New energy-efficient ways of heating running water

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Abstract. The article presents the results of research of a new type of heating, manufactured by a patented technology, designed for efficient operation in devices, designed for heating running water. The authors set the task of reducing the overall dimensions of devices and reducing their cost. Also, in the article the research goal is formulated and the research of parameters of heating blocks with tubular electric heaters and thick-film heating elements are carried out. In accordance with the results obtained, the calculation of the efficiency of these blocks is given. As a result of the work carried out, it was determined that flow-through water heaters using a patented thick-film heating element do not reduce the efficiency of work with a reduction in the overall dimensions of the heating block up to 10 times. The conclusions are drawn that in the manufacture of devices, where flowing heating elements are used, it is possible to produce smaller overall dimensions, which reduces the cost of products.

1. Introduction

Progress, as you know, does not stand still. Any change in any sphere leads to an expansion of the spectrum of proposals from another sphere. It would seem that very recently individual construction in our country was not so widespread and there was no whole class of equipment for this sphere. The use of flow-through electric water heaters for hot water systems has not been used as widely as currently used. We get used to the existing comfort and take for granted that a wide class of equipment has already been introduced into our everyday life [1,2]. For a hot water system, when the demand for hot water is not significant, another type of equipment is used, but we do not pay attention to the fact that the dishwasher and washing machine are equipped with a built-in instantaneous water heater. More modern capacitive water heaters are also equipped with flow-through water heaters, as traditionally used capacitive water heaters are characterized by a number of drawbacks, one of the main ones is the long time of water preparation [3]. This means that if the user needs a large amount of water, then the preparation of a new portion of hot water will take a long time, and, conversely, if a small portion of water is needed, the electricity will be wasted [4]. Therefore, in some cases, it is advisable to use a flow-through water heater in conjunction with a capacitive water heater, which has a certain supply of hot water for current needs, and during peak hours they work simultaneously, thereby reducing the overall load on the electrical network. Despite the fact that for flow-through water heaters requires a high installed capacity, they are not replaceable in those places where a large amount of hot water is required. Flow-through water heaters are convenient in operation, they are economical, compact and hygienic in operation.
The disadvantage of hot water systems with flowing water heaters is:

1. The mode of operation repeatedly short-term. In devices of this class, heating elements with an increased specific power are used to reduce the overall dimensions, and consequently, the cost of the product.

2. It is difficult to control the heating layer. Work, with an overestimate specific power, is associated with the occurrence of various kinds of deposits on the heating element. This causes overheating of the heating layer and, as a result, a violation of the insulation resistance, an increase in leakage currents, a decrease in the efficiency and failure of it.

3. Not uniform heating of the heat transfer surface along the water flow, which reduces the efficiency of work, especially in short operating cycles.

To increase the reliability of hot water systems, these shortcomings must be eliminated.

2. Literature review

Despite the fact that the need for running water heaters is increasing every year, the share of Russian producers of this product is not significant. In developed capitalist countries (USA, England, Germany, etc.) the demand for this product is not commensurately higher, this is due to the peculiarity of the organization of the heating and water supply system [5-7]. According to experts, the cost of "electric" hot water is much lower, since hot water is heated in the immediate vicinity of the place of its analysis. Savings occur at the expense of the amount of energy consumed, not its cost. In technological processes, savings are also achieved by accurate dosing of heat energy and by the absence of losses in heating systems. As a result, electric heating is more advantageous due to the flexibility of control, autonomy and high efficiency [8,9].

Different countries are characterized by the specifics of constructive solutions for water heating systems. For example, in Japan the most popular devices for heating baths, in Germany - 3-phase flow-through electric water heaters [10,11]. The peculiarity of the Russian market is manifested in the presence of a significant number of flowing gas water heaters [12]. However, in recent years, the number of such water heaters in humans characterized by a tendency to decrease. If in 1998 flow-through gas water heaters accounted for almost half of all water heaters in Russia, in the second decade of the new century their share is about 30%. There is a correlation between the preferences of different types of water heaters and the factor of residence of consumers. So, according to the results of research, residents of cities are more interested in accumulating electric water heaters, to a lesser extent - inhabitants of rural areas where there is no gas supply. Flow-through electric water heaters are most in demand among owners of summer houses and summer cottages, as well as non-residential premises like cafes and restaurants. Foreign manufacturers of electric water heaters as a heating element, mainly use tubular electric heaters. But, modern requirements, due primarily to overall dimensions, require manufacturers to use new technical solutions to reduce overall dimensions [13]. Reducing the overall dimensions leads to the use of heating elements with a higher specific power, which requires new studies in this area [14].

3. Materials and methods

The research was held in the research and development laboratory in the IrNRTU "Modern Heating Equipment".

The composition of the technical means used during the tests:

- The device for measuring the temperature of OVEN firm IMS-F1.Sh1 with a set of thermocouples;
- Stopwatch;
- Multimeter V7-35;
- Device "Energomere" brand MT-4014.

The tests were carried out in accordance with the procedure described in State Standard 27754-88. During the tests, quantitative characteristics were evaluated:

a) installation power and power during heating;
b) the time of heating the water to the maximum set temperature;
c) Current [A];
d) amount of electricity spent on heating;

Based on the results, Efficiency was calculated by the formula:

\[
Efficiency = \frac{Q}{E} \times 100\%
\]

where, 
- \( Q \) – quantity of heat;
- \( c \) – specific heat of water;
- \( m \) – mass of water;
- \( t_f \) – the temperature is finite;
- \( t_i \) – initial temperature;
- \( E \) – amount of energy spent on heating;

For the experiments, a heating block was made (Figure 1) for a flow-through water heater with a power of 1.6 kW, consisting of two heating plates manufactured according to thick-film technology with a positive coefficient of resistance according to the utility model patent № 172386 [15]. The manufacturing process used the technology of serial production of thick-film elements described in patent for invention № 2463748 [16].

As an analogue, was chosen a heating block (Figure 2) from the flow-through water heater of the company «Kaizer» similar power as heating elements use tubular electric heaters. To date, similar appliances are a new innovative solution for use in a residential building [1]. Heating blocks differ only in overall dimensions, manufactured in accordance with the patent for the utility model by volume is 10 times smaller than the analog.

![Figure 1. Heating block with thick-film heating elements.](image1)

![Figure 2. Heating block with tubular heating element.](image2)

4. Results of the study

Both heating units were tested as their application for heating running water in the shower and in the dishwasher of the company "Bosch". The testing of the blocks as flowing water heaters for a shower cabin showed that their characteristics are identical.

The following experiments were carried out using blocks as flow-through heaters for a dishwasher. According to the passport data, the installed capacity was reduced to 800 W. Figure 3 shows a graph of water heating using a block with tubular electric heaters, and figure 4 is a graph of water heating using a block with thick-film heaters.

Experiment parameters:
- Initial water temperature = 16.5 °C.
- The temperature mode on the control panel is set to = 48 °C.
Time spent on heating water with a heating unit with tubular electric heaters up to the set temperature (48°C): 19m.11 sec.
The amount of energy spent on heating up to 48°C: 267 W.h.

Time spent on heating water with a heating block with thick-film heating elements up to the set temperature (48°C): 18m.45s.
The amount of energy spent on heating up to 48°C: 245 W.h.

![Figure 3. Graph of water heating using a block with tubular electric heaters.](image)

The design value of the Efficiency of a heating unit with tubular electric heaters:

\[
\left( t_f \times 0,98 - t_i \right) = 48 \times 0,98 - 16,5 = 30,5 \\
Q = 4183 \times 6 \times 30,5 \times 0,28 = 215 \\
Efficiency = \frac{215}{267} \times 100\% = 80,52\%
\]

![Figure 4. Graph of water heating using a block with thick-film heating elements.](image)

Estimated value of Efficiency at heating with thick-film heaters:

\[
\left( t_f \times 0,98 - t_i \right) = 48 \times 0,98 - 16,5 = 30,5 \\
Q = 4183 \times 6 \times 30,5 \times 0,28 = 215 \\
Efficiency = \frac{215}{245} \times 100\% = 87,6\%
\]
5. Conclusions
A disadvantage of the heating elements used for heating running water is that their use in these devices is associated with large temperature differences. The heat transfer side is cooled by running water, the temperature of which varies from +5 to +100 °C, and the temperature of the heat transfer surface in some cases reaches a value of up to 350 °C. The difference in the temperature of the heating layer and the heat transfer surface of the heaters manufactured by thick-film technology, in a stationary mode, is usually not significant and does not exceed a value of 100 °C, which substantially differs from other types of heating elements, in this case from tubular heating elements [17]. Modern requirements for household appliances, at the current moment, require new opportunities from heating elements, first of all it is minimization of overall dimensions, increased specific power and maximum efficiency [18]. In addition, flow-through water heaters are mainly used in periodic device operations, when a certain amount of water needs to be heated in a short period of time. In contrast to the stationary regime, at the moments of on-off of the heating element, the temperature gradient between the heating layer and the heat transfer surface can, for a short time, reach a value of 300-400 °C, since in order for the entire heating element to be heated to take some time depending on the heat capacity of the materials and the heat transfer coefficient from the heat transfer surface. Since materials for this class of heaters are selected with approximately the same thermal coefficient of linear expansion, at the moment of switching on at a high specific power the expansion of materials occurs at different values, which leads to the appearance of microcracks, and to premature failure of them. To avoid these defects in operation, it is necessary either to reduce the specific power or to increase the area of the heating element. This in turn leads to an increase in overall dimensions of the devices themselves and an increase in the cost of heating elements. The use of a new type of heating elements manufactured according to thick-film technology opens up new possibilities for reducing the overall dimensions of not only heating blocks, but also instruments, and thus to reducing the cost price [19].

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