Study on a fuel layering sequence of the foam target for the FIREX project

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Abstract. To develop the fuel layering sequence for the FIREX cryogenic target, redistribution of surrogate fuel, solid H₂ in a shell with cooling duration has been studied. Two kinds of dummy targets with a foam and a polystyrene shell (~800 µm and 2 mm in diameter, respectively) were tested. The solid H₂ layer in the polystyrene shell was accumulated on the shell bottom as time elapsed. On the other hand, the foam shell had less elapsed time dependence than the polystyrene shell. Furthermore, elapsed time appeared to make the solid H₂ layer uniform.

1. Introduction

The cryogenic target for the Fast Ignition Realization EXperiment (FIREX) project is developed by collaboration between the Institute of Laser Engineering (ILE), Osaka University and National Institute for Fusion Science (NIFS). The project is separated into two phases: FIREX-I and FIREX-II which correspond to laser powers. The target has a unique design which is proposed by ILE. It consists of a foam shell, a cone guide for a heating laser, and a fuel feeder. As fuel for the target, D₂ and DT of solid and liquid state with lower saturated pressure will be applied for stable fuel compression. Development of the prototype foam shell has been completed.[1] Its assembling method had been proved [2,3] and is continuously modified to meet its required specification. Most important remaining issue is fuel layering.

Preliminary cool-down tests of a dummy foam shell target have been conducted with a surrogate fuel of normal-H₂.[4] Liquefaction and solidification in the foam shell succeeded through a narrow capillary. The liquid and the solid quantity were roughly adjustable. However, some defects were observed in the solid normal-H₂ (SH₂), and then, they disappeared when the cooling temperature was being lowered to ~12 K in a few ten minutes. Therefore, the solid condition might depend on temperature and cooling duration. This paper focuses on the elapsed time dependence of the condition.

Heat loads such as thermal radiation and self-heating from ortho-para conversion of normal-H₂ might redistribute SH₂ in the shell, like the beta-layering phenomenon for DT fuel[5]. These heat loads would be related to the cooling duration dependence of fuel layering. To show whether SH₂ formed in a shell can be affected by the heat loads, redistribution was observed during more than 24 hours using the dummy foam shell and a polystyrene shell targets for comparison. The results would depend on temperature gradients in the shells. Therefore, temperature profiles in the shells filled with normal-H₂ were calculated. This paper describes the comparison between the SH₂ redistribution results in the shells and their calculated temperature profiles.
2. Experimental details
Two kinds of dummy targets with a foam and a polystyrene (PS) shells (~800 µm and 2 mm in diameter, respectively) were used. The foam shell was supplied from General Atomics (GA) because a foam shell for FIREX-I had been being developed at the point of this experiment. Figures 1(a) and (b) show photographs of the targets with dimensions. Cone guides attached to the PS and the foam shell targets were upward and horizontal, respectively. Both targets were assembled using epoxy resin, which is the same way as a typical FIREX-I target.

![Figure 1(a)](image1a.png) (a) PS shell target with 2mm in diameter  
![Figure 1(b)](image1b.png) (b) Foam shell target with 800 µm in diameter

Figures 1(a) and(b). Photographs of the dummy targets.

The target was set in the target can of the apparatus which was already reported in reference [6]. Heat exchange gaseous helium (GHe) cooled the target with free convection. Its temperature was controlled by a thermal shield and heat exchanger which was attached inside the target can without thermal insulation. SH\(_2\) redistribution was observed by a CCD camera with 200 mm macro-lens through viewing windows coated with infrared cut-off filter. A Mach-Zehnder type interferometer was also employed for brief characterization of the foam shell target.

Liquid H\(_2\) (LH\(_2\)) was supplied in the shells after temperature was controlled at 12.5 K. For the foam shell target, LH\(_2\) was slightly overfilled to the foam layer. Then, the temperature was lowered to 12.4 K and solidification was observed. Redistribution tests were conducted at 12.0 K corresponding to the temperature of the previous cool-down test. As the temperature was kept constant, photographs of SH\(_2\) in the shells and an interference pattern were taken every 30 minutes during 24 and 40 hours for the PS and the foam shells, respectively.

3. Results and discussion
Figures 2(a)-(d) and figures 3(a)-(d) show redistribution of SH\(_2\) in the polystyrene and the foam shells with cooling duration. The two shells have different redistribution results. In the PS shell, coarse-grained crystalline state was observed at first, and then SH\(_2\) was accumulated to the bottom as time elapsed. This result shows that redistribution was occurred even if normal-H\(_2\) was used as surrogate fuel. In the case of the foam shell, after solidification, defects or something were observed and moved as time elapsed. Three hours and a half later, they almost disappeared. Subsequently,

![Figure 2(a)-(d)](image2a.png) (a) 0 h  
![Figure 2(b)](image2b.png) 3.5 h later  
![Figure 2(c)](image2c.png) 24 h later  
![Figure 2(d)](image2d.png) 40 h later

Figures 2 (a)-(d). Redistribution of SH\(_2\) in the PS shell target.
redistribution of $\text{SH}_2$ in the foam shell looks to reach equilibrium. Figures 4(a)-(d) show variation of their interference images with cooling duration. Elapsed time turned fringes of the interferogram concentric and clear. This means that the foam layer with $\text{SH}_2$ became uniform. The interference images are consistent with the real images. The foam shell appeared to realize uniform re-layering within the resolution of this optical system.

To discuss the redistribution results on the PS and the foam shells, temperature profiles in the shells were calculated using the ANSYS code from the ANSYS Inc. Simplified 2D models were applied as shown in figure 5. It was assumed that $\text{SH}_2$ was fully filled in both the shells for simplification of calculation. Possible heat loads to the shells were the ortho-para conversion heat of normal-$\text{H}_2$, the absorption of visible light through viewing windows by the foam shell and thermal radiation. The radiation was negligible small in our experimental configuration, and the estimated absorption was one order lower than the conversion heat. Therefore, the heat generation of 500 W/m$^3$ from ortho-para conversion [7] was applied to these models. To simulate free convection, different heat transfer coefficients were associated with angles from bottom to top of a shell.[8] The calculated temperature profiles in the shells are shown in figures 6(a) and (b). Contour plot of temperature in the polystyrene shell can explain the redistribution result. Therefore, accumulation of $\text{SH}_2$ to the shell

**Figure 5.** Simplified 2D model of the PS and the foam shells filled with $\text{SH}_2$. Four different heat transfer coefficients: 0.4h, 0.7h, 0.9h and h for zenith angle ranges from 0° to 45°, 45° to 90°, 90° to 135° and 135° to 180°, respectively, related to free convection cooling are assigned along the shell surface. A certain heat transfer coefficient is assigned to h. $T_{\text{He}}$ is temperature of exchange GHe.
Figures 6(a) and (b). Calculated temperature profiles in the shells. Bottom may be attributed to non-uniform heat transfer of the shell surface related to free convection. For the foam shell, temperature variations are quite small compared to those for the PS shell. Consequently, redistributed \( \text{SH}_2 \) in the foam shell appeared to become a uniform layer.

Judging from these results and discussion, redistribution of \( \text{SH}_2 \) was observed in the shells with cooling duration and can cause the disappeared defects observed in the previous experiment. The re-layered \( \text{SH}_2 \) in the foam shell appears to be uniform within the limits of our optical system. However, the system doesn’t have enough resolution to characterize the foam target. Therefore, a new system for the foam shell target is developing based on an interference technique.

4. Summary
Redistribution of \( \text{SH}_2 \) in the PS and the foam shells was observed as time elapsed. According to the calculated temperature profiles of the shells, the re-layered \( \text{SH}_2 \) obeyed an isothermal line. In the case of the foam shell target, redistributed \( \text{SH}_2 \) appeared to become a uniform layer within the resolution of our optical system. However, the optical system doesn’t have enough resolution to discuss the characterization of the foam shell target in detail.

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