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Reflector Effect on Neutronic Performance of Small Molten Salt Fast Reactor

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1. Introduction

Molten Salt Reactor (MSR) with the fuel dissolved into the liquid salt are selected as one of the six Generation-IV reactor types due to its advanced fuel utilization. The excess reactivity and conversion ratio of MSRs can be flexibly adjusted by varying the fissile-to-fertile material ratio in the fuel salt composition. Long term operation can be achieved in MSRs by removing the fission products from the salt to reduce parasitic neutron capture and feed the fissile and fertile materials while the reactor is running. However, the fission cross-sections of U-235 in fast reactors are such lower than in the thermal energy ranges. Furthermore, the fast neutron spectrum is critical for fast reactor neutron economy. In addition, neutron leakage from the active core is much greater in fast reactors [1]. This characteristic is deteriorating even in SMR design. Therefore, the importance of reflector design has grown and it is now necessary to reduce high neutron leakage by reflector in order to improve neutron economies [2,3].

In this study, various material candidates were evaluated to select reflectors for small sized molten salt reactors with improved performance in fast neutron systems.

2. Sensitivity Evaluation and Result

2.1 reactor concept

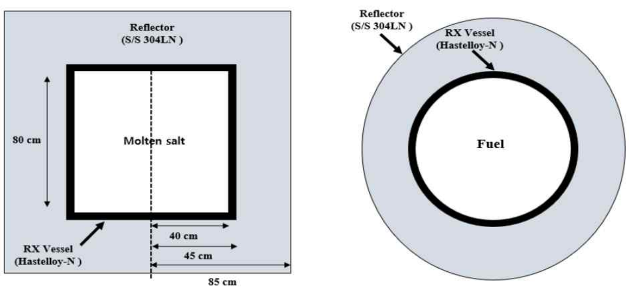

Fig. 1. Axial and radial configuration of reference core.

The schematic drawings in Fig. 1 show the preliminary design of our conceptual core. From the inside, three cylindrical columns are divided into active core, vessel, and reflector regions. The core radius is 40 cm, the second layer vessel thickness is 5 cm and the last layer reflector thickness is 40 cm. Total diameter of the reactor is approximately 170 cm. Also, the external core structures are protected by 40cm thick Stainless Steel 304 LN reflectors. This core size was thought to be small enough to transport on its own.

However current reflector design appears to be somewhat heavy and thick. To select alternative reflector materials, reflector sensitivity needs to be evaluated. The initial fuel salt is composed of 62NaCl-8$MgCl_2$-30$TRUCl_3$, and the total fuel salt volume is split evenly between the core and the external fuel circuit. OpenMC, a Monte Carlo neutron transport code developed at the Massachusetts Institute of Technology, has been carried out the reflector sensitivity evaluation. Current calculation model assumed stationary fuel at BOC and evaluated by using the ENDF/B-VII.1 cross-section library.

2.2 Single layer reflector sensitivity study

Table I: Material Properties of Various Reflector Candidates

Properties	SS304LN	SiO2	SiC	BeO	MgO	ZrC
Melting temperature, ℃	1400	1710	2730	2507	2852	3532
Boiling temperature, ℃	-	2950	3350	3900	3600	5100
Density, g/cm^3	8	2.65	3.21	3.01	3.58	6.73
Heat conduction,W/mk	16.2	1.4	190	330	45-60	21.25

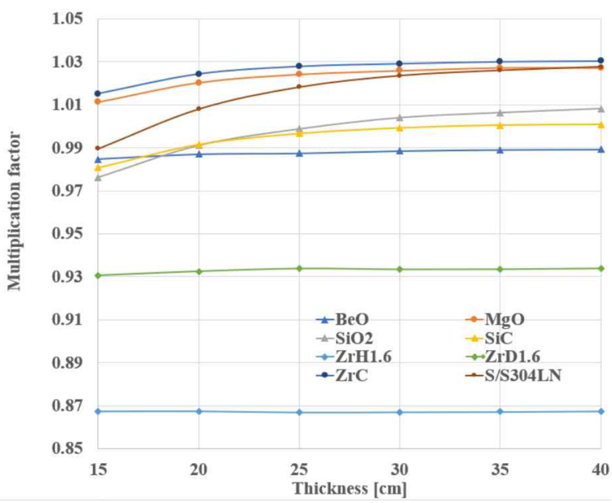

Fig. 2. Multiplication curve according to the thickness of the reflector candidates.

In this study, several material candidates for reflectors were considered: BeO, MgO, SiO_2, SiC, $ZrH_{1.6}$, $ZrD_{1.6}$, ZrC and SS304LN. Table I lists the properties of each material. The reflective effect was calculated by increasing the thickness of the reflector by 5 cm between 15 cm and 40 cm. The results clearly show that the $ZrH_{1.6}$ and $ZrD_{1.6}$ have the poorest reflector performance and are therefore unsuitable for small MSFR designs. This is due to the presence of H or D, which soften the neutron spectrum in the near reflector region and significantly absorb neutrons. Also, BeO exhibits similar properties to $ZrH_{1.6}$ and $ZrD_{1.6}$. The sensitivity of reactivity does not change as reflector thickness increases. Because the absorption effect is small in comparison to $ZrH_{1.6}$ and $ZrD_{1.6}$, but the moderation effect is significantly larger. SiC and SiO_2 have a similar tendency to SS304LN, and a reflector effect converges only when the reflector thickness is around 40 cm. In the case of ZrC and MgO, the reactivity of the same thickness with SS304LN was calculated to be higher. Furthermore, the weight of MgO reflector could be reduced by 0.44 times that of the SS304LN. Although sufficient comparative calculations have not been performed yet, MgO is currently the most promising option for achieving high efficiency with the least weight.

2.3 Multi layered reflector sensitivity study

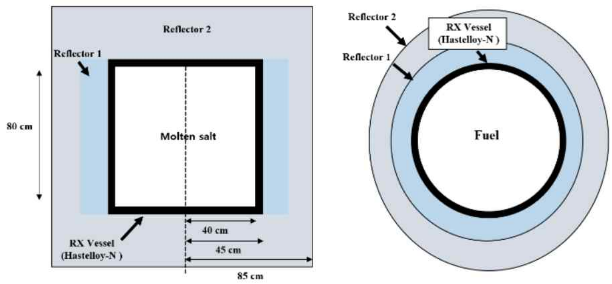

Fig. 3. Axial and radial configuration of modified core.

Table II: Sensitivity Result of Reflector Candidates

Case (Reflector 1 / Reflector 2)		Weight [M/T] (Reflector 1, 2 thickness = 20 cm)	Difference [pcm]
SS304LN (Reference)		26.28	1.02770± 0.00022
BeO	SS304LN	23.18	+42
MgO		23.53	-137
SiO2		22.96	-22
ZrD1.6		24.84	+30
ZrC		25.49	+280
SS304LN	BeO	12.99	-3745
	MgO	14.51	-5
	SiO2	12.03	-594
	ZrD1.6	20.10	-9377
	ZrC	22.9	-592

Unlike conventional solid-fuel nuclear reactor, MSFRs with flowing liquid fuel have few concerns about power peaking and flux distribution. As one of the strategies for improving reflector performance, a two-layer reflector model was analyzed by varying the combination of the two reflector candidates.

According to the results, using $ZrD_{1.6}$ and BeO with high moderation characteristics as the first layer reflector increased reactivity by 9,415 pcm and 3,884 pcm, respectively.

Also, in the case of SiO_2, MgO, and ZrC, using two layers of SS304LN yielded similar or slightly higher reactivity than using a single material. However, when SS304LN was placed on the first layer reversely, the reactivity was similar or lower.

More specifically, there is no significant reactivity difference between MgO and ZrC when used in one layer or two layers with SS304LN. Instead of SS304LN, these materials can be used to reduce weight.

Table III: Sensitivity result of MgO with SS304LN

Case (Reflector 1 / Reflector 2)		Thickness (Reflector 1 = Reflector 2)		Weight	Difference [pcm]
MgO	SS304LN	20	20	23.53	1.02633± 0.00023 (Reference)
		15	25	24.32	+194
		10	30	25.03	+130
		20	15	20.01	+63
		20	10	16.70	-174
SS304LN	MgO	20	20	14.51	+132
		15	25	13.73	+174
		10	30	13.01	+126
		20	15	12.93	+79
		20	10	11.45	+14

MgO cases were also evaluated as primary optimization. When MgO was used in the first reflector layer and 25 cm of SS304LN was used in the second reflector layer, the reactivity was calculated to be the highest at 1.02827. The total thickness of the reflector can be reduced by 5 cm while maintaining a similar reactivity value of 20 cm for MgO and 15 cm for SS304LN. When MgO was applied to the outer layer of the reflector, the weight was reduced by 13.35 M/T compared to the conventional 40 cm SS304LN.

3. Conclusions

Reflector sensitivity evaluation on various materials was performed in order to find a better performing alternative reflector for designing a small sized molten salt fast reactor. According to results, the reflector effect of $ZrH_{1.6}$ and $ZrD_{1.6}$ converges with a thin thickness due to their large moderation features, but the loss of reactivity is too large to be used as a fast reactor. ZrC and MgO had higher efficiency in the same thickness than SS304LN, and MgO can also be used to reduce weight.

Two layered regions were additionally introduced to analyze the effect of two reflector combinations. This strategy has noticeable effect, particularly when the moderator is placed on the first layer, followed by SS304LN. A large amount of reactivity insertion effect was obtained than when only one material was used. MgO has similar properties to SS304LN and has a significant weight reduction advantage.

At the moment, preliminary studies have been performed before delving into detail reflector design and optimization. Many calculations would be carried out in order to select the best materials for our reactor concept.

ACKNOWLEDGMENTS

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