HIGH-TEMPERATURE ELECTRIC FURNACES WITH HEATING BLOCKS MADE OF CARBON-BEARING COMPOSITES

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High-temperature (up to 2200°C) furnaces with blocks made of carbon-bearing materials can be operated either in vacuums up to 1.33 \(10^{-3}\) (10\(^{-5}\) mm Hg) or in gases that are inert to carbon (argon or nitrogen). The operation of high-temperature furnaces with a vacuum offers the following advantages over furnace operation with controlled atmospheres (hydrogen, endothermic gases, etc.):

- facilitates changing of the flow rate and pressure of the gaseous medium during heating and soaking;
- allows the preliminary removal of air from porous semifinished products, including ceramic products;
- simplifies the system needed to remove and trap harmful gases, including carbon monoxide;
- does not affect environmental conditions, is safe from fire and explosion, and improves working conditions for furnace personnel by the absence of heat and gas generation in the shop building.

Different models of furnaces are recommended for use, depending on the production process being carried out (Table 1).

Different grades of graphite-based materials are used for the structural elements of high-temperature furnaces [1, 2]. Composites of the UKM type (carbon-bearing composites) are the most useful materials for these applications. Compared to graphite materials GMZ, PPG, MG, MPG-6, and similar materials that have traditionally been used, UKM composites are stronger and more resistant to shock loads (by a factor of 3-5). This makes it possible to use them to make thin-walled products with a wall thickness as low as 1.5 mm. These composites can also be employed for the mechanically loaded elements of furnace structures (supports, suspensions, plungers, pushers, fasteners, containers, boxes, trays, etc.), which improves the reliability of the heating blocks and facilitates their repair [3].

The unique combination of thermal, electrophysical, and strength properties offered by UKM composites, with a density of 0.2-1.8 g/cm\(^3\), has allowed the "Termovak" company to develop several designs of gas-filled (argon, nitrogen) and vacuum batch electric furnaces with heating blocks made of UKM composites [3]. The main parameters of these furnaces are shown in Table 2, which for comparison also shows the characteristics of furnaces with heating blocks made of refractory metals (RMs). The use of UKM blocks also reduces heat losses (Table 3).

An additional (compared to the data in Table 3) 10-12% reduction in heat losses could be achieved by cladding the thermal insulation with foil of the Graflex type. To increase the temperature at which the oxidation of UKM composites begins, a method developed by the author is used to impregnate the UKM with titanium carbide. This practice also lowers the electrical resistivity of the heater by as much as 30%.

Blocks of UKM composites can easily be installed in furnaces built earlier with refractory blocks: models SNVE — 1.3.1/16, SNVE — 1.3.1/20, SShVE — 1.2.5/25, and SNVE — 2.4.2/16 in their different modifications (there are more than 3000 furnaces of these types). The change does not involve any reconstruction of the electrical or vacuum equipment, the automation system, or the cooling system, and the useful volume of the furnace will be increased by at least 30%.

The savings realized from the use of UKM blocks instead of refractory blocks come from the reduced annual consumption of electric power that results from the reduction in heat losses (with allowance for heat accumulation), the longer service life of UKM blocks, and the corresponding reduction in the number of blocks required.

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TABLE 1. Production Processes and Furnaces Designed for Them

<table>
<thead>
<tr>
<th>Main production processes</th>
<th>Process conditions</th>
<th>Recommended furnace models</th>
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<tbody>
<tr>
<td>Sintering titanium and its alloys, magnetic of Nd−Fe−B, SmCo₅, etc. alloy steels, copper and its alloys; annealing copper, iron, molybdenum; soldering</td>
<td>Temperature, °C: 1000–1300, medium: vacuum, pressure: 10⁻²</td>
<td>SNVE-1.3.1/16И4, SNVG-4/16, SNVE-2.4.2/16И1, SNVG-16/16</td>
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<tr>
<td>Annealing molybdenum and niobium and their alloys</td>
<td>Temperature, °C: 1400–1600, medium: vacuum, pressure: 10⁻²</td>
<td>SNVE Y-1.3.1/16И4, SNVE-1.3.1/20И2, SNVE-2.4.2/16И1</td>
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<tr>
<td>Sintering hard alloys, carbide steels</td>
<td>Temperature, °C: 1600–1800, medium: vacuum, pressure: 10⁻²</td>
<td>SNVE-1.3.1/20И2, SNVE-1.2.5/5И3</td>
</tr>
<tr>
<td>Sintering oxide ceramics; annealing molybdenum, niobium and tungsten and their alloys, fayalite; degassing products of refractory metals</td>
<td>Temperature, °C: 1800–2000, medium: vacuum, nitrogen, argon, pressure: 10⁻²</td>
<td>SNVE-1.3.1/20И2, SShVE-1.2.5/25И3</td>
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<tr>
<td>Sintering nitride, boride, carbide, and partial oxide ceramics; synthesizing nitrides</td>
<td>Temperature, °C: 2000–2200, medium: vacuum, argon, pressure: 10⁻²</td>
<td>SShVE-1.2.5/25И3, SNVG-16/22</td>
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<tr>
<td>Sintering tantalum, tungsten, and alloys of tungsten with borides and oxides; refining and degassing carbon-bearing materials</td>
<td>Temperature, °C: 2200–2500, medium: vacuum, argon, pressure: 10⁻²</td>
<td>SShVE-1.2.5/25И3, SShVГ-4.22 (briefly to 2400°C)</td>
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</table>

The amount of electrical energy expended on heating the charge is determined by the sum of the heat expenditures for useful heating, the accumulated heat, and the amount of heat needed to compensate for losses. Electric power consumption for heat accumulation in furnaces with a chamber volume of up to 4 dm³ is at least 1.5 kWh, while it ranges up to 5 kWh for larger furnaces (this parameter is not considered when cost efficiency is being calculated).

The amount of power required to compensate for heat losses in refractory and UKM heating blocks depends on the quality of the thermal insulating materials and the design of the furnace components (Table 3).

In evaluating the efficiency of UKM blocks compared to refractory blocks, we conditionally assumed that the duration of the heating cycle is 10 h. Of this amount, 2 h is the time of operation at the nominal temperatures.

In performing the calculations, we did not consider the consumption of electrical energy for useful heating because the material of the charge and its weight are parameters specific to the given situation. The projected annual savings in electric power at the nominal temperatures was calculated with allowance for the increase in the size of the chamber when UKM blocks are used. As a result, a savings of 14,000-64,000 kWh of electric power (for operation in a vacuum) can be expected each year on furnaces with UKM blocks.