Development of an experimental setup for studying heat removal by a dispersed flow

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Abstract. The work provides description of a new test bench for the cooling efficiency of a working area with a high energy density using a two-component dispersed coolant flow. The pneumatic atomizer design and a scheme of the working area, cooled by a two-component dispersed flow are described. A measurement method of the working area wall temperature is proposed. Arrays of primary test data are obtained for coolant operating parameters $p_{\text{water}} = 2.0 \times 10^{5}$ Pa, $p_{\text{air}} = 1.6 \times 10^{5}$ Pa, $G_{\text{water}} = 0.042$ kg/c; $G_{\text{air}} = 1.6 \times 10^{-3}$ kg/c.

1. Introduction

When developing experimental thermonuclear energy systems of the near future, such as a thermonuclear source of neutrons, a demonstration thermonuclear reactor DEMO, and international thermonuclear experimental reactor ITER, besides problems, directly related to stationary long-term plasma confinement, a number of technological difficulties arise that are still to be solved or require further study.

Provision of the reliable thermal protection of structural elements of a thermonuclear reactor, such as a divertor, limiter, blanket and other systems in contact with plasma and high-energy particle flows is among these problems.

The approach to use of liquid metals, mainly, lithium, in combination with capillary porous structures (CPS) has been developed for a long time, and this idea has demonstrated its high potential, as well as broad prospects for development of this direction. But implementation of this idea requires solution of its related specific scientific and technical problems. Development and justification of new highly efficient methods for cooling intrachamber elements of thermonuclear reactors are the most urgent ones.

One of the most promising methods of a high-temperature surface cooling is use of a dispersed two-component coolant flow. A dispersed mixture of drops is ensured using devices designed for small and, if possible, uniform distribution of liquid over the jet cross section. These devices are called "atomizers" and today are represented by a huge number of all possible types and designs, differing both in the operating principle and purpose. The jet cooling method has already proven itself in the energy sector, mechanical engineering, metallurgy, but its application is not limited to these industries. Thanks to its high efficiency and relative simplicity of implementation, it may well be applicable for cooling individual structural elements of modern thermonuclear reactors under powerful thermal loads.
2. Description of the test bench and main systems

The test bench consists of three main systems: a heating system, based on high-frequency generator VCH-60AV, a cooling, collection and information processing systems built on L-Card equipment.

An induction heating method was chosen to heat the working area. For long-term continuous operation of the VCH-60AV high-frequency generator, including at high powers, a cooling circuit had to be developed. Figure 1 shows the cooling scheme of a high-frequency (HF) generator, its main elements are as follows:
- distilled water tank;
- frame-mounted distilled water cooling unit;
- HF-generator cooling unit.

![Cooling scheme](image)

**Figure 1.** HF-generator cooling scheme

Use of a frame design for water cooling is due to the mobility and multipurpose use of the cooling unit.

The wiring diagram of the cooling unit is shown in Figure 2. A mechanical filter is used to purify the water coming from the dispensing unit. A pressure gauge and a float flow meter are used respectively to control flow parameters (pressure $p_w$ and flow rate $G_w$). Through dispensing manifold 34, water is distributed to cool a transformer unit, control unit and inductor. Waste water is collected using manifold 37 and then the tank is filled. Thus, the HF-generator cooling circuit is closed.

To cool the working area, a dispersed flow is used, formed using a pneumatic atomizer due to air and tap water mixing.

Figure 3 shows a schematic diagram of the cooling circuit of working area 3. The maximum pressure of water and gas is $p_w = 5.0 \cdot 10^5$ Pa and $p_g = 10.0 \cdot 10^5$ Pa respectively. To control operational parameters of the dispersed flow components, pressure sensors, float flow meters and cable chrome-alumel thermocouples are used.
3. Description of the atomizer design and working area.

The schematic diagram of the cooling unit is shown in Figure 4. The working area is electrically isolated from fasteners using fluoroplastic sleeves and is a tube made of stainless steel 12X18H10T, with an internal diameter of 16 mm and an external diameter of 24 mm, with a wall thickness of 4 mm. The working area is 100 mm long. 8 thermocouples are installed on it to determine heat flow magnitude and temperature of the working area walls. Internal thermocouples are isolated from the water flow using thin plates made of stainless steel of the same class as the working area, 0.5 mm thick. External thermocouples are isolated from the inductor effect using ceramic straw. The location of the 4th pair of thermocouples is due to uneven heat removal, occurring at some operating parameters. The working area inlets is also made of stainless steel 12X18H10T, 2 mm thick.

Figure 4 shows an assembly drawing of a unit, where dispersed flow is formed. Channel 1 is used for tap water supply, channel 2 is used for air supply. Atomizer 4 is fastened in casing 3. The dispersed flow is formed at the atomizer outlet, then the flow enters a working area.
Figure 5. Assembly drawing of a mixing unit: 1 - water supply line, 2 - air (gas) supply line, 3 - sealing unit, 4 - nozzle, 5 - working section

After assembly and preparation of the test facility, commissioning was performed, thermocouples and atomizers were functionally checked.

4. Results of commissioning tests.
The thermocouples installed at the working area, are connected to L-card electronic signal converter. The signal converter, in its turn, is connected to a computer with relevant software. As a result of commissioning tests, the following parameters were measured: mass flow rate of the dispersed mixture components, working area inlet and outlet pressure and temperature, electric heating power, wall temperature along the target length. Test results in one of the modes are presented in Table 1.

Table 1. Results of commissioning tests

| Mode: $q = 0.58$ MW·m$^{-2}$; $G_{water} = 0.042$ kg/c; $G_{air} = 1.6 \cdot 10^{-3}$ kg/c; $p_{water} = 2.0 \cdot 10^{5}$ Pa; $p_{air} = 1.6 \cdot 10^{5}$ Pa; cooling - dispersed mixture of water and air |
| $T_{1,\text{out}}$ °C | $T_{2,\text{out}}$ °C | $T_{3,\text{out}}$ °C | $T_{4,\text{out}}$ °C | $T_{1,\text{in}}$ °C | $T_{2,\text{in}}$ °C | $T_{3,\text{in}}$ °C | $T_{4,\text{in}}$ °C | $T_{\text{out}}$ °C | $T_{\text{in}}$ °C |
| 207.86 | 207.86 | 205.21 | 198.15 | 96.45 | 98.18 | 91.21 | 96.64 | 28.09 | 5.27 |
| 207.60 | 207.60 | 201.32 | 201.52 | 92.80 | 97.93 | 87.76 | 96.38 | 27.83 | 5.02 |
| 207.60 | 211.06 | 201.32 | 197.89 | 92.80 | 97.93 | 81.02 | 96.38 | 27.83 | 5.02 |
| 212.18 | 207.86 | 201.58 | 201.77 | 96.45 | 98.18 | 81.28 | 100.04 | 28.09 | 5.27 |
| 211.92 | 207.60 | 204.96 | 197.89 | 99.41 | 101.33 | 77.66 | 96.38 | 29.23 | 5.02 |
| 207.86 | 207.86 | 201.58 | 201.77 | 93.06 | 98.18 | 77.92 | 96.64 | 28.09 | 5.27 |
| 211.92 | 207.60 | 201.32 | 197.89 | 96.20 | 97.93 | 74.49 | 96.38 | 29.23 | 6.46 |

5. Conclusions
A new test bench to study a working area cooling efficiency with a high energy density using a two-component dispersed coolant flow was developed. A hydraulic cooling circuit to support operation of a high-frequency generator for a long time was designed and developed. The working area design to perform tests on cooling using a dispersed coolant flow was developed and mounted. A measurement method of the wall temperature is proposed, thermocouples were calibrated and installed at the working area, commissioning tests were performed. Primary test data were obtained.

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