Development of Fuel Performance Models of Dual Cooled Annular Fuel : Current Status and Future Plan

Yong Sik Yang, Chang Hwan Shin, Jae Yong Kim, Yang Hyun Koo
Innovative Fuel Development Division, Korea Atomic Energy Research Institute
(150-1 Deokjin-Dong), 1045 Daedeokdaero, Yuseong, Daejeon, 305-353 Korea
**Corresponding author : yys@kaeri.re.kr*

1. Introduction

A dual cooled annular fuel is expected that it has many advantages in fuel safety and integrity even under a power up-rating condition.

The merit of annular fuel is originated from its structural characteristics; for example, an expanded fuel-coolant interface surface reduces the heat flux and can increase thermal hydraulic margin. Fuel temperature of annular fuel is decreased due to a reduction of pellet thickness and it serves to lower failure probability at LOCA and RIA condition[1]. But, from a fuel performance analysis point of view, many new models and analysis methodology are required because the in-reactor behavior of fuel material depends greatly on temperature and shape.

Because of a very low pellet temperature and structural characteristics of dual cooled annular fuel, in-pile performances such as densification, swelling, fission gas release and high burnup structure formation may show different behavior from current solid type fuel. Especially, coolant flow and heat balance between inner and outer channel, which are closely related to the in-reactor behavior of materials, are one of the key issues in dual cooled annular fuel design. Therefore, new models must be developed which can be applied to dual cooled annular fuel.

Over the past few years, several studies have been made on the development of performance models of dual cooled annular fuel. In this paper, a current status of model development is summarized and future plan is introduced such as an additional model development and validation test.

2. Current Status of Fuel Performance Model Development

A principal fuel performance models which were developed up to now are listed below.

- Heat flux and flow balance model of inner and outer coolant channel
- Heat conduction from pellet to cladding
- In –reactor deformation of pellet
- Gap conductance model
- Elasto-plastic stress & strain of cladding
- Various material property models

Material property and gap conductance model are identical with those of current solid type fuel but other models were newly developed for annular type fuel.

In case of a current solid fuel, heat flux and coolant flow rate of fuel rod are nearly constant during steady state operation. But, as mentioned in previous work[2], a flow and heat flux ratio between inner and outer channel are not constant and must be determined by coupling with fuel temperature calculation result. For example, a boundary condition for temperature calculation is decided by TH model of coolant but heat flux can be determined based on the fuel temperature calculation result. To solve this interdependency, a new methodology was proposed to decide fuel temperature and TH condition of coolant by iteration method. Verification of a new TH model was performed by code-to-code benchmarking with sub-channel analysis code MATRA-AF[3]. Fig. 1 shows the pressure drop verification results between new model and MATRA-AF. The pressure drop calculation result is a key factor which determines the coolant's flow rate of inner and outer channel.

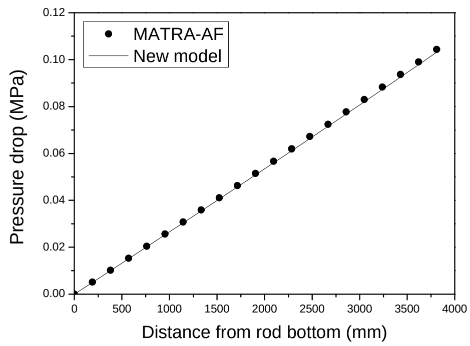

Fig. 1. Pressure drop prediction result of inner channel between new model and MATRA-AF

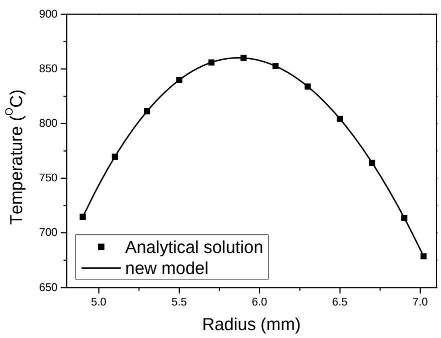

Fig. 2. Verification result of pellet temperature calculation

A new heat conduction model from pellet to cladding was proposed[4]. 1-D steady state heat conduction equation of hollow cylinder was solved coupled with TH model of coolant by finite difference method and then verified with analytical solution. The verification result of heat conduction model is shown in Fig. 2.

As mentioned in chapter 1, it is expected that densification and swelling behaviors of an annular fuel are somewhat different from that of conventional fuel due to very low temperature. But, at current stage, solid type fuel model is used to predict in-reactor deformation of pellet. In addition to deformation model of pellet for densification and swelling, thermal deformation of pellet is modeled using 1-D and plane strain assumptions[5]. Fig. 3 shows the verification results of new thermal deformation model of pellet.

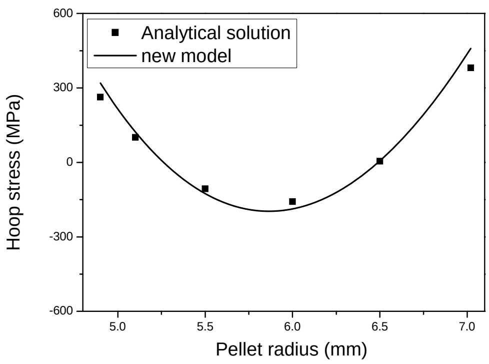

Fig. 3. Comparison of hoop stress prediction between new model and analytical solution

The main causes which can induce cladding deformation during operation are thermal, elastic and plastic strains due to temperature and pressure difference between rod internal and coolant. And a creep of inner and outer cladding is another major mechanism. At current stage, 1-D cladding stress/strain analysis module was developed for open or closed gap condition and a creep model is being developed.

To calculate fuel temperature and heat&flow balance of dual cooled annular fuel, all models mentioned above, were coupled and solved by iteration method. A schematic diagram for calculation flow is shown in Fig. 4.

3. Future Plan

Some models which are indispensable for fuel performance analysis, particularly densification and swelling model, should be developed using in-reactor test results. Therefore, ~~a~~ post irradiation examination result for annular pellet which was irradiated in the HANARO[6] would be useful for developing densification and swelling models.

A fission gas release and high burnup structure formation model requires long term irradiation test result. At current stage, long-term irradiation test is planned by using the FTL(Fuel Test Loop) of HANARO. Long-term test of FTL can provide fission gas release data through instrumented LVDT. In addition, the FTL test results can be applicable to other performance models such as cladding oxidation and hydrogen pick-up, cladding creep, radial power and burnup distribution and rod internal pressure prediction model.

Due to the interdependency between fuel performance behavior, fuel performance code system must be established. A structure and calculation flow of fuel performance code of dual cooled annular fuel was designed and its construction is progressing.

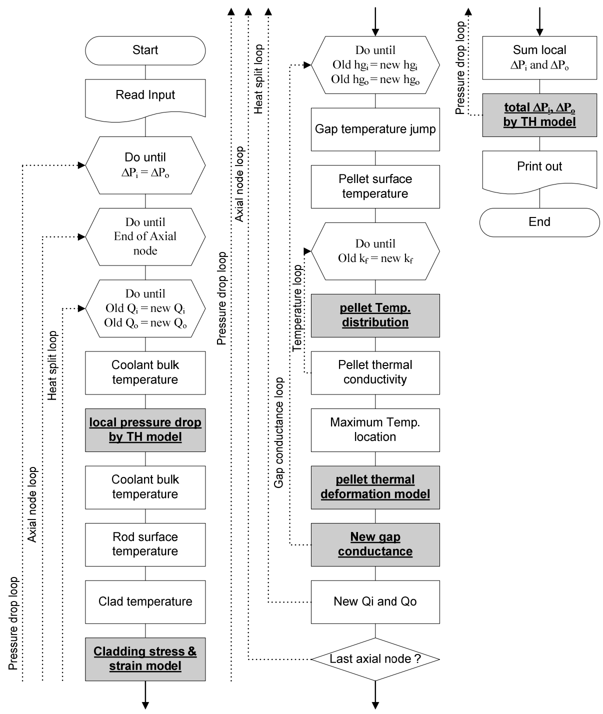

Fig. 4. Calculation flow of fuel performance models to calculate fuel temperature of an annular fuel

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