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Experimental study of local coolant hydrodynamics in TVS-Kvadrat PWR reactor fuel assembly using mixing spacer grids with different types of deflectors

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Abstract

Results of experimental studies of local hydrodynamic characteristics of coolant flow in fuel assemblies of RWR reactors using different types of mixing spacer grids are presented. Specific features and regularities of coolant flow in fuel pin bundles of TVS-KVADRAT fuel assemblies with different types of mixing spacer grids were revealed in the course of experiments. Analysis of space distribution of projections of absolute flow velocity allowed detailed description of coolant flow beyond the spacer grid with installation of three different types of deflectors. Optimal design of deflector for spacer grid of the TVS-KVADRAT fuel assembly in the standard cell in the area of guiding channels was identified. Results of studies of local hydrodynamics of coolant flow in the TVS-KVADRAT fuel assembly are accepted for subsequent practical application by the JSC Afrikantov Experimental Design Bureau for Mechanical Engineering (OKBM) in the evaluations of thermal engineering reliability of PWR reactor cores and were included in the database for verification of computational fluid dynamic codes (CFD-codes) and implementation of detailed cell array calculations of PWR reactor cores.

Keywords: Nuclear reactor; Fuel assembly; Coolant fluid dynamics; Heat and mass transfer; Mixing spacer grid.

Introduction

Design of TVS-Kvadrat fuel assembly with competitive performance characteristics as compared with foreign analogues in terms of reliability, safety, cost effectiveness and engineering versatility was developed at the JSC Afrikantov Experimental Design Bureau for Mechanical Engineering (OKBM) for PWR reactor cores. Experience gained during many years of development, manufacturing and operation of nuclear fuel for VVER-100 reactors was used as the basis for the development of new fuel assemblies. In particular, design solutions pertaining to fuel assembly structure and spacer grid configuration recognized and tested in fuel assemblies for VVER-reactors and allowing enhancing reliability of nuclear fuel in PWR reactors [1] were used in the design of the TVS-Kvadrat fuel assembly.

Design of TVS-Kvadrat fuel assembly is equipped with spacer grids and additionally installed mixing grids playing the role of flow turbulence promoters and heat exchange intensifiers. Installation of such elements influences the coolant mixing efficiency and, as the consequence, the values of critical heat flows and burnout safety margins. Application of domestically developed design of the TVS-Kvadrat fuel assembly with mixing spacer grids for PWR reactor requires substantiation of thermal engineering reliability of reactor cores and determination of effects of spacer structures on fluid dynamics of coolant flows [2].

Assessment of effects of mixing devices on critical flows is achievable only using thermal physics test facilities in full scale experimental conditions of coolant flow, while studies of reactor cores are advisable to be performed on aerodynamic and hydrodynamic test facilities using small and full scale models of fuel bundles and assemblies and reactor cores [3,4].

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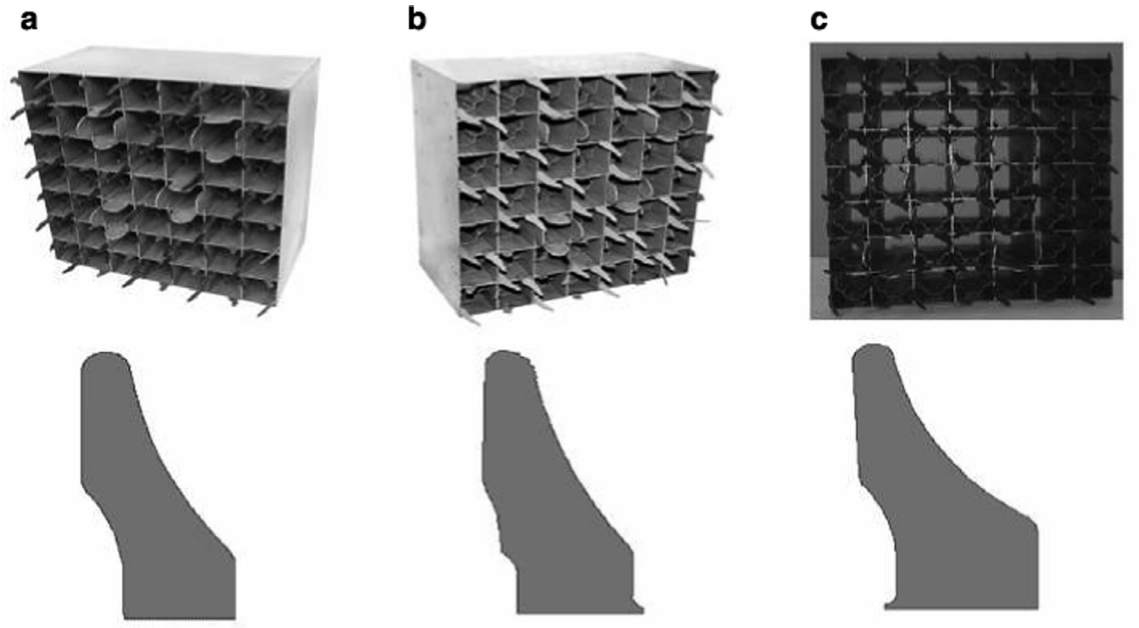

Fig. 1. Outlet section of the experimental model: (a) – "forward bend line" deflector; (b) – "sideways bend line" deflector; (c) – "backward bend line" deflector.

Experimental facility

Investigation of coolant flow fluid dynamics and comparison of mixing spacer grids from the viewpoint of flow mixing intensity in the TVS-Kvadrat fuel assembly were implemented using aerodynamic test facility at the Nizhny Novgorod State Technical University n.a. R.E. Alekseev.

The test facility is operated based on the following principle: air flow is supplied to the receiver tank by high pressure radial ventilator, air passes through the flow rate metering device and the flow stabilizing section and, after passing through the experimental model (EM), it is ejected in atmosphere [5].

Experimental model represents a fragment of PWR reactor fuel assembly of the TVS-Kvadrat type manufactured in full geometric similarity with standard fuel assembly.

Investigated sections of mixing spacer grids (MSG) with different types of deflectors are characterized in Fig. 1. MSG section represents mutually perpendicular rows of plates bound with common strap.

Deflectors are installed on upper edges of the MSG plates in such a way as to have two diagonally arranged deflectors provided for each of the fuel pins [6].

Methodologies of studies of coolant fluid dynamics in the TVS-kvadrat fuel assemblies of PWR reactor

Studies of local fluid dynamics characteristics of coolant flow consist of the measurement of absolute value of velocity vector, flow angles and static pressure using five-channel pneumometric probe inside the tube bundle of the experimental model. For obtaining full information about 3D coolant flow investigation was performed in the standard cell and in two cells adjacent to the guiding channels (cells No. 44 and 27, 28, respectively) (Fig. 2).

Coordinates for each measurement point are presented in Cartesian frame of reference in Fig. 3.

Analysis of distribution of transverse components of velocity vector in the cross-section and along the model length in two areas selected beyond the MSG of the experimental model allowed determining specific features and regularities of coolant flow in the TVS-Kvadrat fuel assemblies of PWR-reactor.

Measurement complex

Composition of the measurement complex includes computer with downloaded software, Pitot-Prandtl probe, five-channel pneumometric probe and analog-to-pressure converter unit.

Measurements of coolant flow velocity vector were performed using five-channel pneumometric probe. Maximum deviations of projections of relative velocity did not exceed 7% of absolute velocity value for X, Y and Z axes. Prior to the implementation of studies the probe was calibrated in the air flow with velocity direction and value known and constant over the channel cross section.

Readings of five-channel pneumometric probe were made by the analog-to-pressure converter unit. Limit of permissible intrinsic uncertainty for the above instruments amounts to ±0.25% [7,8].

Results of experimental studies of coolant fluid dynamics in TVS-Kvadrat fuel assemblies of PWR reactor

Vortex flow disappearing at the distance of $\Delta l/d_\Gamma = 3$–5 behind the deflectors of "sideways" and "backward" bend line types (Fig. 4a,b) and $\Delta l/d_\Gamma = 10$–12 behind the deflectors of "forward" bend line type is formed behind any of the