained by the low signal-to-noise ratio of thin-root water uptake signals within the thick substrate and by the inherent limitation of 2D projection capturing only the cylindrical surface roots.

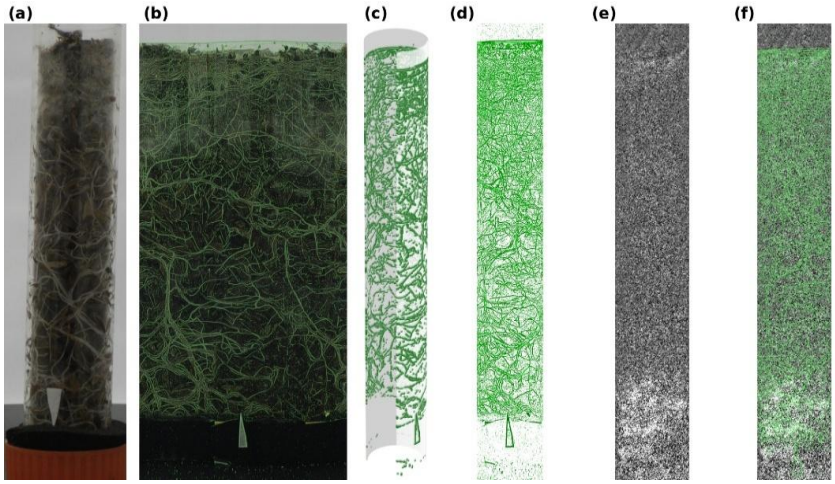

Fig. 1. (a) Quartz glass-tube pot used for Komatsuna cultivation. (b) Cylindrical panoramic unrolled image with root regions detected by a Frangi filter overlaid in green. (c) Three-dimensional reconstruction of the root system on the cylindrical surface (cut model). (d) Virtual transmission image generated from the reconstructed root model. (e) Neutron relative transmittance map showing D_2O absorption. (f) Overlay of the virtual transmission image (green) and the neutron D_2O absorption map (white) after geometric correction.

PR1-8

In-situ Observation of Lithium Migration in Solid Electrolyte by Using Neutron Radiography

S. Takai[1], H. Ezaka[1], T. Yabutsuka[1], N. Odaira[2], D. Ito[2], and Y. Saito[2]

[1]*Graduate School of Energy Science, Kyoto University*
[2]*Institute for Integrated Radiation and Nuclear Science, Kyoto University*

INTRODUCTION: In recent years, research on All-Solid-State Batteries (ASSBs) has been intensively pursued from various perspectives. Lithium ions migrate from the anode to the cathode during discharge, the visualization of which is one of the key challenges for the investigation of ASSBs. We have carried out the lithium diffusion coefficient measurement through the neutron radiography (NR) technique by exploiting the large differences in neutron attenuation coefficients between ^{6}Li and ^{7}Li [1-3].

In the present study, we applied the electric field to the model cell to observe the lithium migration in the solid electrolyte through the neutron imaging.

EXPERIMENTS: ^{7}Li-LAGP ($^{7}Li_{1.5}Al_{0.5}Ge_{1.5}(PO_4)_3$) solid electrolyte and ^{6}Li-LMO ($^{6}LiMn_2O_4$) electrode material were prepared by the conventional solid-state reaction method using lithium isotopes. A test cell of Cu / ^{6}Li-LMO / PEO / ^{7}Li-LAGP / PEO / ^{6}Li-LMP / Al was fabricated and conducted a current at 200 - 250°C. The mounted amount of cathode and anode materials are 3 and 6 mg, respectively. Before, after, and during the electrolysis, NR images were measured by CCD camera at the B4 guide tube in IIRNS, Kyoto University.

RESULTS: Fig. 1 represents the (a) NR image of the test cell before the electrolysis, (b) divided image of the cells (after electrolysis by before), and numerical plot of the divided image. Anode and cathode correspond to the right and left side of the image in (b) and (c). Through electrolysis, a part of ^{6}Li of the anode is introduced into the electrolyte, decreasing the gray value at the anode with increasing it at the electrolyte in the vicinity of the interface. On the other hand, when ^{7}Li is introduced into cathode, gray value decreases at the cathode interface. The trend of the variation in radiography image can explain the direction of lithium migration in the solid electrolyte.

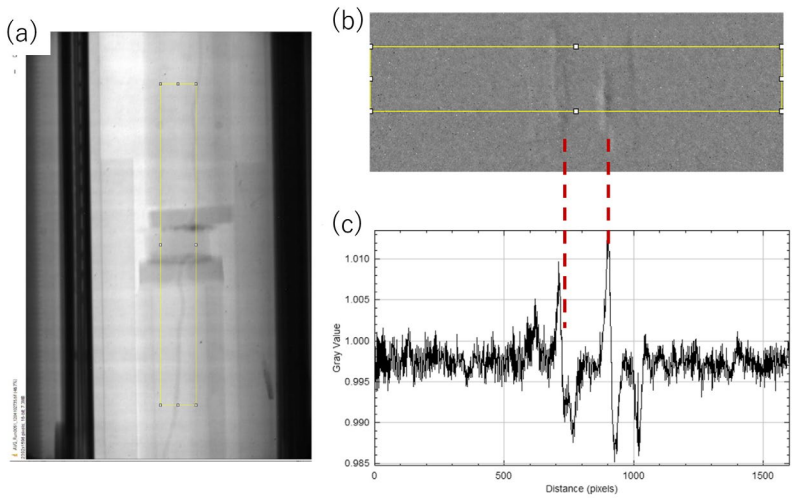

Fig. 1 (a) Neutron radiography image of the test cell heated up to 250°C. (b) Divided image of the cell after the electrolysis by the pristine one. (c) numerical plot of the divided image. Right side: anode and left side: cathode.

REFERENCES:

[1] S. Takai, M. Kamata, S. Fujine, K. Yoneda, K. Kanda, T. Esaka, *Solid State Ionics*, 123, 165-172, 1999.
[2] S. Takai, K. Yoshioka, H. Iikura, M. Matsubayashi, T. Yao, T. Esaka, *Solid State Ionics*, 256, 93-96, 2014.
[3] H. Takagi, T. Yabutsuka, H. Hayashida, F. Song, T. Kai, T. Shinohara, K. Kurita, H. Iikura, N. Yamamoto, M. Nakajima, S. Takai, *Solid State Ionics*, 417, 116716, 2024.

PR1-9

Applications of Neutron Imaging to Cultural Heritage and Paleontology

D. Ito[1], N. Odaira[1] and Y. Saito[1]

[1] *Institute for Integrated Radiation and Nuclear Science, Kyoto University*

INTRODUCTION: Non-destructive imaging techniques play a crucial role in the study of cultural heritage objects and paleontological specimens. Among these, X-ray CT is widely used due to its accessibility and high spatial resolution. However, X-ray imaging is primarily sensitive to electron density and often provides limited contrast for materials with similar atomic numbers. Neutron imaging, in contrast, is sensitive to nuclear interactions and exhibits high contrast for light elements such as hydrogen, even in the presence of dense materials. This complementary sensitivity makes neutron imaging particularly valuable for investigating fossil structures embedded in mineral matrices. In this study, neutron CT and X-ray CT were applied to fossilized bivalves. The objective is to compare the imaging characteristics of both techniques and evaluate the effectiveness of neutron imaging for paleontological analysis.

EXPERIMENTS: Neutron CT measurements were carried out at the B-4 port of the Kyoto University Research Reactor (KUR). A series of neutron transmission images were acquired while rotating the specimen, and tomographic reconstruction was performed to obtain three-dimensional internal structures. The sample used in this study is a fossilized bivalve collected in Fukui Prefecture. The fossil is embedded in a sedimentary matrix, making internal observation challenging by conventional methods. For comparison, X-ray CT measurements were also conducted using a general-purpose laboratory X-ray CT system. The reconstructed volumes of both neutron and X-ray CT datasets were analyzed to evaluate differences in contrast, visibility of internal structures, and the detectability of features such as shell morphology and internal fillings.

RESULTS: The reconstructed cross-sectional images obtained from neutron CT and X-ray CT are shown in Fig. 1. X-ray CT clearly visualizes the overall morphology of the fossil; however, the contrast between the fossil shell and the inclusions is limited due to their similar X-ray attenuation coefficients. In contrast, neutron CT provides enhanced contrast between the fossil and the inclusions. This enables improved identification of internal structures that are difficult to distinguish in X-ray CT images. Furthermore, neutron CT reveals fine structural features within the fossil, including variations in shell density and possible internal voids or infillings. The complementary nature of neutron and X-ray imaging is evident: X-ray CT is effective for capturing high-resolution morphological information, while neutron CT provides unique sensitivity to compositional differences, especially involving light elements. The combined use of neutron and X-ray CT provides a more comprehensive understanding of paleontological specimens, highlighting the potential of neutron imaging in cultural heritage and fossil studies.

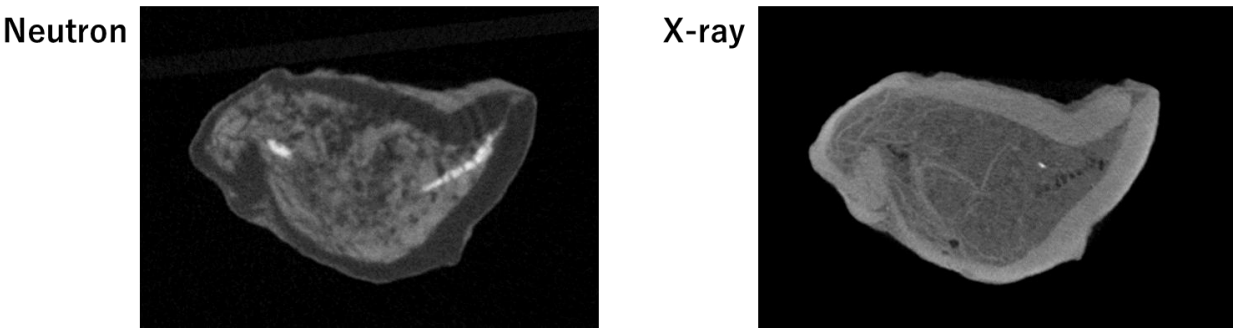

Fig.1. Reconstructed cross-sectional images obtained from neutron CT and X-ray CT