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THE USE OF CCCM FOR THE CREATION OF THE HIGH-TEMPERATURE DETECTORS OF THE WATER WAPOR

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A technique for assessing the presence of water vapor in a mixture using high-temperature detectors made of carbon-carbon composite material (CCCM) is proposed. The change in the electrical resistance of CCCM in a mixture containing water vapor at a temperature of 1000 °C is presented. The efficiency of such detectors has been tested and experimentally confirmed.

Recent events have shown that nuclear energy is one of the most important industries in Ukraine. It was nuclear energy that made it possible to maintain Ukraine's energy system in the conditions of military operations, and support, improvement and development of new generation nuclear energy systems is one of the priority directions of the country's development. The development and improvement of power reactors requires new approaches to the creation of reactor core materials. Such materials must work in conditions of high temperatures, have high mechanical strength, radiation and corrosion resistance, which allow maintaining the operability of the systems during the time necessary to eliminate the accident.

Carbon and graphite materials, carbon-carbon composites are one of the materials traditionally used in modern nuclear power reactors [1]. However, their potential has not yet been exhausted. Graphite carbon and composite materials are also considered as one of the most prioritized in the design of power reactors of the IV generation. Thus, previously conducted experiments on the corrosion resistance of CCCM in aggressive environments, including in the conditions of salt coolant $NaF+ZrF_4$ at 1000 °C, confirmed the high chemical and radiation resistance of CCCM – itis stable in relation to the model coolant even in conditions of emergency temperatures [2].

During the examination of emergency situations, critical situations were usually considered, during which there is significant damage to the active zone of the reactor. However, less significant accidents are also of special interest, which, for example, may be associated with the ingress of a small amount of water vapor into the gas carrier. Timely detection of such situations can prevent the occurrence of more critical accidents.

The aim of this work is to develop a methodology for assessing the ability of CCCM to determine the presence of water vapor in a gas mixture at high temperatures by changing its resistance.

As part of this research, a methodology was developed for assessing the corrosion resistance of CCCM based on its electrical resistance. An experiment was conducted on the direct effect of water vapor on the electrical resistance of CCCM, the value of which is inversely proportional to its mass and, accordingly, can characterize its corrosion properties.

To carry out a series of experiments, cylindrical model samples of resistive sensors from CCCM were made. The blanks for them were made using thermogradient gas-phase pyrodensification technologies. Three cylindrical rods Ø 35x550 mm were produced. One resistor sample was made from each rod (Fig. 1) in the form of a cylindrical spiral Ø 24x71 mm. In work [2], it was experimentally confirmed that the silicification of CCCM using the methods developed at the NSC KIPT allows to increase the service life of products in emergency conditions. Accordingly, the produced samples were also siliconized and subjected to additional annealing.

After the production of resistor samples, their quality certification was carried out and the electrical resistance in the initial state was measured. The resistance of the resistors at the beginning of the experiment was:

– sample # 1 – 3.542 Ω;
– sample # 2 – 3.227 Ω;
– sample # 3 – 3.187 Ω.

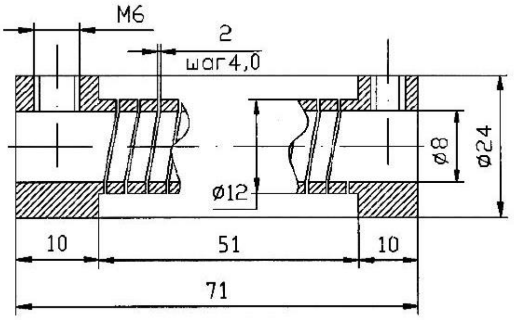

Fig. 1. Dimensions of a research CCCM resistor sample

By measuring the resistance of the test sample after heating and holding at a temperature of (1000±50) °C, as well as after cooling in a vacuum chamber to an ambient temperature of (20±2) °C, by the difference between the initial resistance of the sample and its resistance after cooling, it is possible to determine the effect of water gas on the change in electrical characteristics of CCCM.

A binary mixture of chemically neutral gaseous argon and water vapor was used to determine the effect of only water vapor directly (without other components of atmospheric air). In gaseous argon supplied in cylinders, the volume fraction of water vapor is no more than 0.0009% [3]. The production of a binary mixture of argon with water vapor was carried out in a bubble reactor with a gas disperser made of porous CCCM, which ensures a constant flow rate of the mixture at a pressure at the reactor outlet of 0.2 MPa.

Experimental studies to determine the change in electrical resistance of the resistor at a temperature of (1000±50) °C were carried out in three stages in the following sequence:

- in vacuum without argon supply (sample No. 1);
- in an argon environment (sample No. 2);
- in an environment of argon with vapors of water gas (sample No. 3).

During the first stage of testing, the test sample of resistor No. 1 was installed in a vacuum chamber and connected to a stabilized direct current power source with an adjustable output voltage. When the vacuum of at least 2.7 Pa was reached, voltage UH=24 V was applied to the resistor. Temperature control was carried out using a thermocouple placed inside the resistor. The value of the resistance was determined by the readings of the voltmeter and the ammeter with the minute-by-minute registration of the values of IH and UH. Each of the ten measurement sessions lasted for 11 min after the resistor temperature reached 1000 °C.

After each session, the resistive element was kept in a vacuum chamber to naturally cool the resistive element to ambient temperature. Then the sample was removed from the chamber and its resistance was measured with a high-precision RLC E7-8 meter.

The results of resistance measurements are presented in Fig. 2.

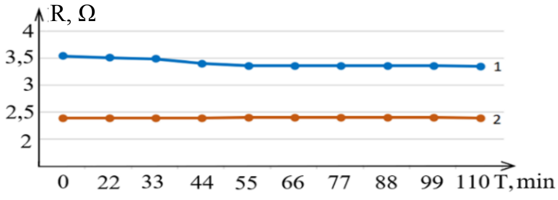

Fig. 2. Resistance of sample No. 1 from CCCM in vacuum at (20±2) °C (1) and (1000±50) °C (2)

Experimental study of sample No. 2 were carried out in an argon environment at a pressure of $2\cdot10^4$ Pa according to the above mentioned method. The results of resistance measurements at temperatures of (20±2) °C and 1000±50°C are presented in Fig. 3.

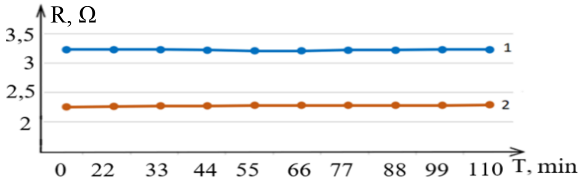

Fig. 3. Resistance of sample No. 2 from CCCM in an argon environment at (20±2) °C (1) and (1000±50) °C (2)

The obtained results show that the resistance of the resistive element during its heating in a vacuum and argon environment practically does not change (Figs. 2, 3) and, accordingly, the specific density and mass of CCCM did not change. Thus, there is no corrosion of the material.

During tests in an environment of argon with water vapor, the sample of resistive element No. 3 was installed in a titanium case and placed in a vacuum chamber. A mixture of gases from the bubbling reactor was supplied through a pipeline to the inlet fitting of the titanium case. In this way, the gas was saturated with water vapor to a volume of ~ 2.5% by volume. After passing through the resistor sample, the mixture of gases was discharged into the external atmosphere through a pipeline with a water gate.

After reaching the working temperature of 1000 °C inside the case, the valve for supplying the gaseous argon-water mixture was opened. At the end of the session, the power supply was turned off and the inlet and outlet valves of the gas argon-water mixture were closed. During the session, minute-by-minute registration of IH and UH parameters was carried out.

The results of measurements during the tests are presented in Fig. 4.

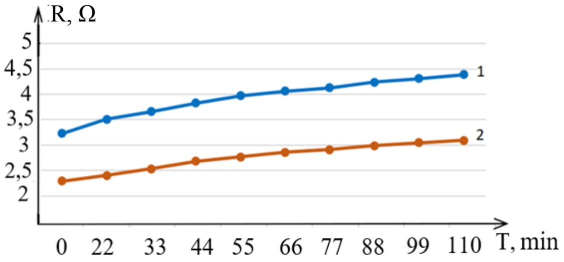

Fig. 4. Resistance of sample No. 3 from CCCM in an environment of argon with water gas vapor at (20±2) °C (1) and (1000±50) °C (2)

As one can see, the slope of the electrical resistance curves is significantly different from the previous results. The obtained results show that the resistance of the resistive element when heated in an argon environment with water gas vapor tends to increase by an average of 0.021 Ω per minute and is close to linear at least in the studied range.

Thus, the given results clearly allow determining the appearance of water vapor in a gas mixture at high temperatures.

CONCLUSIONS

1. The obtained results of research on CCCM samples confirmed that in a vacuum and in an argon environment the resistance of the resistive element does not change in time after heating, which confirms the preservation of the stable structure of the material.

2. It was established that the appearance of water vapor at a temperature in the range of (1000±50) °C leads to an increase in the value of the electrical resistance of CCCM by the value from 0.015 to 0.027 Ω/min.

3. Thus, the use of resistive detectors from CCCM allows to reliably detect the appearance of water vapor in an inert gas environment, which can be used, for

example, to monitor the state of the gas coolant in VTGR and prevent critical emergency situations.

4. The proposed method of assessing the corrosion resistance of CCCM based on the change in its electrical resistance can be used in research with other gaseous substances.

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ВИКОРИСТАННЯ ВВКМ ДЛЯ СТВОРЕННЯ ВИСОКОТЕМПЕРАТУРНИХ ДЕТЕКТОРІВ НАЯВНОСТІ ВОДЯНОЇ ПАРИ

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Запропоновано методику оцінки появи водяної пари в составі суміші із використанням високотемпературних детекторів із вуглець-вуглецевого композиційного матеріалу (ВВКМ). Проведено дослідження зміни електричного опору ВВКМ у суміші, що містить водяну пару при температурі 1000 °С. Перевірено та експериментально підтверджено ефективність таких детекторів.