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Research Article

# Investigation of the thermal parameters of an aluminum heater with nanoporous alumina

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## Abstract

An important task faced in the industry of permanently installed heating systems addressed by a large number of manufacturers is power saving. Heating systems may have variegated designs, yet there are basic design requirements, i.e., high operational reliability, resource saving, environmental resistivity and stability of electric parameters. The key component of any heating unit is the heater. Flat resistive heaters have found wide application in heating units aimed at sustaining healthy indoor microclimate, maintaining preset process parameters on industrial premises, as well as in anti-icing systems, agriculture and general industry. We studied the thermal parameters of flat aluminum heating units containing carbon fiber ribbon heaters. To ensure the required insulation of the heater from the metallic base plate, the aluminum surface had a 20 mm thick porous aluminum oxide layer. The ends of the carbon fiber were metalized with a layer of copper for further soldering upon integration into the electric heating unit assembly. The electrical resistance of the electric heater with a carbon fiber was 60 Ohm. The propagation of heat flows inside a plate of aluminum with nanoporous aluminum oxide was studied using thermal imaging measurements. Temperatures on the surface of the aluminum heater cover and on the opposite heat emitting side were shown as a function of heating time. The experimental results suggest that the heat generated by the linear carbon fiber heater distributes rapidly in the entire bulk of the aluminum heater plate. This indicates a high heat conductivity of the heater aluminum base plate whose parameters provide for the required thermal parameters of the heating unit.

## Keywords

heater, aluminum, porous anodic alumina, carbon fiber, thermal pattern, thermal imaging study.

## 1. Introduction

The number of heating units and their designs finding application in various industrial machines and consumer appliances increase from year to year. Flat electric heaters are most frequently used in the design of highly resource-efficient heating units. Their preferred use is explained by the higher heat transfer efficiency of contact heat transfer in comparison with other heating methods.

It is well-known that an important task faced in the industry of permanently installed heating systems addressed by a large number of manufacturers is power saving. Heating systems may have variegated designs, yet there are basic design requirements, i.e., high operational reliability, resource saving, environmental resistivity and stability of electric parameters. The key component of any heating unit is the heater. Flat resistive heaters have found wide application in heating units aimed at

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sustaining healthy indoor microclimate, maintaining preset process parameters on industrial premises, as well as in anti-icing systems, agriculture and general industry.

The use of a metallic base plate with a thin dielectric layer in heater designs develops conditions as are required for rapid and uniform heat transfer to the heat receiver [1, 2]. This approach allows designing fast heaters providing uniform temperature distribution over the working surface and a high thermal yield due to lower heat loss [3–8].

The aim of this work is to study the heating uniformity and thermal parameters of flat heating units consisting of aluminum plates with ribbon carbon heaters.

## 2. Experimental

The test flat aluminum heater was 60 × 24 mm in size (Fig. 1). The thicknesses of the base plate and the anodized aluminum cover were 0.5 and 0.3 mm, respectively. The porous anodic alumina **(PAA)** layer which was synthesized on aluminum specimens by electrochemical anodizing [9–17] was 20 mm thick. The structure of PAA is highly ordered and contains parallel vertical capillaries (pores) [18–22]. This PAA thickness provides for the required level of heater insulation from the metallic base plate. The heater used in the experimental heating unit design was in the form of an electrically conducting carbon wire based on technical viscose wire. The resistive heater in the form of a carbon fiber was 80 mm (thickness) × 4 mm (width) × 170 mm (length) in size [23]. The ends of the carbon fiber were metalized with a layer of copper (30 mm, galvanization) for further soldering upon integration into the electric heating unit assembly. The carbon fiber was attached to and further sealed on the anodic aluminum oxide surface with an epoxy sealant.

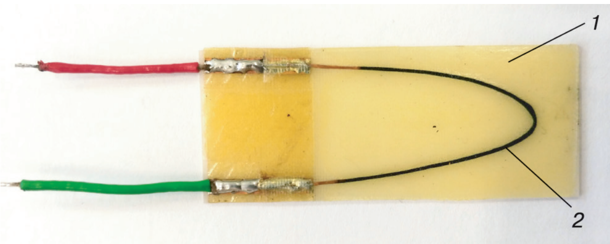


**Figure 1.** The upper surface of the heating element with nanoporous alumina (*1*) and a linear heating element made of carbon filament (*2*).

The electric heater with a carbon fiber had an electrical resistance of 60 Ohm. The resistance of the dielectric insulation was measured with an F4101 mOhmmeter. The thermal patterns of the flat heater surface were obtained with a MobIR M4 thermal imaging camera.

## 3. Results and discussion

An important parameter of a heater is the capability to provide uniform heating over the entire heater area. This work presents detailed experimental data on the thermal parameters of the heater for a 6 W electric power.

Figures 2, 3 show thermal patterns of the heater surfaces at the cover side at the heat emitter base plate in 10 and 60 sec after the start of heating, respectively.

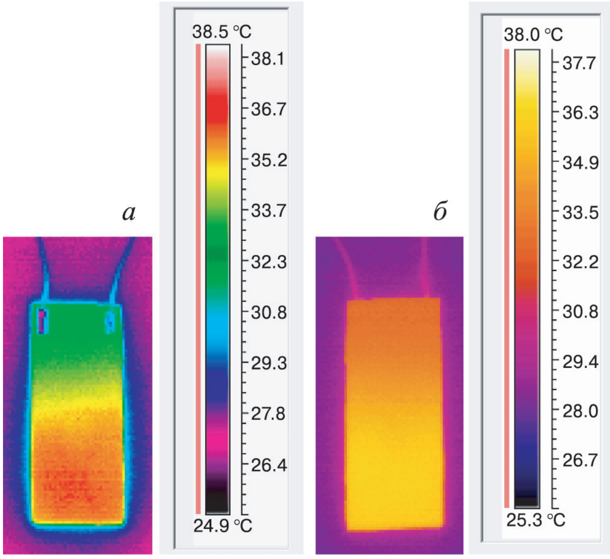


**Figure 2.** Thermograms of the surface of the heating element from the side of the cover (*a*) and from the opposite side of the heat transfer base (*b*) after 10 s of heating.

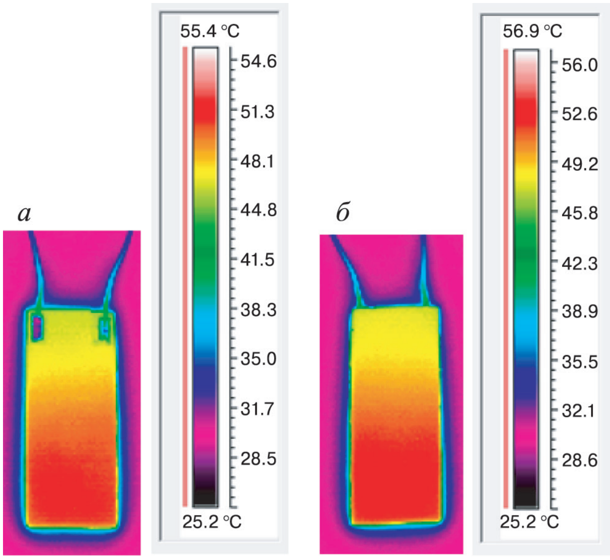


**Figure 3.** Thermograms of the surface of the heating element from the side of the cover (*a*) and from the opposite side of the heat transfer base (*b*) after 60 s of heating.

The heat imaging study showed that the aluminum surface temperature at the cover side had a slight scatter at an early stage of heating. Heat removal through the contacts and the connection wiring caused temperature reduction from the average level of 38 °C in the working area to 33 °C in the contact area. In 50 sec after the start of heating the temperature in the test areas reached following levels: the average working area temperature was 52.3 °C and the contact area temperature was 46.5 °C. The aluminum surface temperature at the heat emitting base plate side was

38 °C in the working area and 32.2 °C in the contact area in 10 sec after the start of heating. After heating for 1 min the working area temperature was 56.5 °C and the contact area temperature was 52.0 °C. Thus a flat heater with a 6 W applied power provided heating to 56 °C on the heat emitting surface in 60 s without heat removal.

Figure 4 shows temperature *vs* heating time curves for the heater cover surface and for the heat emitting side.

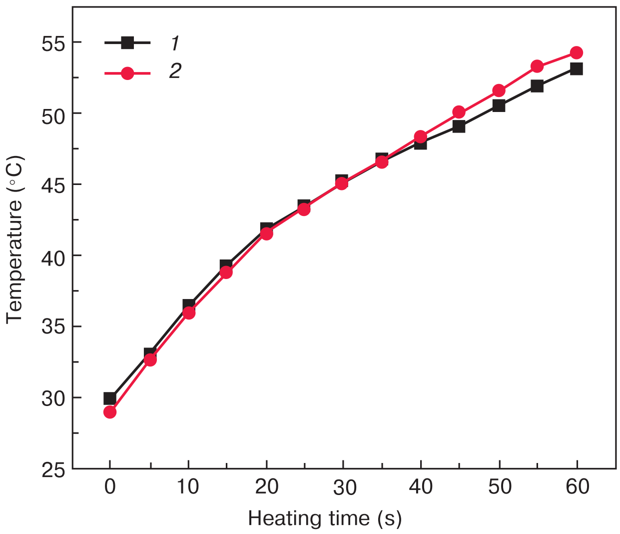


**Figure 4.** Changes in temperature on the surface of the aluminum heating element cover (*1*) and on the heat-emitting side (*2*) from heating time.

The experiments showed that the heater cover temperature both at the cover side and at the rear side were close throughout all heating stages. This indicates a high heat conductivity of the aluminum base plated of the heater which, even for a ribbon carbon heater with a small contact area, provides for a uniform temperature distribution at both heater sides.

## 4. Conclusions

Thus the experimental results show that the high heat conductivity of aluminum allows the heat generated by the ribbon heater on a relatively small local surface area to rapidly redistribute over the entire bulk of the heater aluminum plate and achieve the required thermal parameters of the heater.

Hence the use of linear carbon fiber heaters is an effective tool for heating aluminum heaters providing for high heating rates and uniform temperature distribution on the aluminum heater surface at every stage of heating.

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