Development of Multidimensional Flow Model of SPACE Code

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***Keywords :** SPACE code, multidimensional flow model

1. Introduction

There have been various efforts to implement multidimensional flow models in system codes for more than 30 years. The multidimensional flow model generally refers to the convection and diffusion terms in the momentum equations. Table 1 shows the current status of the multidimensional flow model in existing system codes. Basically, the convection term is included in all codes. The differences between the codes are whether they reflect the momentum diffusion (viscosity) term, fluid porosity, and turbulence effects.

Table I: Multidimensional Flow Model in System Codes

	Diffusion	Porosity	Turbulence	Ref.
RELAP5-3D	O	X	X	[1]
TRACE	X	X	X	[2]
MARS	O	O	O	[3]
SPACE	X	O	X	[4]

The study presents the recent effort to implement the momentum diffusion and turbulence effects into the SPACE code.

2. Implementation of Momentum Diffusion

As shown in Fig. 1, MARS is the most advanced code in view of the equation structure. However, it neglected the diagonal terms in the strain tensor as follows:

$$\mathbf{S}_k = \frac{1}{2}\begin{pmatrix} 0 & \frac{\partial u_k}{\partial y}+\frac{\partial v_k}{\partial x} & \frac{\partial u_k}{\partial z}+\frac{\partial w_k}{\partial x} \\ \frac{\partial v_k}{\partial x}+\frac{\partial u_k}{\partial y} & 0 & \frac{\partial v_k}{\partial z}+\frac{\partial w_k}{\partial y} \\ \frac{\partial w_k}{\partial x}+\frac{\partial u_k}{\partial z} & \frac{\partial w_k}{\partial y}+\frac{\partial v_k}{\partial z} & 0 \end{pmatrix}. \quad (1)$$

This study included diagonal terms, thereby yielding

$$\mathbf{S}_k = \frac{1}{2}\begin{pmatrix} \frac{\partial u_k}{\partial x} & \frac{\partial u_k}{\partial y}+\frac{\partial v_k}{\partial x} & \frac{\partial u_k}{\partial z}+\frac{\partial w_k}{\partial x} \\ \frac{\partial v_k}{\partial x}+\frac{\partial u_k}{\partial y} & \frac{\partial v_k}{\partial y} & \frac{\partial v_k}{\partial z}+\frac{\partial w_k}{\partial y} \\ \frac{\partial w_k}{\partial x}+\frac{\partial u_k}{\partial z} & \frac{\partial w_k}{\partial y}+\frac{\partial v_k}{\partial z} & \frac{\partial w_k}{\partial z} \end{pmatrix}. \quad (2)$$

Therefore, the following momentum equation was implemented by adding the momentum diffusion term.

$$\gamma_k \frac{\partial \mathbf{u}_k}{\partial t} + \nabla\cdot(\gamma_k \mathbf{u}_k \mathbf{u}_k) - \mathbf{u}_k \nabla\cdot(\gamma_k \mathbf{u}_k)$$
$$= -\frac{\gamma_k}{\alpha_k \rho_k}\nabla p + \ldots + \underbrace{\frac{\gamma_k}{\rho_k}(\mu_k + \mu_k^t)\nabla\cdot\left(\nabla \mathbf{u}_k + \nabla \mathbf{u}_k^T - \frac{2}{3}(\nabla\cdot\mathbf{u}_k)\mathbf{I}\right)}_{\text{Momentum diffusion term}} \quad (3)$$

3. Results and Discussion

Preliminary simulations were conducted to verify the momentum diffusion term. Figure 1 shows the two-dimensional simulation domain (0.2 m x 0.03 m), which is modeled using the multi-d component. The working fluid is a subcooled water (10^6 Pa and 370 K). The pressure difference between inlet (left boundary) and outlet (right boundary) is 0.011 Pa.

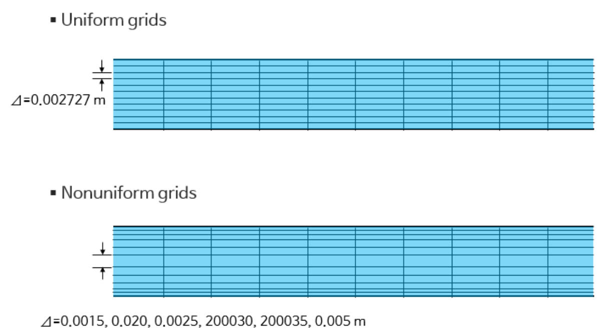

Fig. 1. Simulation geometry for a pressure-driven fully-developed flow of 2D channel

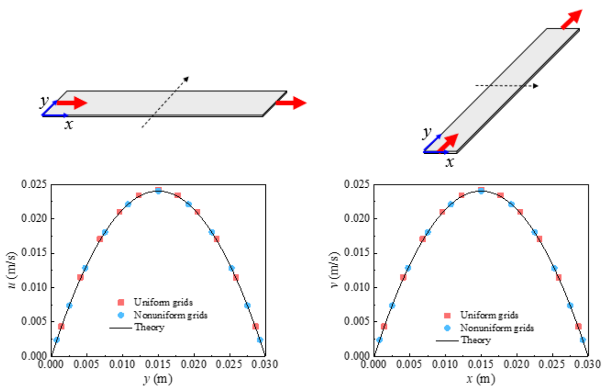

Fig. 2. Liquid velocity profiles

Figure 2 shows the simulation results for two horizontal fully-developed channel flows. The predicted velocity profiles agree well with the theoretical parabolic profiles.

4. Conclusions

The multi-dimensional viscosity term has been correctly implemented in the SPACE code. Various verification test results will be presented at the conference. In addition, a simple turbulence model will be implemented into the SPACE code.

ACKNOWLEDGEMENT

본 연구는 2022 년도 산업통상자원부의 재원으로 한국에너지기술평가원(KETEP)의 지원을 받아 수행한 연구 과제(No.20224B10200020)입니다.

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