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Waste Minimization and CHF Enhancement using Multi-functional Magnetic Nanoparticles during Severe Accident and Decontamination Process in Nuclear Power Plant

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1. Introduction

During severe accident progression and when some representative mitigation strategies, such as IVR-ERVC and core catcher, are activated, thermal margin is one of major criteria to determine the success of the process. At the same time, radioactive nuclides reside inside the coolant in the form of ions or aerosols which should be removed or kept inside the containment before releasing to the environment. In addition, decontamination inside the primary loop or components decontamination is a big market and issue around the world. In terms of decontamination process in nuclear power plant, conventional methods accompany secondary pollution or big amount of radioactive wastes as byproducts. Therefore, for the severe accident mitigation process, two purposes-enhanced thermal margin & removal of radioactive nuclides inside the coolant-should be achieved, and for the primary loop & components decontamination, waste minimization and easy control should be considered in the future.

2. Methods and Applications

In this paper, a system with 'multi-functional magnetic nanoparticle' is introduced to be applied to nuclear power plants.

2.1 Multi-functional Magnetic Nanoparticle

Multi-functional magnetic nanoparticle is composed of a core particle such as magnetite(Fe3O4), which contains strong magnetic property, and surrounding porous coating layer on which functional groups are attached. Magnetic property of the core particles enables magnetic attraction with an external magnetic field, and porous coating layer maximizes the surface area around the particles. Functional groups will be chosen based upon target nuclides.

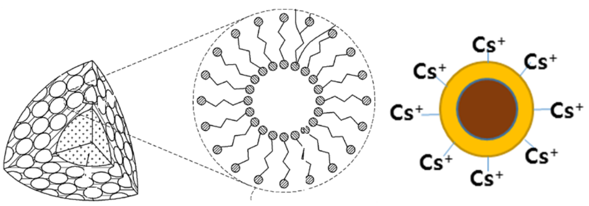

Fig. 1. Schematic example of multi-functional magnetic nanoparticle

2.2 Overall System

When the multi-functional magnetic nanoparticles are inject into the target system, maximized number of functional groups attached on the surface will capture the target nuclides to be removed. Throughout certain cycles, saturated amount of nuclides will be attached on the particle surface. Flow the 'contaminated' nanofluid through a purifying system called 'collector.' In the collector part, external magnetic fields are made with ferrite cores which reside inside the collector part. The cores are to make magnetic field gradient where the magnetic particles will be collected. After passing through the collector part, purified water can be ejected or reused for the additional cycles. After the passage, external magnetic field is turned off, and the multi-functional magnetic nanoparticles can be collected as solids. Those particles can be gathered and removed, or they also can be reused by means of certain methods such as pH condition control. Since surface to volume ratio is maximized with the nano-sized particles, only single process can guarantee the reduced amount of waste compared with the conventional methods, but reuse of them will minimize it.

2.3 Applications-Severe Accident

During severe accident mitigation strategies, the multi-functional magnetic nanoparticles can be injected to perform two purposes: thermal margin enhancement & decontamination of the coolant. With the system, we can expect enhanced Critical Heat Flux(CHF) during the process, and the contaminated coolant used for the strategies can be decontaminated with the particles. With an external magnetic field, we can gather the contaminated particles locally before releasing to the environment and can minimize the amount of radioactive waste.

Nanoparticle inside the coolant has been widely studied because of its role to enhance the CHF margin. By way of forming porous structures on the heated surface, water can be supplied easily near the CHF point, which delays the value. Lee et al. [1] used magnetite nanofluid to enhance the thermal margin. With increased concentration, additional enhancement can be expected according to the results (figure 2). In addition, when an external magnetic fields are applied, more enhanced results can be made by localizing the magnetic particles where CHF occurs (figure 3).

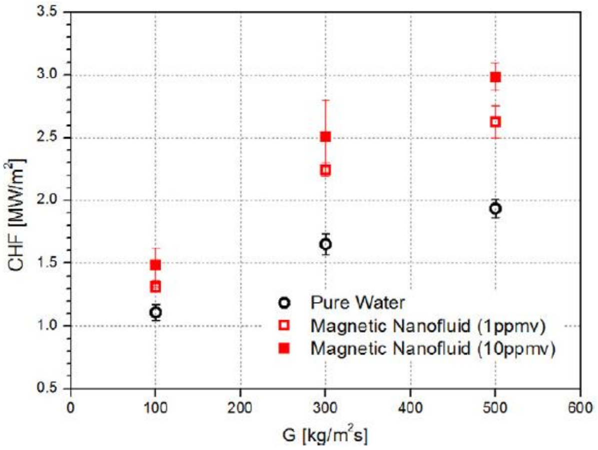

Fig. 2. Magnetic nanofluid used for CHF enhancement where concentration effect is also shown.

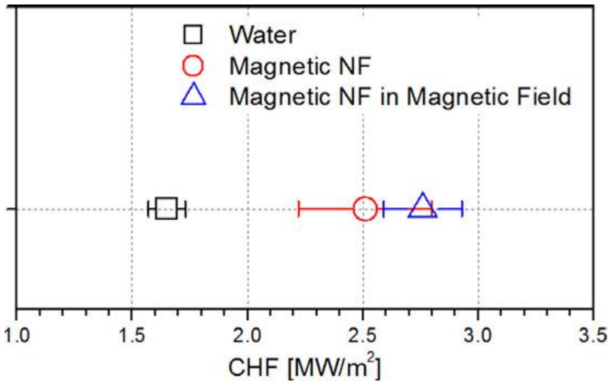

Fig. 3. Magnetic field effect on CHF enhancement.

2.4 Application-Decontamination Process

We can apply the system to the nuclear power plants for primary coolant or component decontamination processes. Throughout certain cycles of the decontamination process, saturated amount of radioactive nuclides will be attached on the surface of multi-functional magnetic nanoparticles. By flowing the contaminated coolant through the collector part, purified coolant can be extracted. In the mean time, we can also reuse the particles with some additional methods such as pH control loops.

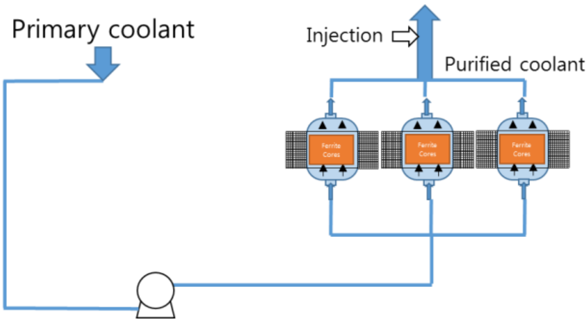

Fig. 4. Primary coolant decontamination process.

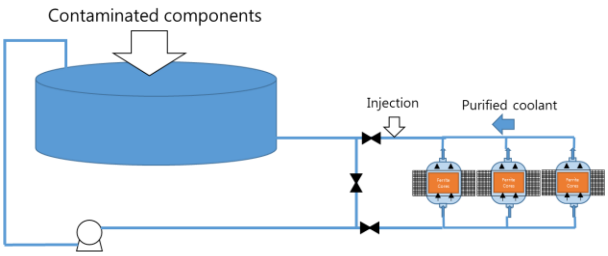

Fig. 5. Components decontamination process.

2.5 A Few Points to be Considered

During severe accident condition, generally, pressurized environments are made. According to Lee et al.[2]'s study, CHF continuously increases with pressure when magnetite nanoparticles were used under pool boiling condition (figure 6). Also, Lee et al.[3] considered sonication effect on CHF enhancement. It is related to dispersion and agglomeration effect before being used as a working fluid (figure 7).

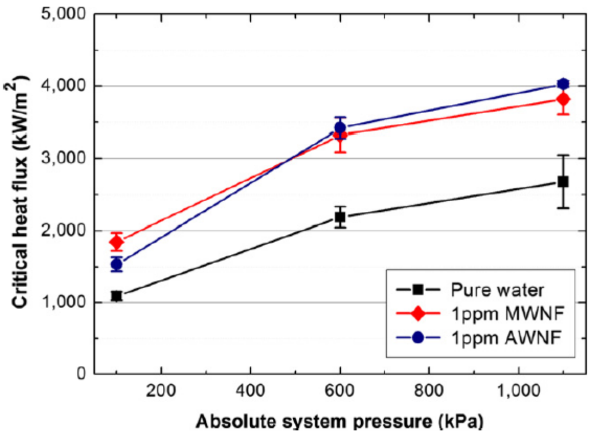

Fig. 6. Pressure effect on magnetic nanofluid.

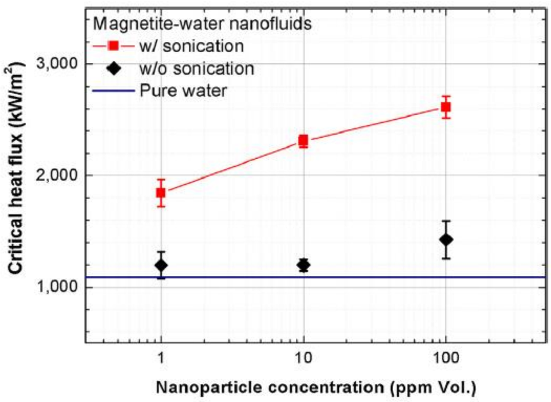

Fig. 7. Sonication effect on CHF enhancement.

When we are to minimize the storage volume of the particles inside the nuclear power plant, dilution effect should also be considered. Lee et al.[3] assessed dilution effect using various concentration of magnetic nanofluids (figure 8).

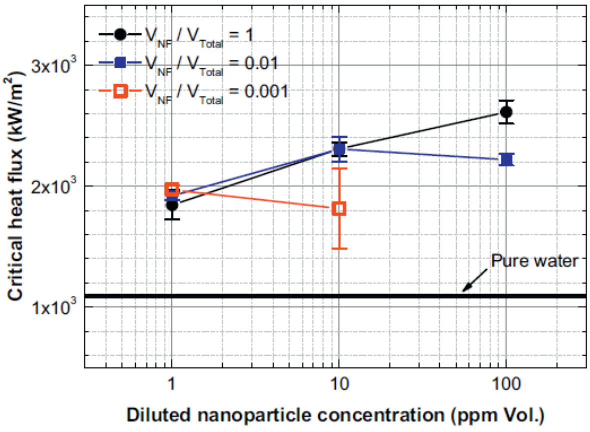

Fig. 8. Dilution effect on CHF enhancement.

Also, before the injection, those particles should be kept inside the containment for certain period of time. In this respect, Lee et al.[3] considered storage time effect on CHF enhancement. The effect was explained mainly by agglomeration phenomenon during storage (figure 9).

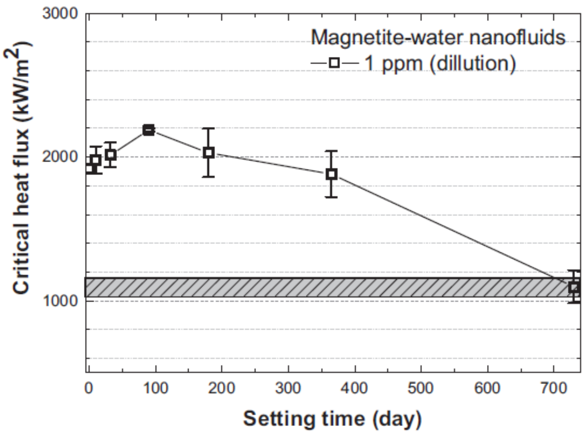

Fig. 9. Storage time effect on CHF enhancement.

At the same time, forms of nuclides should be confirmed, and it strongly depends on pH conditions. With varying pH conditions, adsorption of target nuclide on the surface changes according to the previous studies such as in Granados et al.[4] and Feng et al.[5].

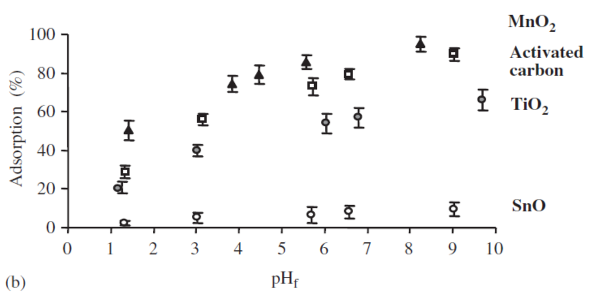

Fig. 10. pH conditions and adsorption rate[4].

Solution	Concentration (ppm)							K_d of Hg
	Hg	Ag	Cr	Pb	Ba	Zn	Na	
				No treatment				
WW, pH 3	6.20	1.80	1.79	7.22	7.18	3.96	2220	
WW, pH 7	6.00	0.45	1.13	5.25	7.12	2.75	2212	
WW, pH 9	6.35	1.04	0.58	2.90	7.15	1.32	2222	
Oil	12.10							
				After treatment, 10% FMMS				
WW, pH 3	0.0108	<0.005	1.45	1.66	7.60	3.93	2236	55,670
WW, pH 7	0.0064	<0.005	0.70	0	7.35	2.23	2202	90,974
WW, pH 9	0.0056	<0.005	0.71	0	7.40	1.41	2218	110,056
Oil	0.635							1,806
				After treatment, 25% FMMS				
WW, pH 3	0.0008	<0.005	1.67	2.26	8.64	5.06	2185	290,588
WW, pH 7	0.0008	<0.005	0.07	0	8.21	1.54	2114	281,213
WW, pH 9	0.0007	<0.005	0	0	8.82	1.19	2201	340,141
Oil	0.06							3,467

Fig. 11. Nuclide removal dependence on pH conditions[5].

3. Conclusions

A system with multi-functional magnetic particles is introduced in the paper. With the system, radioactive waste can be minimized and CHF margin during severe accident mitigation strategies can also be enhanced. Several considerations in previous experiments can provide kind of criteria and recommendations for the application in nuclear power plants.

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