Materials Physics and Mechanics. 2023;51(6): 127-134
Research article
http://dx.doi.org/10.18149/MPM.5652023_12

Submitted: September 6, 2023
Approved: November 8, 2023
Accepted: November 14, 2023

Electromagnetic radiation reflection, transmission and absorption characteristics of microwave absorbers based on dilatant liquids and powdered activated wood charcoal

O.V. Boiprav ✉, **V.A. Bogush**, **L.M. Lynkou**

Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus

✉ smu@bsuir.by

Abstract. The paper presents new microwave absorbers based on dilatant liquids and powdered activated wood (birch) charcoal. The patterns of changes of electromagnetic radiation reflection, transmission and absorption coefficients values in the frequency range 2.0–17.0 GHz of the indicated absorbers are described. In accordance with these patterns, electromagnetic radiation reflection coefficient values in the frequency range of 2.0–17.0 GHz of the absorbers based on a dilatant liquid containing water vary from –2.0 to –15.0 dB, and absorbers based on dilatant liquid containing magnesium chloride water solution or sodium chloride water solution – from –2.0 to –17.0 dB and from –2.0 to –10.0 dB, respectively. Electromagnetic radiation transmission coefficient values of the above absorbers vary respectively from –15.0 to –27.0 dB, from –15.0 to –28.0 dB, from –15.0 to –30.0 dB. Electromagnetic radiation absorption coefficient values of these absorbers achieve a value of 0.95. These absorbers are recommended for use in lining the walls of containers intended for storage and transportation of electronic devices sensitive to microwave interference.

Keywords: absorption coefficient; activated wood charcoal; dilatant liquid; magnesium chloride; microwave absorber; reflection coefficient; sodium chloride; transmission coefficient

Citation: Boiprav OV, Bogush VA, Lynkou LM. Electromagnetic radiation reflection, transmission and absorption characteristics of microwave absorbers based on dilatant liquids and powdered activated wood charcoal. *Materials Physics and Mechanics.* 2023;51(6): 127-134. DOI: 10.18149/MPM.5162023_12.

Introduction

Water or water solutions are used for the fabrication of microwave absorbers at present [1–5]. This is due to high dielectric energy losses of microwave radiation provided by water, water solutions, and materials containing them [6]. In addition, based on water or water solutions, microwave absorbers can be obtained, which are characterized by the flexibility [5,7,8]. This property makes it possible to use such absorbers to cover the surfaces of objects that need to be protected from exposure to microwave radiation [9].

As a rule, currently proposed technologies for the fabrication of the considered absorbers (including flexible ones) consist in filling the cells of containers obtained by 3D printing with water or water solutions [9–11]. The main disadvantage of flexible microwave absorbers based on water or water solutions is low mechanical strength. Paper [12] presents the results of an experimental substantiation of the prospectivity of hydrogel use for mechanically strong microwave absorbers fabrication. However, hydrogel-based microwave absorbers [12] are high cost ones. This is due to the corresponding property of the hydrogel.

Publisher: Peter the Great St. Petersburg Polytechnic University

The authors of the paper proposed the following decisions for the obtaining of mechanically strong and low-cost flexible microwave absorbers on the base of water or water solutions:

1. to use of dilatant liquids;
2. to include the powdered electrically conductive materials particles in the content of dilatant liquids used for the microwave absorbers fabrication (to increase the electromagnetic radiation absorption coefficient and expand the operating frequency range of the absorbers) [13,14].

In this regard, the following was determined as the aim of the study, the results of which are presented in this paper:

1. to establish the dependence of electromagnetic radiation reflection, transmission and absorption coefficients values of microwave absorbers based on dilatant liquid and powdered electrically conductive material from this liquid composition;
2. based on the established patterns, to determinate the content of the dilatant liquid, which is most suitable for obtaining high effective microwave absorbers.

The process of aim achieving was targeted at improving the existing water-containing microwave absorbers.

Materials and Methods

In course of aim achieving, three kinds of experimental samples of microwave absorbers were fabricated. Samples of the 1st kind were based on the dilatant liquid containing water. Samples of the 2nd kind were based on the dilatant liquid containing 35.0±1.0 wt. % magnesium chloride water solution. Samples of the 3rd kind were based on the dilatant liquid containing 35.0±1.0 wt. % sodium chloride water solution. The concentration of the indicated solutions corresponded to the solubility limit of sodium chloride in water.

The use of magnesium or sodium chloride water solution for the production of the dilatant liquids for microwave absorbers seems appropriate for the following reasons:

1. The specific electrical conductivity of magnesium or sodium chloride water solution exceeds the specific electrical conductivity of water. In this regard, electromagnetic radiation transmission coefficient values of microwave absorbers based on the dilatant liquid containing this solution are lower than electromagnetic radiation transmission coefficient values of microwave absorbers based on the dilatant liquid containing water.
2. The crystallization temperature of magnesium or sodium chloride water solution is lower than the crystallization temperature of water. In this regard microwave absorbers based on the dilatant liquid containing this solution, in contrast to microwave absorbers based on the dilatant liquid containing water, can be operated in conditions of negative temperatures.

Powdered activated wood (birch) charcoal was used as an electrically conductive material for these samples fabrication. The main advantages of this material compared to other electrically conductive powder materials are as follows:

– powdered activated wood (birch) charcoal is characterized by low cost [15];
– the particle size of powdered activated wood (birch) charcoal is close to the microwave length value; as a result, powdered activated wood (birch) charcoal ensures the loss of energy of microwaves interacting with it, not only due to the reflection and absorption phenomenon, but also due to the scattering phenomenon [16].

The thickness of the fabricated samples was 0.5 ± 0.1 cm. The top view of a fragment of the surface of one of the fabricated samples is shown in Fig. 1.

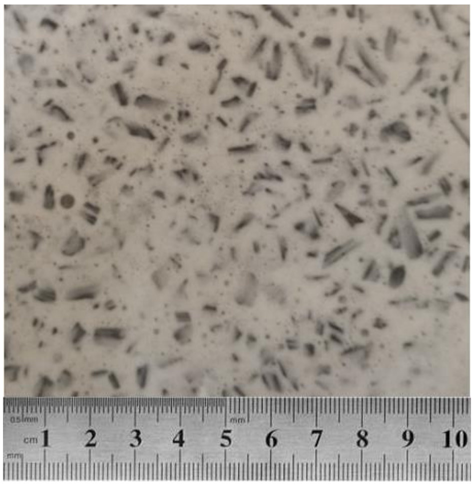

Fig. 1. Top view of the fabricated sample surface fragment

Electromagnetic radiation reflection and transmission coefficients (S_{11} and S_{21} respectively) values of the fabricated samples were measured in the frequency range of 2.0–17.0 GHz. The range was chosen because it belongs to the operating frequency bands of modern radio-electronic transceivers. The radiation generated by these devices can affect the performance of electronic devices that are sensitive to interference. Scalar network analyzer SNA 0.01–18 was used for measurements of S_{11} and S_{21} values of the fabricated samples. The measurements were carried out in accordance with the algorithm presented in [17].

Measurements of S_{11} values of the fabricated samples were carried out under the following conditions.

Condition 1: the sample was between the transmitting antenna and the matched load in course the measurements.

Condition 2: the sample was between the transmitting antenna and the short circuit (metal plate) in course the measurements.

Based on the results of measurements carried out under the first condition, it was estimated the fraction of the energy of electromagnetic radiation reflected by the surface of the experimental sample. Based on the results of measurements carried out under the second condition, it was estimated the fraction of the energy of electromagnetic radiation, which is a superposition of:

1. electromagnetic radiation reflected by the sample surface;
2. electromagnetic radiation reflected by the metal plate surface and after that absorbed by the sample.

Electromagnetic radiation absorption coefficient (A) values of the fabricated samples were calculated on the base of the measured S_{11} and S_{21} values. The algorithm presented in [17] was used for calculation.

To substantiate the patterns of change of electromagnetic radiation reflection, transmission and absorption coefficients values of experimental samples, the specific electrical conductivity values (σ) of dilatant liquids, on the base of which these samples were made, were measured. The method presented in the paper [18] was used for the measurements. This method is based on use of the two-electrodes measurement cell. The method includes the following four steps:

1. Filling with dilatant liquid of two-electrodes measurement cell.
2. Connection of the resistance meter to the electrodes of the measurement cell.
3. Measurement of the dilatant liquid resistance.

4. Calculation of the dilatant liquid specific electrical conductivity according to the formula $\sigma = \frac{l}{R \cdot S}$, S/m, where l is the distance between the electrodes of the measurement cell, m; S is the area of the measurement cell electrodes, m^2.

Results and Discussion

2.0–17.0 GHz frequency responses of S_{11} values of the fabricated samples are shown in Fig. 2.

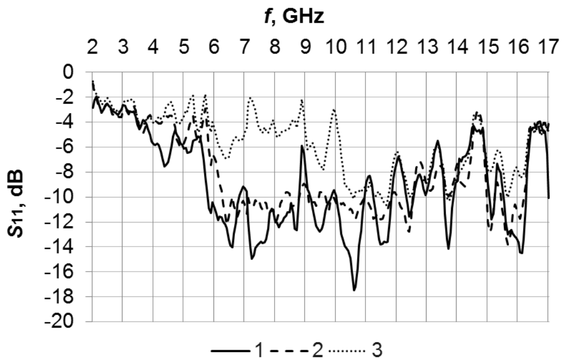

Fig. 2. 2.0–17.0 GHz frequency responses of S_{11} values of the samples of the 1st kind (graph 1), the samples of the 2nd kind (graph 2) and the samples of the 3rd kind (graph 3)

It follows from Fig. 2, that S_{11} values in the frequency range of 2.0–17.0 GHz of the samples of the 1st kind, the samples of the 2nd kind and the samples of the 3rd kind vary respectively from –2.0 to –17.0 dB, from –2.0 to –15.0 dB, from –2.0 to –10.0 dB. There are following average S_{11} values of the above samples: –8.9 dB, –8.0 dB and –5.7 dB respectively. S_{11} values of the samples of the 1st kind are lower compared with S_{11} values of the samples of the 2nd kind and the sample of the 3rd kind due to the set of the following facts:

1. σ value of the dilatant liquid containing water is lower than σ value of the dilatant liquid, containing magnesium chloride water solution or sodium chloride water solution (see Table 1); this is because σ value of water is lower than σ value of magnesium chloride water solution and lower in more degree than σ value of sodium chloride water solution [19];
2. electromagnetic radiation reflection losses in the material are connected with its σ value through the following formula [13]: $39.5 + 10\,lg\frac{\sigma}{2\pi f \mu}$, dB (as it follows from the given formula, material S_{11} value increases if its σ value increases).

Table 1. The σ values of the dilatant liquids used for the samples fabrication

Dilatant liquid kind	σ, S/m
Liquid used for the samples of the 1st kind fabrication	4.4
Liquid used for the samples of the 2nd kind fabrication	5.5
Liquid used for the samples of the 3rd kind fabrication	6.8

2.0–17.0 GHz frequency responses of S_{21} values of the fabricated samples are shown are shown in Fig. 3. It follows from Fig. 3, that S_{21} values in the range of 2.0–17.0 GHz of the samples of the 1st kind, the samples of the 2nd kind and the samples of the 3rd kind vary respectively from–15.0 to –27.0 dB, from –15.0 to –28.0 dB and from –15.0 to –30.0 dB. There are following average S_{21} values of the above samples:: –21.7 dB, –22.7 dB and –24.8 dB respectively. As it also follows from Fig. 3, S_{21} values in frequency range 2.0–12.0 GHz of the considered microwave absorbers based on dilatant liquid containing sodium chloride water solution are higher than S_{21} values of the considered microwave absorbers based on dilatant liquid containing water or magnesium chloride water solution. This is because σ value of the first specified dilatant liquid is higher than σ value of the second and the third dilatant liquids (see Table 1). Electromagnetic radiation transmission coefficient values of the considered microwave absorbers don't significantly depend on the content of dilatant liquid used for their fabrication, if this radiation frequency changes from 12.0 to 17.0 GHz. It may be because to the set of the following features:

1. the wavelength in the specified frequency range (~ 1.0 cm) is comparable with the size of the particles of activated wood (birch) charcoal (~ 0.5 cm);
2. the transmission losses of electromagnetic radiation interacting with the considered microwave absorbers due to its reflection and absorption is lower than transmission losses of such radiation due to its dissipation (scattering) on the particles of activated wood (birch) charcoal containing in these absorbers.

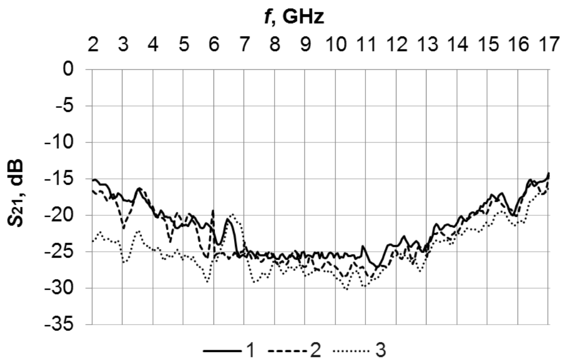

Fig. 3. 2.0–17.0 GHz frequency responses of S_{21} values of the samples of the 1st kind (graph 1), the samples of the 2nd kind (graph 2) and the samples of the 3rd kind (graph 3)

2.0–17.0 GHz frequency responses of *A* values of the fabricated samples are shown in Fig. 4. As it follows from Fig. 4, *A* values of the samples of the 1st kind and the samples of the 2nd kind achieve 0.95. *A* values of the samples of the 3rd kind achieve 0.9. Table 2 presents the parameters of electromagnetic radiation absorption characteristics of the samples. These parameters are based on the frequency responses presented on Fig. 4.

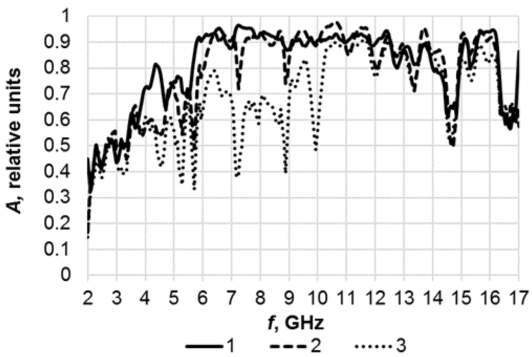

Fig. 4. 2.0–17.0 GHz frequency responses of *A* values of the samples of the 1st kind (graph 1), the samples of the 2nd kind (graph 2) and the samples of the 3rd kind (graph 3)

As it seen from Table 2, microwave absorbers fabricated on the base of dilatant liquid containing water or magnesium chloride water solution are wideband ones. This is because their effective absorption band width is more than central frequency value in this band. Microwave absorbers fabricated on the base of dilatant liquid containing sodium chloride water solution are multiple narrow band ones. There are three effective absorption bands of these absorbers in the frequency range 2.0–17.0 GHz. The width of these bands is lower than their central frequency. Average *A* value of the samples of the 3rd kind is lower than average *A* value of the samples of the1st kind and the samples of the 2nd kind. This is because the energy of electromagnetic radiation reflected by the samples of the 3rd kind is more than the energy of electromagnetic radiation reflected by the samples of the 1st kind and the samples of the 2nd kind. It seen from the frequency responses presented in Fig. 2.

Table 2. The parameters of electromagnetic radiation absorption characteristics of the samples

Sample kind	Average *A* value	Effective absorption band	Effective absorption band width (absolute / relative to the central frequency)
1st	0.85	3.5–17.0 GHz	13.5 GHz / 135.0 %
2nd	0.83	3.5–17.0 GHz	13.5 GHz / 135.0 %
3rd	0.72	6.0–7.0 GHz; 7.5–8.8 GHz; 9.0–17.0 GHz	1.0 GHz / 15.4 %; 1.3 GHz / 16.0 %; 8.0 GHz / 61.5 %

2.0–17.0 GHz frequency responses of S_{11} values of the fabricated samples fixed on the metal plates are shown in Fig. 5. It follows from Fig. 4, that S_{11} values in the range of 2.0–17.0 GHz of the samples of the 1st kind, the samples of the 2nd kind and the samples of the 3rd kind fixed on the metal plates vary respectively from –2.0 to –15.0 dB, from –2.0 to –17.0 dB, from –2.0 to –10.0 dB. There are the following average S_{11} values of the above samples: –10.3 dB, –9.4 dB and –8.2 dB respectively. The average S_{11} values of the samples fixed on the metal plates are lower than average S_{11} values of the samples which are not fixed on the metal plates. This is may be due to the big phase difference between the electromagnetic waves reflected from the sample surface and the electromagnetic waves reflected from metal plate surface and after that absorbed by the sample [20,21].

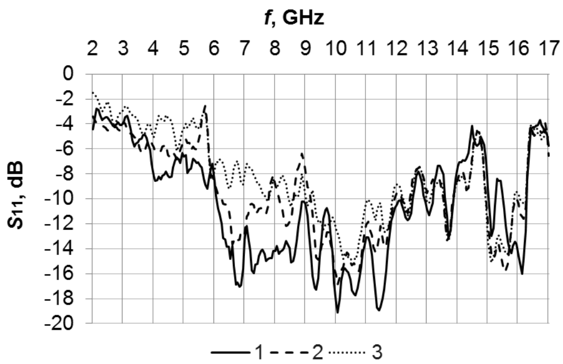

Fig. 5. 2.0–17.0 GHz frequency responses of S_{11} values of the samples of the 1st kind (graph 1), the samples of the 2nd kind (graph 2) and the samples of the 3rd kind (graph 3) fixed on the metal plates

2.0–17.0 GHz frequency responses of *A* values of the fabricated samples fixed on the metal plates are shown in Fig. 6. As it follows from Fig. 6, *A* values of all studied samples fixed on the metal plates achieve 0.98. Table 3 presents the parameters of electromagnetic radiation absorption characteristics of such samples. These parameters are based on the frequency responses presented on Fig. 6. As it seen from Table 3, all studied absorbers fixed on the metal plates are wideband ones. The average *A* values of the samples fixed on the metal plates is more than average *A* values of the samples which are not fixed on the metal plates. This is because S_{11} values of the first specified samples are lower than S_{11} values of the second specified samples, as it follows from Figs. 2 and 5.

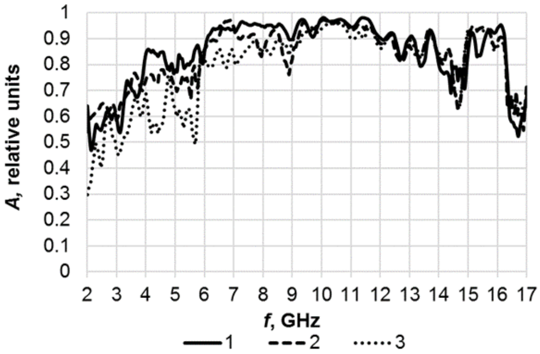

Fig. 6. 2.0–17.0 GHz frequency responses of *A* values of the samples of the 1st kind (graph 1), the samples of the 2nd kind (graph 2) and the samples of the 3rd kind (graph 3) fixed on the metal plates

Table 3. The parameters of electromagnetic radiation absorption characteristics of the samples fixed on the metal plates

Sample kind	Average *A* value	Effective absorption band	Effective absorption band width (absolute / relative to the central frequency)
1st	0.88	2.0–17.0 GHz	15.0 GHz / 158.0 %
2nd	0.86	2.0–17.0 GHz	15.0 GHz / 158.0 %
3rd	0.83	3.5–17.0 GHz	13.5 GHz / 135.0 %

Conclusion

The absorbing properties of microwave absorbers based on the dilatant liquid containing water or magnesium chloride water solution and powdered activated wood (birch) charcoal are better than absorbing properties of microwave absorbers based on the dilatant liquid containing sodium chloride water solution and powdered activated wood (birch) charcoal. This is because the electromagnetic radiation reflection coefficient values of microwave absorbers based on the dilatant liquid containing sodium chloride water solution and powdered activated wood (birch) charcoal is higher than electromagnetic radiation reflection coefficient values of microwave absorbers based on the dilatant liquid containing water or magnesium chloride water solution and powdered activated wood (birch) charcoal. This is due to the fact that specific electrical conductivity value of the dilatant liquid containing sodium chloride water solution is higher than specific electrical conductivity value of the dilatant liquid containing water or magnesium chloride water solution.

It’s possible to expend on 20.0 % the effective absorption band of the microwave absorbers based on the dilatant liquid containing water or magnesium chloride water solution and powdered activated wood (birch) charcoal. It’s necessary to add the metal plate (or better a foiled polymer film) for this. The effective absorption band of the specified microwave absorbers is wider than effective absorption band of hydrogel-based microwave absorbers [12].

The absorbers are recommended for use in lining the walls of containers intended for storage and transportation of electronic devices sensitive to microwave interference.

References

1. Wei S, Zhao J, Sun Z, Chen K, Feng Y. Water Droplets: Toward Broadband Metamaterial Microwave Absorber. In: *2016 IEEE International Workshop on Electromagnetics: Applications and Student Innovation Competition.* IEEE; 2016. p.16124944.

2. Meng ZF, Tao Z, Ruan JF, Zou RZ, Ji SW. Broadband-Absorption Mechanism in a Water-Based Metamaterial Absorber. *Physics Letters A.* 2022;445: 128269.

3. Kwon H, D’Aguanno G., Alú A. Optically Transparent Microwave Absorber Based on Water-Based Moth-Eye Structures. *Optics Express.* 2021;29(6): 9190-9198.

4. Zhao J, Wei S, Wang C, Chen K, Zhu B, Jiang T, Feng Y. Broadband Microwave Absorption Utilizing Water-Based Metamaterial Structures. *Optics Express*. 2018;26(6): 8522-8531.
5. Wu Z, Chen X, Zhang Z, Heng L, Wang S, Zou Y. Design and Optimization of a Flexible Water-Based Microwave Absorbing Metamaterial. *Applied Physics Express*. 2019;12(5): 057003.
6. Qin M, Zhang L, Wu H. Dielectric Loss Mechanism in Electromagnetic Wave Absorbing Materials. *Advanced Science*. 2022;9(10): 2105553.
7. Zhou Q, Xue B, Gu S, Ye F, Fan X, Duan W. Ultra Broadband Electromagnetic Wave Absorbing and Scattering Properties of Flexible Sandwich Cylindrical Water-Based Metamaterials. *Results in Physics*. 2022;38: 105587.
8. Zhou Y, Shen Z, Wu J, Zhang Y, Huang S, Yang H. Design of Ultra-Wideband and Nearunity Absorption Water-Based Metamaterial Absorber. *Applied Physics B*. 2020;126: 52.
9. Chen Y, Chen K, Zhang D, Li S, Xu Y, Wang X, Zhuang S. Ultrabroadband Microwave Absorber Based on 3D Water Microchannels. *Photonics Research*. 2021;9(7): 1391-1396.
10. Deng G, Chen W, Yu Z, Yang J, Yin Z. Broadband High-Power Microwave Absorber Based on Water-Based Metamaterial. *Chinese Journal of Lasers*. 2022;49(21): 2103001.
11. Deng G, Chen W, Yu Z, Cai F, Yang J, Yin Z. 3D-Printed Dielectric-Resonator-Based Ultra-Broadband Microwave Absorber Using Water Substrate. *Journal of Electronic Materials*. 2022;51: 2221-2227.
12. Chen X, Du L, Jiang G, Wu Z, Zou Y, Zou Y. Hydrogel-Based Optically and Mechanically Manipulable Broadband Microwave Absorber. *Nano Research*. 2023;16: 10175-10182.
13. Shukla V. Review of Electromagnetic Interference Shielding Materials Fabricated by Iron Ingredients. *Nanoscale Advances*. 2019;1: 1640-1671.
14. Winarno N, Firdaus RA, Afifah RMA. The effect of Conductivity and Permittivity on Propagation and Attenuation of Waves Using FDTD. *Materials Physics and Mechanics*. 2019;42(5): 617-624.
15. Boiprav OV, Belousova ES, Ahmetdinova ES, Bogush NV. Charcoal-Containing Building Materials for Electromagnetic Radiation Shielding. *Magazine of Civil Engineering*. 2023;117(1): 11709.
16. Krylova NG, Ovsiyuk EM, Ivashkevich AV, Red'kov VM. Maxwell Electrodynamics in Media, Geometry Effect on Constitutive Relations. *Materials Physics and Mechanics*. 2022;49(1): 1-16.
17. Boiprav O, Ayad H, Abdaljlil SA, Lynkou L, Abdulmawlay M. Charcoal- and Foil-Containing Materials for Radio Electronic Control Systems Protection from Electromagnetic Interferences. In: *2022 IEEE 21st international Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA)*. IEEE; 2022. p.299-304.
18. Dobrego KV, Chumachenko MA, Boiprav OV, Grinchik NN, Pukhir HA. Measurement of Electrical Resistance of Liquid Electrolytes and Materials Containing Them. *Journal of Electromagnetic Analysis and Applications*. 2020;12(2): 98175.
19. Matsushima T, Ito T, Prasanta Kumar Som P. Density and Electrical Conductivity of Fused Magnesium Electrolyte, (I) Typical Magnesium Electrolyte with Additives of NaCl, KCl, and $CaCl_2$. *Transactions of the Japan Institute of Metals*. 1969;10(3): 161-165.
20. Kolokolova L, Petrova E, Kimur H. Effects of Interaction of Electromagnetic Waves in Complex Particles. In: Zhurbenko V. (Ed.) *Electromagnetic Waves*. InTech; 2011.
21. Nefedov IS. Effects of Electromagnetic Interaction in Periodic Arrays of Single-Wall Metallic Carbon Nanotubes. *Materials Physics and Mechanics*. 2012;13(1): 1-8.

THE AUTHORS

Boiprav O.V.
e-mail: smu@bsuir.by

Bogush V.A.
e-mail: bogush@bsuir.by

Lynkou L.M.
e-mail: leonid@bsuir.by