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Computer analysis of the system during generation ceramic covering on a cladding of a fuel element simulator with sublayer lead – magnesium - zirconium

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Abstract

The method of computer analysis of system parameters at formation of protective coating on the shell of fuel element of fast reactors is presented, which can serve as a prerequisite for development of cognitive architecture of control of nuclear power engineering processes by control of composition of gas phase in reactor core, containment, other tanks and making decisions on results of process parameters deviation from stationary function. The work was carried out to justify the prospects of using a liquid metal sublayer (LMS) instead of a gas sublayer in fuel elements, which allows, due to the high thermal conductivity of the liquid metal, to increase the width of the gap between the fuel and the shell and, therefore, to increase the fuel element life limited by the contact of the fuel with the shell. At the same time, safety in case of UTOP (uncontrolled increase of power), ULOF (termination of coolant flow through the reactor) accidents is increased due to significant decrease of temperature in the fuel center. However, the possibility of using LMS is limited by the substantial mass transfer - corrosion dissolution in the lead of the components of the fuel element shell in the hot zone and precipitation in the cold zone. In this article, the basis for computer analysis was studies on the absorption of gas (nitrogen) when forming a protective ceramic coating of zirconium nitride on the surface of the shell of a pipe-in-pipe type fuel element simulator to suppress the corrosion process from eutectic alloy lead-magnesium-zirconium. Abnormal intense decrease of nitrogen pressure (p, kPa) in expansion tank with Pb-Mg-Zr alloy at increased temperature (about 950 K) according to linear kinetic law (t, c), connected with its interaction with system components, was revealed: $p, kPa = -0.0002 \cdot t - 77.867 \quad R^2 = 0.942$. Method of diagnostics of system parameters at formation of anticorrosive coating by nitrogen absorption is developed, empirical dependencies of process flow in wide range of temperature are built.

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1 Introduction

Computer analysis of the gas phase in the cavities of nuclear power engineering makes it possible to make decisions and perform adequate actions to ensure the standard modes of operation and safety of the reactor plant in a timely manner (due to the rapid response of the monitoring devices to changes in the system parameters).

The work was carried out in support of the prospects of using a liquid metal sublayer (LMS) in fuel elements instead of a gas layer [1], which allows, due to high thermal conductivity of the liquid metal, to increase the width of the gap between the fuel and the shell and therefore increases the fuel element life limited by the contact of the fuel with the shell. At the same time, safety in case of UTOP (uncontrolled increase of power), ULOF (termination of coolant flow through the reactor) accidents is increased due to significant decrease of temperature in the fuel center.

However, the possibility of using LMS is limited by significant mass transfer - corrosion dissolution of fuel element shell components in hot zone in lead and precipitation in cold zone [2, 3].

For formation of corrosion-resistant protective coating it is proposed to use eutectic alloy lead-magnesium-zirconium as intra fuel element sublayer. Corrosion damage during use of this alloy was absent in ampoule tests of steels of different class with duration up to 500 h at temperature up to 1023 K and loop tests of steel 16Cr12WMoSiVNbB at 813 - 923 K for 1000 h, as well as tests of fuel element models with uranium nitride core at 973 K for 5700 hours. And fuel element simulators of "pipe-in-pipe" type at temperature difference of 693 - 923 K with duration of up to 1000 h [4-8].

In this article, the basis for computer analysis of processes in the system was studies on absorption of gas (nitrogen) when forming a protective ceramic coating of zirconium nitride on the surface of the shell of the fuel element simulator of "pipe-in-pipe" type to suppress the corrosion process from eutectic alloy lead - magnesium - zirconium.

2 Experimental studies

In order to assess the operability of the eutectic melt Pb-Mg in a narrow gap inside the fuel element, in which there may be difficulties in transporting coating components from their source, studies were carried out on the formation of ZrC (N) protective coating [8]. The device consists of two sections - a five-tube model of shortened models of fuel elements for possibility of gravimetric analysis and a single-tube model for verification of the obtained results on zirconium penetration on the length of fuel element fuel part in a narrow gap of 0.15 mm width between coaxially arranged pipes of steel of 16Cr12WMoSiVNbB length up to 1100 mm. The mnemonic diagram of information collection using the PC is shown in Fig. 1.

This article provides data of computer recording of parameters of single-tube model system for expansion tank. Temperature measurement was carried out with the help of chromel-aluminium thermocouples GOST R 8.585-2001, pressure measurement by pressure - vacuum sensors of "Metran" type.

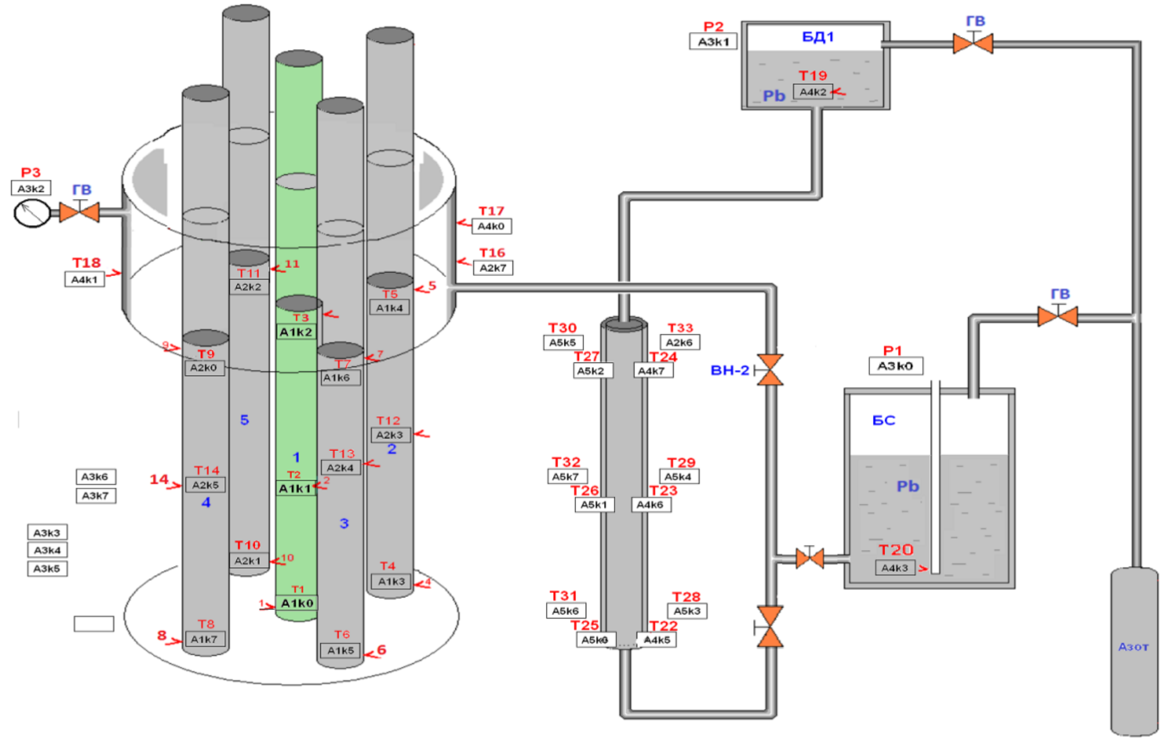


Fig. 1. Mnemonic diagram of information collection with the help of PC

3 Results of computer analysis

Figure 2 shows the dependence of temperature and nitrogen pressure in the expansion tank of the fuel element simulator of "pipe-in-pipe" type on time during the first 100 hours of testing. Parameters were recorded every second, Figure 2 and the following show a minute-by-minute sample of parameter values.

Figure 3 shows the dependence of the nitrogen pressure in the expansion tank on the temperature in the initial time period, approximated by the equation:

$$p, kPa = 0.1659 \cdot T - 63.7 \quad R^2 = 0.9994 \tag{1}$$

where T is the temperature, K.

Nitrogen pressure increases linearly with temperature with value of approximation reliability close to one (R^2 = 0.9994).

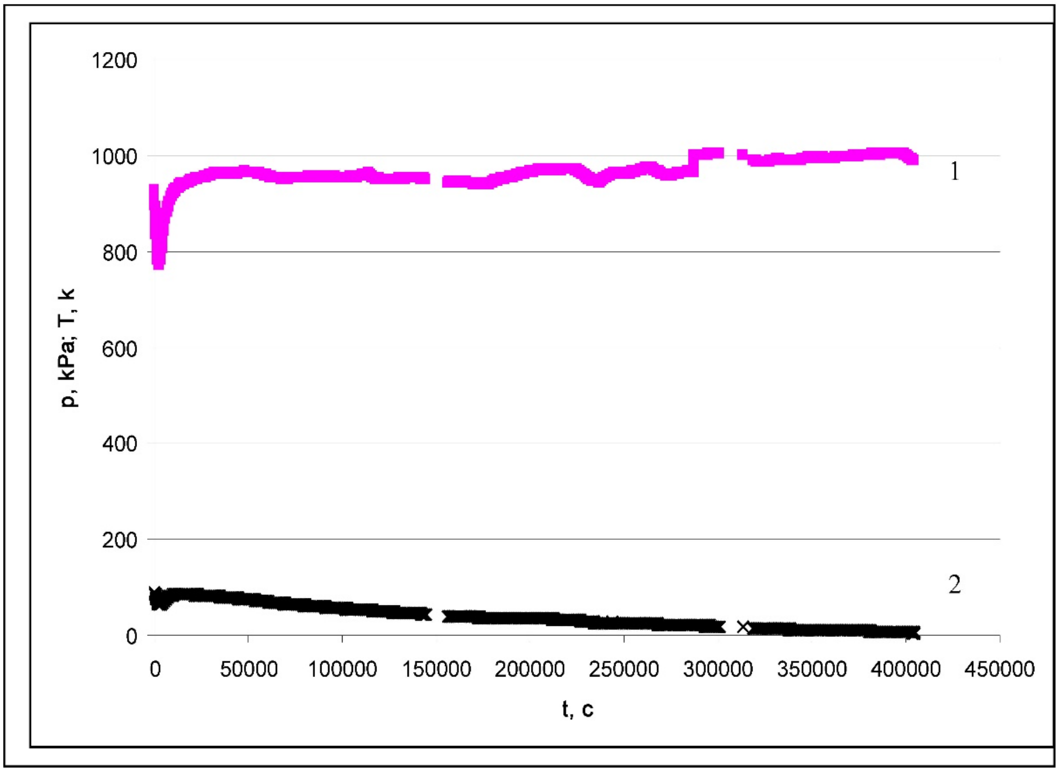


Fig. 2. Kinetics of temperature and pressure change in expansion tank of single-tube model.
1, ■ - temperature, T; K;
2, × — is pressure, kPa

During this period of time, the gas pressure is subject to the law of Clapeyron - Mendeleev.

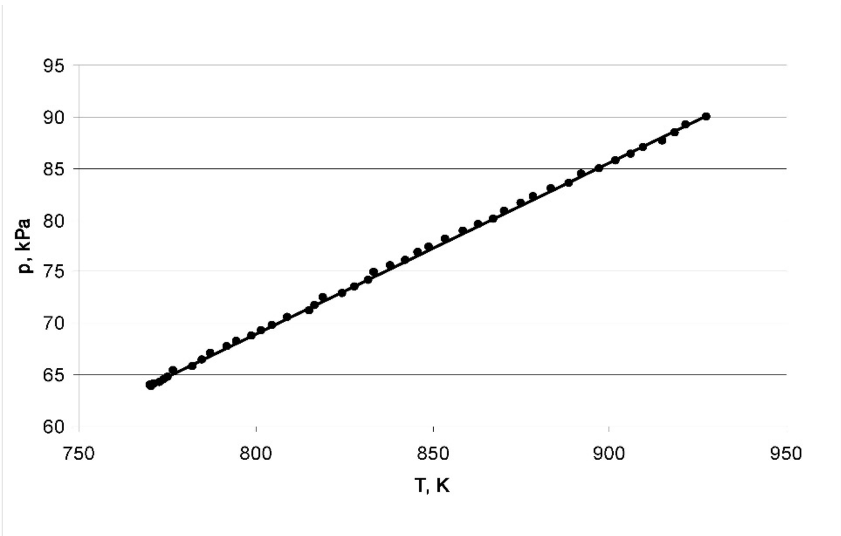


Fig. 3. Dependence of nitrogen pressure in expansion tank on temperature in initial period of time

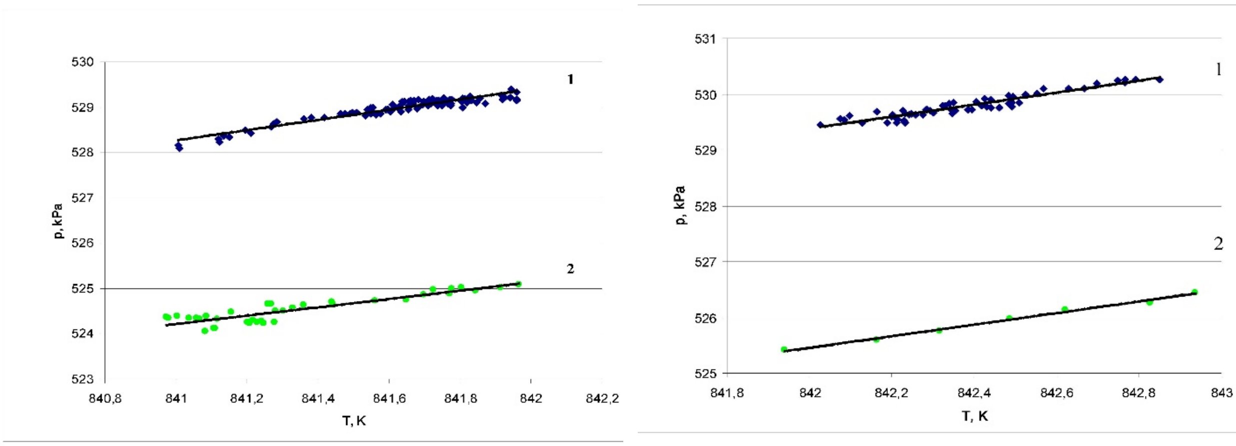
After 4.5 hours, a constant decrease in nitrogen pressure was observed regardless of the temperature value, which can be explained by nitrogen absorption by plant materials, a well-approximated linear function over time:

$$p,\ kPa = -0.0002 \cdot t - 77.867 \quad R^2 = 0.942 \tag{2}$$

where t – time, s

This anomalous phenomenon represents the process of nitrogen interaction in the gas or liquid phase, not aggravated by the presence of a diffusion barrier. The possibility of producing lead azide, which is an explosive substance, should be avoided.

In subsequent studies, no active nitrogen absorption was observed at a lower temperature (840-843K), and nitrogen pressure increased with temperature. Figure 4 shows the dependence of nitrogen pressure in the expansion tank of the single-tube model on temperature, and analyzed the sample with temperature change by 1 degree (841-842 K Figure 4 a and 841-842 K Figure 4 b), which shows a sufficiently high accuracy of measurements.



a b

Fig. 4. Dependence of nitrogen pressure in expansion tank of single-tube model on temperature at temperature change by 1 degree.
a – temperature change from 841 to 842 K. Curve 1 data obtained 1 hour after recording start, curve 2 - 30 hours after recording start
b - temperature change from 842 to 843 K. Curve 1 data obtained at the beginning of recording, curve 2 - 40 hours after the beginning of recording

The value arrays are successfully approximated by linear equations:

a, curve 1 $$p,\ kPa = 1.1263 \cdot T - 418.93 \quad R^2 = 0.8968 \tag{3}$$

a, curve 2 $$p,\ kPa = 1.0456 \cdot T - 354.95 \quad R^2 = 0.9914 \tag{4}$$

b, curve 1 $$p,\ kPa = 0.9358 \cdot T - 258.66 \quad R^2 = 0.9871 \tag{5}$$

b, curve 2 $$p,\ kPa = 0.9083 \cdot T - 239.67 \quad R^2 = 0.8007 \tag{6}$$

where T – temperature, K.

The process stabilized after 1600 hours with virtually no nitrogen reaction with the components of the system.

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4 Conclusion

Thus, the technique of diagnostics of system parameters during formation of anticorrosion coating by nitrogen absorption has been developed, empirical dependencies of process progress in a wide temperature range have been built.

The presented method of computer analysis of formation and damage of protective coating on the shell of fuel elements of fast reactors can serve as a prerequisite for development of cognitive architecture of control of nuclear energy processes by control of composition of gas phase in the reactor core, containment, other tanks and making decisions on results of deviation of process parameters from stationary function.

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