Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

Experimental Setup for Reflood Quench of Accident Tolerant Fuel Claddings

Chan Lee[a], Kwan Geun Lee[ab], Wang Kee In[a]*
[a]LWR Fuel Technology Division, Korea Atomic Energy Research Institute, 111, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon 34057
[b]Dept. of Advanced Nuclear System Engineering, University of Science & Technology, 217, Gajeong-ro, Yuseong-gu, Daejeon 34113
[*]Corresponding author: chanlee@kaeri.re.kr

1. Introduction

The concept of accident tolerant fuel (ATF) is a solution to suppress the hydrogen generation in loss of coolant accident (LOCA) situation without safety injection, which was the critical incident in the severe accident in the Fukushima. Several types of accident tolerant claddings, e.g. Cr-coated, Fe-based, and SiC composites, with new fuel types are currently in development in major nuclear research and engineering organizations [1].

The changes in fuel and cladding materials may cause a significant difference in reactor performance in long term operation. Properties in terms of material science and engineering have been tested and showed promising results. However, numerous tests are still required to ensure the design performance and safety [2].

Thermal hydraulic tests including boiling and quenching are partly confirmed, but not yet complete. We have been establishing the experimental setup to confirm the properties in the terms of thermal hydraulics. Design considerations and preliminary tests are introduced in this paper.

2. Methods and Results

2.1 Temperature measurement

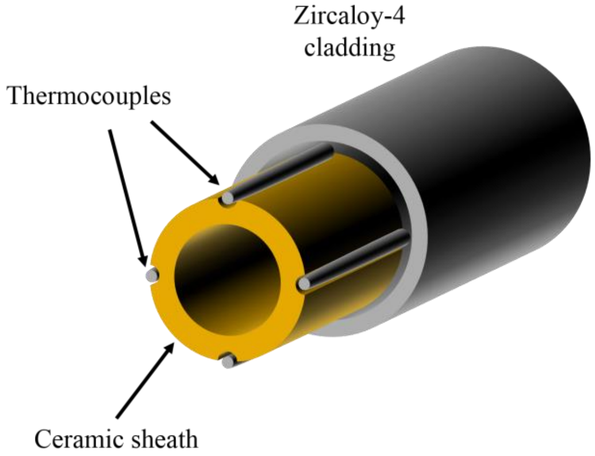

Fig. 1. Schematics of thermocouple assembly inside the cladding. Ceramic sheath makes the thermocouples tightly contact inside the cladding. Coil heaters go inside the hole of ceramic sheath.

The experiment setup is to simulate and watch the transient process at a LOCA situation with and without the safety injection. Since the multiphase thermal hydraulic phenomena occur on the surface of claddings, any disturbances on the surface should be avoided as possible. For an example, welding thermocouples on the target surface with thin metal strips are common techniques to read the temperature. However, the thermocouples itself and strips could make distortions on the flow around the surface and lead to the wrong observations. Thermocouples are therefore inserted inside the claddings as shown in Fig.1. Ceramic tubes are also inserted to keep the thermocouples tightly contact on the inner side of the cladding.

2.2 Heater Fabrication

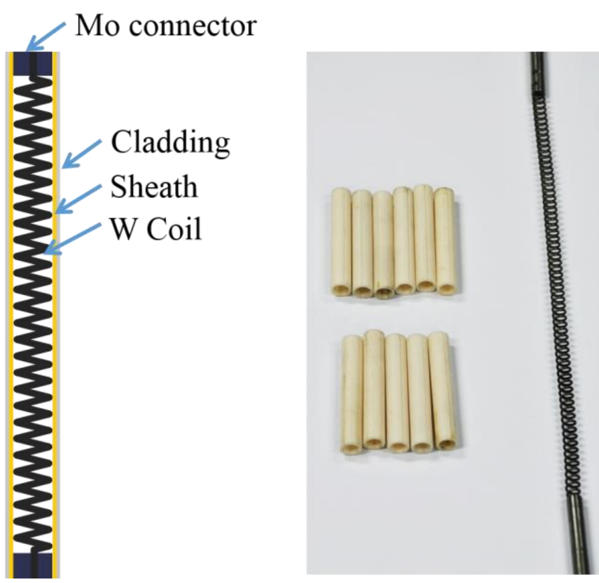

Fig. 2. Schematics of heater assembly and actual product. The coils are about 3 rev/cm and 1 mm in diameter, fit inside the sheath which is 6 mm in inner diameter.

Average linear thermal power output for a fuel rod in OPR-1000 type reactor is known as 17.26 kW/m. The power decreases as low as ~690 W/m (~4 % of the rated power) after the reactor was tripped. As shown in Fig. 2., a tungsten (W) coil in 1 mm diameter was used as a heater material because of its high melting point. Mo rods in 6 mm diameter were selected as conducting materials because of low thermal expansion and attached on the both top and bottom sides of the W coil.

Based on literacy (i.e. temperature coefficient of resistance), electric resistance of W and Mo was calculated and estimated linear heat output on the W coil was 964 W/m in 1000 ℃ with 50 A of electric power input.

Although both materials have similar resistivity and temperature coefficient, much smaller diameter and longer length of W coil cause a large difference in total resistance. A "leakage", heat dissipation on the Mo rods, are estimated lower than 2 % of the W coil part in 1000 ℃ condition. Also, estimated linear expansion of W and Mo parts were ~2.6 mm and ~1.5 mm each.

2.3 Coolant Reflooding

Since the reflooding speed by safety injection in OPR-1000 type reactor is ~0.5 m/s at maximum, a water pump with 240 LPM capacity was attached to the feed line to mimic the maximum filling speed. Coolant reservoir was equipped with PID-controlled heater, to infuse coolants in various temperatures.

The coolant can be injected in two modes, pressure-driven and pump-driven, selectively. The former is for in slow reflooding and the latter for fast reflooding.

2.4 Operation Test

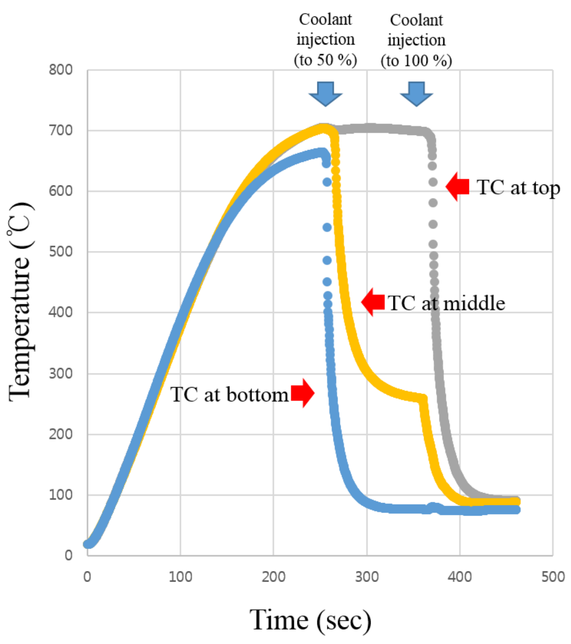

Fig. 3. Temperature curve of heating and progressive reflooding. The specimen was heated to 700 ℃ and coolant was injected to 50 % level first, and to the 100 % level afterwards for the operation test.

The experimental setup was tested to check the performance and operability. The heater was inserted to the zircaloy-4 claddings, assembled with ceramic sheaths and thermocouples. Attached to the program-controlled DC power supply. The assembled tube was vertically set inside a quartz glass chamber.

The cladding reached 700 ℃ in about 4 minutes with fixed 25 A current input. Maximum temperature difference along the heating section was about 100 ℃.

Coolant in room temperature was injected into the chamber in ~1 cm/s speed, while the heater was still powered on during the process. The curve shows successful cooling in less than 100 seconds, also showing the temperature difference along partly immersed tube.

3. Conclusions

An experimental setup to test thermal hydraulic characteristics of new ATF claddings are established and tested. The W heater set inside the cladding is working properly, exceeding 690 W/m linear power with thermocouples and insulating ceramic sheaths inside. The coolant injection control was also working in good conditions. The setup is about to complete and going to simulate quenching behavior of the ATF in the LOCA situation.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) funded by the Korea government (MSIP) (NRF-2012M2A8A5025824).

REFERENCES

[1] S.J. Zinkle, K.A. Terrani, J.C. Gehin, L.J. Ott, L.L. Snead, Accident Tolerant Fuels for LWRs: A Perspective, J. Nucl. Mater., Vol. 448, pp. 374-379, 2014
[2] Y. Koo, J. Yang, J. Park, K. Kim, H. Kim, D. Kim, Y. Jung and K. Song, KAERI's Development of LWR Accident-Tolerant Fuel, Nucl. Tech., Vol. 186, pp. 295-304, 2014.