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SUMP STRAINER PERFORMANCE EXPERIMENTS FOR VVER-440

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Abstract

The emergency core cooling systems of NPPs have been equipped with dedicated filters to prevent insulation material fibers and other impurities in the sump water entering to the process in the accident situations. The performance of the Loviisa VVER-440/V213 sump strainer arrangement with different filtering surface types of the strainer was studied experimentally at Lappeenranta University of Technology.

According to the test results the amount of the fibers passing through the strainer filter, as well as the pressure loss over the fiber bed attached on the outer surface of the filter and the fuel assembly model, were at acceptable level.

Introduction

To ensure long term cooling of nuclear fuel during a possible loss-of-coolant accident (LOCA) situations containment floor drains (sumps) of nuclear power plants have been equipped with dedicated strainers which are designed to limit insulation material debris and other impurities in the sump water flowing inside the reactor core and emergency core cooling systems. Depending on the nature and amount of the debris, considerable damage to the cooling water circulating system equipment or deterioration of the heat transfer can occur if large amount of debris can enter the downstream flow through the sump.

To study filtration capacity of the Loviisa NPP (owned and operated by a Finnish energy company Fortum Power and Heat Oy) original and enhanced sump strainer constructions and to measure pressure drop caused by mineral wool fibers accumulated both on the outer surface of the sump strainer and inside a full-scale fuel assembly (FA) model, a scaled down test rig was designed and constructed at Lappeenranta University of Technology (LUT) in Finland in 2008.

1. Test Rig

The test set-up consisted of a heated water tank for mixing the boric acid to the water (volume 1.35 m3), a tank for mixing insulation material (0.8 m^3), and a sedimentation tank for the strainer with filter element (0.8 m^3), Figure 1. Additional devices were a fine filter element with #0.2 wire mesh filter screen for catching the mineral wool fibers passing the sump strainer, pumps for recirculation of the water and a full scale VVER-440 FA model. The bottoms and walls of the tanks and the piping were insulated with mineral wool to reduce heat losses.

The test facility was equipped with temperature, pressure difference and flow rate measurements. During the experiments the events inside the sump strainer tank and the fuel assembly model were recorded with a video camera through the polycarbonate windows on the sump strainer tank wall and the fuel assembly casing.

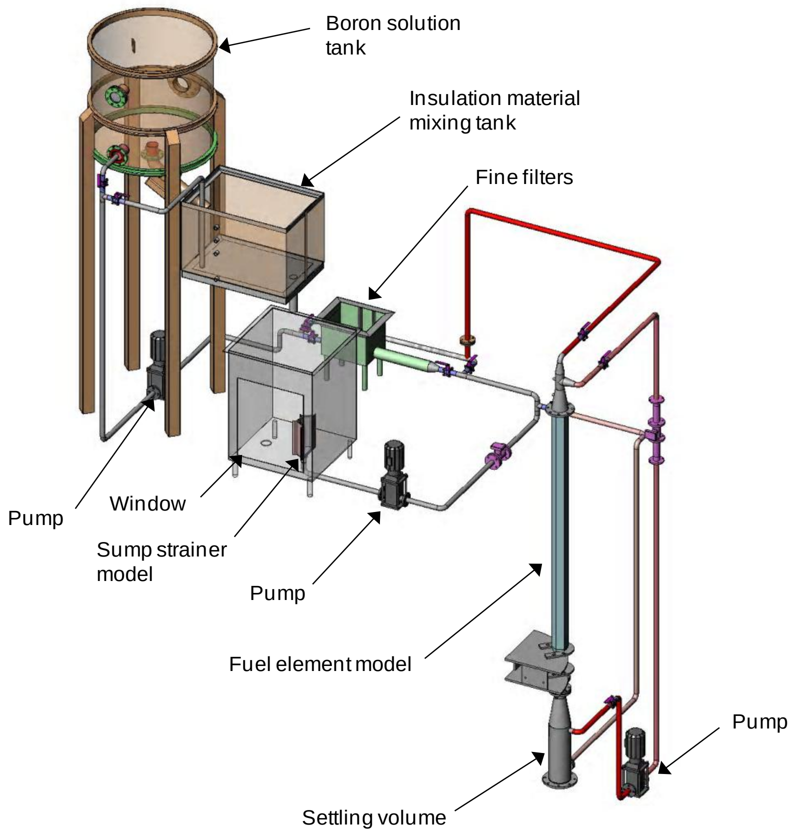

Figure 1 Sump strainer test rig configuration with a scaled down sump strainer model.

2. Test programme

The experiments were carried out in two phases. In the first phase the main objective was to define the amount of the fibers passing through the strainer filter element and the pressure loss over the fiber bed attached on the outer surface of the filter. Both the original filter (Ø2 mm perforated plate) and an enhanced filter structure (#0.7 mm wire mesh over of the original Ø2 mm perforated plate) were used in these tests. In the second phase of tests the aim was to find out the amount of mineral wool fibers accumulating inside a full-scale VVER-440 FA model and the pressure loss caused by fibers with the enhanced sump strainer.

2.1 Experiments with a sump strainer

In the first phase tests were carried out to find out the amount of mineral wool fibers passing through the sump strainer and a pressure loss caused by insulation material accumulating on the surface of the strainer both with the original and the enhanced strainer construction. The most of the experiments were carried out by using a scaled down sump strainer, which screen area (0.08 m^2) corresponded one FA in the VVER-440 reactor, Figure 2. During the test series settling time and concentration of mineral wool and water flow rate through the strainer were varied. Meanwhile, boric acid (H_3BO_3) concentration (13 g/kg_{water}) and water temperature (50 ^oC) remained constant through the test series. After experiments with a scaled down sump strainer two “licensing” experiments were carried out by using a full-scale sump strainer (screen area 0.44 m^2).

Figure 2 A scaled down (left) and a full scale sump strainer model (right).

In the tests the processes in a real NPP were simulated with the accuracy needed for finding out the behavior of the strainer system.

The insulation material, mineral wool, was tempered with heating it for several hours in the temperature of 350 ^oC or more to remove binding agent (phenol formaldehyde resin) and oil from the bulk. After the heat treatment the mineral wool was crushed mechanically with high pressure water jet through a steel wire net.

Fine filters with #0.2 mm wire mesh screen were used for collecting mineral wool fibers passing through the sump strainer.

To measure the maximum pressure loss caused by insulation material accumulating on the outer surface of the strainer, water in the strainer tank was stirred at the end of each experiment until practically all mineral wool used in the experiment attached on the surface of the strainer, Figure 3.

After each test the amount of fibers penetrating through the strainer surface was weighted after collecting them by washing and drying the samples.

Test results (e.g. pressure losses over the strainer surface) were comparable to the results carried out previously. The amount of mineral wool fibers passing through the sump strainer was significantly smaller with the enhanced than original construction. Through the enhanced strainer construction approximately 80 % less mineral wool fibers passed than through the original. In addition the pressure loss over the fiber bed attached on the outer surface of the strainer was also smaller in the experiments with the enhanced filter surface than in the corresponding experiment with the original filter surface.

Figure 3 A full scale sump strainer model before the test (left) and after all mineral wool was accumulated on the surface of the strainer (right).

2.2 Experiments with a fuel assembly model

In the second phase tests were carried out with the enhanced sump strainer (#0.7 mm screen) to find out the amount of mineral wool fibers accumulating inside a full-scale VVER-440 FA model and the pressure loss over the FA caused by the fibers.

After each experiment the FA casing was pulled out and the fuel rod bundle inspected visually to find out if any fibers were accumulated inside the FA. After inspection the fuel rod bundle was flushed with water to remove fibers from the spacer grids. The water used for flushing was filtered through a filtering paper. After filtering the filtering paper was dried and weighed to evaluate the amount of mineral wool accumulated inside the FA.

Mineral wool fibers that penetrated through the filter surface were carried to the FA and the fibres attached to all spacer grids, Figure 4. With a full scale strainer (screen area corresponded conservatively 5.5 FA in the VVER-440 reactor) fibers caused less than 15 kPa pressure loss over the FA with the maximum flow rate of 5.5 kg/s through the FA, Figure 5.

Figure 4 Mineral wool fibers attached at the spacer grid of the VVER-440 FA model in the experiment carried out with a full-scale sump strainer model.

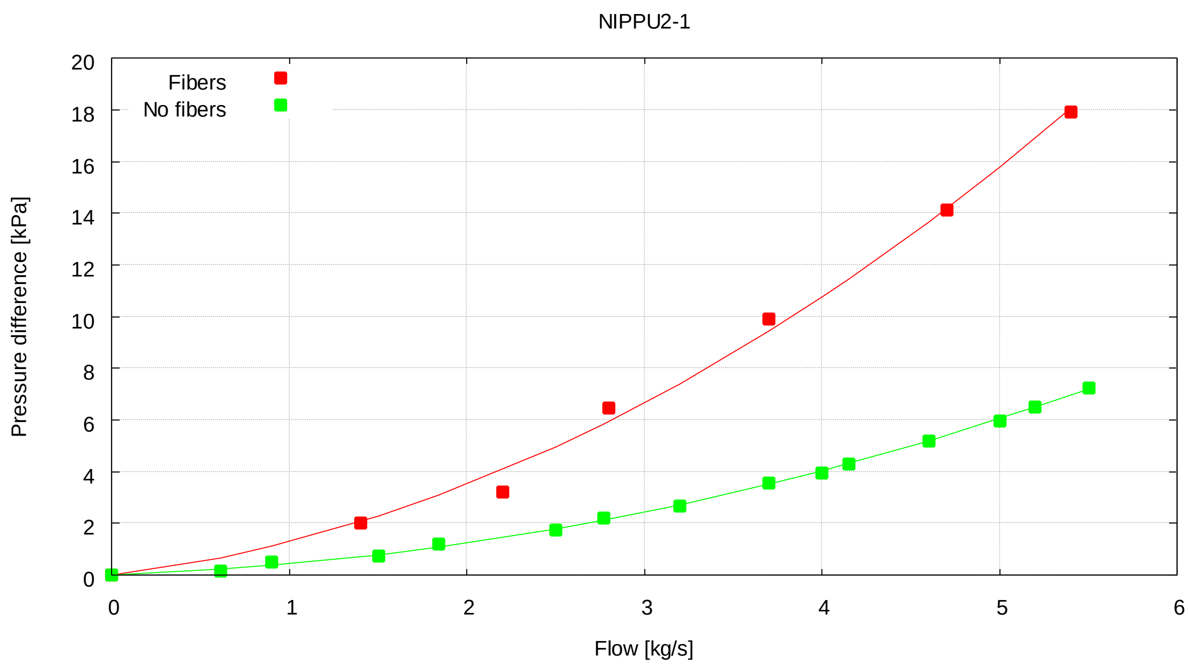

Figure 5 Dynamic pressure difference over the VVER-440 FA model as a function of water flow rate through the FA model.

3. Conclusions

Operation of Loviisa VVER-440/V213 NPP sump strainer arrangement with the original and enhanced filter construction was studied experimentally with a scaled down test rig designed and constructed at Lappeenranta University of Technology. The main objective of the experiments was to study the behaviour of the sump strainer and a full scale FA model.

According to the test results the amount of the mineral wool fibers passing through the sump strainer filter, as well as the pressure loss over the fiber bed attached on the outer surface of the filter and the FA, were at acceptable level.