CFD Simulation of Axial Turbulent Flow in a Triangular Rod Bundle

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Abstract

A CFD analysis has been made for fully developed turbulent flows in a triangular bare rod bundle with pitch to diameter ratio (P/D) of 1.123. The nonlinear turbulence models predicted the turbulence-driven secondary flow in the triangular subchannel. The nonlinear quadratic $k-\varepsilon$ models by Speziale and Myong-Kasagi predicted turbulence structure in the rod bundle fairly well. The nonlinear quadratic and cubic $k-\varepsilon$ models by Shih et al. and Craft et al. showed somewhat weaker anisotropic turbulence. The differential Reynolds stress model appeared to overpredict the turbulence anisotropy in the rod bundle.

Keyword: *Nonlinear $k-\varepsilon$ model, subchannel, triangular rod bundle, secondary flow*

1. Introduction

Most reactor fuel elements generally consist of rod bundles with the coolant flowing axially through the subchannels formed between the rods. The fuel rods are arranged in either square or equilateral triangular pitched arrays. An understanding of the detailed structure of the turbulent flow in the rod bundle, used especially as nuclear fuel elements, is of major interest to the nuclear power industry for their safe and reliable operation. There have been many experiments performed on axially developed turbulent flow in a bare rod bundle. They reported the main features of the turbulence structure in subchannels of the bare rod bundles as secondary flow due to turbulence anisotropy and macroscopic flow pulsation due to large eddy motion. Few computational studies have been performed since accurate prediction is difficult due to the complexity of the turbulence phenomena. The numerical simulation of turbulent flow structure in rod bundles is still required to evaluate the adequacy of numerical work.

This paper presents a numerical analysis of turbulent flows in a triangular bare rod bundle using several nonlinear $k-\varepsilon$ turbulence models and a Reynolds stress model. The nonlinear eddy viscosity models (NLEVMs) uses quadratic or cubic stress-strain relationship with the empirical coefficients proposed by many studies. The second-order moment closure is the differential Reynolds stress model (RSM) proposed by Launder-Reece-Rodi (LRR). The conventional wall functions using a universal law of the wall were applied to specify the turbulence in the near-wall region.

2. Numerical Method

The present analysis simulated the experimental study of axial turbulent flow in a triangular rod bundle by Carajilescov and Todreas [1]. Only the 1/6 triangular subchannel of the bare rod bundle was modeled using flow symmetry to reduce the size of the computational model. Body-fitted and non-staggered grid systems were used to deal with the subchannel geometry. Figure 1 illustrates the triangular rod bundle and the computational grid. The computational grid is 25x45 in radial and azimuthal directions, respectively. Since this study simulates the fully developed flow, only two grid cells were used in main flow direction. The grid size in the nondimensional wall unit (y^+) was calculated to be 15-19, which is the closest distance from the rod surface.

This study used the nonlinear quadratic $k-\varepsilon$ models with the empirical coefficients proposed by Speziale [2], Myong-Kasagi [3] and Shih et al. [4]. The nonlinear cubic $k-\varepsilon$ model by Craft et al. [5] and the Reynolds stress model by Launder et al. (LRR-RSM) [6] were also used in this numerical work. A standard underrelaxation method and hybrid differencing scheme were used to obtain a converged solution.

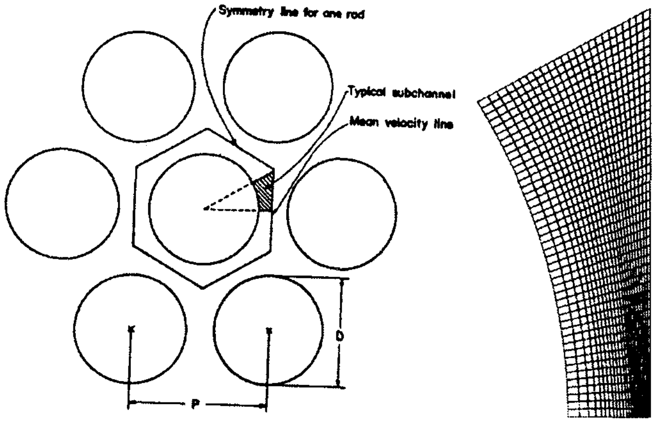
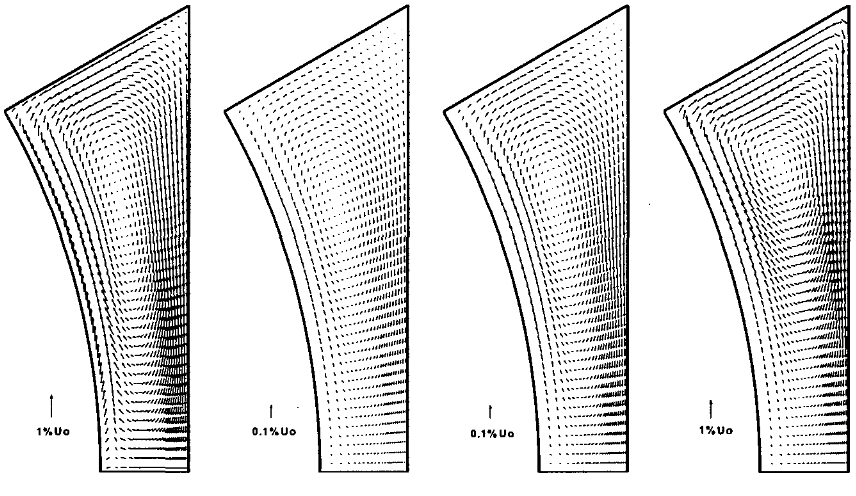


Fig. 1 Layout of a triangular rod bundle and computational grid

3. Results and Discussions

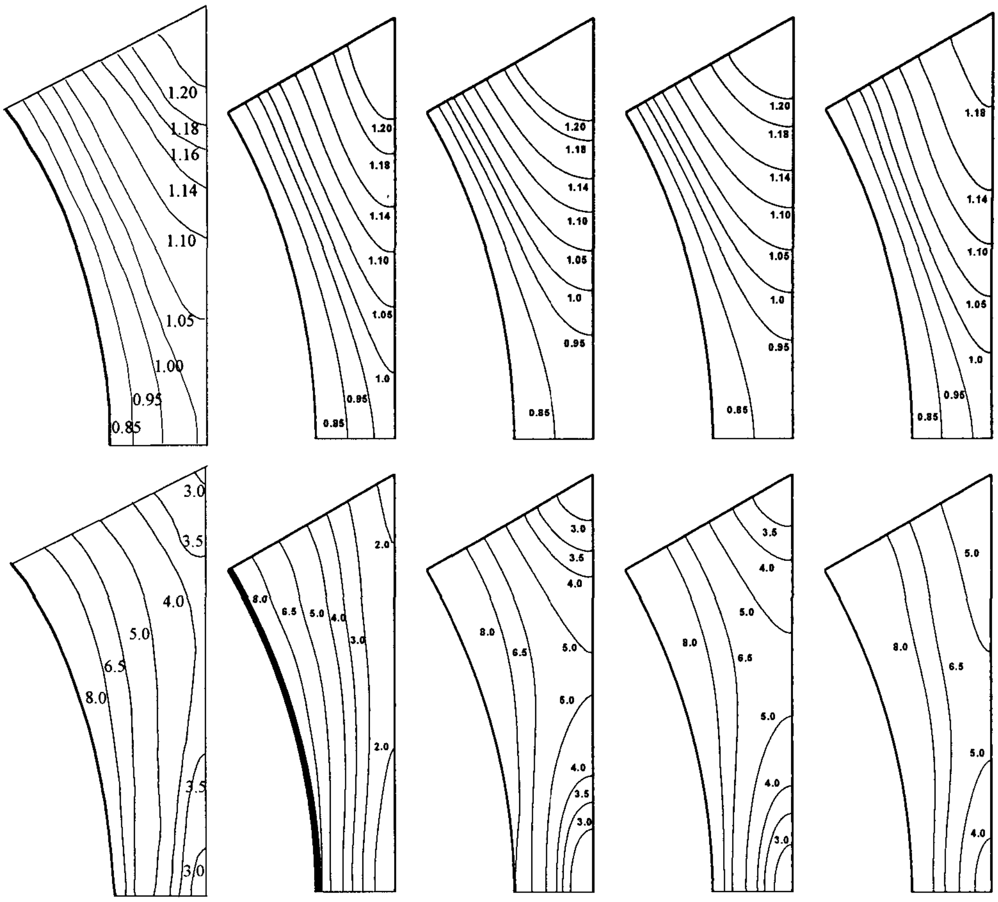
Figure 2 shows the velocity vectors indicating the turbulence-driven secondary flow at Reynolds number of 2.7×10^4. The maximum secondary velocity was estimated to be 0.5% (Myong-Kasagi), 0.06% (Shih et al.), 0.09% (Craft et al.) and 1.3% (LRR-RSM) of the bulk axial velocity (Uo), respectively. The quadratic Speziale model showed a result similar to the Myong-Kasagi model. The experiment [1] reported that the secondary flows were less than 0.67 percent of the bulk axial velocity.

Figure 3 compares the contour plots for normalized axial velocity and turbulent kinetic energy. The axial velocities predicted by NLEVMs using the coefficients of Shih et al. and Craft et al. appear to more rapidly decrease from the center of the subchannel to the gap region. The Myong-Kasagi model and LRR-RSM show relatively better agreement with the measured velocity distribution. The Myong-Kasagi model slightly underpredicts turbulent kinetic energy in core region away from the rod surface while other turbulence models predicted slightly higher turbulent kinetic energy. The predictions of the Speziale model were found to be similar to those of the Myong-Kasagi model.



Myong-Kasagi Shih et al. Craft et al. LRR-RSM

Fig. 2 Turbulence-driven secondary velocity vectors



Experiment Myong-Kasagi Shih et al. Craft et al. LRR-RSM

Fig. 3 Contour plots for normalized axial velocity (top) and turbulent kinetic energy (bottom)

4. Conclusion

A CFD analysis was performed to compare the predictions of nonlinear turbulence models for axial turbulent flow in a triangular bare rod bundle. The nonlinear quadratic and cubic $k-\varepsilon$ models showed a significant difference in the predictions depending on the model coefficients. The quadratic model coefficients proposed by Speziale and Myong-Kasagi resulted in showing the turbulent flow characteristics in the rod bundle fairly well. LRR-RSM appeared to overpredict the turbulence-driven secondary flow and the turbulent kinetic energy.

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