A Study on the Pressure Drop of a Subchannel Analysis Code for an Annular Fuel

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1. Introduction

Recently, MIT proposed an internally and externally cooled annular fuel for an advanced PWR which can endure a substantial power uprating.[1] KAERI is pursuing the development for its reloading to operating PWR reactors of OPR-1000. Thermal hydraulic analysis is critical part of annular fuel design because it determines dimensions of the fuel within acceptable MNDBR margins. An annular fuel subchannel analysis code, MATRA-AF which can be coupled to MATRA[2] and can calculate the coolant flow split and heat split in the internal and external subchannels has been developed.[3] In this paper, the effects of the parameters related with a calculation of a single-phase and two-phase pressure drop have been estimated.

2. Structure of MATRA-AF

MATRA-AF consists of two programs of MATRA and ANNULAR as shown in Fig. 1. The calculations of the mass and energy equations for each subchannel are performed in MATRA. In the ANNULAR, it will adjust the flow split to equalize the pressure loss between the internal and external channel, and the heat split from these results will be recalculated, and then the MATRA recalculates it with the MATRA input regenerated from ANNULAR. This iteration loop is repeated until the mass flow distribution and the heat transfer fraction are within the error tolerance.

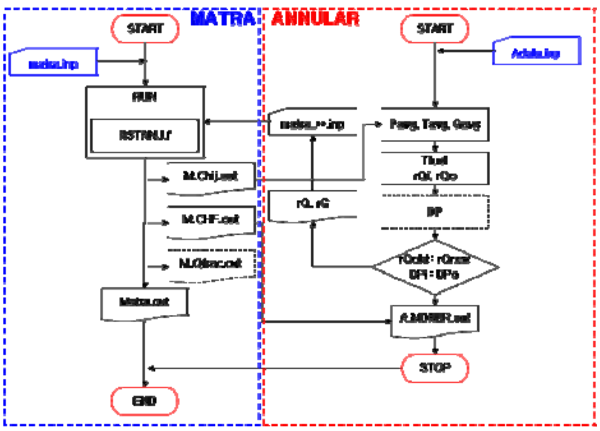

Fig. 1 The sturcture of MATRA-AF

3. Results and Discussion

The subchannel analysis for a single-rod model of an annular fuel is carried out using MATRA-AF. When the annular fuel has a 20% power uprae, the coolant inlet temperature is assumed to be reduced to maintain the same outlet temperature. The analyses were performed with a 18% overpower to allow for a transient and the inlet temperature was increased by 2^{o}C to account for possible non-uniformities of the core inlet temperature due to an imperfect coolant mixing in the lower plenum.

3.1 Single-phase Pressure Drop

The axial pressure gradient from wall shear stress is computed by the friction factor. For single-phase flow, the friction factor is normally determined from the Reynolds number. In the computation, the two coefficient of turbulent friction factor are compared. One is $f=0.32Re^{-0.25}$ and the other is $f=0.184Re^{-0.2}$. The laminar friction factor is neglected since the single-phase friction coefficient uses higher value between the laminar and turbulent friction in the MATRA-AF. As shown in Table 1, the pressure drop by the former correlation is decrease by around 4.2% compared to the latter. However, the flow split(inner/outer channel) is increase by 3.5% from 1.15 to 1.19. The effect of single-phase friction factor correlation is not too high for the flow split, while the MDNBR in an inner channel by the flow split has increased by 7% from 1.07 to 1.14.

Table 1 The effects of single-phase turbulent friction factor

Single-phase turbulent friction factor		$f = 0.184Re^{-0.2}$	$f = 0.32Re^{-0.25}$
Pressure Drop (kPa)	Inner	158.5	151.8
	Outer	158.7	151.7
MDNBR	Inner	1.07	1.14
	Outer	2.97	2.92
Mass Flux (kg/m^{2}s)	Inner	3906	3978
	Outer	3389	3350
Flow Split	G_i/G_o	1.15	1.19

3.2 Two-phase Pressure Drop

For a two-phase flow, the pressure drop equation is rewritten to include a two-phase friction multiplier, Φ.

In the MATRA-AF, the multiplier may be specified by three different models: the homogeneous model, Armand model, or a polynomial function of quality. In this study, two models of the homogeneous model and Armand model are compared. The multiplier, Φ , is defined as a simple density ratio in the homogeneous model, while as a function of quality and void fraction in the Armand model. Therefore, the effects of multiplier and void fraction options are summarized in Table 2.

The difference in the results by the No-model(Case-1) or Levy model(Case-R) for the subcooled void fraction model is slight. Case-2 used the Armand model as the bulk void fraction model is increased by 2.6% for the flow split and increased by 6% in the inner channel for the MDNBR compared to the Case-R. Case-3 used the homogeneous model, however, the flow split is decreased from 1.15 to 1.10 and the pressure drop is increased by 2.8%. Because the pressure drop is proportional to the void fraction, the flow rate of an inner channel, which has a higher heat flux than an outer channel, is influenced more by the void fraction models. The MDNBR shows obvious differences from by the bulk void fraction model. The effect of the two-phase multiplier is estimated for the Armand model(Case-3) and the homogeneous model(Case-4) as shown in Fig. 2. In Case-4, the multiplier is decreased by 54% for an inner channel and 15% for an outer channel. The flow split of Case-4 is increase from 1.10 to 1.19. The MDNBR of an inner channel for the homogeneous model is increased by 22%.

Table 2 The effects of two-phase friction multiplier

Case		Case-R	Case-1	Case-2	Case-3	Case-4
Subcooled Void Fraction		Levy	No	Levy	Levy	Levy
Bulk Void Fraction		Chexal	Chexal	Armand	Homo	Homo
Friction multiplier		Armand	Armand	Armand	Armand	Homo
Pressure Drop (kPa)	Inner	158.5	156.0	154.3	162.9	152.6
	Outer	158.7	156.1	154.4	162.9	152.7
MDNBR	Inner	1.07	1.07	1.13	0.95	1.16
	Outer	2.97	2.97	2.93	3.06	2.91
Mass Flux (kg/m^2s)	Inner	3906	3907	3971	3789	3991
	Outer	3389	3388	3354	3450	3343
Flow Split	G_i/G_o	1.15	1.15	1.18	1.10	1.19

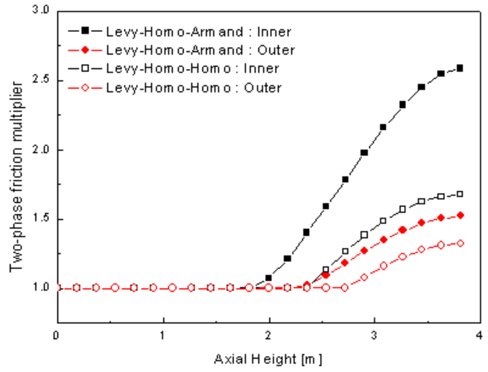

Fig. 2 Two-phase friction multiplier

4. Conclusions

The evaluation of a single-phase and a two-phase pressure drop is performed for a single rod annular fuel. The effect of a flow split by the single-phase turbulent friction factor correlation is slight, but the difference of the MDNBR is slightly high. The subcooled void fraction correlation had little effect on the flow split, but the option of the bulk void fraction correlations showed obvious differences. Therefore, a void fraction model for an annular fuel must be applied carefully. The homogeneous model for the two-phase friction multiplier model was computed as a simple density ratio. The application of a homogeneous model should be seriously considered.

Acknowledgment

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REFERENCES

[1] D. Feng, et al., Thermal-Hydraulic Design of High Power-Density Annular Fuel in PWRs, Nuclear Technology, Vol. 160, pp.16~44, 2007

[2] Y.J. Yoo and D.H. Hwang, Development of a Subchannel Analysis Code MATRA, KAERI/TR-1033/98, 1998

[3] C.H. Shin, et al., A Parameteric Study on the Thermal Hydraulic Design for an Annular Fuel Assembly, KNS Autumn Meeting, 2008