Nuclear Engineering and Design 275 (2014) 344–351

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Numerical study of the turbulent flow and vortex structures in a new lattice

Hongguang Xiao*, Binghuo Yan

Department of Nuclear Energy Science and Engineering, Naval University of Engineering, Wuhan 430033, China

HIGHLIGHTS

- A new lattice with non-uniform wall thickness is introduced.
- The flow pulsation and vortex structure in a new lattice is analyzed with URANS approach.
- The new lattice is superior to the traditional rod bundles.
- There is a critical value for the wall thickness.

ARTICLE INFO

Article history:
Received 8 November 2013
Received in revised form 16 May 2014
Accepted 17 May 2014

ABSTRACT

Quasi-periodic large scale vortex structures are the major reason for the enhancing of transverse fluid mixing and heat transfer in rod bundles. In this work, the turbulent flow, heat transfer and vortex structures in a new lattice with enhanced heat transfer and fluid mixing are investigated. The numerical simulations are executed by Unsteady Reynolds-Averaged Navier–Stokes (URANS) method with the Reynolds Stress Model (RSM). It is revealed that the transverse fluid mixing and the vortex structures are enhanced as the local wall thickness increases, whereas the Nusselt number shows a peak value. The streamwise velocity in gap regions and the global frictional resistance coefficient will monotonically decrease as the local wall thickness increases. This new lattice is superior to the traditional rod bundles and an optimized value of the local wall thickness with $\Delta R/\delta = 20\%$ is recommended.

1. Introduction

Recent investigations revealed that the heat transfer in tight lattice is better than that in traditional lattice with wide gap regions. In the beginning, researchers supposed that the enhanced heat transfer was due to the secondary flow (Bartzis and Todreas, 1979). However, the effect of the secondary flow was proved to be very small (Seale, 1982; Rapley and Gosman, 1986; Vonka, 1988; Baglietto and Ninokata, 2004). There should be another cause for the high mixing rates between subchannels in tight lattice.

Rowe (1973) mentioned the macroscopic flow process in rod bundle flow in his Ph.D. thesis. Rowe and coworkers carried out experiments with pitch to diameter rations (P/D) of 1.25 and 1.125. They concluded that the periodic macroscopic flow pulsation would be enhanced as the rod spacing reducing. Guellouz and Tavoularis (1992) measured the heat transfer characteristics in rod-bundle subchannels with varying wall subchannel width to rod diameter (W/D). They pronounced that the local heat transfer coefficient was minimum near narrow gaps and maximum in main stream regions. Meyer and Rehme (1994) organized a range of experiments to validate the assumption that the phenomenon would also occur in square channels connected by a narrow flow cross-section. They proposed a flow model analogous to the rod bundle model: two vortices driven by the higher velocities outside the gap and rotating in opposite directions transported with the velocity U_c axially within the gap. Krauss and Meyer (1996, 1998) principally analyzed the turbulent flow characteristics in wall and central channels with two pitch to diameter ratios and width to diameter ratios ($P/D = 1.12$, $W/D = 1.06$ and $P/D = 1.06$, $W/D = 1.03$) in a heated 37-rod bundle. Their experimental results not only indicated the existence of coherent structures, but also gave some quantitative analysis about the turbulent flow and heat transfer parameters. Their results in central channels with $P/D = 1.12$ and $P/D = 1.06$ are cited to validate the veracity of the numerical simulations.

* Corresponding author at: Department of Nuclear Energy Science and Engineering, Naval University of Engineering, Wuhan, Hubei Province, China.
Tel.: +86 027 13477011607.
E-mail address: xhghg@21cn.com (H. Xiao).

http://dx.doi.org/10.1016/j.nucengdes.2014.05.024
0029-5493/

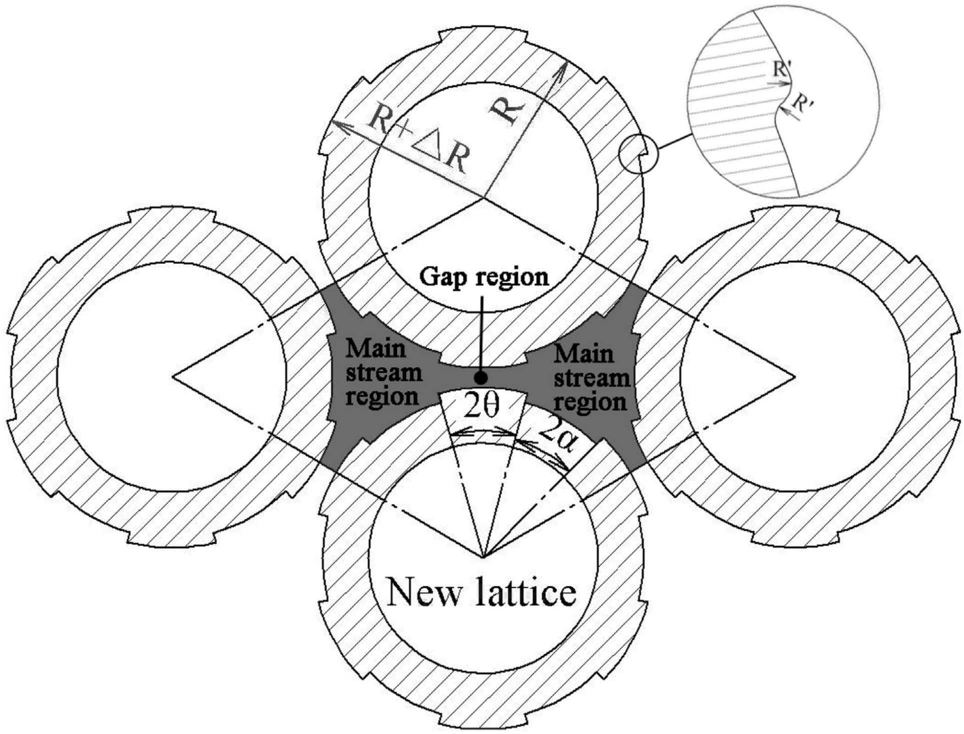

Fig. 1. Sketch of new lattice ($\theta = \alpha = 15^\circ$).

At present, the development of accurate predictive methods by numerical simulation for the flow through rod-bundles is of major importance in designing of nuclear reactors (Chen et al., 2013). Chang and Tavoularis (2007) numerically investigated the fully developed isothermal turbulent flow in a 60° sector of a 37-rod bundle which contains both central and wall channels. Their simulation results proved the applicability of URANS method in a similar channel. Merzari et al. (2008) validated the accuracy of URANS method by comparing a Large Eddy Simulation (LES) for similar flow conditions inside a simplified geometry with

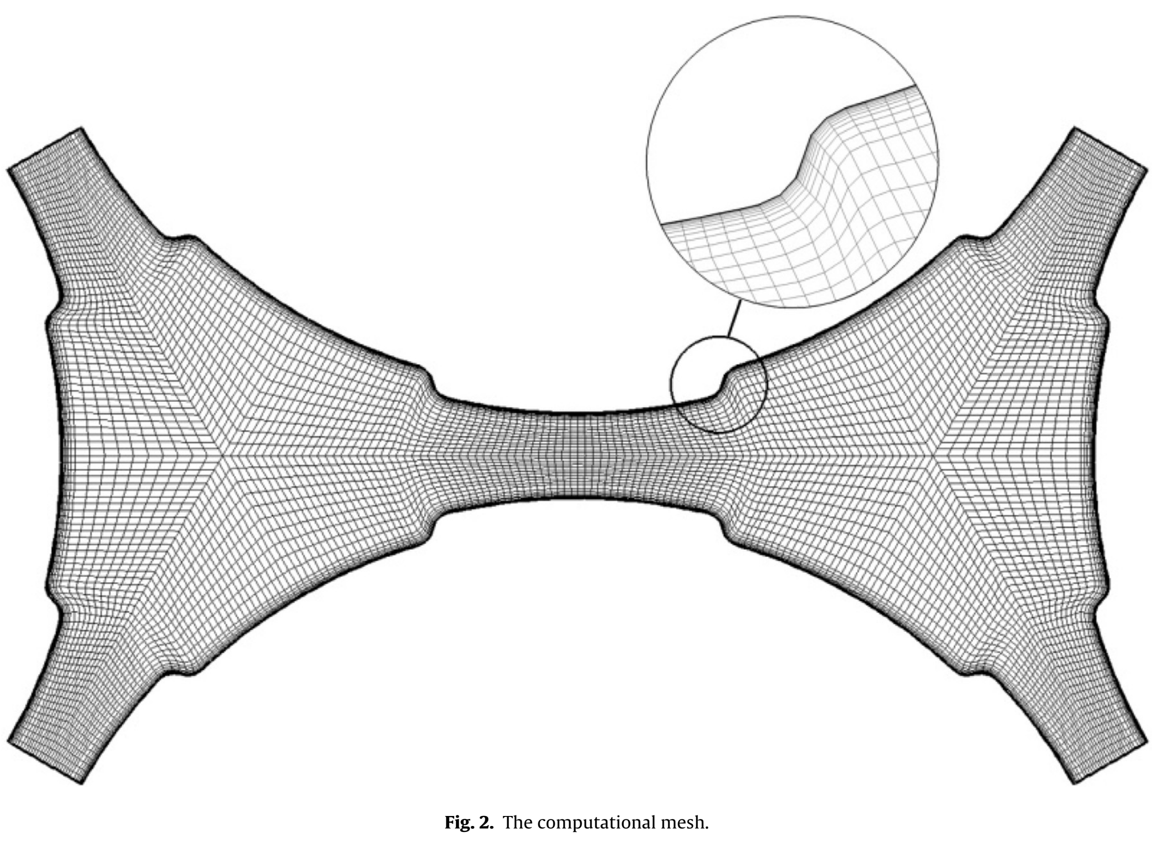

Fig. 2. The computational mesh.