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Combined numerical and experimental study of temperature pulsations in the fragment of header unit of heat exchanger of nuclear power unit clean-up and cooldown system

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Abstract

Experimental model of fragment of header unit of light-water nuclear power reactor clean-up and cooldown system was developed and manufactured. Experimental studies of temperature conditions were performed using the developed experimental model.

Experimental distributions of temperature in characteristic zones of the header unit under study were obtained. The most thermally stressed zones of heat-exchanging surface were determined. Analysis of intensity of temperature pulsations on the heat-exchanging surface and coolant flow in different zones was performed, statistical and spectral characteristics of temperature pulsations were represented. Solutions were suggested aimed at the reduction of intensity of thermal pulsations.

Calculation model of the fragment of header unit was developed and recommendations were given on the development of calculation models. Results of numerical modeling of transient temperature conditions and characteristics of temperature pulsations for different regimes of flow streamlining the model obtained using ANSYS CFX 14.0 CFD-code are presented here.

Comparative analysis of experimental and calculated data was performed. It was demonstrated that calculated data are in agreement with experimental data with sufficient accuracy which gives the possibility to use the developed calculation model in the future for subsequent substantiation of heat exchanger design.

Keywords: Heat exchange; Temperature conditions; Temperature pulsations; Coolant; Header unit; CFD.

Introduction

Significant impact on the lifespan of highly stressed heat exchanging equipment is produced by hydrodynamic and thermodynamic processes accompanied with temperature pulsations. Temperature pulsations can produce significant fluctuations of thermal stresses on the heat-exchanging surfaces leading to the fatigue destruction of elements of equipment. Temperature pulsations must be taken into consideration in the designing of heat and power generation plants and must be reduced to permissible levels by rational selection of operational regime parameters or by application of special design solutions in order to ensure reliable operation of the equipment during the required service life [1–3]. Determination of characteristics of thermal pulsations is often associated with the need to carry out experiments. However, substatiation of design of heat generating equipment of nuclear power installations on the basis of experimental studies of hydrodynamics and heat exchange using pilot samples of equipment is associated with extremely high costs. In contemporary conditions combined calculation and experimental approach using CFD-codes allowing reducing the costs of designing heat exchanging equipment appears to be the most promising. Experimental studies which perform the function of a tool for verification of the software must be implemented within the general framework of the approach in question using scaled models of equipment or of separate parts of the equipment.

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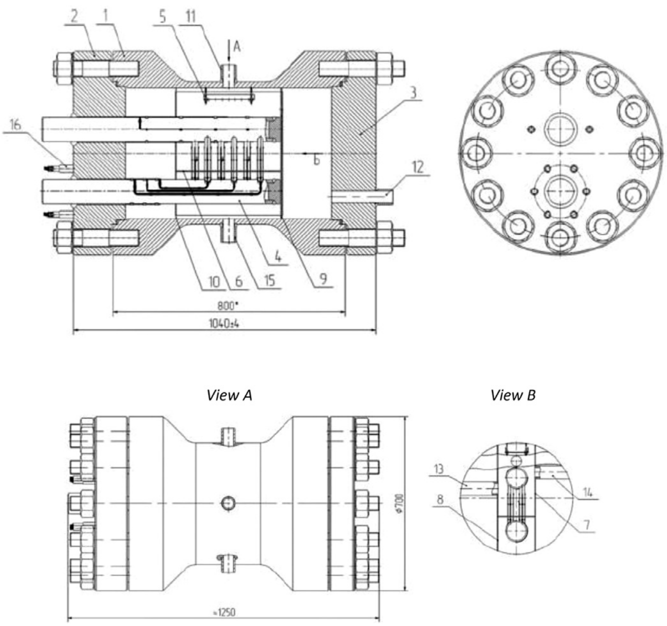

Fig. 1. Overall view of the heat exchanger model.

Combined calculation and experimental approach with application of 3D thermal hydraulics code ANSYS CFX 14.0 was realized in the present study. Results of complex studies of temperature pulsations caused by the presence of mixed convection were obtained using the experimental model of fragment of header unit of heat exchanger. The study is dedicated to the choice of optimal operational regime parameters and design solutions ensuring reduction of intensity of temperature pulsations, as well as to the development of recommendations for adaptaion of methodologies of numerical modeling of temperature pulsations to the heat exchanger model under investigation.

Expeimental facility and methodology

Experimental studies were conducted on the thermal hydraulic test facility FT-80 constituting part of the experimental complex of the Department of Nuclear and Thermal Power Plants of the R.E. Alekseev NNSTU. The test facility consists of three hydraulically closed loops imitating the power generating unit. Heating medium is circulating within the first loop, working medium is circulating in the second loop and cooling water is circulating in the third loop. Water with high degree of purity is used both as the coolant and as the working medium. The design of the test facility allows conducting studies within the range of operational regime parameters corresponding to those of contemporary nuclear power installations.

Experimental section is incorporated in the structure of the first and third loops of the test facility. General view of the experimental section is represented in Fig. 1. The experimental model under study consists of the following main elements: vessel 1; two side flat covers 2 and 3; header unit 4 composed of the upper and lower headers connected with each other by six straight tubes $Ø20 \times 1.5\,mm^2$; divider 5; resistance lattice 6; side (7 and 8) and end (9 and 10) walls installed in such a way as to form a channel with rectangular cross-section in which the header assembly is installed; tube joints 11–14 for coolant inlet to and outlet from the test section 15; couplings for thermal element outputs 16; fastening parts, etc. Overall length of the experimental model amounts to 1250 mm with model diameter equal to 700 mm. Length of the investigated section of heat exchanging surface is equal to 360 mm and its diameter is equal to 450 mm.

Propagation of heating medium is performed within the annulus and that of cooling water is organized inside the tubes. Propagation of cooling water is achieved by the principle of forced circulation. Lower header of the experimental model serves as the outlet and the upper one as the inlet of cooling water.

Several different options of coolant supply to the header unit were incorporated in the heat exchanger design: in order to use these options the heat exchanger is equipped with four tube joints, three of which are located in the central cross-section of the experimental model and the fourth is positioned on the vessel cover [4].

Chromel-copel thermal microelements with individual calibration curves (calibration uncertainty equal to $\pm 0.2\,°C$) were used in the studies of temperature field in the experimental model. Sensitive part of the element is rolled to reach the diameter equal to 0.5 mm. Since the areas where tubes are fixed to the headers and tube plates are often subjected to destruction as the result of temperature pulsations, the following methods are used in the heat exchanger experimental model to install thermal elements (Fig. 2):

t1,3,…,47 are the sensors installed in metal-coated slots on the surface of heat exchanging tubes in the cross-section removed from the upper header by 200 mm (in four directly opposite points of the circumference);

t2,4,…,48 are the sensors installed in the same cross-section inside the coolant flow above the surface of heat exchanger tubes in alignment with metal plated ones;

tt1,2,3 are the immersed thermocouples installed above the surface of heat exchanger tubes in the cross-section located 30 mm lower.

Determination of the most thermally stressed zones of the upper header was performed using metal plated thermal elements tk1,2,…,12 installed on the upper header surface (in three cross-sections in four directly opposite points of circumference of the cross-sections).

In general representation the methodology of experimental studies consisted of sequential implementation of the following operations:

- Organization of circulation of working media through the experimental model by manipulating shutoff valves;
- Reaching and maintaining the preset thermal physical parameters;
- Stabilization of thermal physical parameters, waiting for completion of transient processes;