Available online at www.sciencedirect.com

ScienceDirect

Nuclear Energy and Technology 1 (2015) 54–59

www.elsevier.com/locate/nucet

Combined numerical and experimental investigation into the coolant flow hydrodynamics and mass transfer behind the spacer grid in fuel assemblies of the floating power unit reactor

S.M. Dmitriev*, D.V. Doronkov, A.N. Pronin, D.N. Solntsev, V.D. Sorokin, A.E. Khrobostov

Nizhny Novgorod State Technical University n.a. R.E. Alekseev.24 Minin st., Nizhny Novgorod 603950 Russia

Available online 28 February 2016

Abstract

The results of experimental investigations into the local hydrodynamics and inter-cell mass transfer of the coolant flow in representative zones of the KLT-40C reactor FAs behind the plate-type spacer grid are presented. The investigations were conducted on an aerodynamic rig using the admixture diffusion method (the tracer-gas method). A study into the spatial dispersion of the absolute flow velocity projections and into the distribution of the tracer concentration allowed specify the coolant flow pattern behind the FA plate-type spacer grid of the KLT-40C reactor. The results of measuring the flow friction coefficient in the plate-type spacer grid, depending on the Reynolds number, are presented. Based on the obtained experimental data, recommendations have been provided for updating the procedures to calculate the coolant flow rates for the KLT-40C reactor core by-channel codes. The results of investigating the coolant flow local hydrodynamics and mass transfer in the KLT-40C reactor FAs have been adopted for practical use by Afrikantov OKBM for estimating the heat-engineering reliability of the KLT-40C reactor cores and have been data based for verification of CFD codes and detailed by-channel calculation of the KLT-40C reactor core.

Keywords: floating power unit; Core; Fuel assemblies; Spacer grid; Coolant flow hydrodynamics; Coolant flow mass transfer; Flow friction coefficients.

Introduction

The construction of *Akademik Lomonosov*, the world's first floating power unit, is at its final stage in Russia. The power source for the unit is the KLT-40C reactor plant. The principal designer, the manufacturer and the only supplier of components for the KLT-40C plant is Afrikantov OKBM.

One of the key components of the KLT-40C reactor is an assembly-type core. The KLT-40C reactor core development technology is based on the experience of designing, manufacturing and operating nuclear icebreaker reactor cores. The KLT-40C core consists of jacketed fuel assemblies (FA) with plate-type spacer grids (SG)) [1]. The design features of the KLT-40C reactor core, as compared to conventional nuclear icebreaker core designs, have dictated the need for its heat-engineering reliability to be justified.

To a great extent, thermal-hydraulic calculation forms the basis for justifying the nuclear reactor core reliability [2]. The prime task in the calculation is to analyze the core's thermal and hydraulic performance throughout the lifetime across the spectrum of operating modes to justify the thermal-hydraulic reliability of the core and to ensure normal conditions for the operation of the core's components.

Codes for detailed cell-wise calculation of the water-cooled water-moderated nuclear reactor cores are used for thermal-hydraulic calculations [3]. However, most of such codes are based on mathematical models including empirical coefficients that take into account the effects of different FA structural parts on the coolant's hydrodynamics and heat and flow mass exchange, so activities need to be undertaken to additionally validate them.

Therefore, the design features of the KLT-40C reactor FAs require an experimental research into the formation

* Corresponding author.

E-mail addresses: dmitriev@nntu.nnov.ru (S.M. Dmitriev), nevid000@mail.ru (D.V. Doronkov), proninaleksei@mail.ru (A.N. Pronin), dn.solntsev@pochta.ru (D.N. Solntsev), vlad.sorokin1987@mail.ru (V.D. Sorokin), khrobostov@nntu.nnov.ru (A.E. Khrobostov).

Peer-review under responsibility of National Research Nuclear University MEPhI (Moscow Engineering Physics Institute).

http://dx.doi.org/10.1016/j.nucet.2015.11.012

2452-3038/

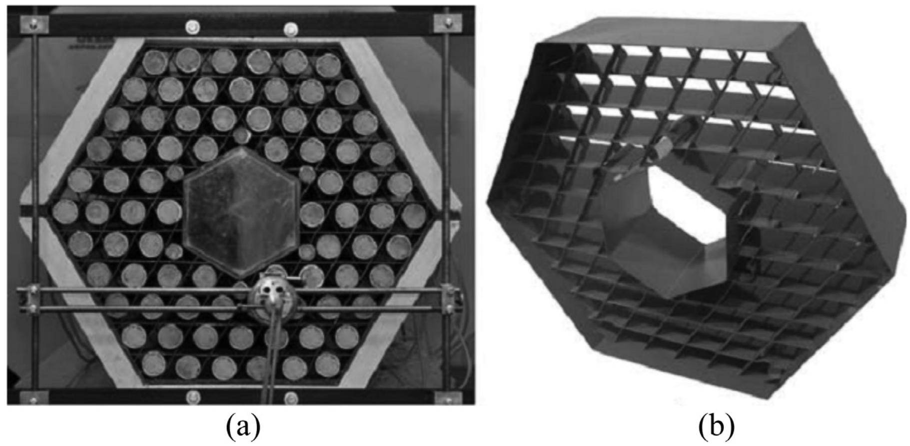

Fig. 1. Experimental model of the KLT-40C reactor FA (a) and the SG belt (b).

dependencies of local hydrodynamic and mass-exchange characteristics of the coolant flow in the fuel element bundles behind the SG, which is a critical task. Its solution enables the heat-engineering reliability of the KLT-40C reactor cores to be justified.

Test bench

An aerodynamic rig with an open circuit through which an air flow is pumped was built at the Nizhny Novgorod State Technical University n.a. R.E. Alekseev to investigate the coolant flow hydrodynamics and mass exchange in the KLT-40C reactor FAs [4]. The rig comprises a high-pressure fan, a receiving tank, an experimental model (EM) (Fig. 1a), a flow meter, a tracer gas supply and extraction system, and a measuring system.

The EM of the KLT-40C reactor FAs has been built based on the principle of a full geometrical similarity and consists of a hexagonal jacket, fuel element simulators, burnable absorber rod simulators and the SG belts in the form of a structure comprising a hexagonal shell and a set of parallel plates arranged in three tiers (Fig. 1b).

Measuring system

The measuring system comprises a gas analyzer, a gas flow meter, a computer with respective software, a Pitot static tube, a five-channel Pitot probe, and an assembly of analog pressure transducers.

The gas analyzer was used to measure the concentration of C_nH_m hydrocarbons in the gas-air mixture. The C_nH_m measurement principle is based on measuring the infrared radiation absorption value. The range of measured concentrations is 0 to 10000 ppm, and the measurement errors, with an allowance for individual calibration, are equal to ±15 ppm (0 to 1000 ppm) and ±1.5% (1000 to 10000 ppm) [5].

The preset flow rate of the tracer gas was maintained by a mass flow meter with a gas flow measuring and adjustment capability. The error was no more than 0.5%.

The coolant flow velocity vector was measured using the five-channel Pitot probe. The threshold deviations of the absolute velocity projections on the axis X, Y, Z did not exceed 7% of the absolute velocity. Prior to the experiment, the probe was calibrated in an air flow with the known and cross-sectionally constant direction and velocity value [6].

The tracer samples for the gas analyzer were taken using a sampling probe in the form of a Pitot static tube that could be also used to determine the flow velocity axial value [7].

The five-channel Pitot probe's readings were taken by the assembly of analog pressure transducers. The permissible maximum main error for these instruments was ±0.25%.

KLT-40C FA Coolant flow hydrodynamics and mass exchange investigation procedures

The inter-cell mass exchange in the KLT-40C FAs is studied using the impurity diffusion method [8] based on recording of the transverse mass flow using a certain transported substance. Propane was selected as the impurity because of having the properties most similar to those of air and not leading to a distorted coolant flow pattern.

The coolant local mass exchange investigation procedure was as follows: the tracer gas was fed through an intake probe into a representative EM cell up to the SG belt in the direction of the coolant flow; the tracer gas concentration was measured by the gas analyzer using the sampling probe at center-points of all cells behind the investigated SG belt in representative sections lengthwise of the EM, and then, based on the data obtained, maps and diagrams were plotted for the dependencies of the tracer concentration distributions on the relative coordinate for the EM representative cross-section areas. The flow pattern was identified based on the plotted maps and diagrams.

Experimental studies into the local hydrodynamic performance of the coolant flow in the EM tube bundle consisted in measuring the velocity vector modulus, the flow angles and the static pressure. The five-channel Pitot probe was used for the measurements. The velocity vector was measured in representative areas of the EM periphery and displacer region (Fig. 2). In each of such areas, measurements were performed in 19 cross-sections lengthwise of the EM.