VOL. 9, NO. 11, NOVEMBER 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

TECHNOLOGY OF ELECTRICALLY CONDUCTIVE COMPOSITES OF ALKALINE EARTH METALS CARBONATES AND CARBON DISPERSIONS

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ABSTRACT

Electrical conductivity of composite materials based on alkaline earth metal carbonates and carbon dispersions was studied, the possibility of regulation of the electro-physical properties, temperature coefficient of electrical resistance, electrical conductivity was shown. Samples of compositions of composites with different conductive phase content were obtained and studied. A model of an experimental installation of an instantaneous water heater with a heating element based on alkaline earth metal carbonates and carbon dispersions was developed and its main technical parameters were identified. In the instantaneous water heater water is heated when passing through the heater, and electric power is consumed only during the use of hot water. Heating temperature of water is 353 K and does not dependent on water flow rate in the range of 50 - 100 ml/min. The required voltage for water heating is 12 ... 40 V (this low voltage is safe and is a guarantee of reliable and long-term work).

Keywords: electrically conductive composites, alkaline earth metal carbonates, carbon dispersion, positive temperature coefficient, electrical resistance.

INTRODUCTION

Trends of development of modern low-temperature composite materials and innovative heating systems based on them cause the adoption of energy-efficient heating technologies in various fields: agriculture, industry, power engineering, housing and utilities infrastructure and household activities [1, 2]. Due to the improvement of life quality in the system "man-material-environment" it is necessary to create high-efficiency competitive composites and climate systems based on them with better physico-chemical properties and performance characteristics as compared to serial systems. The work objective is to develop composite electric heating elements in order to create hot water systems in premises of household and industrial purpose. Selection of components of a conductor, adhesive and dielectric filler in resistive composites [3] and their distribution in the mixture has a significant influence on electrical, thermal and physical and mechanical properties of the finished product.

Currently, heat sources based on carbon dispersions increasingly win the world markets of electric heating systems [4]. This is grounded on their unique properties which are that carbon heating systems provide thermostatic limitation and control at each point of the heated surface without the use of special automatics [5], which makes them reliable and economical. These properties are implemented by internal thermal feedback [6] in the heating element.

Tailored compositions of conductive composites based on alkaline metals carbonates and carbon dispersions were developed in this work. Resistive composites components were selected on the basis of the specified requirements to their characteristics. The electrically conductive mixture for instantaneous water heater relates to the heating composite materials formulation and solves the problem of expansion of the raw material base for production of heating elements with an extended range of application characteristics: extra-low voltage, low power consumption and ease of operation. It allows consuming a small amount of energy at low voltage compared to similar modern water heaters. Practical implementation of the researches consists in the establishment of a technology of heating products with a positive temperature coefficient of electrical resistivity, in particular, of instantaneous water heaters. Heaters are used when it is impossible to heat water in another way or when there is a problem with temporary hot water outage. All currently existing water heaters can be divided into the following types [4]: gas instantaneous; gas storage; electrical instantaneous; electrical storage; indirect heating boilers.

METHODOLOGY

The following materials were used to obtain conductive composite materials for low temperature heating systems: dielectric filler - alkaline earth metal carbonates, conductive component - carbon and graphite filler and binder - sodium metasilicate. The tailored composition of the modified composites was selected based on the studies of electrical, electrosurface and performance characteristics. Selection of the type and design of low-temperature heating elements was made on the basis of the requirements to ensure thermo-electro-physical properties, electrical safety, efficiency, corrosion resistance.

In order to study the performance characteristics of the developed composites graphite dispersions were bolted, primary components were dried at 200°C, cylindrical samples with a diameter of 2.10^{-2} m, length of

VOL. 9, NO. 11, NOVEMBER 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

1.10^{-2} m were formed under a pressure of 2.10^{8} Pa. Electrical conductivity was measured using alternating current bridge at a frequency of 1000 Hz.

In measuring the electrical conductivity the sequence of operations include [7, 8]:

a) samples preparation, defined shaping and sizing;
b) sample end surfaces electroding;
c) equipment preparation for use, meter switching on and warming up for 20 minutes, installation of the sample into the measurement cell;
d) furnace switching on and cell heating up to 200 K;
e) resistance measurement using an automatic meter;
f) sequential temperature incensement with a pitch of 10 °C, automatic meter recording.

RESULTS AND DISCUSSIONS

Figure-1 shows the electrical conductivity of carbon dispersions in alkaline metal carbonates dependence on temperature. Electrical conductivity in magnesium and calcium carbonates increases with increase of temperature achieves plateau and reduces at temperatures of 650-700 K, Figure-1.

Probably, the reduction of dispersions electric conductivity is based on the fact that the state of magnesium [6] and calcium carbonate crystals become stressed (the beginning of carbonates decomposition into metal oxides and carbon oxide (IV)). In strontium and barium carbonates the electrical conductivity of graphite dispersions increases at temperatures of above 700 K, which is due to a higher decomposition temperature of strontium and barium carbonates which reaches 1200 - 1500 K [6, 9]. Thus, these patterns of electrical conductivity change can be explained by structural changes in alkaline earth metals carbonates with rising temperature.

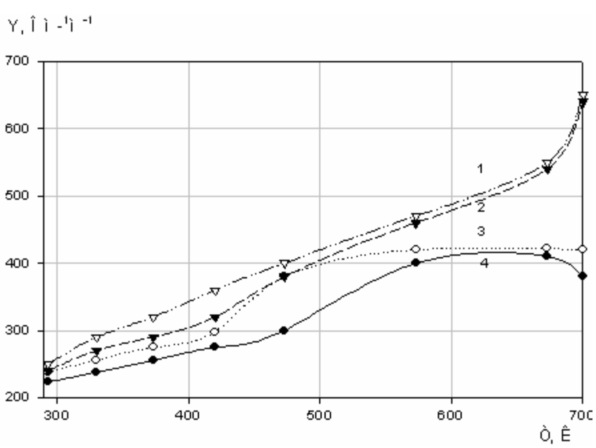

Figure-1. Electrical conductivity of carbon dispersions in alkaline metal carbonates dependence on temperature: 1-4 - barium, strontium, magnesium and calcium carbonates respectively.

An instantaneous water heater was developed on the basis of the low-temperature composite tested composition. The problem of sustainable operation and reliability of the heating system is solved by creating a positive temperature coefficient of electrical resistance of the composite. In case of non-compliance with the heat exchange parameters the system can be self-regulated, reducing or increasing thermal flow power depending on ambient temperature, Figure-2.

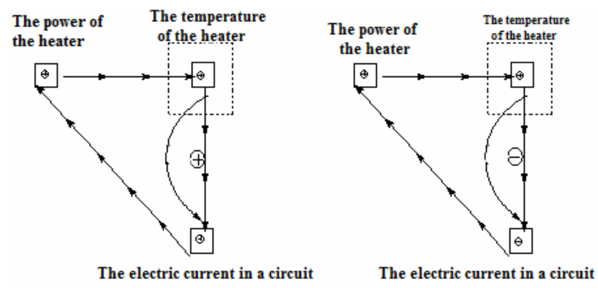

Figure-2. Scheme of stable and unstable operation (right to left) of the electric heater.

The availability of functional feedback in the system provides automatic regulation of temperature without any additional devices, made in the form of temperature sensors and switching devices. A fragment of heater design is shown schematically in Figure-3.

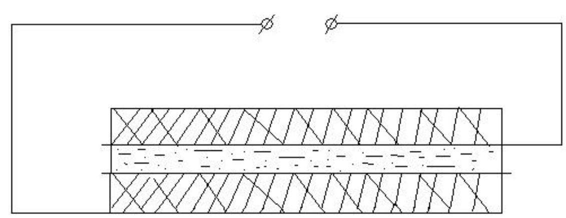

Figure-3. Water heating element diagram: 1 - composite resistive electrically conductive material; 2 - water; 3 - metal housing.

The results of key parameters determination and check measurements of the instantaneous water heater pilot unit are presented in Tables 1-3. The parameters adopted for the test unit state estimation:

- initial water temperature - T_i, K
- final water temperature - T_f, K
- test duration - t, s
- mains input voltage υ, V
- water heater capacity N, W

Table-1. Water heater key parameters.

Water heater flow channel section d, m	0,0035
Water heater flow channel length l, m	0,095
Water heater service voltage υ, V	up to 22

VOL. 9, NO. 11, NOVEMBER 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Table-2. Check measurements results: at water passage volume $V = 7.7 \cdot 10^{-7}$, m^3/s.

Measurement parameters	Test number							
	1	2	3	4	5	6	7	8
Initial water temperature T_i, K	292							
End water temperature T_e, K	296	297	300	304	306	305	310	309
Test duration t, sec	100							
Mains input voltage υ, V	2.9	4.7	7.1	9.6	12.8	15.9	18.8	21
Water heater capacity N, Вт	14.0	36.8	84.0	153.6	273.1	421.4	589.1	735.0

Table-3. Check measurements results: at water passage volume $V = 2 \cdot 10^{-6}$, m^3/s.

Measurement parameters	Test number							
	1	2	3	4	5	6	7	8
Initial water temperature T_i, K	292							
End water temperature T_e, K	294	294	294	295	295	297	298	304
Test duration t, sec	50							
Mains input voltage υ, V	3.5	6.3	9.0	11.5	14.0	16.6	19.4	22.2
Water heater capacity N, Вт	20.4	66.2	135.0	220.4	326.7	459.3	627.3	821.4

In an instantaneous water heater water is heated when passing through the heater, and electric power is consumed only during the use of hot water. As a result of voltage U supply to electrodes resistive composite layer is heated to a desired heating temperature T [4].

Because of the positive temperature coefficient of the heater electroconductive phase the water heating temperature is 353 K and does not dependent on water flow in the range of 50 - 100 ml/min. The required voltage for water heating is 12 ... 40 V (this low voltage is safe and is a guarantee of reliable and long-term operation). Power consumption is 290 ... 600 W, other factors being equal with conventional water heating systems, which is significantly lower than other available solutions of modern water heaters.

Use of low-temperature composite materials in water heating systems has a number of advantages [7, 8]:

- high efficiency;
- no need to use an intermediate heat transfer agent;
- high level of electrical safety;
- low costs for operation and maintenance;
- the equipment does not occupy useful space, providing free space;
- fire safety;
- quiet operation, environmental safety;
- maintenance-free;
- cost saving: compared with traditional water heating systems, savings are 40 to 70%.

Heating elements on the basis of carbon dispersions provide thermostatic limitation and control at each point of the heated surface without the use of special automatics, which makes them reliable and economical. These properties are implemented by internal thermal feedback in the heating element [10].

CONCLUSIONS

Modified composites based on carbon dispersions, electrical properties of which can be purposefully changed by way of their composition variation [2, 7] become widespread in modern construction technologies. There is a need for innovative solutions for reliable and efficient electric heaters and devices that meet comfort requirements and are suitable for mass construction.

Modeling of electrical conductivity processes in composite materials allows creating modified conductive products with desired properties. The developed compositions of conductive composite materials based on carbon and graphite modifiers for heating elements are safe (operating voltage low values, 12-40V) in operation, relatively low cost and stable during long time operation.

ACKNOWLEDGEMENTS

The research was made within the framework of the grant No. B1-14 dtd. 10.04.2014, which is in force since April 10, 2014 till December 31, 2014, in the framework of implementing of the Strategic Development Program of BSTU named after V.G. Shoukhov for 2012-2016 (No. 2011-ПР-146) on the subject “Aggregation and electrical properties of carbon compounds dispersions in alkaline earth metal carbonates”.

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