Analysis of the IR-8 reactor’s IRT-3M FA hydraulic tests results using the ATHLET code

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Abstract. This article presents the results of the calculated-experimental determination of the parameters of hydraulic tests with the fuel assembly model used in a number of IRT type research reactors. Coolant velocities were obtained by experiments on a hydraulic stand with a model of an eight-tube IRT-3M fuel assembly at the Kurchatov Institute. A model of a hydraulic stand with a model of eight-tube fuel assembly for the ATHLET code has been developed. The ATHLET code was validated on experimental results of determining the velocities in the gaps of this fuel assembly. A virtual stand was created for a six-tube IRT-3M FA with a division of hydraulic gaps into flat and angular sectors. For the first time, the values of water velocities in the corner sections of the gaps of the six-tube IRT-3M FA were determined. The results of this work can be used in determining the permissible power of the IRT type research reactors: IR-8 at NRC KI (Moscow), IRT-MEPHI at NRNU MEPHI (Moscow), IRT-T at TPU (Tomsk) and WWR-SM at INP (Tashkent).

1. Introduction

This article is related to the analysis of the obtained hydraulic testes results of the IR-8 reactor’s IRT-3M fuel assemblies (FAs) using the ATHLET code. Reactor IR-8 is a pool-type research reactor with a thermal power of 8 MW, using ordinary water as a moderator and coolant [1]. The core consists of 16 IRT-3M FAs. IRT-3M FAs with tubular square-section fuel elements are produced in three types: eight, six, and four-tube [2]. Direction of the coolant in the core is from top to bottom. For the thermal-hydraulic calculations of the IR-8, hydrodynamic characteristics (in particular, coolant velocity in the FA gaps) are used, which were obtained during experiments on a hydraulic stand with an eight-tube fuel assembly model of IRT-3M at the Kurchatov Institute [3]. At present, only six-tube assemblies are used in the IR-8 reactor, for which experimental results are not available.

The purpose of this work is to model using the ATHLET code a hydraulic test with six and eight-tube IRT-3M FA, validate the ATHLET code on the experimental results for determining the velocities in the gaps of the eight-tube fuel assembly and than based on the created virtual model determination of the velocities in the gaps of the six-tube IRT-3M FA.
2. Description of the hydraulic stand and FA

The measurement was carried out on a special hydraulic stand (figure 1). The main element of the stand is a column (figure 2), simulating a section of the core. In addition to a FA model that is different from a real FA by absence of fuel, plate packs to simulate neighboring fuel assemblies are installed in the column. Thanks to the latest, the movement of coolant at the boundaries of fuel assemblies does not differ from actual conditions. Water is circulated through the column using a centrifugal-type pump with a maximum capacity of 58.2 m³/h. The flow rate is measured using an orifice gage, a magnehelic gage and is controlled by a valve installed on the pressure line of the pump. The method of determining the velocity and processing of the results are described in detail in [3].

In brief, the essence of the technique is as follows: in each gap, the dynamic pressure was determined, based of which the velocity of water was calculated. From the known velocity and cross section, the water flow through the gap was determined.

2.1. Stand parameters with eight-tube IRT-3M FA

IRT-3M FA consists of coaxial tubular fuel elements of square section with rounded corners fixed in the upper and lower end parts. Each fuel element is three-layered, consists of a fuel meat and cladding. The length of the fuel meat is 600 mm, the fuel element is 630 mm. The thickness of the fuel element is 1.4 mm, the gap between the fuel elements is 2.05 mm. The transverse dimensions of the fuel elements, as well as the perimeters and the area of the transverse gaps for the eight-tube fuel assembly are shown in table 1.

| Figure 1. Schematic diagram of the stand: |
| 1 – drainage; 2 – model of FA; 3 – detectors; 4 – vessel; 5 – high-water overflow; 6 – top tank; 7 – orifice gage; 8 – pump; 9 – bottom tank |
| Figure 2. Column cross-section: |
| 1, 2 – model and imitators FA, respectively; 3 – shell; 4 – detectors; 5 – vessel |
Table 1. Parameters of the eight-tube IRT-3M FA

| № gap | The radius of the outer part of the fuel element, mm | The radius of the inner part of the fuel element, mm | Gap cross section, cm² |
|-------|--------------------------------------------------|--------------------------------------------------|----------------------|
| 0     | 35.75                                            | 33.3                                             | 2.96                 |
| 1     | 34.70                                            | 29.85                                            | 5.29                 |
| 2     | 31.25                                            | 26.40                                            | 4.73                 |
| 3     | 27.80                                            | 22.95                                            | 4.16                 |
| 4     | 24.35                                            | 19.50                                            | 3.60                 |
| 5     | 20.90                                            | 16.05                                            | 3.03                 |
| 6     | 17.45                                            | 12.60                                            | 2.46                 |
| 7     | 14.00                                            | 9.15                                             | 2.64                 |
| 8     | 10.55                                            | 6.00                                             | 1.09                 |
| 9     | 7.00                                             | -                                               | 1.13                 |

2.2. Parameters of the six-tube IRT-3M FA
The cross-section of a six-tube FA is shown in figure 3. The external 6 gaps of the six-tube FA are no different from the eight-column gaps.

![Figure 3. Cross section of a six-tube IRT-3M FA; 1 – fuel elements, 2 – channel, 3 – displacement tube](image)

3. A Simulation of the stand using the ATHLET code

3.1. ATHLET code description
The TH system analysis code ATHLET (Analysis of Thermal-hydraulics of Leaks and Transients), based on the finite volume approach is continuously developed by the Gesellschaft für Anlagen- und
Reaktorsicherheit (GRS) for the analysis of the whole spectrum of operational transients, design-basis accidents and beyond design-basis accidents without core degradation, anticipated in nuclear or non-nuclear energy facilities [4]. The thermo-fluid-dynamic module is based on a two-fluid model with fully separated balance equations for liquid and vapor, while a five equation model with a mixture momentum equation and a full range drift-flux formulation for the calculation of the relative velocity between phases is also available [5]. ATHLET provides in the current code release version 3.1A a classical 1D flow model, a pseudo-multi-dimensional method, where the 1D model equations are applied separately to each coordinate direction of a multidimensional numerical grid, and an enhanced model with a genuine multidimensional set of TH conservation equations, for a better and a more realistic representation of the complex flow phenomena [6]. This approach comprises the 3-D momentum equations implemented in both Cartesian as well as cylindrical coordinates as an extension of the one-dimensional two-fluid model of ATHLET [7].

3.2. Simulation of the eight-tube IRT-3M FA

Figure 4 shows the model of the hydraulic stand for ATHLET code. All elements are built using the branch and tube objects. A pump was also used. With the help of GCSM signals, the differential pressure was adjusted per column to obtain the necessary flow.

Figure 5 shows the model of an eight-tube FA. During the modelling of plate packs imitators, there was a problem with the inaccuracy in the drawings of hydraulic stand, which did not allow to simulate local hydraulic resistances with sufficient accuracy. Therefore, a method was developed using the GCSM ATHLET system, which allowed to determine the necessary pump head and local resistances at the input to the plate packs imitators. As an estimate the values that allows with flow rate through the column of 54.8 m³/h obtain the flow rate through plate packs imitators equals the experimental value were taken. The obtained values of pump head and local resistance of the valve in further calculations remained unchanged.

Figure 4. Stand model

Figure 5. Model of eight-tube FA in ATHLET code;
IN_FA, OUT_FA – top nozzle and bottom nozzle;
0-10 – hydraulic clearance numbers
3.3. Simulation of the six-tube IRT-3M FA

At present, six-tube IRT-3M FAs are used in the IR-8 research reactor. This type of assembly is used in various research reactors, not only in Russia, but also abroad. In research centers where reactors are used IRT-M type FAs, all the calculations performed use the coolant velocity values in the fuel assembly gaps obtained in the experiment of determining the velocities on the hydraulic test bench described above. In this connection, the actual problem is the calculation of the hydraulic part of the inter-branch space. Therefore, the next task was to simulate a virtual stand, in which, unlike the real one, the eight-tube assembly was replaced by a six-tube one without changing the rest of the stand geometry.

As mentioned above, the external 6 gaps of a six-tube FA are no different from those of an eight-tube FA. Instead of the 7 gap, there is a displacer (figure 6). The model of a six-tube FA in the ATHLET code is presented in figure 7.

![Figure 6. Cross section of a six-tube fuel assembly; 1-7 – hydraulic clearance numbers](image)

![Figure 7. Model of six-tube FA in ATHLET code; IN_FA, OUT_FA – top nozzle and bottom nozzle](image)

In the ATHLET code, using the CROSSCONNECTION object, it is possible to simulate mass transfer in a system of parallel connected channels, which makes it possible to divide each gap in the fuel assembly model according to the model currently used to calculate neutron fluxes using the Monte-Carlo method [8-10]. This allows to obtain a more detailed spatial distribution not only of the coolant velocity, but also of the other thermophysical parameters that can be used in the physical calculation. The modernized model for calculating the spatial distribution of hydrodynamic parameters is shown in figures 8 and 9, which shows the cross-section of a six-tube FA with azimuthal splitting and its model in the ATHLET code, respectively.
4. Results of calculations

During calculations, the values of velocities were obtained in different gaps of the eight-tube FA. The results are shown in figure 10. From the above results it can be seen that the velocity values obtained in the ATHLET code coincide, within the limits of errors, with the values obtained by experiments on a hydraulic stand.

![Figure 8. Cross section of a six-tube FA with azimuthal splitting; 1-12 sector numbers](image)

![Figure 9. Model of a six-tube FA with azimuthal splitting in the ATHLET code; 1-7 hydraulic clearance numbers](image)

![Figure 10. Calculated and experimental water velocities in the gaps of the eight-tube FA](image)
Table 2 presents the velocities obtained during calculation of a hydraulic stand virtual model with a six-tube FA with azimuthal splitting and without splitting, as well as, for comparison, the velocities obtained during the experiment with a model of eight-tube FA.

| Gap number | eight-tube FA | six-tube FA |
|------------|--------------|-------------|
|            | Experiment (E) | Calculation (C) | Without azimuthal splitting | azimuthal splitting |
| 1          | 2.51          | 2.49         | 2.79          | 2.73 | 3.10 |
| 2          | 2.33          | 2.46         | 2.79          | 2.80 | 3.12 |
| 3          | 2.55          | 2.55         | 2.81          | 2.81 | 3.12 |
| 4          | 2.65          | 2.77         | 2.81          | 2.82 | 3.12 |
| 5          | 2.54          | 2.70         | 2.81          | 2.84 | 3.12 |
| 6          | 2.97          | 2.80         | 2.82          | 2.82 | 3.11 |
| 7          | 2.90          | 2.83         | 2.82          | 2.82 | 3.11 |

*The error of experimental values is ~ 6%*

The table shows that the average values of the velocities in the gaps of the six-tube FA, calculated using the ATHLET code, differ from the experimental values obtained on a hydraulic stand with a FA model.

5. Conclusions
The analysis of the hydraulic tests results of the IRT-3M FA of the IR-8 reactor was carried out using the ATHLET code. A model of a hydraulic stand with a model of eight-tube FA was developed. The obtained values of the calculated velocities coincide with the experimental ones within the limits of errors. A virtual stand for IRT-3M FA with a division of hydraulic gaps into flat and angular sectors was simulated. For the first time, the values of water velocities in the gaps of a six-tube IRT-3M FA were determined using the ATHLET code.

The results of this work can be used in determining the permissible power of IRT type research reactors: IR-8 at NRC KI (Moscow), IRT-MEPHI at NRNU MEPHI (Moscow), IRT-T at TPU (Tomsk) and WWR-SM at INP (Tashkent).

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Acknowledgments
The authors appreciate the support and effort of National Research Nuclear University MEPhI. This work was supported by Competitiveness Program of National Research Nuclear University MEPhI.