Study on Sodium Nanofluid for Fast Reactor (2) Reaction Suppression of Sodium Nanofluid

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ABSTRACT

Liquid sodium is used as coolant of fast reactor because it has the excellent properties which are thermal property, flow property and a good compatibility with structural materials. However it shows high chemical reactivity with water or oxygen. In this study nanoparticles are suspended in liquid sodium and high chemical reactivity is suppressed by an atomic interaction which is formed between nanoparticles and sodium atoms. It was confirmed that chemical reactivity which was sodium combustion and sodium-water reaction was suppressed experimentally. This suppression is due to the atomic interaction between nanoparticles and sodium atoms. As a result safety of fast reactor was enhanced and increased freedom of a design of plant.

Keywords: Liquid sodium, Chemical reactivity, Nanoparticle, Fast reactor, Reactivity suppression

1 INTRODUCTION

Fast reactor is promised as a new type reactor and it has been studied in some countries. Our research object is a sodium cooled fast reactor. Liquid sodium has the excellent properties as the coolant, because of its superior thermal properties and high boiling temperature etc. However liquid sodium has high chemical reactivity with oxygen or water. It shows a large amount of reaction heat and high reaction rate. These are the only weak point of liquid sodium. Plant design has to consider taking account of countermeasures against high reactivity of sodium.

We have developed sodium which possesses suppressed chemical reactivity in previous studies [1-4]. The idea of the reactivity suppression is suspension of metallic nanoparticles in liquid sodium. We call it sodium nanofluid. When the nanoparticles suspend in liquid sodium, an atomic interaction is formed between the nanoparticles and sodium atoms. There are two atomic interaction which are an atomic bonding and a charge transfer. The atomic bonding between nanoparticle and sodium atoms strengthens compared to that between sodium atoms. The charge transfer takes place to nanoparticle from sodium atoms surrounding nanoparticle.

Recently more safety of fast reactor plant is demanded. The purpose of this study is to investigate experimentally the chemical reactivity suppression of sodium nanofluid in severe environment. And an applicability of sodium nanofluid to the fast reactor is confirmed.

2 PREPARATION OF SODIUM NANOFLUID

Sodium nanofluid and sodium were prepared as follows. The nanoparticles were produced by the vapor deposition method in vacuum atmosphere [5]. They were observed on Cu mesh by the transmission electron microscopy (TEM) (JEM-2010F, JEOL Ltd.). Titanium nanoparticles used for sodium nanofluid are shown in Fig.1. The average diameter of nanoparticle is approximately 10nm.

The oxygen concentration of sodium employed was 4.1 ppm (high purity grade). A volume fraction of nanoparticles in liquid sodium is 2%. The concentration of nanoparticles in liquid sodium is dilutive. Prepared sodium nanofluid and sodium were always handled in the atmosphere of high purity argon gas (99.9999%) to avoid oxidation.

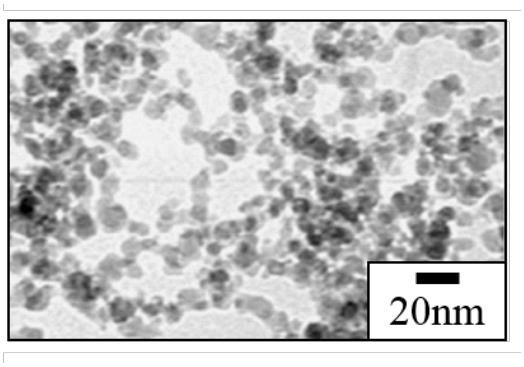

Fig. 1 Titanium nanoparticles used for sodium nanofluid.

3 FOCUSED EVENTS

In fast reactor accidents which are caused by the high chemical reactivity of liquid sodium are sodium combustion and sodium-water reaction. Sodium combustion is an accident of oxidation reaction of leaked sodium from sodium pipe in air. Sodium-water reaction is an accident of water reaction of leaked steam from the steam generator in liquid sodium. If the sodium reaction of the both accidents is suppressed, a scale of accident will decrease certainly. Therefore the reaction behavior of sodium combustion and sodium-water reaction were investigated using sodium and sodium nanofluid.

4 REACTION AND SUPPRESSION

4.1 Sodium Combustion

Sodium combustion assumed at high temperature, and the combustion behavior of sodium and sodium nanofluid were observed experimentally. We took into account the thermal damage by sodium combustion, then we measured temperature of structural material (floor steel plate). In fast reactor the floor steel plates are put on the concrete floor to avoid the sodium-concrete reaction.

An evaporation rate of sodium nanofluid decreased compared to that of sodium. It is caused by the increase of the atomic bonding of the suspended nanoparticles [1]. If the evaporation rate of sodium nanofluid reduces, the combustion temperature is supposed to decrease. The difference of temperature between sodium and sodium nanofluid is shown in Fig.3. The vertical axis denotes temperature of steel plate. The horizontal axis denotes combustion time. From these experimental results temperature of the steel plate of sodium nanofluid decreased clearly compared to that of sodium. It means the thermal damage of structural material decreases and soundness of structural materials was maintained even if high temperature.

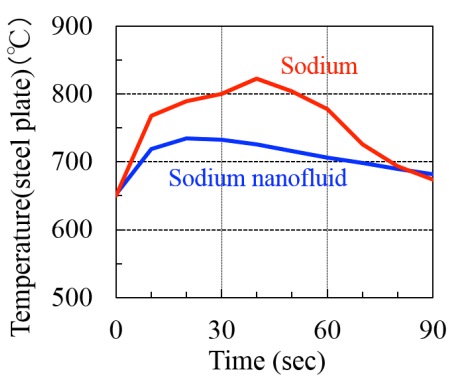

Fig. 3 Difference of thermal damage between sodium and sodium nanofluid.

Reaction heat of sodium and sodium nanofluid by combustion was measured. As mentioned above it is expected that the heat of reaction of sodium nanofluid reduces because temperature of the reaction decreased. The integrated quantity of heat sodium and sodium nanofluid was measured in previous study [2]. As a result the reaction heat of sodium nanofluid was the same as that of sodium until the surface reaction range after ignition. After that, in the gas phase reaction range the reaction heat of sodium nanofluid was suppressed significantly. The reaction heat in the gas phase range depended on the evaporation rate. As explained earlier, it suggested that the reaction heat of sodium naofluid was suppressed because the evaporation rate decreased. This result means the effect on heat radiation to the environment of sodium nanofluid is small.

Next the reaction rate of sodium nanofluid also was measured experimentally compared with that of sodium [2]. The reaction rate was evaluated using the weight change of sample by oxidation. It is expected that the reaction rate of sodium nanofluid in the gas phase range reduces if the evaporation rate decreased.

As a result the reaction rate of sodium nanofluid in the surface reaction range did not change compared with that of sodium. However the reaction rate of sodim nanofluid in the gas phase range reduced significantly. The reaction rate of sodium nanofluid depended largely on the evaporation rate. Hence the reaction rate of sodium nanofluid reduced compared with that of sodium. The reduction of reaction rate affects not only sodium combustion but also sodium-water reaction.

Furthermore the combustion phenomena of sodium and sodium nanofluid are shown in Fig.4. At 20sec after ignition the combustion phenomena of sodium nanofluid were similar to that of sodium. But the combustion of sodium nanofluid stopped at 30sec after ignition. But the combustion of sodium had continued at the

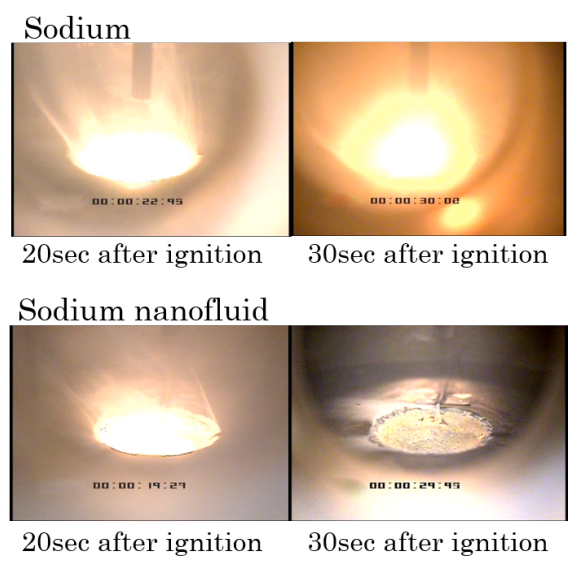

Fig. 4 Combustion phenomena of sodium and sodium nanofluid at 30sec and 40sec after ignition.

(a) Sodium nanofluid (b) Sodium

Fig. 5 Comparison of residuum after combustion between sodium and sodium nanofluid.

time. The combustion duration of sodium nanofluid shortened certainly compared to that of sodium. In the case of sodium nanofluid there was uncombusted sodium under the oxidation surface. In fact, sodium nanofluid combusted only the surface. On the other hand, sodium combusted completely. This particular behavior appeared on only sodium nanofluid. We call it "self-extinguishing effect". We have already understood its mechanism [6]. Many stable oxides including nanoparticles were formed on the surface of sodium nanofluid. And the progress of oxidation reaction stopped by the stable oxide. A residuum after combustion of sdoium and sodium nanofluid was shown in Fig. 5(a) and (b), respectively. In the case of sodium nanfluid, the thin oxide layer covered all over and there was uncombusted sodium nanofluid under the oxide layer. It was confirmed by the observation of residuum sample and the analysis using mercury amalgam method. But in the case of sodium, all sodium became the oxide. There was no uncombusted sodium completely.

From these results, not only the decrease of combustion temperature but also self-extinguishing effect contributes to the combustion suppression of sodium nanofluid. Consequently the thermal damage of floor steel plate and heat radiation to the environment will be prevented by the application of sodium nanofluid.

4.2 Sodium-Water Reaction

Sodium-water reaction is one of important accidents because the reaction rate with water is very rapid and the reaction heat is very large. The reactivity suppression is evaluated by the reaction heat with water as the measurement of reaction rate with water is difficult.

The small scale sodium-water reaction test was performed using sodium or sodium nanofluid at 500°C. Schematic drawing of experiment is shown in Fig.6. Steam was injected from below into a cylinder which was filled with sodium or sodium nanofluid as shown in Fig.6. The injected steam reacts vigorously and immediately with liquid sodium or liquid sodium nanofluid. A increase of temperature of liquid sodium or liquid sodium nanofluid

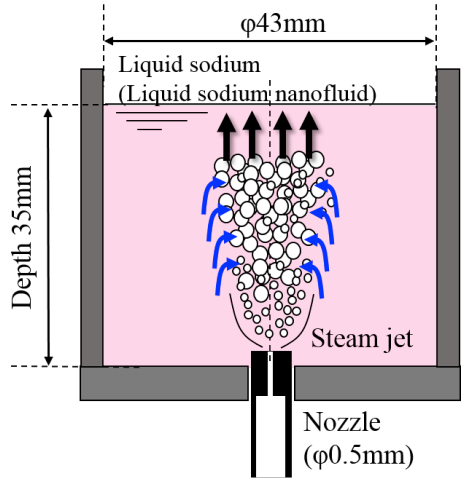

Fig. 6 Schematic drawing of sodium-water reaction experiment.

was measured using a thermocouple at several position from top of nozzle.

The temperature increase of sodium and sodium nanofluid by reaction changing with a distance from the nozzle is shown in Fig.7. From this result the temperature near the nozzle was the highest and the temperature decreased with increasing distance from the nozzle. From this result the temperature near the nozzle was the highest and the temperature decreased with increasing distance from the nozzle. The temperature increase of sodium was approximately 100°C. On the other hand that of sodium nanofluid was approximately 40°C. It became clear that the reaction with steam of sodium nanofluid was suppressed even at high temperature. It is presumed that the reaction suppression of sopdium nanofluid is caused by the reduction of reaction heat with water and the change of the physical properties such as surface tension and evaporation rate of sodium nanofluid. These reaction and physical property changes of sodium nanofluid be concerned in the atomic interaction between nanoparticle and sodium atoms.

This result means that reaction temperature of sodium-water reaction jet around a tube in steam generator

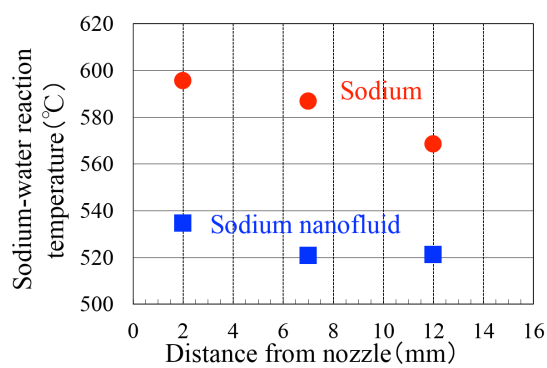

Fig. 7 Reaction temperature of sodium-water reaction of sodium or sodium nanofluid.

of fast reactor certainly decrease. It is mentioned that the creep rupture of the tube of steam generator will be avoided at high temperature and also the rupture propagation will be prevented by the application of sodium nanofluid [7].

5. CONCLUSION

In this study the differences of the reaction behavior with water or oxygen of sodium and sodium nanofluid were understood. As results, the reactivity suppression of sodium nanofluid appeared dominantly in sodium combustion and sodium-water reaction. These suppression behavior were caused by the decrease of evaporation rate of sodium nanofluid. And the decrease of evaporation rate relates strongly to the atomic interaction between nanoparticle and sodium. Furthermore, the self-extinguishing effect of sodium combustion and the decrease of reaction heat of sodium-water reaction are specific effects of sodium nanofluid. It was obtained from these experiments that sodium nanofluid showed the excellent reaction suppression than sodium. It was confirmed that the reaction suppression of sodium nanofluid was due to the atomic interaction between nanoparticles and sodium atoms.

From these beneficial effects to the chemical reactivity the safety of the fast reactor is enhanced by using sodium nanofluid. A potential pitfall of liquid sodium will be purged by this concept and it is possible to create a new concept of fast reactor design.

ACKNOWLEGEMENT

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