Improvement of Multidimensional Thermal-Hydraulic Analysis Code: COMMIX-1ARP

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1. Introduction

The COMMIX-1ARP code is being used for an analysis of the thermal hydraulic phenomena in a fast reactor at KAERI. The code can be used as a thermal-hydraulic system analysis code as well as a computational fluid dynamics code that can handle a detailed simulation in a reactor component. However, the code is based on the old theory and needs a further improvement for a better analysis of various thermal-hydraulic problems. In the present study, the COMMIX-1ARP code is further improved, and the improvements include the extension of memory size, parallelization, introductions of an advanced turbulence model and a higher-order convection scheme.

2. Improvements of COMMIX-1ARP Code

2.1 Extension of Memory Size

The original COMMIX-1ARP code has a limit of memory size, and can only employ 99×99×99 memory in the x-y-z directions. For this reason, the code cannot be used in combination with the one-dimensional design code. It was difficult to improve it owing to the complexity of the COMMIX-1ARP code. In the present study the limit of the memory size is extended to 999×999×999 and the performance is confirmed by applying the code to the analysis of flow field in the IHX exit pipe of the MONJU reactor employing 390×60×52 grids.

2.2 Parallelization using OpenMP

The COMMIX code has iterative solvers for the momentum, energy and turbulent equations. The Successive Over-Relaxation (SOR) solver is mainly utilized to solve the equations and the Conjugate Gradient (CG) solver is also available for only the pressure equation. The programmer can have trouble with the data dependency of SOR and CG. In the case of SOR, the Red-Black Scheme can resolve the data dependency. However, CG cannot be parallelized completely. Only some parts of the CG are parallelizable. As a benchmark test for a parallel performance, the flow inside a duct was chosen. Fig. 1 shows a convergence history. Regardless of the number of CPUs, the convergence histories are the same. Using 12 CPUs, we can obtain 2- and 4-times speedup with CG and SOR, respectively, as shown in Fig. 2.

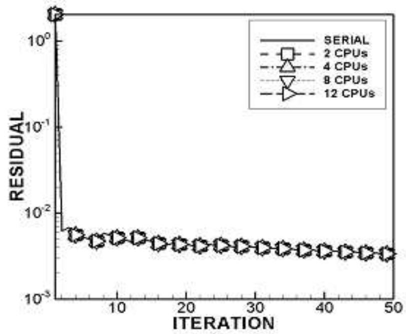

Fig. 1. Convergence history with number of CPUs

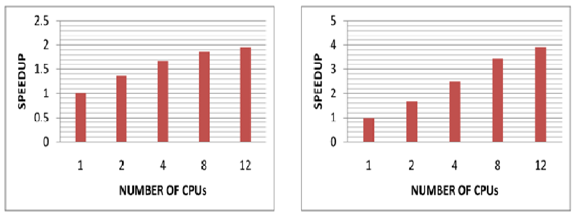

Fig. 2. Speedup with number of CPUs (Left: CG, Right: SOR)

2.3 Improvement of Turbulence Model

An analysis of thermal-hydraulics in the upper plenum of a fast reactor requires special attention to the choice of turbulence model. To better predict the thermal stratification and thermal striping phenomena, the turbulence model given in the original COMMIX-1ARP code should be improved, and a better turbulence model should be introduced. In the present study, the algebraic stress and flux model developed by Rodi [1] is introduced into the original COMMIX-1ARP code and validated against the benchmark test problem. The test problem considered in the present study is a natural convection of air in a rectangular cavity with an aspect ratio of 1:5. The left wall is a hot wall, the right wall is a cold wall, and the top and bottom walls are adiabatic walls. The Rayleigh number based on the height of the cavity is $Ra = 4.3\times10^{10}$, and the Prandtl number is $\Pr = 0.71$. King [2] has carried out extensive measurements for this problem and his experimental data are reported in King [2]. Fig. 3 shows a comparison of the predicted results with the measured data by King [2] for the vertical velocity component at y/H=0.5. As shown in the figure, the agreement between the measured data and predictions by the SGDH and AFM models is fairly good. This shows that the SGDH also predicts well the vertical velocity distribution for this shear type flow. Fig. 4 shows a comparison of the predicted results with the measured data for the local Nusselt number at the hot wall. Both the SGDH and AFM predict them well; however, the AFM predicts slightly better than the SGDH for a distribution of the local Nusselt number. Both the SGDH and AFM models are implemented in the COMMIX-1ARP code. One can choose either of the models. When one solves the thermal stratification phenomenon in the upper plenum of the fast reactor, the SGDH may result in an inaccurate solution or show an unstable solution behavior. The AFM may remedy these kinds of problems.

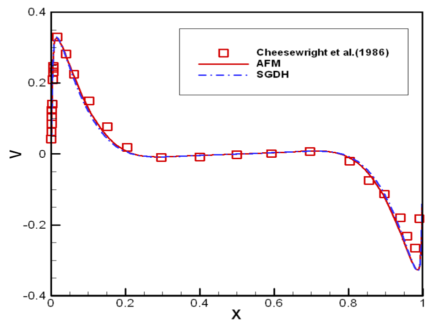

Fig. 3. Vertical velocity distribution (y/H=0.5)

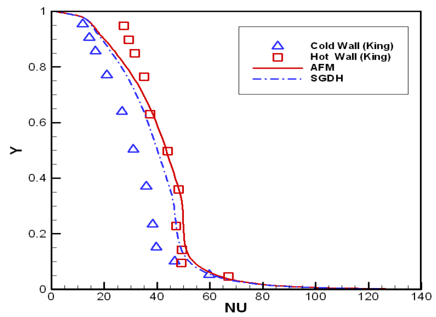

Fig. 4. Local Nusselt number distribution at the hot wall

2.4 Improvement of Convection Scheme

Only an upwind scheme is implemented in the original COMMIX-1ARP code. It is well known that the upwind scheme produces inaccurate solutions when it is applied to the re-circulating flow or separating flow. In the present study the central difference scheme (CDS), which has the second-order accuracy, is also implemented in the COMMIX-1ARP code. The laminar flow in a lid-driven square cavity has been solved in order to validate the CDS implemented in the COMMIX-1ARP code. The numerical solution by Ghia et al. [3] is used to validate the code. Computations are performed for a Reynolds number of 1000 using 82×82 non-uniform grids. Fig. 5 shows the predicted horizontal velocity component at the centerline together with the benchmark solution. The upwind solutions show some deviations from the benchmark solutions in the peak velocity region near the bottom and top walls. It is clearly shown that the CDS results in a more accurate solution than the upwind scheme. Both the upwind scheme and CDS are implemented in the COMMIX-1ARP code, and users can choose either of the convection schemes.

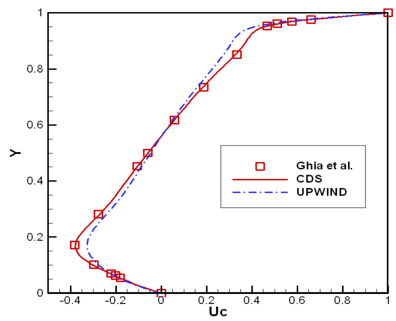

Fig. 5. Centerline velocity distributions

3. Conclusions

(1) The memory size of the COMMIX-1ARP code is extended from 99×99×99 to 999×999×999 in the x-y-z directions so that the code can be used in combination with the one-dimensional design code.

(2) The COMMIX-1ARP code is parallelized with the OpenMP compiler and using 12 CPUs, we can obtain 2 and 4 times speedup with CG and SOR solvers.

(3) The algebraic stress and flux model is implemented in the COMMIX-1ARP code and this model is validated through applying to the natural convection flow. The algebraic stress and flux model results in slightly better results than the original model.

(4) The treatment of the convection term is improved from the first order-upwind scheme to the second-order central difference scheme. The two schemes are validated by applying to the laminar cavity problem, and the results show that the central difference scheme results in a more accurate solution.

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