Validation of MATRA-S Code for Studsvik Nine-Rod Bundle Experiment with Power Tilt

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1. Introduction

This study has been prepared for validation of MATRA-S code with the nine-rod Studsvik test bundle experiment with strong power tilt measurements [1]. This experiment has been used to validate and evaluate various subchannel codes [2, 3]. MATRA-S [4] is a subchannel code which has been developed for thermal hydraulic design and analysis of SMART core.

The test was conducted under two-phase flow of typical BWR operation conditions. A series of calculation have been done for various operational conditions of the experiment to evaluate the mass velocity and steam quality distributions.

This paper describes an experimental method as well as the measurement and the errors between the measurement and the predicted results.

2. Studsvik 3x3 Rod Bundle Experiment

This experiment measured mass velocity and steam quality at the exit of a nine-rod test section.

The test section consists of a 3x3 rod bundle in square array with very high radial power gradient, three rods in 1st row were unheated with a diameter of 12.00 mm, 2nd and 3rd rows were electrically heated uniformly 30% and 70% of total electrical power, respectively with a diameter of 12.25 mm. The dimensions of test bundle are; rod-rod center distance (pitch) of 16.30 mm, corner radius of 3 mm, and rod -wall of 9.65 mm. Configuration is shown in Fig.1.

Four spacer grids were located different axial heights, which were similar of those used in BWR reactors. Table 1 shows the subchannel spacer loss coefficient.

The total length of rods was 1800 mm, an unheated length of 300 mm, and active heated length of 1500 mm. There were eight spacer coefficients installed at the test bundle as shown in Table 1. Four splits channels were experimentally measured and listed in Table 2. Seven cases of operation conditions tested with various inlet pressure, enthalpy, mass velocity and heat flux. Both mass velocity and steam quality were measured at exist and operation conditions are listed in Table 3.

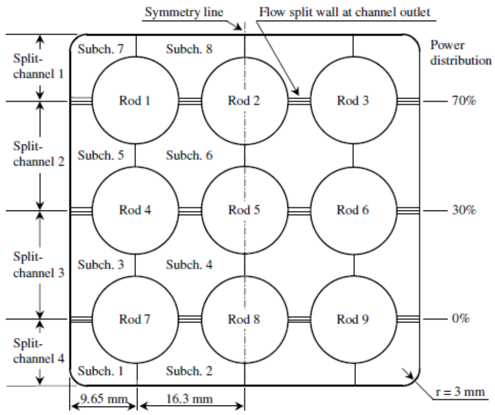

Figure 1. Cross section view of test bundle (Reprinted in Figure 1 of reference 3)

Table 1. Sub-channel spacer loss coefficient and area [3]

Sub-channel	Spacer loss coefficient	Flow Areas ($x10^{-6}$ m^2)
1	1.22	62.9
2	2.03	100.7
3	2.08	99.6
4	1.53	150.2
5	2.13	98.4
6	1.58	147.8
7	1.27	61.7
8	2.13	98.4

Table 2. Splits-channels [3]

Split Channel 1	Sub-channel 7 + sub-channel 8
Split Channel 2	Sub-channel 5 + sub-channel 6
Split Channel 3	Sub-channel 3 + sub-channel 4
Split Channel 4	Sub-channel 1 + sub-channel 2

Table 3. Operational conditions of the experimental tests [3]

Cases	Pressure (bar)	Inlet Enthalpy (kJ/kg)	Mass velocity (kg/m^2s)	Total Power (kW)
1	70.3	1220	907	380
2	70.0	1172	897	384
3	70.8	1112	908	381
4	70.9	1213	1209	422
5	70.9	1110	1239	421
6	70.3	1215	2064	498
7	69.8	1160	2013	501

3. Methodology

This study validated MATRA-S code; mass velocity and steam distribution in split-channels of the test assembly are calculated and compared with measured values which are defined by Eqs.1 and 2 as follow:

$$\boldsymbol{G_i} = \frac{G_j A_j + G_k A_k}{A_j + A_k} \tag{1}$$

$$\boldsymbol{X_i} = \frac{X_j G_j A_j + X_k G_k A_k}{G_j A_j + G_k A_k} \tag{2}$$

where,
G_i & X_i = mass velocity and steam quality of split channel i
G_j& G_k = mass velocity of subchannel j and k to calculate mass velocity of split channel i
X_j & X_k = steam quality of subchannel j and k to calculate steam quality of split channel i
A_j & A_k = area of subchannel j and k

Considering the symmetry of the test assembly, a half assembly was selected as an analysis model as shown in Fig.1.

EM (Equal Mass) model which assumes that the net mass transfer due to the turbulent flow mixing equal to zero and proportional to average mass flux between the adjacent channels ($w'_{I\leftrightarrow J}$) was used as follows:

$$w'_{I\leftrightarrow J} = w'_{IJ} - w'_{JI} = 0 \tag{3}$$

$$w'_{I\leftrightarrow J} = \beta s_{IJ}\overline{G} \tag{4}$$

where, w'_{IJ} refers to the lateral flow rate from subchannels I to J (kg/m-s), β refers to the turbulent flow mixing factor, s_{IJ} is the gap distance between subchannels I and J in the lateral direction (m) and $\overline{G}$ is the average mass flux (kg/m^2-s).

For the case of EVVD (Equal-Volume exchange and Void Drift) model, the net flow transferred from channels I to J turbulent flow mixing can be expressed as follows:

$$w'_{I\leftrightarrow J} = \beta s_{IJ}\overline{G} \times \theta \times \left[(\alpha_J - \alpha_I) - K_{VD}\frac{(G_J - G_I)}{\overline{G}}\right] \tag{5}$$

Where, θ refers to the angle between flow direction and gravity direction (rad), α_J is the area ratio occupied by each phase in section of two-phase mixture due to J, α_I is the area ratio occupied by each phase in section of two-phase mixture due to I, K_{VD} = Void drift coefficient

Uniform axial power shape is included. Homogeneous sub-cooled bulk void fraction and two-phase friction multiplier models are applied. Levy model is used as to calculate subcooled void fraction.

4. Result

The calculation results are summarized in Table 4 and 5. As shown in Table 4, the averages of P/M for mass flux are evaluated as 1.00 and 1.00 when the EVVD and EM models are respectively applied. In case of quality, 0.07 and 0.35% are evaluated as average of P-M for each model, respectively. At this time, P and M indicate predicted and measured value, respectively.

4.1 Mass Velocity

The EM and EVVD models have been applied using MATRA-S to calculate mass velocities for the experiment. The comparison between measured and predicted results is depicted as shown in Fig. 2. From the results, the difference of calculation results between EVVD and EM model is small as shown in Fig.2. In case of split channel 2 and 4, both of EVVD and EM models underestimated the mass velocity as shown in Table 5. Meanwhile, mass velocity of split channel 1 and 3 was overestimated for two models.

4.2 Steam Quality

The MATRA-S code results of quality at exit of channel are shown with the comparison between predicted and measured values. The qualities predicted by EM and EVVD models for split-channels are shown in Fig. 3. From the results, the mean and standard deviation of P-M of EVVD model is lower than that of EM model as shown Table. 4. However, the difference between two models is also small. In case of using EM model the predicted results of the split-channel 1 have the largest error, where smallest error is observed at split-channel 4. The maximum error found in the predicted values of the quality (difference between the predicted value and the measured value), is 5.20% and 6.4 % at split-channel 1 in Case 1 for EVVD and EM model, respectively.

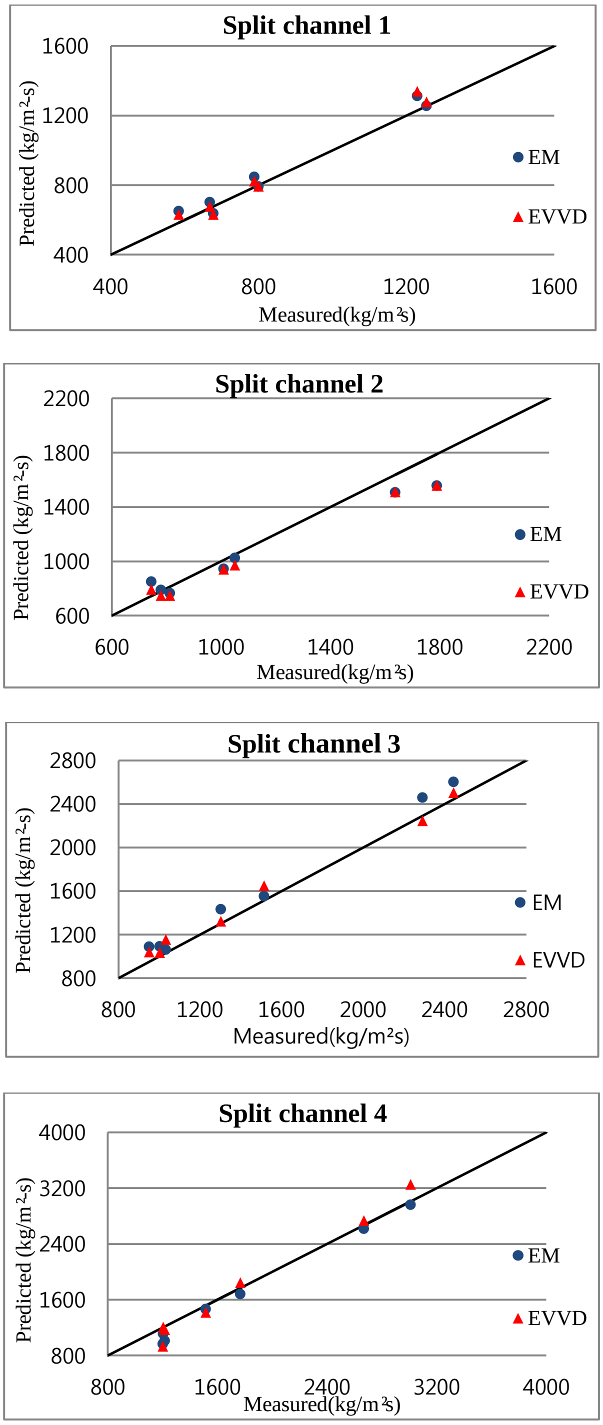

Figure 2. Comparison of the predicted and measured values for mass velocity

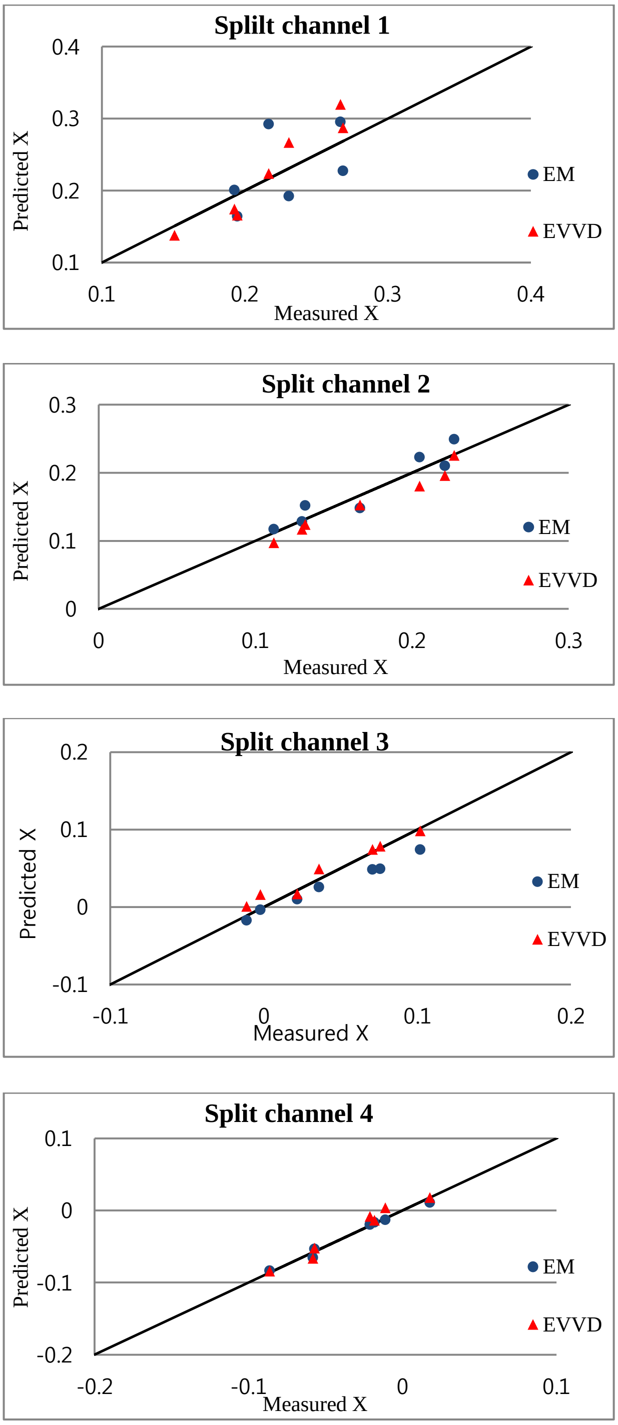

Figure 3. Comparison of the predicted and measured values for steam quality

Table 4. Comparison between EVVD and EM Model

Case	Mass Velocity (P/M)			
	EVVD		EM	
	Mean	STD	Mean	STD
1	0.99	0.08	0.99	0.10
2	1.01	0.06	1.01	0.13
3	0.99	0.15	1.01	0.14
4	1.00	0.05	0.99	0.07
5	1.00	0.08	1.01	0.05
6	1.01	0.10	1.00	0.09
7	1.00	0.05	0.99	0.06
Total	1.00	0.08	1.00	0.09
Case	**Quality (P-M, [%])**			
	EVVD		**EM**	
	Mean	**STD**	**Mean**	**STD**
1	1.19	2.74	1.35	4.16
2	0.02	1.83	-0.15	2.11
3	-0.53	0.90	-0.71	1.27
4	0.70	2.53	1.24	3.73
5	-0.46	1.38	-0.16	0.36
6	-0.29	2.00	0.40	1.27
7	-0.13	1.55	0.50	0.63
Total	0.07	1.81	0.35	2.21

Table 5. Average Value of Each Split Channel

		SCH1	SCH2	SCH3	SCH4
Mass Velocity	EVVD	1.02	0.94	1.05	0.98
	EM	1.03	0.97	1.07	0.92
Quality	EVVD	0.76	-1.46	0.55	0.43
	EM	2.63	0.47	-1.57	-0.13

5. Conclusion

In this paper, calculations to validate MATRA-S code for 3x3 bundle with high power tilt were conducted. As the results, it was found that the MATRA-S code showed a similar prediction performance to the existing subchannel analysis codes.

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