Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

A CFD Analysis of the HANARO Irradiation Test Rigs for DUPIC Mini-elements

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1. Introduction

The DUPIC(Direct Use of Spent PWR Fuel In CANDU Reactor) fuel cycle is based upon dry thermal and mechanical processes to directly fabricate CANDU(Canada Deuterium Uranium) fuel from spent PWR(Pressurized Water Reactor) fuel material, without separating fissile material and stable fission products. The DUPIC fuels contains 0.9 wt% fissile uranium and 0.6 wt% fissile plutonium, so that this fuel could be burned in CANDU reactors using the natural uranium fuel with 0.71 wt% U-235. Therefore, the DUPIC fuel cycle offers several benefits to countries operating both PWR and CANDU reactors. The benefits include the efficient natural uranium utilization and a significant reduction in spent fuel arising though a proliferation resistant process of reusing spent PWR fuel.[1.2]

Because the DUPIC fuels contain large amount of fission products as well as 0.6 wt% fissile plutonium, their neutronic, thermal, and mechanical behaviors in reactors would be quite different from those of UO_2 fuels.[3] That is, the conductivity, fission gas release, particle growth, and creep behavior of the DUPIC fuel would be different from the UO_2 fuels, so that the material properties and the experimental data are required for analyzing the fuel behavior in reactors. To perform irradiation test of the DUPIC fuel elements at HANARO reactor, the instrumented/non-instrumented irradiation test rigs has been developed for several years.[4,5,6]

The purposes of this study were to estimate the flow characteristics of the HANARO irradiation test rigs and to evaluate the effect of the design changes of the DUPIC-6 test rig by using a CFD(Computational Fluid Dynamics) tool. The flows through the DUPIC-2 irradiation test rig were simulated by a commercial CFD code, CFX-5.7(ANSYS Inc.), and the results were compared with the experimental data. Finally, the flows through the DUPIC-6 irradiation test rig were analyzed to determine whether the new rig satisfies the licensing limits for the HANARO irradiation test.

2. DUPIC-2 Instrumented Test Rig

2.1 Hydraulic Tests

Prior to the installation of the DUPIC irradiation test rig into the HANARO research reactor, out-of-reactor hydraulic experiments[7,8] had been performed to determine if structural strength of the irradiation test rig was enough to endure the irradiation test, and if the test rig satisfy the hydraulic design requirement for the HANARO irradiation test. These out-of-reactor hydraulic experiments include endurance tests and measuring pressure losses and vibration. Measuring pressure drop across the test rig confirms whether the rig satisfies hydraulic design limits of the HANARO irradiation test. The vibration tests and endurance tests examine the mechanical wears by FIV(flow-induced-vibration) to confirm the integrity of the DUPIC test rig during irradiation. Table 1 summarizes the licensing limit of a irradiation test rig to be installed in the HANARO reactor.[9]

Table 1 Licensing Limits of an Irradiation Test Rig for HANARO

Pressure Drop	> 200 kPa
Flow Rate	< 12.7 kg/s (for 18 fuel element) < 19.6 kg/s (for 36 fuel element)
Max. Displacement of Vibration	< 300 μm (grapple head)

2.2 Simulation Method

Unstructured grid structures were generated for the 1/2 computational domain across a vertical center plane. Small parts such as helical and supporting springs were omitted in the grid generation, because their effects on fluid flows were negligible. Total number of tetra elements was 2,214,999, and total number of nodes was 613,441. The standard k-ε model was used to model turbulence generation and dissipation.

In the mass flow range of 5 ~ 11 kg/s, four CFD simulations were performed for the flow rates of 6.0, 8.0, 9.6, and 11.0 kg/s. Each computation cost about 5 hours of CPU time on the PC machine with a Pentium IV 3.2 GHz cpu, and the convergence criteria were the residual of 0.5×10^{-3} for velocity components and the residual of 1.0×10^{-4} for turbulent parameters.

2.3 Simulation Results

Figure 1 shows a comparison of the measured and the calculated pressure losses between the two pressure taps. The measurements were repeated four times. It was observed that the flow rate of 9.632 kg/s produced a pressure loss of 200kPa across the DUPIC-2 test section. These predicted pressure losses agree well with the measured data.

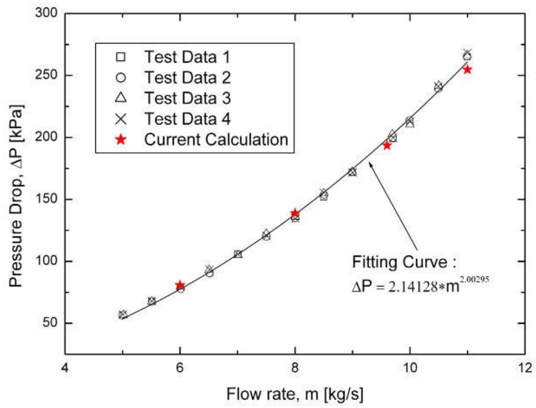

Figure 1. Pressure Drop as a Function of Flow Rate for the DUPIC-2 Irradiation Test Rig

3. DUPIC-6 Non-Instrumented Test Rig

3.1 Design Changes

For the design of the DUPIC-6 irradiation test rig, measuring instruments with connecting lines were installed and the design of a grapple head was changed from the non-instrumented DUPIC-2 test rig. Also, the outer tube surrounding the test rig had been removed and the guide tube would be additionally installed to secure the instrumentation lines. The gap between the inner diameter of the guide tube and the maximum outer diameter of the test rig was one of the main design parameters. The other small design changes such as drilling fuel elements for instrumentation were not considered in this study.

3.2 CFD Analysis

For grid generation, it was assumed that only one censor holder to support a instrumentation line had been installed and the flexible instrumentation line from the censor holder's end was not accounted for in the mesh generation. Total number of tetrahedral elements was 2,481,963, and total number of nodes was 584,117. The standard k-ε model was used. Figure 2 shows the optimization process of the guide tube gap varying the gap size from 0mm to 1.0mm. From this optimization study, a gap size of 0.3mm gave a mass flow rate of 8.0 kg/s at ~200 kPa pressure difference across the test rig, which was the most satisfying condition for the design limit.

4. Conclusion

In this study, CFD analyses were performed to determine the flow characteristics of the HANARO irradiation test rig for DUPIC mini-elements. The conclusions are as follows.

(1) It is confirmed that the predicted pressure losses by CFX-5.7 agreed well with the measured pressure losses of the DUPIC-2 hydraulic experiments.

(2) The gap between the irradiation test rig and the guide tube, one of the DUPIC-6 design parameter, was set as 0.3 mm after optimization study. When the gap was 0.3 mm, the CFD analysis estimated the mass flow rate to be 8.0 kg/s at the pressure difference across the irradiation test rig of 200 kPa, which satisfies the design limits for HANARO irradiation tests.

(3) The maximum velocity at the narrow throat is about the same level(15~18m/s) as the DUPIC-2 hydraulic test. Thus, maximum displacement by vibration would be less than 50 μm, which satisfies the licensing limit.

Acknowledgement

This project has been carried out under the Nuclear R&D Program by MOST.

REFERENCES

[1] J.S. Lee et al., 1995, "Burn Spent PWR Fuel again in CANDU Reactors by DUPIC", Global '95, Versailles

[2] H.S. Park et al., 1996, "The DUPIC Fuel Cycle Alternative Status & Perspective", Proceedings of the 10th PBNC, Kobe, Japan

[3] M.S. Yang et al., 1997, "Characteristics of DUPIC Fuel Fabrication Technology", International Symposium on Nuclear Fuel Cycle and Reactor Strategies, Vienna, Austria

[4] K.K. Bae et al., 1999, Irradiation Test Plan of the Simulation DUPIC Fuel, KAERI/TR-1428/99, KAERI (in Korean)

[5] K.C. Song et al., 2001, The 3rd Irradiation Test Plan of Dry Process Fuel, KAERI/TR-1830/2001, KAERI (in Korean)

[6] K.C. Song et al., 2002, The 4th Irradiation Test Plan of Dry Process Fuel, KAERI/TR-2201/2002, KAERI (in Korean)

[7] H.J. Chung et al., 1999, Endurance Test for DUPIC Capsule, KAERI/TR-1367/99, KAERI (in Korean)

[8] H.G. Jun et al., 2001, Hydraulic Test for DUPIC Irradiation Test Rig-003, KAERI/TR-1806/2001, KAERI (in Korean)

[9] J.-S. Ryu and H.J. Chung, 2000, Technical Specification for Endurance Test of HANARO Irradiation Test Assembly, KAERI/TR-1474/2000 (in Korean)

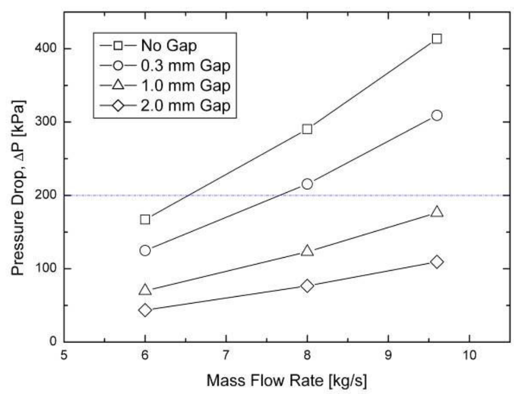

Figure 2. Optimization of the Guide Tube Gap Depending on Total Pressure Drop