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Technical note

On turbulence models for rod bundle flow computations

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Abstract

In commercial computational fluid dynamics codes there is more than one turbulence model built in. It is the user responsibility to choose one of those models, suitable for the problem studied. In the last decade, several computations were presented using computational fluid dynamics for the simulation of various problems of the nuclear industry. A common feature in a number of those simulations is that they were performed using the standard k–ε turbulence model without justifying the choice of the model. The simulation results were rarely satisfactory. In this paper, we shall consider the flow in a fuel rod bundle as a case study and discuss why the application of the standard k–ε model fails to give reasonable results in this situation. We also show that a turbulence model based on the Reynolds stress transport equations can provide qualitatively correct results. Generally, our aim is pedagogical, we would like to call the readers attention to the fact that turbulence models *have to* be selected based on theoretical considerations and/or adequate information obtained from measurements.

1. Introduction

The application of commercial computational fluid dynamics (CFD) codes does not have a long history in the nuclear industry. It was recognized only in the last

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decade that such codes may be applied with success to study problems, like mixing in the reactor vessel or fuel assembly.

In the years past several authors made an attempt to simulate the hydrodynamics of fuel rod bundles by CFD techniques (Lestinen and Gango, 1999; Bergeron et al., 1999; Kriventsev and Ninokata, 1999; Rautaheimo et al., 1999; Tzanos, 2001, 2002, 2004). A common feature of these simulations is that the researchers performed the computations using the k–ε turbulence model. Comparison of the simulation results with experimental data was seldom satisfactory. Recently Tzanos (2004) has reported simulation results comparing the performance of a number of variants of the k–ε models. His final conclusion is that the models have to be improved in order to achieve reasonable simulation results for fuel rod bundle simulations. However, the reasons of the failure of the standard k–ε model and its clones were not elucidated.

Here, we show that the application of the standard k–ε model is questionable a priori for rod bundle flows, basically because the assumptions applied during the development of these models do not hold in such flows. Using the standard k–ε model the results are not only inaccurate, but those are qualitatively incorrect.

Furthermore, we demonstrate that other models, e.g., models based on the Reynolds-stress transport equations can provide qualitatively correct solutions.

In Section 2, some properties of rod bundle flows are briefly introduced. In Section 3, simulation results are presented using the standard k–ε model and a model based on the Reynolds-stress transport equations. We compare these simulation results with the basic characteristics of rod bundle flows. We briefly discuss why the standard k–ε model is not a good choice for such flows. Finally some conclusions are drawn in Section 4.

2. Flow in a fuel rod bundle

In pressurized water reactors the coolant flows through in rod bundles. The rods are arranged in a triangular or rectangular array and spacers ensure that the distance between the rods does not change during normal operation. Here, we shall consider the geometrical parameters of a VVER-440 reactor fuel assembly without spacers ($P/D \cong 1.3$ see Fig. 1). It deserves a comment. Obviously, the spacers have significant effect in the flow dynamics of rod bundles (Rehme, 1973a; Grover and Venkat Raj, 1980; Trippe and Weinberg, 1979a). For instance, it is well known that grid spacers increase significantly the mixing and the pressure loss. Nevertheless their effect is not known in details; at least the information available is insufficient for critically evaluating turbulence models and demonstrating their deficiencies.

Hydrodynamics of rod bundles have been studied since the late fifties. Sparrow and Loeffler (1959) presented first highly accurate analytical results for longitudinal laminar flows in rod bundles. Recently, these solutions were improved further by Drummond and Tahir (1984). From our point of view the practical relevance of such results is negligible because the flow is turbulent in the fuel assemblies during normal