Validation of Turbulent Momentum Mixing of MATRA-S Code for CNEN 4x4 Single Phases Flow Mixing

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1. Introduction

This study has been prepared for validation of the turbulent momentum mixing of MATRA-S code [1] by comparing the results with the CNEN4x4 experiment measurements. MATRA-S is a subchannel code which has been developed for thermal hydraulic design and analysis of SMART core.

The calculation of various turbulent flow mixing coefficients has been done to evaluate the exit velocity distributions for corner, side and central subchannels with the measurement results for each subchannel. Furthermore, the effect of the turbulent flow mixing coefficient will be as the main point of this study.

CNEN4x4 is an experiment which was done in unheated assembly under single-phase flow condition which had been performed by Studsvik Laboratory [2] to obtain information about the heat transfer due to the flow turbulent mixing between adjacent subchannels under a single-phase flow regime.

2. CNEN4x4 Experiment

This experiment involves velocity and mass flux measurements taken at the exit of a 16-rods test section. The test section consists of a bundle which has 16 rods with the following dimensions; diameter of 0.593″, rod-rod center distance (pitch) of 0.76″, corner radius of 0.438″, and rod -wall of 0.1415″. Configuration is shown in Fig.1.

The test section is fitted with a grid of low form loss coefficient (k=0.3) located at the middle of the fuel assembly. The friction factor used for this experiment is described in terms of total wall shear stress.

The bundle had an unheated length of 1.312 ft, and active length of 3.281 ft. Five average mass velocities of the fluid were imposed, which are 0.5, 1, 2, 3 and 4 (Mlbm/hr.ft^2). Table 1 summarizes the measurement results of the velocities at the exit of each subchannel.

Table 1 Experiment results of exit velocity

G_{avg} (Mlbm/ft^2-hr)	Exit Velocity (m/sec)		
	Corner	Side	Center
0.5	0.728	0.641	0.527
1	1.458	1.302	1.039
2	2.873	2.630	2.174
3	4.370	3.887	3.351
4	5.889	5.101	4.444

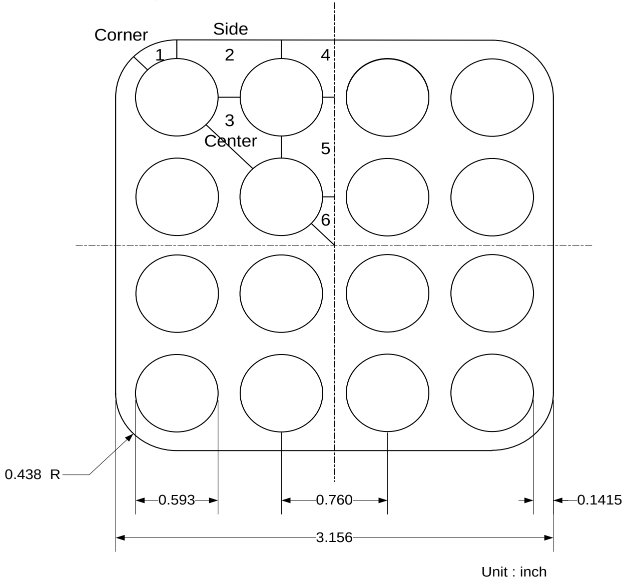

Fig. 1 CNEN- Studsvik 4x4 rod bundle assembly and subchannel analysis model

3. Methodology

This study is focuses on the momentum mixing of MATRA-S code, the EM (Equal Mass) model is used as a momentum mixing model that assumes the net mass exchange due to the turbulent flow mixing between the adjacent channels is equal to zero, since the lateral flow rate between subchannels is defined in Eq.1 as follows:

$$w'_{IJ} = \beta . s_{IJ} . \overline{G} \qquad (1)$$

where,

w'_{IJ} = Lateral flow rate from subchannels I to J due to turbulent flow (kg/m-s)
β = Turbulent flow mixing factor
s_{IJ} = Gap distance between subchannels I and J in the lateral direction (m)
$\overline{G}$ = Average mass flux (kg/m^2-s)

In order to investigate the turbulent momentum mixing effect, comparisons with measured velocity at exit plane are conducted with 5 different turbulent flow mixing factors also called as TDC (Turbulent Diffusion Coefficient) which are 0.0, 0.005, 0.02, 0.1 and 0.2. In the subchannel analysis code, the turbulent mixing parameter is normally determined from a thermal mixing experiment under single phase condition.

The axial momentum mixing between the subchannels will affect the results. It is generally used to analyze the thermal mixing in bundle test that the turbulent momentum factor for the axial momentum mixing assumes to be 0.0 as shown in Eq.2. This assumption was applied to obtain conservative mixing value to prevent the effect of the axial momentum mixing factor on the axial velocity distribution. Also, to maintain that there are no other mixing factors effect on the distribution except the TDC.

The turbulent momentum factor is similar to turbulent Prandtl number as shown in Eq.3. It is represented as a scaling factor between the energy mixing and the momentum mixing due to turbulence between subchannels. In the bundle test, thermal mixing value which is obtained from the experiment results is different from the general pipe experiment. The momentum mixing can be derived by the thermal mixing value and turbulent momentum factor using as shown in Eq.2. The turbulent momentum mixing factor used was 1.0 based on the assumption of that turbulent momentum mixing is nearly equivalent to turbulent thermal mixing.

$$\tau'_{IJ} = w'_{IJ} F_{TM} (U_I - U_J) \qquad (2)$$

where,

τ'_{IJ} = Axial Turbulent momentum flux (kg/s^2)
F_{TM} = Turbulent momentum factor
U = Axial flux (m/s)

$$F_{TM} \sim \mathrm{Pr}_t = \frac{\nu_t}{\alpha_t} \qquad (3)$$

The calculations have been done by simulating the geometry as 1/8 symmetric geometry in MATRA-S code as shown in Fig.1. The geometry used consists of a single spacer grid in the middle of the fuel assembly which has 0.3 loss coefficient, three center subchannels, two side subchannels and one corner subchannel.

The operation condition parameters were room temperature, atmospheric pressure as in the CNEN4x4 experiment. In order to find the differences of velocities distributions and mass fluxes predicted for each subchannel in the fuel bundle, in addition to check the calculating capabilities of MATRA-S code. Five inlet average mass fluxes (0.5, 1, 2, 3, 4 Mlbm/hr.ft^2) were used. In order to have more accurate results along the axial direction of the fuel assembly, sixty uniform nodes were used to evaluate the mixing effect of the TDC. Starting with TDC equal to zero, that means there is no effect due to the turbulent mixing added to the velocity. Then increasing the TDC value and calculating the percentage error between the measured and the predicted results for each TDC value, to see the mixing effect if added to the subchannel or removed from it for each subchannels. The optimum TDC value will be considered as the minimum percentage error between the measured and predicted values at all corner, side and the center subchannels.

4. Result

As shown in Table 2 the percentage error between the measured values of exit velocities with the predicted values using the different turbulent mixing factors for corner, side and the center subchannels. Fig.2 shows the velocity profile along the axial direction of the subchannels when the TDC equal to zero with the measured exit velocities. There is a big difference between the predicted values of the corner subchannel with the measured value of the same subchannel, while the side and the center subchannels have smaller difference than the corner subchannel.

As the TDC value increases the differences between the predicted and measured values will decrease until it reaches the optimum value, then will start to increase again as depicted in Fig.3 and Fig.4. The TDC used in Fig.3 and Fig.4 are 0.005 and 0.02, respectively. The remaining TDC values (0.1 and 0.2) have bigger differences with the exit measured velocity.

The turbulent momentum mixing has a high effect on the velocity distribution and the appropriate factor used will be results to have much accurate data. As shown in Fig.4 the profile of the velocity that has the optimum TDC with the exit velocity measured is more accurate than Fig.2 and Fig.3.

As the TDC value increases, the velocity of the corner and side subchannel will increase while the center subchannels will decrease due to the crossflow of the turbulence momentum between the subchannels. The change of velocity as shown in Fig.2 is due to the axial momentum generated by the pressure difference and gravity.

Table 2 Percentage error between the measured and predicted exit velocity with different TDC value

TDC	Corner	Side	Center
0	19.200	4.104	4.326
0.005	12.398	4.146	3.198
0.02	2.607	2.994	2.206
0.1	18.132	3.609	5.672
0.2	23.387	4.866	6.547

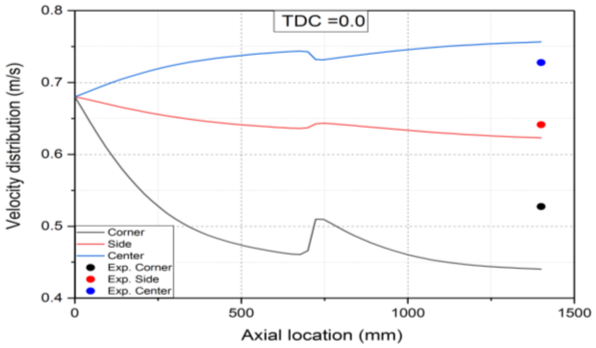

Fig. 2 Velocity profile along the axial direction using TDC =0.0

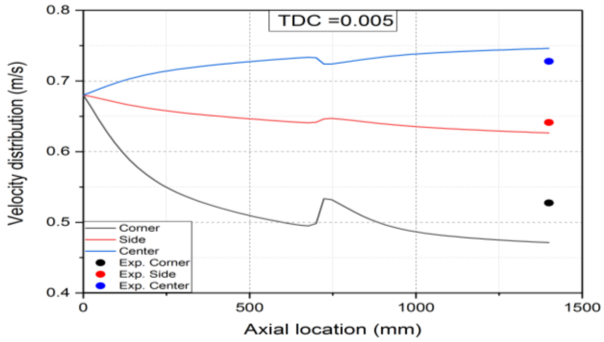

Fig. 3 Velocity profile along the axial direction using TDC=0.005

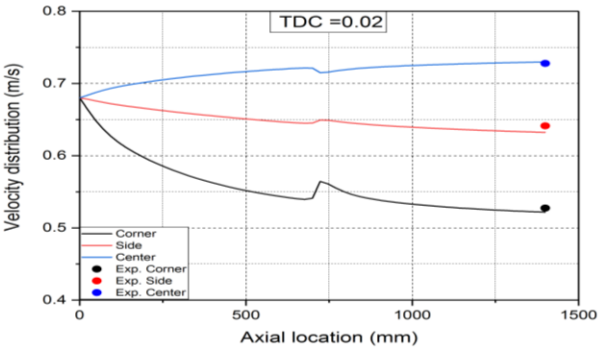

Fig. 4 Velocity profile along the axial direction using TDC =0.02

5. Conclusion

Turbulent momentum mixing in MATRA-S code was investigated by analyzing the flow distribution and generate the results as flow velocities with CNEN 4x4 rod bundle test. Optimum momentum mixing coefficient was estimated and applied to this analysis.

MATRA-S predicted accurately the flow velocities profiles along the axial direction, by comparing the measured data using the optimum TDC value with the maximum percentage error which turned to be 3.0 %. The comparison with CNEN4x4 measurement was successfully validated by using the appropriate model applied in MATRA-S code which is EM turbulent model and optimizing its coefficient.

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