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HEAT AND MASS TRANSFER AND PROPERTIES OF WORKING FLUIDS AND MATERIALS

Development and Investigations of Compact Heat-Transfer Equipment for a Nuclear Power Station Equipped with a High-Temperature Gas-Cooled Reactor

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Abstract—The project of a nuclear power station the reactor coolant system of which includes a high-temperature gas-cooled reactor combined with a gas-turbine energy conversion unit supposes the use of high-efficient gas-cycle-based heat-transfer equipment. An analysis aimed at selecting the optimal heat-transfer surfaces is presented together with the results from their calculated and experimental investigation. The design features of recuperators arranged integrally with end and intermediate coolers and placed in a vertical sealed high-pressure vessel of limited sizes are considered.

Keywords: high-temperature gas-cooled reactor, compact heat exchanger, heat and power efficiency coefficient, heat transfer coefficient, pressure drop, plate-fin surface coils of small bending radius, micro-channel heat exchanger, experimental study

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The state of art in construction of nuclear power stations (NPSs) has reached a level at which achieving the production of electricity with high efficiency (around 50%) is becoming one of the top-priority tasks. Nuclear power installations equipped with a high-temperature reactor and helium coolant (HTGRs) united with a gas-turbine energy conversion unit (ECU) hold much promise in this respect [1, 2]. The main problems that have to be solved in constructing a commercial-scale reactor and gas-turbine installation united in a single power unit are connected with development of a gas-turbine cycle built into the reactor coolant system, which does not have analogs in the nuclear power engineering around the world as yet.

As is known, it is technically difficult to organize reinjection of gas into the reactor core to implement reheating at an NPS operating based on a gas-turbine cycle. In view of this fact, a recuperative cycle involving intermediate cooling of gas subjected to compression in a compressor is considered as an economically acceptable one in all projects that are being developed. To implement such cycle, additional heat-transfer apparatuses (HTAs), namely, a recuperator and an intermediate cooler are required. The efficiency of these apparatuses, taken in combination with the end cooler, is among the key parameters influencing the efficiency of the gas-turbine cycle and the NPS as a whole.

The HTAs used in NPS projects have mass and dimensions considerably larger than those of the turbine and compressor, and in some cases they serve as determining parameters. Engineers who design HTAs have to find a compromise between the pressure drop in them and their compactness. This contradiction becomes even worse when the heat-transfer equipment and turbine set are integrally arranged in a single housing of limited sizes. Such a solution has been implemented, e.g., in the international project of a GT-MGR nuclear power station equipped with a 600-MW modular helium-cooled reactor.

For selecting the designs of HTAs, a number of heat-transfer surfaces and their layouts in the vertical housing of the GT-MGR station's energy conversion unit were subjected to a comparative analysis and to combined calculation and experimental investigations [3].

THE EFFICIENCY OF HEAT-TRANSFER SURFACES

Such parameter as compactness, which is used as an indicator characterizing the effectiveness of heat-transfer surfaces, gives an idea only about the specific (per unit area or volume) geometric features of the surfaces, but it does not reflect their thermal–hydraulic properties. It should also be noted that different researchers interpret the notion of compactness in different ways. For example, in characterizing a plate-type surface with two-sided finning, the areas of its heat-transfer surfaces are added on both sides taking the area of fins into account, whereas for nonfinned surfaces or surfaces finned on one side, their heat-transfer surface area is taken equal to that on only one side; in such case, the parameter characterizing compactness can be underestimated by as much as a factor of 2.