An Experimental Study on the Nuclear Fuel Debris Filtering Efficiency Using Wire Debris

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1. Introduction

Fuel rod failure due to debris is the one of the most severe cause of failure in PWR fuel assembly. Piece of metallic debris, such as small wires or metallic chips, involuntarily flow into the bottom of fuel assembly, and may be trapped between the fuel rod and spacer grids. If this debris vibrates over a long period of time, the cladding tubes could wear out. Especially, the wire types of debris from the tools during the plant maintenance operations can induce worn hole or wear scar on the fuel rods and may be make severe damage.

Most of failures due to debris are observed under the first grid from the bottom of fuel assembly. In order to mitigate this defect, the fuel vendor have developed various anti-debris grids, such as protective grid or debris filtering bottom grid, which is located just above the bottom nozzle. The vendors have performed the debris filtering test to evaluate the efficiency of these grids. KEPCO NF (KEPCO Nuclear fuel) also has carried out the debris filtering test for the fuel assembly with protective grid. Some major design parameters, such as the maximum debris passable size or grid axial location, which affect the debris filtering capacity are found out thorough the test.

This paper will discuss the filtering efficiency according to the relative dimensions of wire debris specimens and the effects of the specimen dimensions through simulation tests. The relative dimensions could be useful to develop the debris filtering grid.

2. Debris Filtering Test

2.1 Test Configuration

The schematic diagram of the debris filtering test facility is shown in Fig. 1. The components of the facility consisted of a flow loop with transparent test housing, strainers, water tank, a variable speed pump, and valves. The walls of the test housing were made of transparent materials to identify the debris capture location during the operation. The test housing had a square test section which could test 17x17 fuel assembly. The gap between fuel assembly and test housing is the same as the clearance between fuel assemblies in the reactor core. The strainers trapped the debris to prevent it from being lost in the loop. Debris was inserted between two valves in a bypass line which entered the main flow loop. The flow rate was controlled by the variable speed pump.

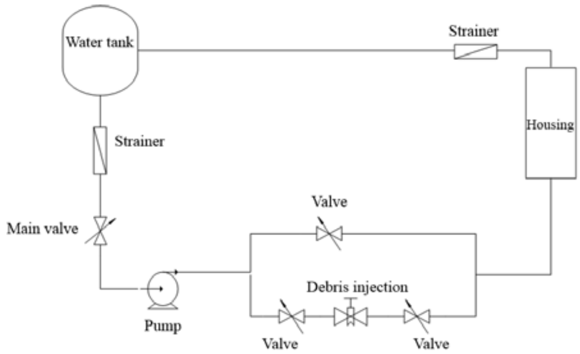


Fig. 1. Schematic diagram of the debris filtering test facility

2.2 Debris Specimens

A variety of types of debris can occur in a reactor core. Observed debris has typically included small metallic chips and fine wires. Usually those are resulted from the general plant maintenance operations during regular overhaul period. Particularly, the fine wire that is originated from metallic wire wheels and brushes during normal use can potentially lead to fuel failures [1]. In addition, the wire debris is more useful to evaluate debris filtering efficiency [2].

Therefore, wire debris is used in the simulation test, and the sizes of wire are 1.0 mm ~ 2.5 mm in diameter and 10 mm ~ 50 mm in length. Some wire debris specimens are shown in Fig. 2. All wire specimens separated into 20 groups according to their size.

Fig. 2. Wire debris specimens

2.3 Test Fuel Assembly

The lower part of 17x17 fuel assembly is used for the simulation test. The test assembly consisted of 264 fuel rods, 24 guide tube, a protective grid, a bottom grid, a mid grid and a bottom nozzle with small flow holes.

Most debris fretting failures were located at or below the first spacer grid above the bottom nozzle. With this in mind, the maximum passable size of the protective grid and the distance for debris capturing region between the protective grid's dimples and bottom nozzle were considered to evaluate how effective dimensions affect the debris filtering efficiency.

The major dimensions and components of debris filtering device in the test fuel assembly are shown in Fig. 3. The capturing region distance, "*g*", is the axial distance between the bottom of the bottom nozzle plate and top of the upper dimple. The maximum passable size, "*d*" is the maximum size of the spaces through which a particle could pass.

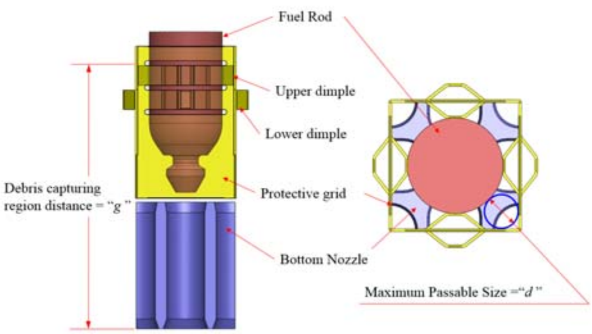


Fig. 3. Structural configuration

2.4 Test Performance

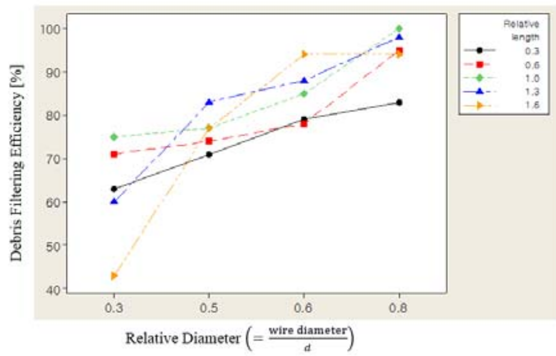
The simulation test was performed at room temperature with the typical reactor flow rate. The simultaneously injected number of debris was determined to prevent individual pieces being caught by other debris. Flow is maintained until the debris is trapped and identified in the test assembly and strainers [3].

3. Analysis of Test Results

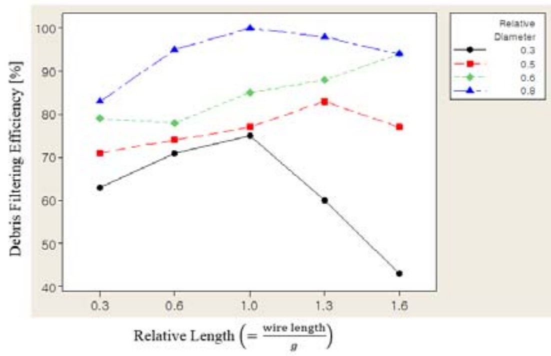
Test results can be expressed as the percentage of debris that is trapped by the bottom nozzle and protective grid. Fig. 4 gives results from the simulation test with wire debris specimens. The relative diameter is the ratio of the wire diameter to maximum passable size in Fig. 3. The relative length is the ratio of the wire length to gap distance in Fig. 3. Fig. 4 (a) shows that the debris filtering efficiency increases in keeping with the relative diameter. Fig. 4 (b) shows that the efficiency rises until the relative length of 1.0, and then decreases with increasing the relative length in some debris specimens. The relative diameter is likely to have a larger effect than the relative length.

Fig. 5 shows the average effect of each debris specimen to identify the tendency of efficiency using the popular statistical software package, Minitab [4]. The efficiency rises proportionally as the relative diameter increases. However, when the relative length is greater than 1.0, the efficiency decreases. For the above reasons, the wire diameter has a larger effect than the length on the filtering efficiency. In addition, the wire debris with a longer length than the capturing region distance could easily pass the filtering device. Also, the efficiency increases proportionally as a function of the wire diameter.

The efficiency regarding wire length was analyzed to be different for the following region. Once the wire with a shorter length than the capturing region distance passes through the bottom nozzle holes, it is rotated in the space below the dimple of grid and trapped between the dimple and fuel rod. On the other hand, the long wire debris passed through the small hole of bottom nozzle passes the protective grid more easily than the short wire debris because the long wire debris can become aligned across the distance.



(a) The relationship between filtering efficiency and relative diameter



(b) The relationship between filtering efficiency and relative length

Fig. 4. Simulation test results

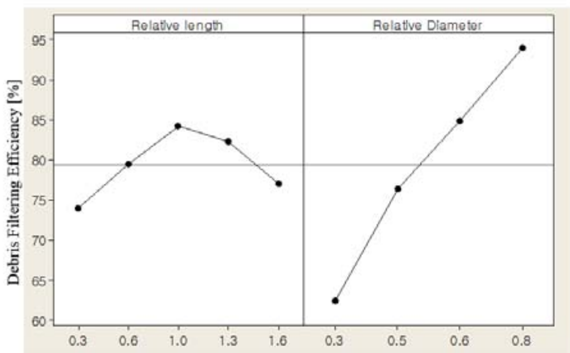


Fig. 5. Main effects plots for efficiency

4. Conclusions

This study discussed the filtering efficiency according to the relative dimensions of wire debris specimens through simulation tests. The wire debris is used since the debris is more useful to evaluate debris filtering efficiency.

Based on the test results, it is concluded that the wire debris with a longer length than the capturing region distance could easily pass the bottom nozzle with small holes and protective grid, and the wire diameter has a larger effect than the length on the filtering efficiency.

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