Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

`

Thermal-Hydraulic Design of Mixed Transition Core for FCM Fuel Assembly

Hyuk Kwon [a*] , K.W. Seo [a], S. J. Kim [a], J. P. Park [a], D. H. Hwang [a], and W.J. Lee [b]
[a] *SMART Development Division, Korea Atomic Energy Research Institute*
[b] *VHTR Development Division, Korea Atomic Energy Research Institute*
, 150, Dukjin-dong, Yuseong, Daejeon, 305-353, Korea
[*]*Corresponding author: kwonhk@kaeri.re.kr*

1. Introduction

The concept of accident-tolerance fuel implied certain fundamental improvement such as reducing fuel centerline temperature, reduced reaction of cladding with water which limits hydrogen and heat production, and improved high-temperature mechanical property[1]. A fully ceramic micro-encapsulated(FCM) fuel based on the dispersed particle fuel concept was considered on the one of accident tolerant fuel(ATF). A mixed core is established using the FCM fuel in the existing LWR core where UO2 fuel pellet was loaded.

In order to demonstrate the thermal-hydraulic compatibility of the FCM fuel in the existing LWR core, pin by pin analysis is performed for transition period from mixed core with FCM fuel and UO2 fuel to the FCM fuel only. Parallelized MATRA code using MPI is developed for pin by pin calculation[2].

2. Methods and Results

2.1 Parallelized MATRA Code

Subchannel analysis code, MATRA was initially developed on the thermal margin evaluation of advanced LWR core and various GEN IV reactor core such as SCWR and block type VHTR. For the purpose of the design, lumping channel analysis has been used to evaluate the MDNBR and thermal margin over the normal operating condition since 1980. The lumping channel analysis, however, tends to evaluate the conserve MDNBR due to the hot channel factor.

To circumvent that, pin by pin analysis model is tried to evaluate the MDNBR using parallel computing to obtain the reasonable calculation time which is known less than 10 minutes. The pin by pin model using MATRA can compute the enthalpy and mass flow rate based on subchannel scale with the aide of parallel algorithm using MPI.

In MATRA code, all field variables such as enthalpy, mass flux, cross flow, are solved at the present axial node, and the domain to solve then advance to next axial node and repeated the marching solution until exit plane. At this time, the planes in which is not affected by previous calculation are simultaneously solved in the multiple processor. The performance of parallelization compared with serial calculation was greatly improved. The speed up of parallelization of MATRA code results in more than factor 8 in total computing time[2].

2.2 Analysis Model

Thermal hydraulic feature of transition core is properly reflected in the MATRA code with ad-hoc thermal hydraulic models. Table I shows the constitutive models for the TH analysis of FCM assemblies. Assembly-wise flow distribution at core inlet is applied with the identical flow distribution of OPR-1000. The distribution used the identical distribution that was applied to the OPR-1000 core design before.

Table I: MATRA models for thermal margin analysis of FCM fuel assembly

Parameters	**Values**
Flow models	
- Field equations	Homogeneous mixture
- Subcooled boiling void fraction	Saha-Zuber model
- Bulk boiling void fraction	Chexal-Lellouche model
- Two-phase friction multiplier	Homogeneous model
Subchannel interaction models	
- Crossflow resistance factor	Reynolds dependent model
-Turbulent mixing parameter for single-phase	0.038
-Two-phase turbulent mixing model	Equal-mass-exchange model
Empirical TH models	
- Bundle friction factor	P/D correction factor model
- Spacer grid loss factor	0.946(MV)
- Critical heat flux correlations	CE-1
Numerical parameters	
- Number of axial nodes in active length	50 (Uniform node)
- Solution scheme	Marching scheme with SOR
- Boundary conditions	Inlet flow/Exit pressure
- Convergence criteria for	
axial flow	1.E-2
crossflow (internal/external)	1.E-3 / 1.E-1

The axial and radial power shape was provided by the MASTER code on the initial core condition and equilibrium core and 4 burn-up conditions per cycle are considered such as BOC, IOC, MOC, EOC as shown in Table II.

Table II: Peaking factors vs. burnup for each cycle

Cycle Burnup (EFPD)	Cycle Burnup (MWD/kgU)	Fq	Fr	Condition
0.000	0.0000	2.0533	1.5006	BOC
150.000	16.5584	1.8645	1.4735	IOC
300.000	33.1167	1.7586	1.4966	MOC
565.216	62.3937	1.8614	1.4854	EOC
0.000	0.0000	1.8428	1.5026	BOC
150.000	16.5590	1.6932	1.4664	IOC
300.000	33.1180	1.7560	1.4872	MOC
450.213	49.7004	1.7782	1.4867	EOC

Operating condition and geometry of fuel assembly for thermal margin evaluation is used to the normal operating condition as shown in Table III.

Table III: Calculation condition for thermal margin evaluation

Parameters	**Unit**	**Reference FA**	**FCM FA**
Rod diameter	mm	9.5	10.0
Guide tube diameter	mm	24.93	24.93
p/d ratio	-	1.36	1.29
Gap size	mm	3.4	2.9
Heated perimeter	mm	7043	7805
Hydraulic diameter	mm	12.92	11.38
Grid type	-	MV	MV
FA power	MW	15.94	15.94
Average heat flux	kW/m2	853	810
FA flow rate	kg/sec	80.75	80.75
Average flux	kg/m2-sec	3362	3635

2.3 Pin by Pin Analysis Results

Pin by pin analysis on the a quarter core with 13310 subchannels(12532 fuel rods) was performed on the radial power distribution and axial power distribution was provided by MASTER code evaluation on 4-cycle such as BOC, IOC, MOC, EOC. Inlet flow distribution of channel by channel was used to the identical inlet distribution of OPR-1000.

The loading pattern of transition core from mixed FCM and reference assembly to FCM only is shown in Fig. 1.

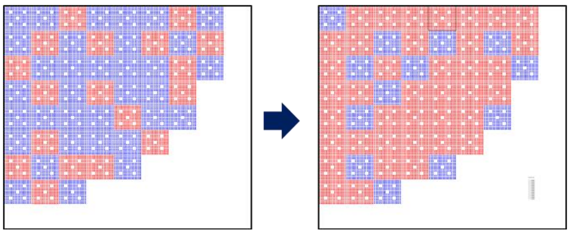

Fig.1. Loading pattern from mixed core of FCM and UO2 fuel assembly; blue = UO2 fuel , red = FCM fuel

In this condition, channel enthalpy rise and flow distribution change was assessed by MATRA code. In case of cycle 1 transition core , Fig. 1 shows calculation results for burn-up such as assembly and pin radial power peaking, channel enthalpy on the plane in which MDNBR occurred

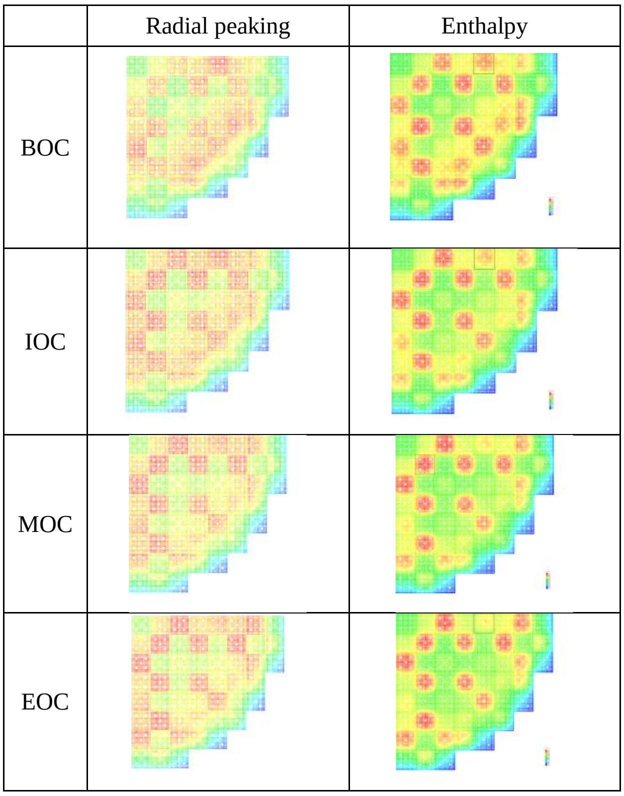

Fig.2. Enthalpy and radial peaking distribution of Mixed core at cycle1

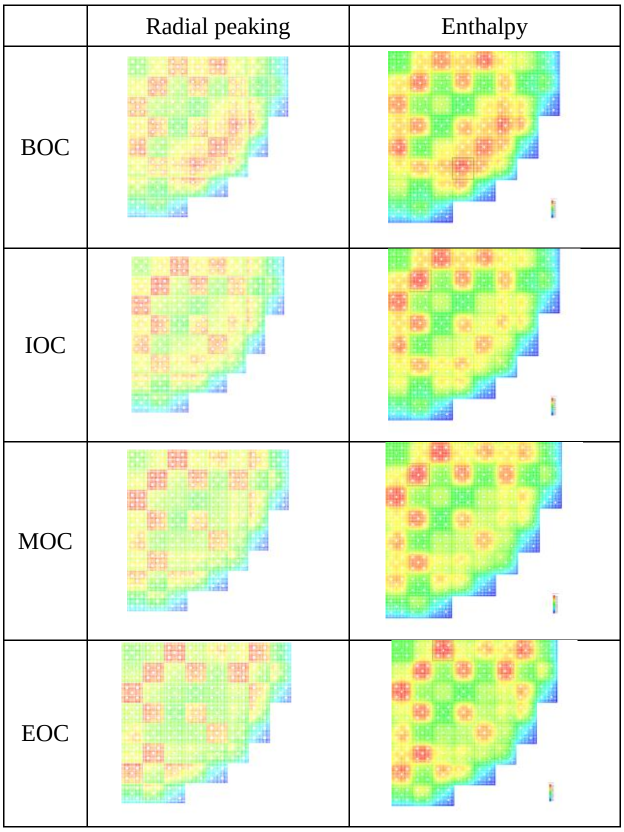

Fig.3. Enthalpy and radial peaking distribution of Mixed core at cycle 2

`

Fig. 2 shows calculation results for radial power peaking, channel enthalpy on the plane in case of cycle 2 transition core. In this figures, bright contour color represented the high enthalpy and high pin peaking. Red color on rod denoted high radial peaking. In this figures, Enthalpy distribution was strongly affected on the radial peaking distribution. The minimum DNBR location was dependent on the enthalpy and axial mass flux distribution as well as radial power distribution provided by MASTER code.

The minimum DNBR of the FCM fuel was estimated to be greater than the reference value owing to the increase of rod diameter. Minimum values of MDNBR of cycle 1 transition core were found to be 2.823 at MOC for FCM fuel assembly and 2.713 at BOC for UO2 reference fuel assembly, respectively. Minimum DNBR of cycle 2 transition core were found to be 2.51 at IOC for FCM fuel assembly and 3.685 at EOC for UO2 reference fuel assembly, respectively.

According to proceeding the burn-up, mixed core is changed to the homogenous core with FCM fuel assembly only. MDNBR for initial core and equilibrium core is investigated as shown in Fig. 4. Minimum DNBR of initial and equilibrium core were found to be 2.60 at BOC for initial core and 2.57 at BOC for equilibrium core, respectively.

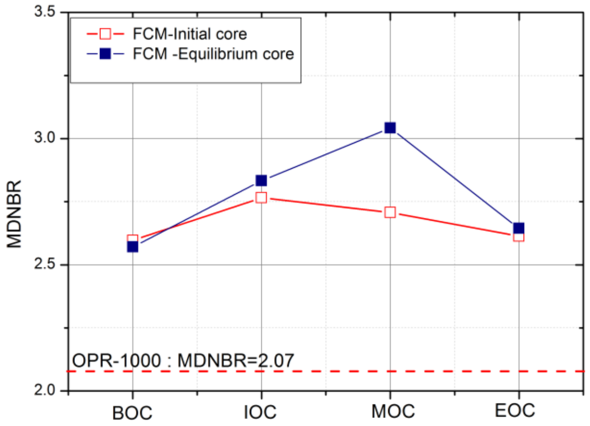

Fig.4. MDNBR for initial core to equilibrium core of FCM fuel core

3. Conclusions

Pin by pin analysis on mixed transition core for FCM fuel and reference UO2 fuel was performed on a quarter core with 13310 subchannels in assistance with the parallel algorithm with MPI with 20 cores. The thermal margin for the pin by pin model was evaluated by employing a quarter-core power distribution data provided by MASTER code that is nodal code. The pin by pin model shows the feasibility of mixed transition core of FCM fuel assembly based on the MDNBR results.

REFERENCES

[1] W.J. Lee, L. L. Snead,and F. G. V. Venneri, Fully Ceramic Micro-encapsulated(FCM) Replacement Fuel Assembly for LWRs,. ICAPP 2013, Jeju, Korea, April 14-18, (2013).
[2] S. J. Kim, et al., Paralleization of Subchannel Analysis Code MATRA, Transactions of the KNS spring meeting, Jeju, Korea, May 29-30, (2014)