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Technology for the Manufacture of Microwave Absorbers from the Dispersed Composite Based on Powdered Activated Charcoal and Iron (III) Oxide

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Abstract

The article presents new technology for the manufacture of microwave absorbers. This technology is based on the implementation of the following processes: 1) obtaining a dispersed composite by incorporating finely dispersed iron (III) oxide from a mixture of the latter with a surfactant into particles of powdered activated charcoal; 2) fixing in the matrix of the resulting dispersed composite. The results of the experimental substantiation of this technology are presented. In the frequency range of 2.0–7.0 GHz, the absorption band width of absorbers manufactured in accordance with the presented technology is 3.0 times greater than the effective absorption band width of absorbers made from powdered activated charcoal. These absorbers seem to be promising for use in instrumentation, in particular, in order to protect the elements used for the manufacture of radio measuring instruments, as well as these instruments themselves, from the effects of active and passive electromagnetic interference in the microwave range.

Keywords: activated charcoal, iron (III) oxide, electromagnetic radiation absorber, microwave range.

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Toz halında aktivləşdirilmiş kömür və dəmir (III) oksidi əsasında dispers kompozitdən mikrodalğalı elektromaqnit şüa uducularının istehsalı texnologiyası

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Xülasə

Məqalədə mikrodalğalı diapazonda elektromaqnit şüalanma absorberlərinin istehsalı üçün yeni texnologiya təqdim olunur. Bu texnologiya aşağıdakı proseslərin həyata keçirilməsinə əsaslanır: 1) səthi aktiv maddə ilə sonuncunun qarışığından nazik dəmir (III) oksidini toz halında aktivləşdirilmiş kömür hissəciklərinə daxil etməklə dispers kompozitin alınması; 2) əldə edilən dispers kompozitin matrisdə fiksasiyası. Təqdim olunan nəticələrə əsasən müəyyən edilmişdir ki, təqdim olunan texnologiyaya uyğun olaraq hazırlanmış mikrodalğalı diapazonda elektromaqnit şüalanma absorberləri çoxzolaqlı tezlik seçici absorberlərdir (metal altlıqlara quraşdırılmaq şərti ilə). 2.0–7.0 GHz tezlik diapazonunda təqdim olunan texnologiyaya uyğun olaraq istehsal olunan absorberlərin udma bant genişliyi toz halında aktivləşdirilmiş kömürdən hazırlanmış absorberlərin effektiv udma bant genişliyindən 3.0 dəfə çoxdur.

Açar sözlər: aktivləşdirilmiş kömür, dəmir (III) oksid, elektromaqnit şüalanma absorber, mikrodalğalı diapazon.

Технология изготовления поглотителей электромагнитного излучения СВЧ-диапазона из дисперсного композита на основе порошкообразного активированного древесного угля и оксида железа (III)

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Аннотация

В статье представлена новая технология изготовления поглотителей электромагнитного излучения СВЧ-диапазона. Эта технология основана на реализации следующих процессов: 1) получение дисперсного композита путем инкорпорирования в частицы порошкообразного активированного древесного угля мелкодисперсного оксида железа (III) из смеси последнего с поверхностно-активным веществом; 2) закрепление в матрице полученного дисперсного композита. На основе приведенных результатов установлено, что поглотители электромагнитного излучения СВЧ-диапазона, изготовленные в соответствии с представленной технологией, являются многополосными частотно-селективными поглотителями (при условии, если они закреплены на металлических подложках). В диапазоне частот 2,0–7,0 ГГц ширина полосы поглощения поглотителей, изготовленных в соответствии с представленной технологией, в 3,0 раза превышает ширину эффективной полосы поглощения поглотителей, изготовленных из порошкообразного активированного древесного угля.

Ключевые слова: активированный древесный уголь, оксид железа (III), поглотитель электромагнитного излучения, СВЧ-диапазон.

Introduction

Microwave absorbers are currently widely used in the field of instrument engineering, in particular, in the development of radio measuring instruments. The main advantage of microwave absorbers compared to reflective electromagnetic shields is that they don't cause the formation of passive electromagnetic interference. This is why microwave absorbers are more often used in the development of radio measuring instruments than reflective electromagnetic shields [1].

The following products are manufactured using these absorbers: housings for radio measuring instruments; containers for storing and transporting components for the manufacture of radio measuring instruments and these instruments themselves; screens designed to separate indoor areas in which radio measuring instruments are manufactured or adjusted.

To manufacture microwave, carbon-containing materials (powdery or fibrous) with a modified composition are currently widely used. Such materials include graphite, expanded graphite, graphene, graphene oxide, single walled and multi walled carbon nanotubes [2–4].

Modification of the listed carbon-containing materials composition is carried out using one of the following methods [5]: ball milling; hydrothermal; acid treatment; electroless plating of surfaces of particles or fibers of carbon-containing materials; electrodeposition; sol-gel.

The use of the listed methods, as a rule, is aimed at including nickel and iron-containing components in the composition of carbon-containing materials. This is due to a combination of the following reasons: nickel- and iron-containing components are characterized by magnetic properties; the level of losses due to the absorption of energy of electromagnetic radiation interacting with a material is directly proportional to the value of the relative magnetic permeability of this material (i.e. microwave absorbers based on carbon-containing materials, which include components characterized by magnetic properties, are more effective than absorbers based on carbon-containing materials, which don't include the specified components) [5, 6].

In [7], the prospects of using powdered charcoal for the manufacture of microwave absorbers were substantiated for the first time. The prospects for using this carbon-containing material for the manufacture of microwave absorbers are due to the fact that it's characterized by a lower cost compared to graphite, graphene and carbon nanotubes.

In [8], it was proposed to modify the composition of powdered activated charcoal by chemical deposition of nickel nanoparticles from aqueous solutions into its pores.

The authors of paper [9] proposed to modify the composition of powdered activated charcoal by including iron (III) oxide nanoparticles into the structure of its particles using the pyrolysis technique.

Papers [10, 11] show that powdered activated charcoal is characterized by high adsorption capacity, and therefore the authors of these papers recommended its use for purifying water from fine suspended matter. In this regard, the authors of the present article put forward a hypothesis about the possibility of modifying the composition of powdered activated charcoal by immersing it in a liquid medium containing a suspension in the form of finely dispersed material characterized by magnetic properties. Essentially, this

modification consists of incorporating a finely dispersed material characterized by magnetic properties into the pores of powdered activated charcoal particles. The result of this modification is the formation of a dispersed composite, the matrix of which is particles of powdered activated charcoal, and the filler is a finely dispersed material characterized by magnetic properties. The cost of implementing such a modification is lower than the cost of implementing modifications using the methods presented in [5]. This is due to the fact that the cost of the equipment necessary to implement such modification is lower than the cost of the equipment necessary to implement the modification using the methods presented in [5].

The Work Aim

The aim of the research, the results of which are presented in the article, was to test the hypothesis put forward and was aimed at experimentally substantiating new microwave absorbers manufacture technology based on modifying the composition of powdered activated charcoal by incorporating finely dispersed material characterized by magnetic properties into its particles. Iron (III) oxide in the form of nanoparticles was chosen as such a material due to the cost effective technology of its manufacturing [12].

The Objectives Statement

To achieve this aim, the following scientific and engineering objectives were stated:

1) to justify the auxiliary components and equipment for producing a dispersed composite based on powdered activated charcoal and iron (III) oxide;

2) to document a new technology for microwave absorbers manufacturing, taking into account the results of the first objective solving;

3) in accordance with the documented technology, to produce experimental samples of microwave absorbers from a dispersed composite based on powdered activated charcoal and iron (III) oxide, characterized by a certain content of the latter;

4) to carry out an assessment of electromagnetic radiation absorption characteristics of the manufactured experimental samples, based on the results of which to establish the following: type of absorbers manufactured in accordance with the new technology, depending on the width of their effective absorption band(s); limit values and width of the effective absorption band(s) of absorbers manufactured in accordance with the new technology; maximum and average values of electromagnetic radiation absorption coefficient in the effective absorption band(s) of absorbers manufactured in accordance with the new technology;

5) to develop recommendations for the practical use of absorbers manufactured in accordance with the new technology.

The results of the Stated Objectives Solving

Based on the results of solving the first objective stated to achieve the research aim, isopropyl alcohol was selected as an auxiliary component to obtain a dispersed composite based on powdered activated charcoal and iron (III) oxide. This choice is due to a combination of the following reasons [13]:

1) isopropyl alcohol is a surfactant;

2) a mixture of a surfactant and a finely dispersed material is characterized by a lower viscosity than a mixture of a non-surfactant

and a finely dispersed material, due to which the porous material (in particular, activated charcoal) immersed in the first of these mixtures absorbs more finer material particles from it than the porous material immersed in the second of these mixtures.

A drying oven was chosen as an auxiliary equipment for producing a dispersed composite based on powdered activated charcoal and iron (III) oxide. The choice of such equipment is due to the need to reduce the time costs associated with waiting for the completion of evaporation of isopropyl alcohol used in the process of obtaining the specified composite. The technology documented based on the results of solving the second objective stated to achieve the research aim includes the following stages.

Stage 1. Preparation of a dispersed composite based on powdered activated charcoal and iron (III) oxide by implementing the following operations.

1.1 Preparation of the mixture based on isopropyl alcohol (50.0–90.0 vol.%) and finely dispersed iron (III) oxide (50.0–10.0 vol.%).

1.2. Immersion of particles of powdered activated charcoal, the size of which is not less than 3.0 mm, into the mixture prepared as a result of operation 1.1, provided that the volume of the immersed particles should be 2.0 times less than the volume of the prepared solution.

1.3. Drying the mixture obtained as a result of operations 1.1 and 1.2 in a drying oven at a temperature of 50.0 °C for 0.5–1.5 hours (depending on the volumetric content of isopropyl alcohol in the mixture prepared as a result of operation 1.1).

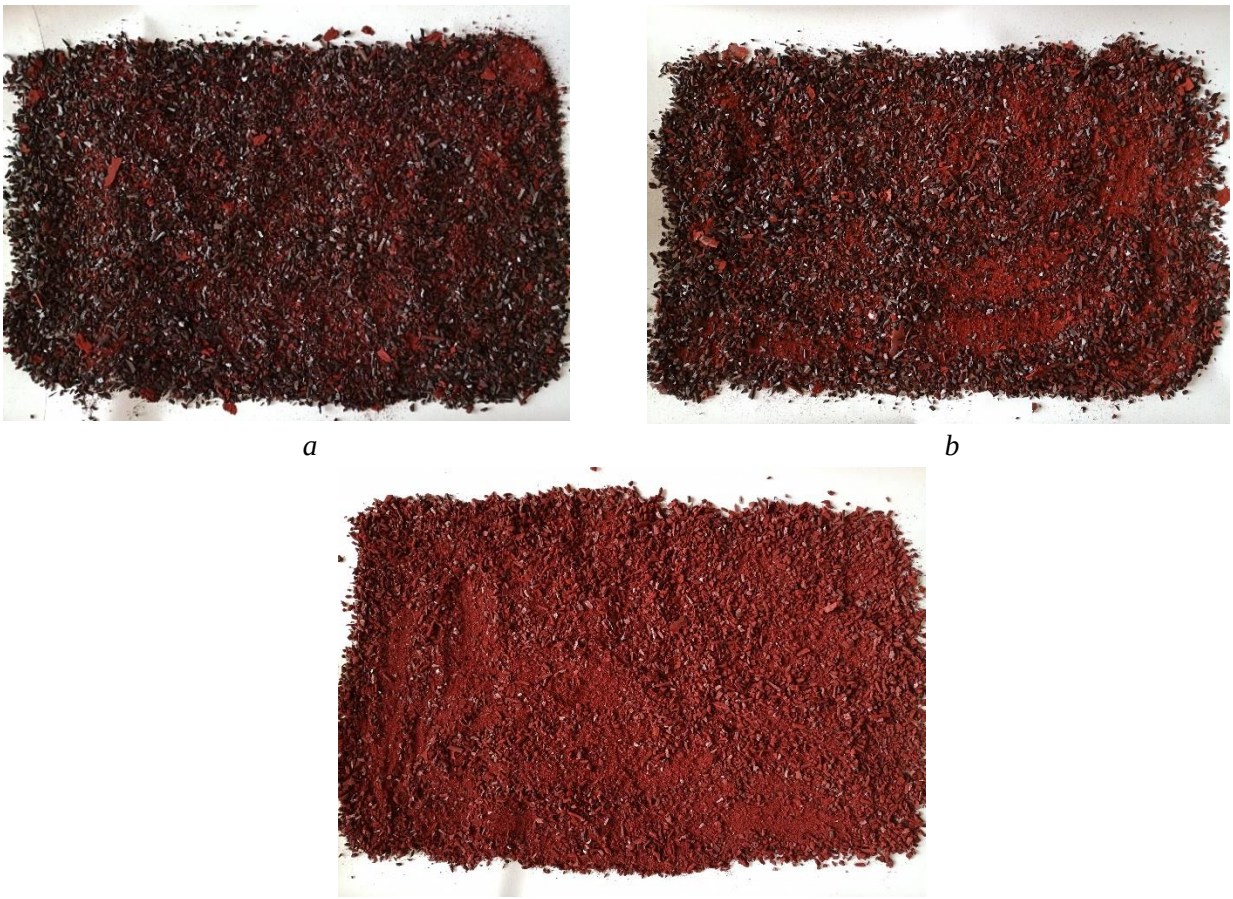
Stage 2. Fixation of dispersed composite particles obtained as a result of Stage 1 in a matrix based on a polymer self-adhesive film, gypsum binder or adhesive composition.

Stage 3. Drying in forms of the material obtained as a result of Stage 2 (if the material is obtained by fixing a dispersed composite in a matrix based on a gypsum binder or adhesive composition). In the course of solving the third objective stated to achieve the research aim, four groups of experimental samples were manufactured. Each group included 10 experimental samples. Samples of group 1 were made by fixing particles of powdered activated charcoal in a matrix based on a polymer self-adhesive film. The thickness of the layer of these particles was 3.0±1.0 mm. Samples of groups 2, 3 and 4 were manufactured in accordance with documented technology. They are characterized by the following features: for the manufacture of samples of each group, a dispersed composite was used, obtained using the mixture based on isopropyl alcohol and finely dispersed iron (III) oxide, characterized by a certain volumetric content of the latter (*C*) – see Table 1; in the manufacture of samples, the matrix based on a polymer self-adhesive film was used; the thickness of the layer of dispersed composite particles based on powdered activated charcoal and iron (III) oxide in the manufactured samples was 3.0±1.0 mm.

Figure 1 shows particles of dispersed composites based on powdered activated charcoal and iron (III) oxide used for the manufacture of groups 2, 3 and 4 samples

Table 1 – *C* values characteristic of each of the mixtures used during the manufacture of samples

Samples name	*C*, vol. %
Group 2 samples	10.0
Group 3 samples	30.0
Group 4 samples	50.0

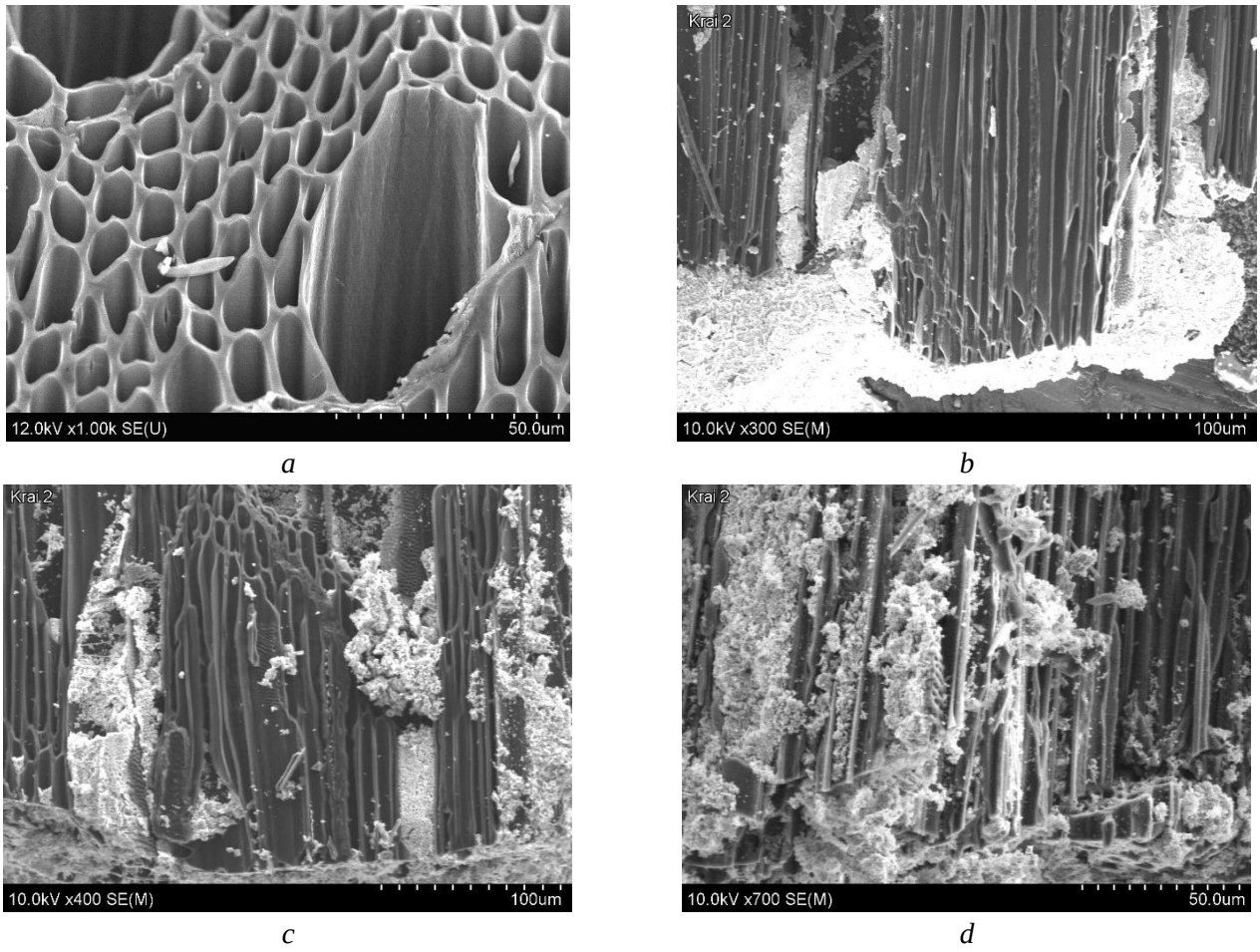


a *b* *c*

Figure 1 – Appearance of particles of powdered activated charcoal used for the manufacture of groups 2 (*a*), 3 (*b*) and 4 (*c*) samples

As it can be seen from Figure 1, the distribution density of fine iron (III) oxide particles over the surface of powdered activated charcoal particles in the dispersed composite used for the manufacture of group 4 samples exceeds the distribution density of fine iron (III) oxide particles over the surface of powdered activated charcoal particles in dispersed composites used for the manufacture of groups 2 and 3 samples.

In addition, the distribution density of particles of fine iron (III) oxide over the volume of internal pores of particles of powdered activated charcoal in the dispersed composite used for the manufacture of group 4 samples exceeds the density of distribution of particles of fine iron oxide (III) over the volume of internal pores of particles of powdered activated charcoal in dispersed composites used for the manufacture of groups 2 and 3 samples. The indicated feature was established based on the results of an analysis of SEM images of particles of dispersed composites used for the manufacture of these groups samples (Figure 2). Such images were obtained using a Hitachi S-4800 scanning electron microscope. Also, in the course of solving the third objective stated to achieve the research aim, the elemental composition of the dispersed composites used for the manufacture of groups 2, 3 and 4 samples was analyzed.



a *b* *c* *d*

Figure 2 – SEM images of chipped particles of dispersed composites, used for the manufacture of groups 1 (*a*), 2 (*b*), 3 (*c*) and 4 (*d*) samples

In particular, the percentage of atoms of elements included in the composition of the dispersed composites used for the manufacture of groups 2, 3 and 4 samples (C_{at2}, C_{at3}, C_{at4}, respectively) was established. For this purpose, the energy dispersive analysis (EDX) method was used. When implementing this method, a Bruker QUANTAX 200 analyzer was used. The results of the study of the elemental composition are presented in Table 2. As it can be seen from Table 2, the content of iron atoms in the dispersed composite used for the manufacture of group 4 samples, is higher in 1.6 times and 2.1 times than, respectively, in the dispersed composites used for the manufacture of groups 3 and 2 samples.

Table 2 – The results of EDX analysis of the powdered activated charcoals, used for the manufacture of groups 2, 3 and 4 samples

Chemical element	C_{at2}, at. %	C_{at3}, at. %	C_{at4}, at. %
C	91.5	89.7	87.89
O	7.54	9.01	10.11
Fe	0.96	1.29	2.0

Based on the results of solving the fourth objective stated to achieve the research aim, the frequency dependences of electromagnetic radiation absorption coefficient

($A(f)$) of the manufactured samples fixed on a metal substrates were obtained. These dependencies were obtained in accordance with the methodology presented in paper [14]. The obtained dependencies are shown in Figure 3. As it can be seen from Figure 3, if the studied microwave absorbers are fixed on a metal substrates, then they are multiband frequency-selective absorbers.

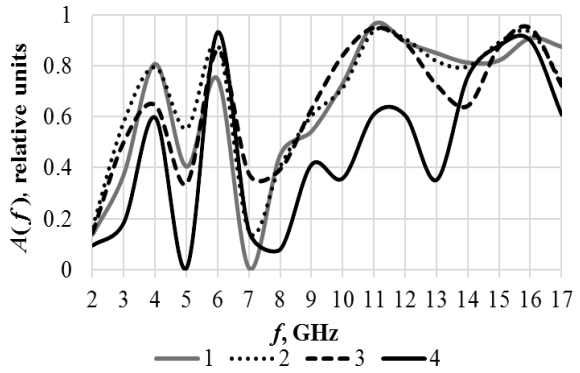


Figure 3 – $A(f)$ of groups 1, 2, 3 and 4 samples fixed on a metal substrates (curves 1, 2, 3 and 4 respectively)

Table 3 – Characteristics of the studied samples fixed on a metal substrates

Samples name	Absorption band ranges, GHz	Δf, GHz	A_{max}, rel. units.	A_{av}, rel. units.
Group 1 samples	3.5–4.5; 5.2–6.2; 8.5–17.0	1.0; 1.0; 8.5	0.8; 0.75; 0.95	0.65; 0.6; 0.8
Group 2 samples	2.8–6.5; 8.5–17.0	3.7; 8.5	0.9; 0.95	0.7; 0.8
Group 3 samples	3.0–4.2; 5.5–6.5; 8.5–17.0	1.2; 1.0; 8.5	0.7; 0.85; 0.95	0.6; 0.8; 0.8
Group 4 samples	3.5–4.2; 5.5–6.5; 10.5–12.5; 13.5–17.0	0.7; 1.0; 2.0; 3.5	0.6; 0.9; 0.6; 0.9	0.55; 0.7; 0.6; 0.8

Table 3 presents the following main characteristics of these absorbers: absorption band ranges; absorption band width (Δf); maximum values of electromagnetic radiation absorption coefficient in absorption bands (A_{max}); average values of electromagnetic radiation absorption coefficient in absorption bands (A_{av}).

As it can be seen from Table 3, in the frequency range of 2.0–7.0 GHz, group 2 samples are characterized by a higher Δf value than groups 1, 3 and 4 samples. In particular, in the specified frequency range, Δf value characterizing group 2 samples is higher in 3.0–5.0 times than Δf value characterizing groups 1, 3 and 4 samples. In addition, samples of group 2 have A_{max} and A_{av} values in the absorption band lying in the frequency range 2.0–7.0 GHz, are higher on 15.0% than that of groups 1, 3 and 4 samples. The indicated features may be due to the combination of the following reasons:

1) the efficiency of electromagnetic radiation absorption by a material (SE_A) is directly proportional to the multiplication of its electrical conductivity (σ) and relative magnetic permeability (μ), as can be seen from the following formula: $SE_A = 8.7d\sqrt{f\pi\sigma\mu}$, where d – material thickness, f – electromagnetic radiation frequency [5];

2) a dispersed composite based on powdered activated charcoal and iron (III) oxide, in contrast to powdered activated charcoal, is characterized by magnetic properties, which is due to the corresponding property of iron (III) oxide [5];

3) specific electrical conductivity value of the dispersed composite based on powdered activated charcoal and iron (III) oxide, obtained using a mixture whose C value is

10.0 vol. %, is higher in ~ 2.0 times than the specific electrical conductivity value of the dispersed composite based on powdered activated charcoal and iron (III) oxide, obtained using a mixture whose *C* value is 50.0 vol. % (see Figure 4).

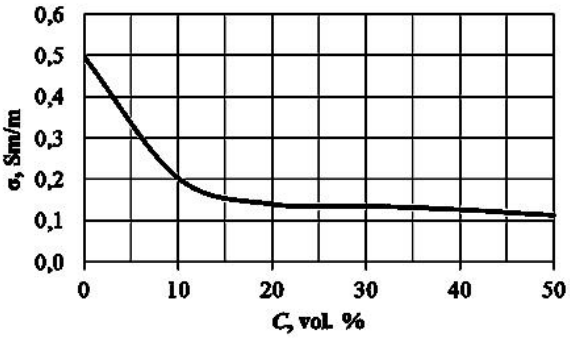


Figure 4 – Dependence of the specific electrical conductivity of dispersed composite based on powdered activated charcoal and iron (III) oxide from the *C* value of the mixture used for this composite obtaining

The dependence presented in Figure 4 was obtained based on the results of measurements of the electrical conductivity of dispersed composites used for the manufacture of groups 2, 3 and 4 samples. These measurements were carried out in accordance with the methodology presented in the monograph [7, p. 30–31].

Conclusion

Thus, the optimal *C* value for a mixture of isopropyl alcohol and finely dispersed iron (III) oxide used to obtain a dispersed composite based on powdered activated charcoal and iron (III) oxide in the manufacture of microwave absorbers in accordance with the proposed technology is 10.0 vol. % (provided that in this process a polymer self-adhesive film is used as a matrix to fix the particles of powdered activated charcoal, into the pores of which the fine iron oxide particles are incorporated). This statement is due to the fact that the absorbers manufactured in accordance with the proposed technology using a mixture with the specified *C* value are characterized by a 3.0–5.0 times greater absorption band width and a 15.0% greater electromagnetic radiation absorption coefficient than absorbers manufactured in accordance with the presented technology using a mixture with a *C* value lying in the range of 20.0–50.0 vol. %.

Compared with the analogs [5, 9] the absorbers manufactured in accordance with the proposed technology are characterized by wider absorption band. Such absorbers seem promising for the manufacture of screens intended to separate indoor zones in which radio measuring instruments are manufactured or adjusted. Also, such absorbers can be included in the structure of the walls and lids of containers used for storing and transporting both components for the manufacture of these devices, and these devices themselves.

Further research will be aimed at obtaining the following data:

– patterns of changes in the electromagnetic radiation absorption characteristics of absorbers manufactured in accordance with the proposed technology, depending on the material of the matrix in which the dispersed composite based on powdered activated charcoal iron (III) oxide is fixed;

– the optimal value of *C* for a mixture of isopropyl alcohol and finely dispersed iron (III) oxide used to obtain a dispersed composite based on powdered activated charcoal and iron (III) oxide in the manufacture of microwave absorbers in

accordance with the proposed technology using matrices based on gypsum binder and adhesive composition.

Conflict of Interest

The authors declare no conflict of interest.

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