KnE Engineering
AtomFuture-2017
XIII International Youth Scientific and Practical Conference
"FUTURE OF ATOMIC ENERGY - AtomFuture 2017"
Volume 2017

Conference Paper

The Development of Models to Predict the Stability of Natural Circulation of Heatoolant

Orekhova E. E., Andreev V. V., and Tarasova N. P.

Institute nuclear energy and technical physics, Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Nizhny Novgorod, Russia

Abstract

Concept of safety of nuclear power plants involves in larger quantities the use of passive systems. One of the main passive systems in nuclear power plant – the system of cooling of the reactor core. This system is based on gravitational forces. In this regard, nuclear energy increases the significance of such physical process, as the natural circulation. In addition to the benefits of the system there are drawbacks. There is the instability of the two-phase coolant, pulsation temperature and pressure, rollover and stagnation of circulation.

In this paper we consider a generalize model of stability of natural circulation of the coolant.

This model is intended to simplify the design of power equipment. Also model will enable the operating staff to predict the limit operating modes of the equipment and to stay within the stability modes of the heat coolant.

Corresponding Author:
Orekhova E. E.
katrinorekhova9669@gmail.com

Received: 23 December 2017
Accepted: 15 January 2018
Published: 21 February 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the AtomFuture Conference Committee.

Keywords: natural circulation, geyser instability, thermal pulsation, stability.

1. Introduction

Currently, one of the most promising sources of energy is nuclear energy. The importance passive safety systems to increase In the process of development of the nuclear industry. The main advantage of these systems is independence of functioning from external power sources, and, in this regard, simplification of structure. This system is based on motion of fluid due to difference of specific weights. Movement occurs without equipment (no pumps) and represents circulation of coolant occurring due to natural forces. In addition, equipment operating on the natural circulation of the coolant, reduces noise level installation, weight, size parameters and energy consumption for self-sufficiency. But, in addition to advantages in this system, there are drawbacks namely there is the instability of the two-phase coolant, pulsations of thermal-hydraulic parameters, rollover and stagnation of circulation.

2. Instability of two-phase flows

In natural circulation channels with two-phase coolant arise flow instability, which is manifested in the periodic change in the basic thermal-hydraulic parameters of the flow at constant external conditions. [1, 2]

Unstable flow regime may result in reducing reliability of thermal power equipment. Multiple periodic oscillations of heat coolant parameters can lead to premature loss of equipment serviceability, destruction of canals material, low frequency vibrations affecting entire installation.

3. Geyser instability

The results of experimental studies showed that one of main types of instabilities in low-pressure coolant flow is volatility of flow by volume of boiling coolant in lifting section of the circulation loop. This type of instability is characterized by periodic emission of a two-phase mixture from lift area and then filling path of circulation by water.

Instability type geysering got its name because of the resemblance to natural geysers, which are characterized by the periodic emission of the water-steam mixture from the depths of the Earth.

First geyser instability was studied in vertical tubes, closed at the bottom and filled with water [3]. When heating the pipe with some heat flow in the lower part starts boiling water. In systems with low pressure, this leads to a sudden increase in steam and quick release water-steam mixture in the expansion vessel. Liquid whose temperature is below saturation temperature, is discharged from the expansion vessel into the pipe. The system returns to initial state. Cycle is repeats. [5, 6]

Cycle divided into several stages:

- accumulation of energy;
- boiling of the coolant at a temperature slightly above the saturation temperature;
- the release of the steam jet;
- return to the initial state.

4. Methods and techniques for prediction of flow regimes of the coolant

In this paper, we assume study of stability natural circulation of coolant with a few different methods with aim of creating a common generalized system.There are three methods is used: experimental method, computational method with use of computer codes for hydrodynamics, method of application of artificial neural networks (ANN). The results are obtained using aforementioned methods, are combined to create a generalizing model. This model allows to predict the stability of systems to determine the limiting boundary conditions of the stable operation of system.

5. Experimental research methods

Experimental studies were carried out at the Department "Nuclear reactors and power plants", Institute of nuclear energy and technical physics, N. Novgorod state technical University. R. E. Alekseev.

The experiments were conducted at atmospheric pressure. This experiments are model of operation of the system at atmospheric pressure, simulating the process emergency cooling of installation. The stand scheme is shown in fig. 1

The experiments were conducted in the following order:

- initial water temperature in the circulation loop was measuring;
- initial temperature in the cooling circuit was measuring;
- water flow of the cooling water was measuring;
- power to the heater was turned on;
- recording and archiving of data was turned on.

registering parameters:
power of the heater;
the heat capacity of refrigerator;

- coolant temperature at inlet and outlet of heating contour;
- temperature of channel walls
- temperature of cooling water outlet from fridge
- differential pressure in channel
- steam content at exit of heated channel.

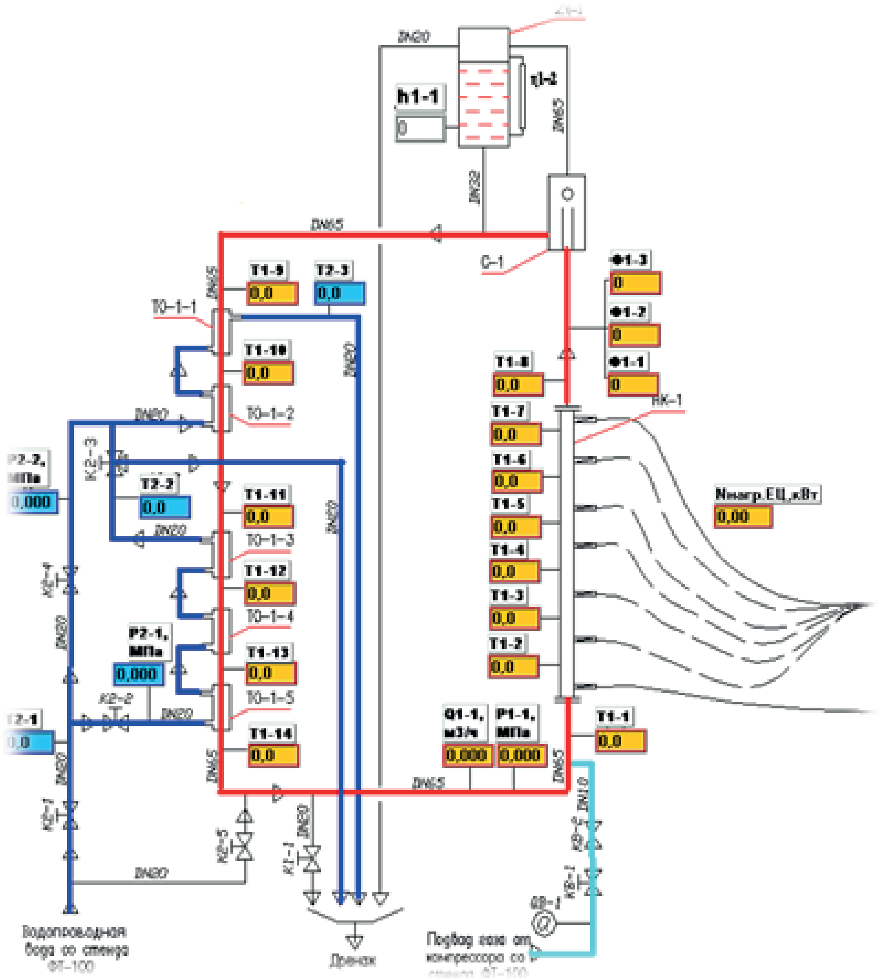


Figure 1: Scheme of experimental stand. Symbol: TO1-1 – TO1-5 – heat exchangers, T1-2 – T1-8 - thermocouple of the heating phase, T1-9 to T1-14 –thermocouple cooling phase, T1-1 – T1-3 – thermocouples on the inlet and outlet of the cooling sections, F1-1 – F1-3 – ultrasonic sensors for the measurement of void fraction.

When pulsation modes was setting, next parameters were recorded: frequency and duration of pulsations, magnitude of pressure drop, coolant temperature at exit of heated section and temperature at which pulsations are appeared. As a result of processing of experimental data the curve of stability of the natural circulation presented in Figure 2.

The curve has the left branch at an angle to the axis of relative temperature, a pronounced minimum and the right branch. In mode of operation, characterized by right branch, includes interval of unstable operation of system. Therefore, left branch is interesting in results.

Similar results on the stability of natural circulation of coolant was found in the literature [7] and presented in Figure 3.

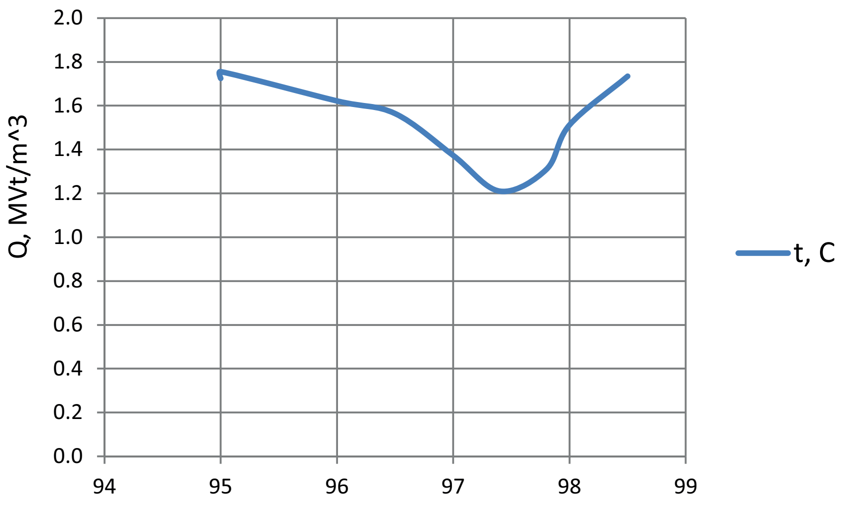


Figure 2: Stability curve obtained experimentally.

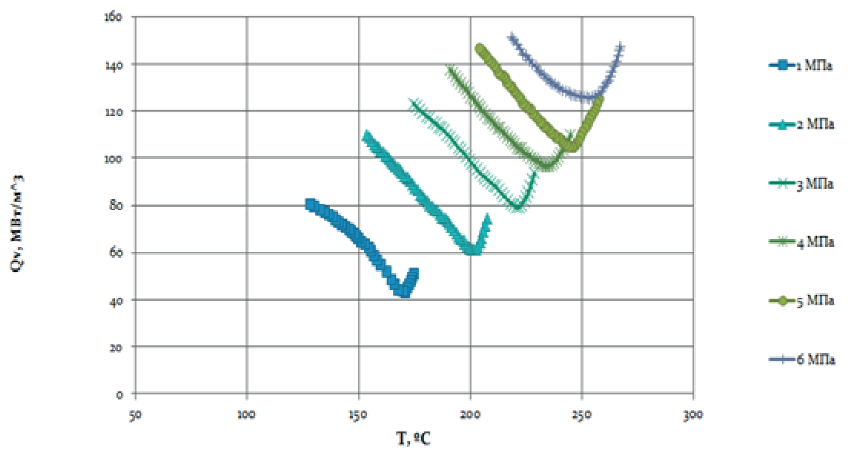
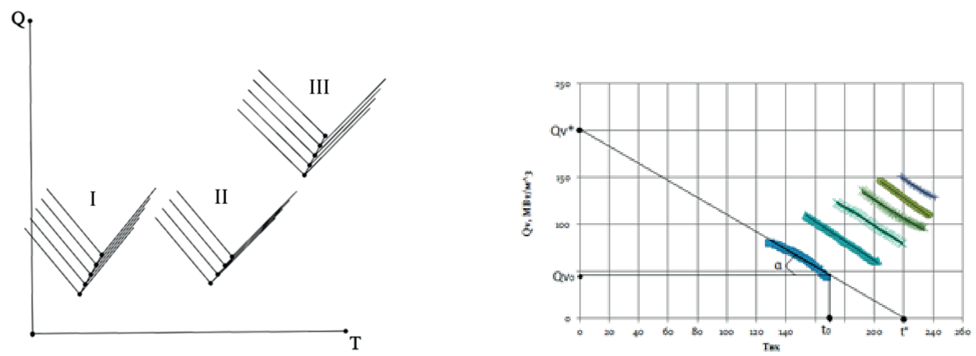


Figure 3: Curves of resistances for circuits with natural circulation, the literary sources.

Technique of developing generalized model to predict the process stability of natural circulation is based on found in literature experimental data and experimental results.

6. The experimental-computational system for studies of natural circulation of coolant

General model is a set of lines of the boundary conditions the existence of a stable system, built-in axis Q-T. This system of boundary conditions is uniqued for specific technical system and allows to determine limits of stable operation of equipment. The system of boundary conditions is family of characteristic curves: the left branch of the family is tilted at certain angle to the axis of the temperature (T), the angle depends on



a) I, II, III - different geometry of circulation contours

б)

Figure 4: Features of the boundary conditions of the existence of natural circulation in the circuit.

the geometry of contour. Breaking point moves depending on the conditions in which the heat transfer fluid.

The model is presented in Figure 4.

The introduction of generalized coordinates is allows to modify the study model:

$$Q_{np} = \frac{Qv_0}{Qv*}$$

$$Qv* = f(x = 0)$$

$$Qv_0 = f(x_{\max})$$

$$t_{np} = \frac{t_0}{t*}$$

$$t* = f(y = 0)$$

$$t_0 = x_{\max}$$

$$tg(\alpha)$$

7. General model of boundaries of stability of systems with natural circulation of coolant

The generalized model is a generalization of results are obtained with application of experimental methods, computer simulations and artificial neural networks (ANN). This model allows to predict marginal density of heat flow under which system will still be stable and boundary temperature of coolant at inlet to the heated area, above which system enters an unstable state. This model allows to simplify design and analysis of

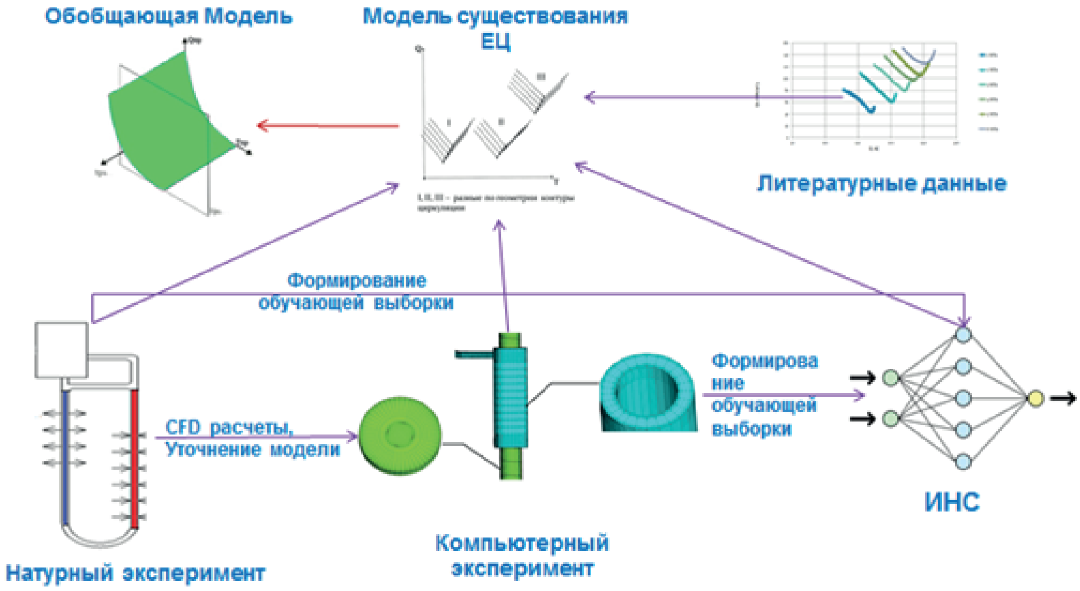


Figure 5: Scheme of the generalized model.

heat exchangers based on principle of natural circulation. Diagram of development of a generalized model is shown in Fig. 5

8. Application of numerical methods of modeling the process of natural circulation

Results are obtained experimentally, are used for modeling systems by methods of computational fluid dynamics. For applications method of computational fluid dynamics necessary to build a geometric model of study system, to build calculation – grid model, to create a mathematical model.

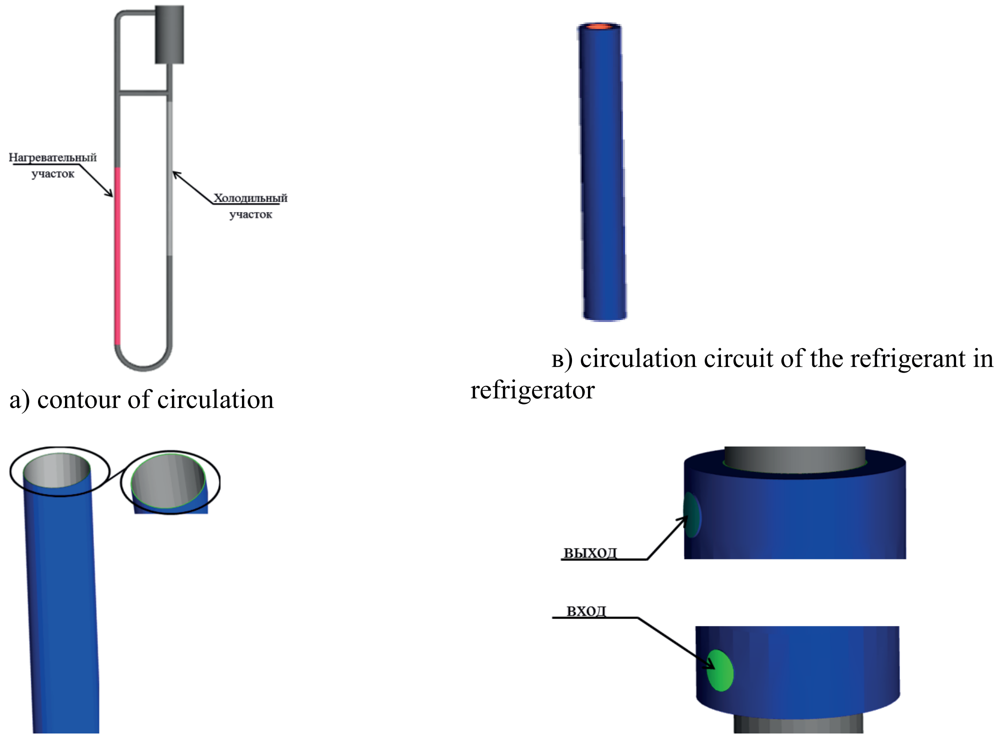
Methodology for conducting experiments on natural circulation coolant by CFD

For experiment necessary:

- to create geometry of studied contour;
- to create calculation – grid model;
- to determine physical and mathematical models of investigated processes;

9. Description of geometric model used for numerical experiments

Geometric model consists of several components:



a) contour of circulation

в) circulation circuit of the refrigerant in refrigerator

Walls of contour

Entrance of the refrigerant into the refrigerator and out of it.

Figure 6: Computer geometric model of stand.

- circulation contour of heat coolant, corresponding to studied stand;
- circulation contour of heat coolant in refrigerator corresponding to the studied stand;
- metal wall of refrigerator.

All geometrical parameters of computer model correspond to studied full-scale stand. A computer geometric model is shown in Figure 6

Physical and mathematical model

- physical parameters of fluid are modeled by temperature-dependent with use of built-in library;
- influence of gravity are accounted;
- process of evaporation in the system is simulated;
- walls of contour are modeled without slip;
- heating of metal is defined by specific heat flux on wall;
- thermal conductivity of metal is modeled;
- flow rate of coolant at inlet of heat exchanger is simulated

10. Description of mathematical model

Mathematical model of liquid based on solution of system of Navier-Stokes equations [8]:

- the equation of continuity:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u_i)}{\partial x_i} = 0 \tag{1}$$

where ρ is the density, u_i is projection of the velocity on a given axis, *t* – time; *x* - coordinate, which is considered the flow.

- the equation of motion:

$$\frac{\partial(u_i)}{\partial t} + u_j \frac{\partial(u_i)}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{1}{\rho}\frac{\partial(\sigma_{ij})}{\partial x_j} + J_i \tag{2}$$

where the indices *i* = 1,2,3 is the index of the coordinate axis;

j- the index of the summation;

J- external force acting on the system (gravity)

- the energy equation:

$$\rho \frac{\partial h}{\partial \tau} = -div(\vec{q}) + \omega \tag{3}$$

Where *q* - projections of heat flux density on the coordinate axes;

ω- internal sources of heat.

11. Application of artificial neural networks to simulate the process of natural circulation

On basis of obtained results by described methods, the modeled Ann. Applied Ann type is multilayer perceptron. [9]

Input parameters are characteristic of geometry and coolant condition. Output parameters: limit heat flux, temperature and tg(α). Modeling scheme of the Ann is shown in Figure 7

f(Г) is a characteristic of circulation channel;

f(У) – characteristics of conditions yet;

tg(α), Qnp, TNP – output ANN- parameters of system stability.

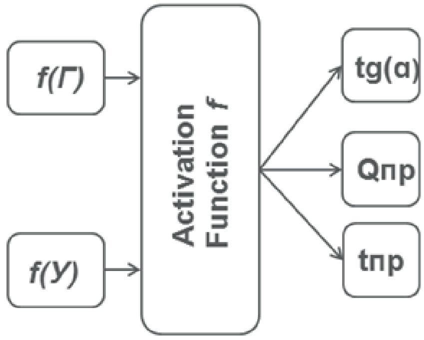


Figure 7: The scheme of NAA used for generalized model creating.

12. Conclusion

Methodology of creating a generalized model to predict the stability of systems with natural circulation is develop. Methods are used to create model are described. This model will predict limiting heat load under which system will still be in steady mode of operation.

References

[1] D Butterworth, G. Hewitt Two – phase flow and heat transfer // Oxford University press, 1977

[2] V. B. Khabensky, V. A. Gerliga Instability of the coolant flow in the elements of power equipment. S.-Petersburg: Nauka, 1994.

[3] Griffith P. Geysering in Liquid-Filled Lines. ASME Paper No. 62-HT-39, 1962

[4] Subki, M. H., Watanabe N., M. Aritomi, Multi Parameters Effect On Thermohydraulic Instability In Natural Circulation Boiling Water Reactor During Startup // 11th International Conference on Nuclear Engineering. Tokyo. Japan. 2003.

[5] Takemoto, T., Aritomi, M., Matsuzaki M., Experimental Study On The Driving Mechanism Of Geysering // Third International Conference on Multiphase flow. Lyon. France.,1998

[6] Verbitsky, Yu. G. Simulation of the thermalhydraulic processes in the elements of the reactor equipment at low parameters of the coolant.- Sosnovyy Bor.: NITI im..P. Alexandrova, 2011.- 124 p.

[7] Tong, L. S. boiling Heat transfer and two-phase flow, translation from English under the editorship of Sidorov. – M.: Mir, 1969. – 344 p.

[8] Bykov L. V., Molchanov A. M., Shcherbakov M. A., Yanyshev D. S. Computational continuum mechanics in the problems of aviation and space technology.// LENAND. 2015.668 S.

[9] Simon Haykin Neural networks: a complete course, 2nd edition. // Per. from English. TO "Williams". 2006. 1104 S.