

Experimental study for thermal striping in LBE loop by using UVP with high-temperature ultrasonic transducer

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Japan Atomic Energy Agency (JAEA) has been proceeding with the research and development on accelerator-driven system (ADS) for the transmutation of long-lived radioactive nuclides. The ADS proposed by JAEA utilize the Lead-Bismuth Eutectic (LBE) as a spallation target and core coolant. Understanding and precise prediction of the flow condition in spallation target is one of the important items for estimate the soundness of materials for beam window, flow guides and irradiation samples. To examine the feasibility and applicability of the LBE to accelerator-driven transmutation systems, JAEA has an experimental lead-bismuth loop for investigate the problems caused by LBE flow. As a result of the experimental surveys, LBE flow is connected closely with a lot of serious problems in development of ADS. Therefore, the development of the high-temperature transducer that can be used at the high temperature condition (over 150 degrees Celsius) is a pressing need because it establishes the velocity measurement techniques for LBE flow. We adopted the wave guide method. And we conducted a survey of the suitable guide material for LBE flow by using the wave equation. As a result, it is forecast that Al and Si are excellent materials in the present situation.

Keywords: Liquid metal, High temperature, UVP, Erosion, ADS

1 INTRODUCTION

Japan Atomic Energy Agency (JAEA) has been proceeding with the research and development on accelerator-driven system (ADS) for the transmutation of long-lived radioactive nuclides. The ADS proposed by JAEA utilize the Lead-Bismuth Eutectic (LBE) as a spallation target and core coolant. The conceptual design study on the Transmutation Experimental Facility (TEF) to study the basic science and engineering of the transmutation technology was continued under a framework of Japan Proton Accelerator Research

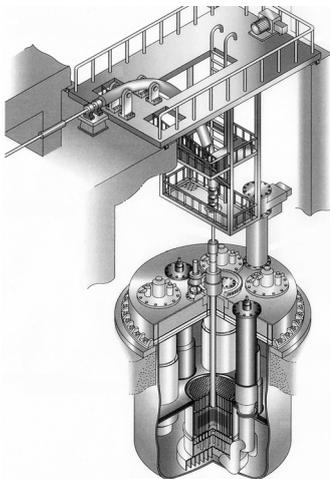


Figure 1: Image of a target for Accelerator Driven System

Complex (J-PARC) project. Understanding and precise prediction of the flow condition in spallation target is one of the important items for estimate the soundness of materials for beam window, flow guides and irradiation samples. To examine the feasibility and applicability of the LBE to accelerator-driven transmutation systems, there are three experimental LBE loop.

The measurement of the flow of the high temperature liquid metal is extremely difficult, and there are no practical measurement techniques other than neutron radiography [1-4] and ultrasonic velocity profiling.[5-7] Therefore, UVP measurement techniques that can be equivalent to high temperature liquid metal are studied in JAEA.

The objective of this study is measurement of the LBE flow related to the thermal characteristic of the beam window and the problem of erosion-corrosion. In the process of this study, various problems caused by the flow of LBE were clarified by the experiment that used the three LBE loop. This paper introduces the clarified problem caused by the LBE flow, and shows the result of examining the validity of the technique for applying UVP to the high temperature LBE flow.

2 EXPERIMENTAL SURVEYS

2.1 Erosion of materials

In the experiment with the LBE loop operation, it has been found that corrosion-erosion of materials

would be caused by flowing LBE. In this report, “corrosion” points at a phenomenon caused by the chemical action on the boundary surface of materials and LBE. And “erosion” points at a mass loss phenomenon caused by LBE flows on the surface of corroded material. The experiments of corrosion-erosion were conducted by using a LBE loop. In this loop, a test pipe (see. Figure 2) was installed at the test section. The total length of the test pipe was 420 mm, and nominal inside diameter of the diffuser section was 15 mm. And the straight section was 9.8 mm. Temperature of the test section was kept at 350 degrees Celsius. The operating time was 3000-3600 hours. Table 1 shows the result of erosion-corrosion test. When SUS304 stainless steel was used for the material of test pipe, the decrease of material caused by erosion was about 100 μm at the straight tube section. In the diffuser section, decrease of material was 500 μm. on the other hand, when F82H Ferritic steel was used for the material of test pipe, decrease of material was 50-100 μm at the diffuser section. In the straight tube section, the extremely little mass loss was observed.

SUS304 stainless steel and F82H Ferritic steel are contained in the materials proposed for the target

Table 1: Result of the mass loss thickness caused by erosion in LBE loop

Materials	Straight tube section	Diffuser section
SUS304	100 μm	500 μm
F82H	< 20 μm	50 μm

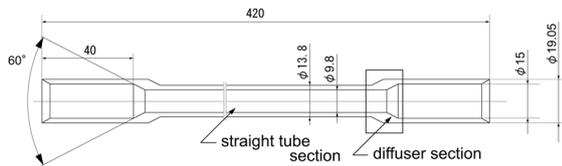


Figure 2: Illustration of the test pipe for corrosion-erosion test in LBE loop

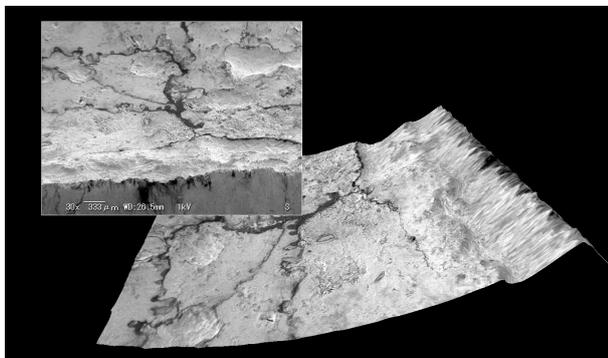


Figure 3: SEM image of the erosion on the surface of straight tube section (SUS304 stainless steel)

beam window and the flow path of ADS. Because the thickness of beam window under the examination is 2 mm, the decrease in the thickness of 25 % (Maximum) gives a serious bad influence to the safety of target system.

2.2 Thermal striping

In an experiment of the thermal characteristic on the surface of the mock up model of beam window, an unnatural phenomenon was observed. This experiment was conducted by using the other LBE loop that installed a mock up in a model of target vessel filled with LBE. Thermo-couples were installed at the surface of the hemispherical mock up model. A result of the temperature data measured by a thermo-couple (TC8) is Figure 5. In this experimental condition, LBE inlet boundary flux at test section was 500 l/min and reference temperature was 330 degrees Celsius. In this figure, the horizontal axis represents the measurement time, and vertical axis represents temperature measured by a thermo-couple. This result shows a typical temperature fluctuation at a tip of the model. The gap between the maximum temperature and the minimum temperature was about 15 degrees Celsius and the fluctuation shifted to the high temperature side. In this condition, it was forecast that the huge thermal stress (about 50 GPa) attacked the beam window. And thus, the beam

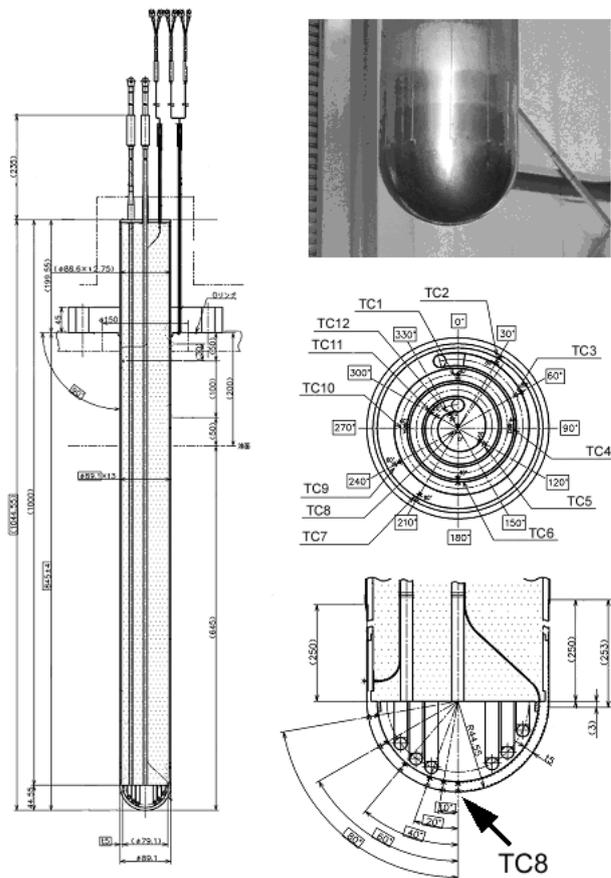


Figure 4: Mock up model of beam window

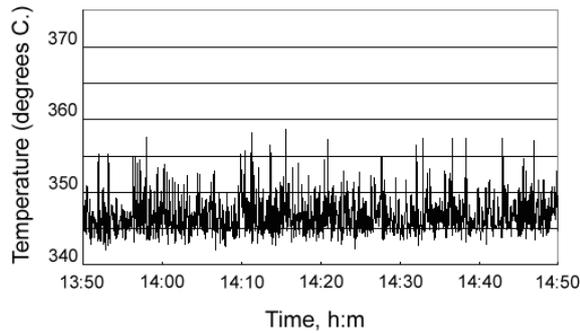


Figure 5: Typical temperature fluctuation at a tip of the mock up model of the target beam window

window would get the serious damage by the thermal striping phenomenon.

It is necessary to measure the temperature and the velocity profiles simultaneously, because it is thought that this phenomenon originates in the fluctuation of the stagnation region of LBE flow at the tip of mock up model.

2.3 UVP measurement of LBE flow

LBE would be enclosed as a neutron source and a coolant in the target vessel of ADS. It is impossible to confirm the cooling performance of the target loop without knowing of the LBE flow. And the flow structure and erosion of the materials of the loop are closely related. And thus, it is necessary that the development of velocity measurement techniques could be applied to LBE flow.

An experimental measurement of LBE loop was successfully realized by using UVP at low temperature condition (at 150 degrees Celsius).

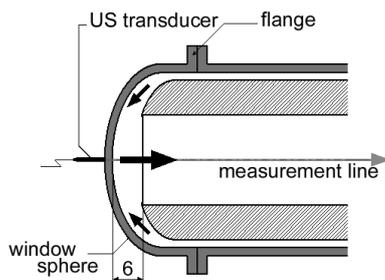


Figure 6: Flow passage of LBE loop

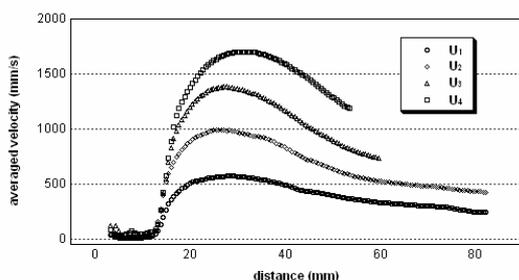


Figure 7: Averaged velocity profile in LBE loop; where velocity conditions are U₁,U₂,U₃,U₄=0.25,0.50,0.75,1.00 m/sec

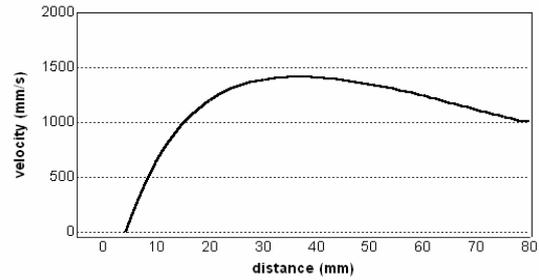


Figure 8: velocity profile given by numerical calculation; where velocity condition is U₃=0.75 m/sec

4 FUNDAMENTAL STUDIES FOR HIGH-TEMPERATURE TRANSDUCER

In operating ADS, the temperature of the LBE is expected to reach 500 degrees Celsius. Therefore, it is indispensable that the ultrasonic transducer which could apply to a high temperature condition. Lithium niobate (LiNbO₃) element and the other piezo elements used for the ultrasonic testing for materials could work at a high temperature condition. LiNbO₃ element is used for measurement of sodium flow in Fast Breeder Reactor (FBR); however, the voltage of about 1000 V is required for operating the transducer because the sensitivity is too bad.

In this study, a technique to attach the signal guide to the conventional ultrasonic transducer is developed. This idea was given by S. Eckert and others.[8-10] Their “acoustic wave guide” succeeds in a velocity profile measurement of CuSn flow at 620 degrees Celsius. Therefore, we conducted a survey of the suitable guide material for LBE flow by using the wave equation.

4.1 Formation of Ultrasonic beam

To estimate the beam formation in LBE and the permeability in guide materials, the sound field was calculated by wave equation.

$$\frac{\partial^2 P(t,x,y)}{\partial t^2} = c(x,y)^2 \left\{ \frac{\partial^2 P(t,x,y)}{\partial x^2} + \frac{\partial^2 P(t,x,y)}{\partial y^2} \right\} \quad (1)$$

A result of wave calculation for a continuous wave signal is shown in Figure 9. The mesh size was 0.02×0.02mm, and time step was 0.1 nsec. The diameter of was 5 mm, and the frequency of signal was 4 MHz. As for the shape of the guide, the column type was selected. The diameter of the guide was 10 mm, and the length was 30 mm. The material of this guide was SUS304 stainless steel. The target medium was LBE. In this result, it was confirmed that the ultrasonic beam was formed without trouble after the guide material had been penetrated. The comparable result is obtained for other materials.

4.2 SURVEY OF TRANSMITTANCE FOR MATERIALS

To know the permeability in guide materials, the

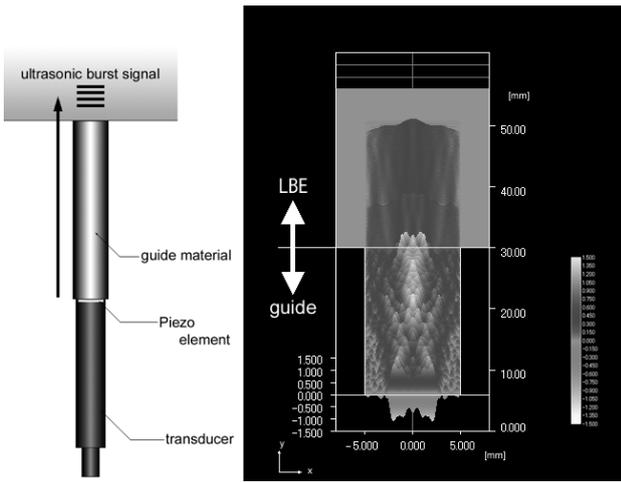


Figure 7: Simulation result of beam formation (continuous signal)

simulations of wave propagation were conducted by using the pulse signal. The length of guide cylinder was 25 mm. The other parameters were set to the same condition as the previous calculation. The number of cycles was 4. A simulation result is shown in Figure 7. The transmittances for each material obtained by dividing the amplitude of signal that immediately passed through the guide by the amplitude of initial signal were shown in Table 2. In these result, Al and Si showed the good permeability because the acoustic impedance of LBE($Z=19.6$) is a value close to these materials.

Table 2: Transmittance of pulse signal for each material

Materials	Z [MRayl]	Transmittance [%]
Ti	27.3	35
W	100.9	19
Zr	30.1	33
Mo	63.0	28
SUS304	45.7	30
Al	17.1	48
Si	17.5	52

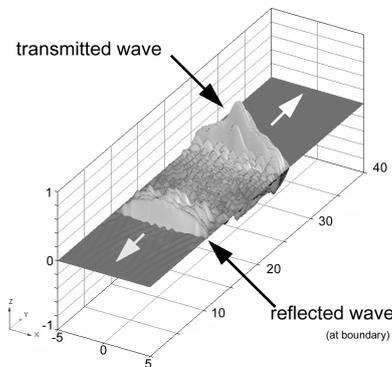


Figure 7: Simulation result of beam formation (pulse signal)

5 CONCLUSIONS

As a result of the experimental surveys, LBE flow is connected closely with a lot of serious problems in development of ADS. The development of the high-temperature transducer that can be used at the high temperature condition (over 150 degrees Celsius) is a pressing need because it establishes the velocity measurement techniques for LBE flow. We adopted the wave guide method. And we conducted a survey of the suitable guide material for LBE flow by using the wave equation. As a result, it is forecast that Al and Si are excellent materials in the present situation.

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