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Experimental study for the effects of fuel relocation on the rod bundle

Jongrok Kim[a,*], Jong-kuk Park[a], Sang-Ki Moon[a]
[a] *Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong, Daejeon 305-353, Korea*
[*] *Corresponding author: jongrok@kaeri.re.kr*

1. Introduction

There are four steps, which are blowdown, refill, reflood, and long-term cooling, for a large break loss-of-coolant accident (LBLOCA). The first step (blowdown) is around 0 ~ 30second, until the emergency core coolant reaches lower plenum of reactor vessel after the system has break point. The second step (refill) is around 30 ~ 40 second, until the coolant touches bottom of fuel bundle after blowdown. And then, the injected coolant decreases temperature of the heated fuel rods for 40 ~ 200second (reflood). After core vessel is filled by coolant, it is long-term cooling.

During the single-phase steam flow in the early phase of the reflood, the cladding temperature may increase and have a peak value due to low heat transfer from the fuel to the steam. The increased temperature can make a ballooned fuel rods [1]. As a result, the flow passage area of sub-channel is reduced and it leads the redistribution of flow and heat transfer in sub-channels. The flow rate through the sub-channel between ballooned fuel rods is decreased while the flow rate through the sub-channel between intact fuel rods is increased. The reduction of flow reduces the capacity of coolibility and ballooned fuel rods have higher temperature than non-deformed fuel rods. If a LBLOCA condition and ballooned fuel rods are occurred, the effect of reduced flow passage on the convective heat transfer by single-phase steam flow is important phenomena to analyze the safety of a reactor.

During the LOCA condition, accumulation of fuel debris in the ballooned region of the bust cladding, which resulted from fuel fragments slumping from upper regions, can be occurred [2]. This fuel relocation makes different thermal hydraulic behavior.

The present experiments were performed in various Reynolds numbers (about 2600~13000) and Heater power (0.14 ~ 1.12 kW/m) to investigate the effect of the Fuel-relocation on heat transfer phenomena by single-phase steam flow. The experiments were performed in three rod bundles in KAERI reflood ATHER test facility. One is a non-deformed 6x6 rod bundle, which consists of 36 non-deformed heater rods. Another is a deformed 5x5 rod bundle that consists of 9 deformed heater rods and 16 non-deformed heater rods. The other is a fuel-relocated 5x5 rod bundle that consists of 9 deformed heater rods that have power peak to simulate the fuel relocation and 16 non-deformed heater rods. The cladding temperature and convective heat transfer for two rod bundles are compared for each flow conditions and the effects of experimental parameters are analyzed..

2. Experimental facilities and Results

Fig. 1 shows a schematic diagram of the reflood test facility, ATHER (Advanced Thermal Hydraulic Evaluation of Reflood phenomena), which consists of a test section, a separating system for measuring the amount of entrained liquid droplet, a pressure oscillation damping system to control the system pressure, a coolant supply system and a steam supply system. A single phase steam generated in the steam generator is injected into the bottom of the test section.

Fig. 2 shows the cross-sectional view of the rod bundles. Each bundle has the same geometrical configuration with prototype APR1400 nuclear reactors. The heated length and diameter of the heater rods are 3.81 m and 9.5 mm, respectively. The heater rods with a pitch of 12.85 mm are located in a square array and heated indirectly by AC (alternating current) power. The sheath and heating element of the heater rods are made of Inconel 600 and Nichrome, respectively. The intact bundle consists of 36 intact heater rods in 6x6 array (Fig. 2 (a)), and the ballooned and fuel-relocated bundles consist of 9 deformed heater rod (90% blockage ratio), which has sleeve (Fig. 3) to simulate the ballooned rod on middle of the heater rod, and 16 intact heater rods in 5x5 array. The intact bundle and ballooned bundle has same axial power shape (Fig. 4) and the 9 fuel relocated heaters in fuel relocated bundle have the power peak (Fig. 5), which is simulated the power re-distribution by fuel relocation.

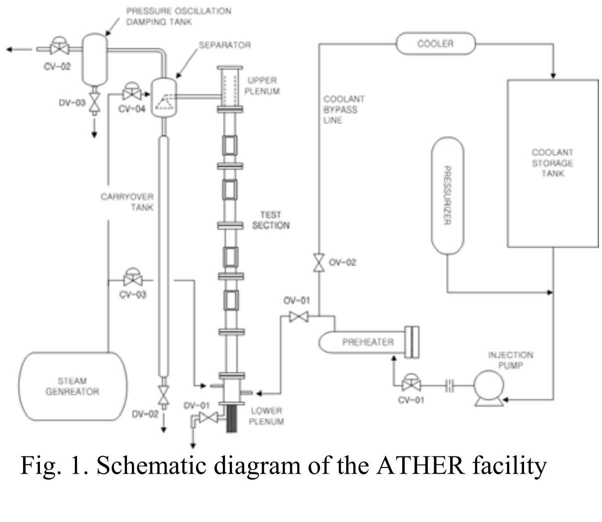

Fig. 1. Schematic diagram of the ATHER facility

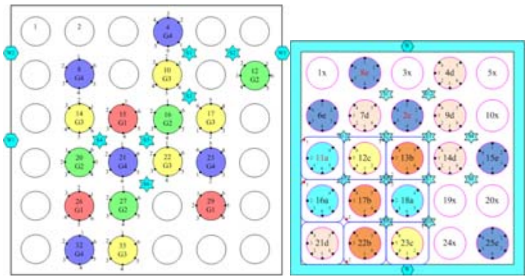

Fig. 2. Rod bundle configuration and radial locations of temperature measurement

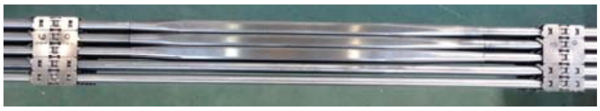

Fig. 3. Installed sleeve of 5x5 deformed rod bundle

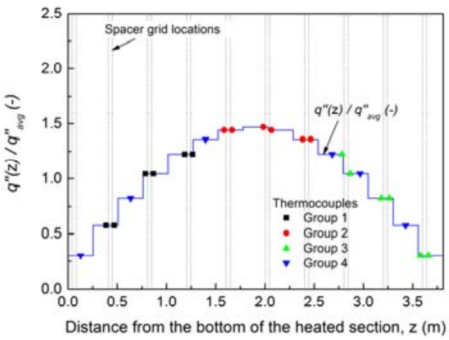

Fig. 4. Axial power shape of the intact and deformed heater rods

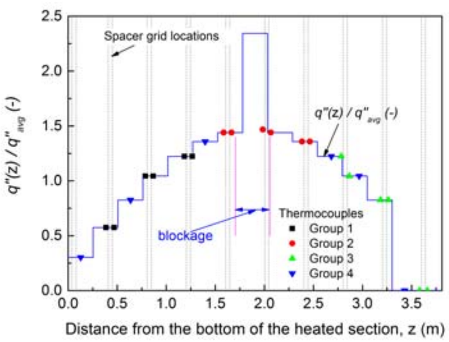

Fig. 5. Axial power shape of the fuel-relocated heater rods

A total of 11 spacer grids are installed to support the heater rods along the axial location in the test section. The spacer grids with mixing vanes have the same geometry with those used in Korean nuclear power plant. The blockage ratio of the spacer grids used in the present experiment is about 0.48. For instrumented heater rods, six K-type thermocouples with a sheath diameter of 0.5 mm are embedded on the outer surface of the heater rod to measure the heater rod surface temperature.

3. Experimental facilities and Results

The characteristics single phase steam flow in the fuel-relocated rod bundle are as follows:

- Measured steam temperatures are similar to calculated steam temperature using heat balance equations
- Heater surface temperatures of ballooned and intact heater rods are similar at up-steam of blockage region.
- Heater surface temperatures of fuel-relocated heater rods have higher temperature at the blockage region because heat transfer rate is decreased by reduced flow rate thorough the blocked region. Low steam flow rate promotes the heat transfer decreasing.

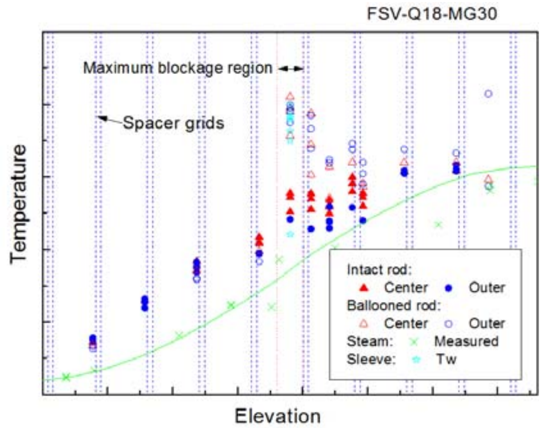

Fig. 6. Heater temperature and steam temperature for fuel-relocated rod bundle

4. Conclusions

Experimental study of heat transfer phenomena by single-phase steam flow using three type heater bundles (intact bundle, ballooned bundle, fuel-relocated bundle) were performed to investigate the effect of fuel-relocation on single-phase steam flow. Fuel-relocated bundle showed its own charateristics.

REFERENCES

[1] C. Grandjean, “A STATE-OF-THE-ART REVIEW OF PAST PROGRAMS DEVOTED TO FUEL BEHAVIOR UNDER LOCA CONDITIONS Part One. Clad Swelling and Rupture Assembly Flow Blockage”, IRSN, NT SEMCA 2005-313, 2005

[2] OECD, “Nuclear Fuel Behavior in Loss-of-coolant Accident (LOCA) Conditions”, NEA No. 6846, 2009