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Development of Ultrasonic Cleaning Technology for a Nuclear Steam Generator

Woo-tae Jeong [a*], Seok-tae Kim [a], Ju-kwon Oh [b], Sang-jung Yoon [b]
[a] *KEPCO Research Institute, Nuclear Power Lab., 103-16 Munji-dong, Yusung-gu, Daejeon, Korea 305-380*
[b] *Sae-An Engineering Corporation, Rm910, Byucksan Digital Valley II, 481-10, Gasan-dong, Geumcheon-gu, Seoul, Korea 153-803*
[*] *Corresponding author: a39leb@kepco.co.kr*

1. Introduction

As an effort to develop ultrasonic means for cleaning nuclear steam generators, we composed and tested magnetostrictive cleaning system. Simulated sludge pallets were made to test the effectiveness of the ultrasonic cleaning methodology. Furthermore, to transmit ultrasonic wave to the center of a steam generator which is 2 meters away, WRS (water resonance system) was applied to remove oxygen in water and make micro bubbles.

2. Ultrasonic Cleaning of SG

In this section we will describe a SG mock-up and ultrasonic cleaning system. A methodology for fabricating simulated sludge for the experiments will be presented. Finally, experimental results with and without water resonance system will be reviewed.

2.1 SG Mock-up

A simulated SG mock-up for experiments on SG ultrasonic cleaning was designed and fabricated as shown in Fig. 1. Tubes are arranged with triangular pitch and no tube zones are periodically allocated for ultrasound sensors. Tubes are firmly fixed to the tube-sheet as in an actual steam generator. An ultrasound sensor is attached to a plate of the structure composed of four round guide bars which provide two degrees of freedom.

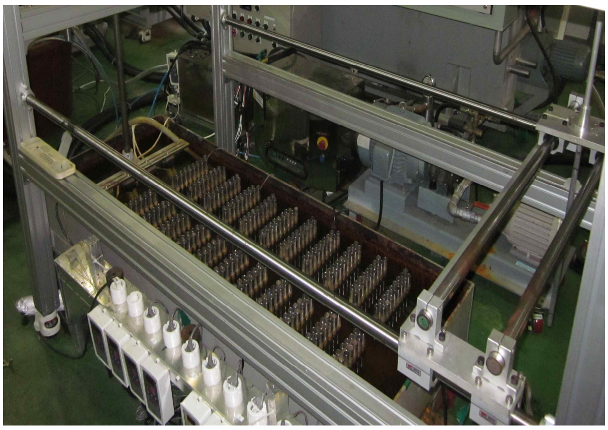

Fig. 1. SG Mock-up and Ultrasonic Cleaning System

2.2 Simulated Sludge Pallet

Making a simulated sludge pallet for ultrasonic cleaning is very important for evaluating the performance of the cleaning technology. SG sludge is mostly composed of magnetite, therefore we tried to make a simulated sludge pallet using magnetite as a major component, and added small amount of ethylene glycol and benzene as bonding liquids. We put mixture of magnetite, ethylene glycol and benzene in a metallic mold, and pressed it with 0.8 ton of weight for 30 seconds. To remove ethylene glycol and benzene from the simulated sludge, we heated the pressed sludge in an electrical heater for two hours.

Fig. 2 shows a researcher making a simulated sludge pallet by using a hydraulic press. An enlarged view of the fabricated sludge pallet is shown below in Fig. 2.

Fig. 2. A Researcher is Making Simulated Sludge Pallets by Using a Hydraulic Press and a Mold

2.3 Ultrasonic Cleaning System

Four magnetosrictive transducers were used to generate ultrasound wave in the SG mock-up. When energy transferred to water is strong enough, cavitation happens. Using pressure wave generated by cavitation, we could remove sludge. However, ultrasound energy tends to decrease as the distance from the transducer increases. Transferring sufficient energy to the center of nuclear SG is not easy considering the size of it.

Therefore, we tried to use water resonance technology to transfer enough energy to the center of SG.

Water resonance system (WRS) removes oxygen from water and makes numerous micro bubbles in water. Excessive oxygen in water makes a barrier for the transmission of ultrasound. WRS system adjusts oxygen contents in water to 3.0 ppm.

2.4 Experimental Results of Ultrasonic Cleaning

We put 9 simulated sludge pallets in 9 small cages made of wire mesh. The distance of each cage with the sludge pallet from the magnetostrictive transducer is 170(#1), 280(#2), 390(#3), 500(#4), 610(#5), 720(#6), 830(#7), 940(#8), 1050(#9) mm respectively. Therefore, we could easily infer that #1 sludge pallet shall be cleaned first because it is the nearest from the transducer. We measured initial weight and weight variation of the sludge pallets after 1 hour, 2 hours, etc. respectively.

Fig. 3(a) and (b) shows the ratio of the weight of the remaining sludge to initial mass of the sludge pallets without and with the WRS. When the WRS system is applied, only 20% of the initial sludge pallet #1 still remains after 9 hours. However, more than 40% of the sludge pallet #1 still remains when no WRS system is applied after 9 hours.

When we measured sound pressure at each 9 measuring points with the WRS, the values were twice or almost three times higher than that without WRS. Assuming that increase in sound pressure will certainly improve cleaning efficiency to that scale, we tried the cleaning experiment. Unfortunately, we could not achieve very successful cleaning efficiency to that scale when the WRS was applied as shown in Fig. 3(a) and (b).

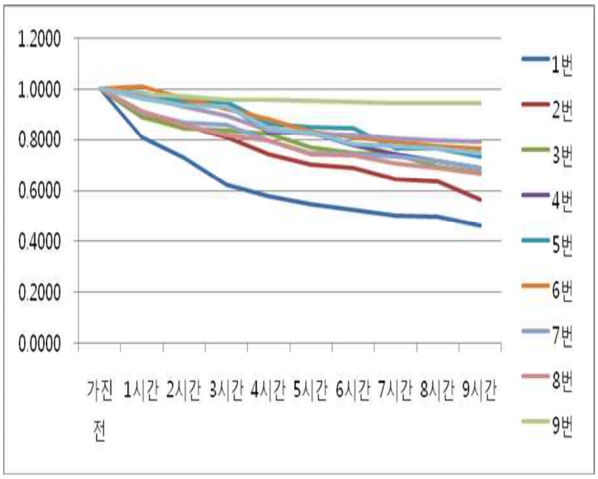

Fig. 3(a). Ratio of Remaining Sludge to Initial Sludge in Weight without WRS
Y axis: Remaining Weight of Sludge/Initial Sludge Weight
X axis: Time Passed in SG Mock-up

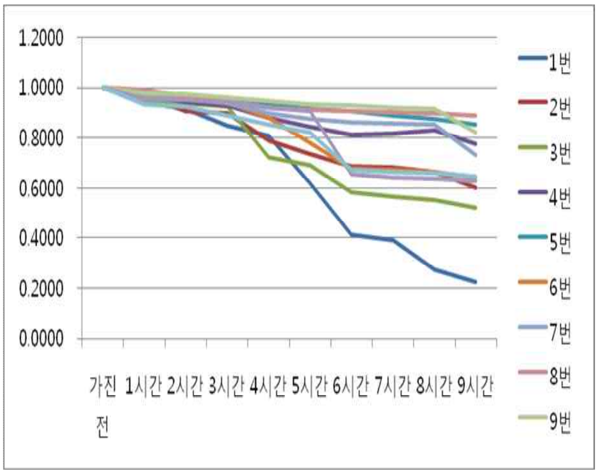

Fig. 3(b). Ratio of Remaining Sludge to Initial Sludge in Weight with WRS
Y axis: Remaining Weight of Sludge/Initial Sludge Weight
X axis: Time Passed in SG Mock-up

3. Conclusions

Based on the experiments on ultrasonic cleaning applying WRS and magenetostrictive transducers, we observed about 20% improvement in cleaning performance. Comparing the test results that 2 to 3 times increase in ultrasound pressure when we apply WRS, the 20% improvement was not very satisfactory. Further research on the relevance between ultrasound pressure and cleaning efficiency shall be made.

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