RADIATION REFLECTION AND ABSORPTION OF MATERIALS BASED ON POLYVINYL ALCOHOL HYDROGELS

L. Pinchuk[1], V. Goldade[2], V.Kestelman[3]

[1]*A. Belyi Metal-Polymer Research Institute, Gomel, Belarus,* [2]*Francisk Skorina Gomel State University, Gomel, Belarus,* [3] *KVN International, King of Prussia, PA , USA*
mpri-otdel8@mail.ru; victor.goldade@gmail.com; kvnint@verizon.net; kvnint@gmail.com

ABSTRACT

Regularities of reflection and absorption of microwave radiation by water during its freezing-thawing have been experimentally established. Characteristics of microwave energy attenuation by polyvinyl alcohol hydrogels, as well as changes of named parameters due to structure transformation induced by conversion of hydrogels into cryogels at subzero treatment, are given. Facilities of the decrease of cryogels radio-transparency by modifying them with water solutions of ferroelectrics have been shown.

Keywords: Radio absorption, Polyvinyl alcohol gels, Hydrogels, Cryogels, Ferroelectrics.

INTRODUCTION

An abnormally high level of anthropogenic electromagnetic radiation (EMR) in the atmosphere emerged in connection with the rapid development of modern industrial production, intensive growth of radio and telecommunications power, mass use of computers, mobile phones and microwave equipment has become a global problem of the 21st century. Raised levels of electromagnetic fields in human environment negatively affect health and metabolism of biological background [1], complicate operation of high-precision equipment with electronic control [2], aggravate problems of the protection of information and electromagnetic compatibility of components of radio electronic systems [3].

To lower the level of undesired EMR locally they use electromagnetic screens made of metal sheets or plastics filled in with ferrites, ferroelectrics, carbon fibers and so on [2, 3]. These scarce ingredients make screens more expensive and give them enhanced materials capacity. Water which absorbs EMR perfectly has been used more and more frequently as a component of electromagnetic screens, although its application is limited by constructive and technological difficulties of capsulation of liquid phase [4] and water’s loss of capability to absorb microwave radiation energy at freezing. These complications can be avoided if water is to be within the screen in the state bound with other materials.

Structural and technological binding of water with screen’s construction material is easier to carry out with regard to polymers. Methodology of binding molecules of water with macromolecules so that neither plastics could lose their inherent manufacturability nor bound water did lose the capacity to radio absorption, has become a new urgent problem of material science. With the purpose to improve quality of parts from plastics and observe requirements of safety engineering, they traditionally tend to wholly remove water from extrusion handled polymer compositions [5].

The optimal variant of water infusion into the composition of electromagnetic screen seems to fix its molecules within the structure of water-soluble polymer, polyvinyl alcohol (PVA) in particular. Its macromolecules $[–CH_2CH(OH)–]_n$ comprise isotactic vinyl links with a large number of –OH groups. Owing to them sets of water molecules join a macromolecule via hydrogen bonds. As a result, PVA gels are forming, hydrogels to be more precise. Macromolecules create stereo chemical and thermal dynamically steady net, its links being connected by covalent or ionic links and its available volume being filled in with bound and inbound water molecules [6].

The aim of the paper is to evaluate the efficiency of PVA-based hydrogels as radio absorbing materials and investigate their radio and physical characteristics at negative temperatures.

EXPERIMENTAL

In our experiments we used powder PVA (Russian State Standard 10779-87), active carbon of BAU mark (Russian Specification 2162-001-72198841-2006), Seignette salt $KNaC_4H_4O_6 \cdot 4H_2O$, sodium chloride NaCl powders as well as distilled and running water.

Gel samples were made from PVA solutions in distilled water with 10% mass concentration. PVA powder was poured with water and exposed to heating at mixing twice, first up to to̊ 80 C and up to 95˚C after cooling-down. When cooling down to room temperature PVA solution was transforming into hydrogel. Cryogels were obtained by freezing solution in low temperature thermostat and subsequent thawing at modes recommended in [7].

Parameters of reflection and radiation absorption of microwave EMR by samples were determined with the help of panoramic radiation power gauge R2-61 by reflection and metric method. Liquid or gel samples were placed into a cell of radio transparent fluoroplastic which corresponds to a gauge wave guide path element. We registered reflection coefficient R and magnitude S of attenuation of microwave radiation power within frequency range of 8 ÷ 12 GHz. The given results are average ones of no less than five identical measurements.

Deformation and strength gel parameters on stretching (tensile strength σ and relative elongation at rupture ε) were evaluated according to Russian State Standards 14236-81 with tearing machine Instron 5567. PVA solution was poured into moulds with 1 mm thickness layer, gel was formed and blade-shaped samples were cut off out of gel plates for mechanical testing.

The structure of gels was investigated by optical microscopy techniques (Olimpus BX41), scanning electronic microscopy (SEM, microscope Vega/Tescan), infrared (IR) spectroscopy (Nicolet 5700 FT-IR), differential scanning calorimetry (DSC, calorimeter Diamond).

RESULTS AND DISCUSSION

Water as component of electromagnetic screens

Atoms of hydrogen and oxygen in H_2O molecule form H–O–H angle of valence equal to 104.5^o, therefore molecule has a large dipole moment ($\boldsymbol{D} = 6.17 \cdot 10^{-30}$ Kl·m) and is able to solvate, to be more exact – to hydrate impurities [8]. It gives the possibility to regulate water capacity to weaken EMR energy in a simple way, changing its dielectric permeability and electrical conductivity. Dielectric losses make a major contribution to weakening EMR, if going through water solution. Dielectric permeability of water $\boldsymbol{\varepsilon}$ is great enough and dependent on EMR frequency: $\boldsymbol{\varepsilon} = 81$ at $\boldsymbol{\nu} = 50$ Hz and $\varepsilon = 65$ at $\boldsymbol{\nu} = 10$ GHz [9]. This is caused by the fact that field intensity of electric component of EMR changes with time. Polarization of inbound water molecules fails to follow the field and decreases with field frequency growth while electrical conductivity of water increases at the expense of reduction of dielectric losses.

The majority of electromagnetic screens work at temperature drops. Nevertheless, regularities of changing radio-physical parameters of water at freezing-thawing have not practically been studied. There is no such information in the works on physics of interaction of condensed media and EMR. Electrical conductivity of ice is known to be by an order of magnitude lower than that of water: specific resistance of ice at electric field frequency 50 Hz and temperature $\boldsymbol{T} = 0^{\circ}$C is equal to $\boldsymbol{\rho} = 3.7 \cdot 10^7$ ohm·m, while that of source distilled water is $\boldsymbol{\rho} \sim 10^6$ ohm·m. Mineralization abruptly reduces electrical resistance of water: river water's $\boldsymbol{\rho} = 2.6 \cdot 10^4$ ohm·m and that of sea water's is 0.3 ohm·m [10]. One can imagine that EMR initiates oscillatory movements of molecules and reorientation of dipoles, as a result conduction and displacement currents emerge in water, radiation energy being expended to generate them.

Mobility of dipoles in ice is by several orders of magnitude lower than that in water. Physical properties of ice are abnormal: melting is accompanied by reduction of volume by 9 % [8]. This stipulates sharp reduction of radio waves absorption intensity by ice as compared with water. To ascertain the mechanisms of radio absorption at ice thawing the following experiment had been carried out.

Distilled water was poured into a cell, frozen and placed into a gauge waveguide. Thickness of ice screen was 30 mm. Values ***R*** and ***S*** were registered in the process of melting at room temperature (+20˚C). Kinetic regularities of changing the temperature of the contents of the cell have been determined in a separate experiment.

Figure 1 shows kinetic dependence of changing reflection coefficient of ice in the process of thawing. The initial high reflecting power of crystal structure of ice (***R*** ≈ 1) sharply dropped during the first ~150 s. (stage I), then smoothly increased (II), sharply grew (III), and got stable (IV) reaching constant value ***R*** = 0.85. The trend of this curve can be explained in the following way.

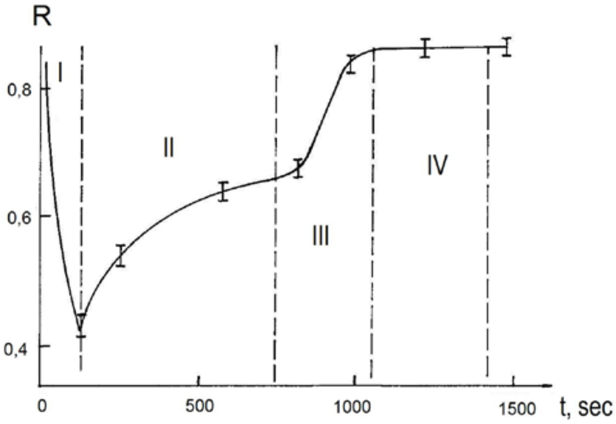

Figure 1. Changes of reflection coefficient of ice in the process of thawing. Microwave radiation frequency, ***ν*** = 10 GHz

Lowering ***R*** values at stage I is related with uneven thawing of a surface layer of an ice sample. Ice can exist in nine crystal modifications differing by melting temperature T_{mlt} and dielectric permeability **ε.** Under atmospheric pressure hexagonal **(*Ih*)** and cubical ***(Ic)*** phases of ice form. Orientationally disordered modification ***Ih*** has a high value **ε** ≥ 100 and a lower T_{mlt} than ***Ic*** phase [11]. Uneven thawing of ***Ih*** and ***Ic*** phases in the surface layer of a sample stipulates forming structural defects and lowering reflecting power of ice at stage I. This has been experimentally confirmed by observations the surface of a thawing ice sample with an optic microscope. On a perfectly smooth surface a grid of 2÷5 μm thickness grooves forms, obviously corresponding to ***Ic*** and ***Ih*** phases boundary. At stage II the surface of a sample gets covered with water film screening defects. At stage III a critical thickness water layer forms in a cell, it performing the function of a thermal insulator which retards thawing. Accumulation of external thermal energy by a sample results in accelerated thawing of ice remainder, this being accompanied by ***R*** growth at stage III. In the beginning of stage IV all ice in a sample had melted and value ***R*** = 0.85 corresponds to reflecting power of distilled water.

Figure 2 shows kinetic dependences of microwave radiation energy attenuation (***ν*** = 10 GHz) by ice samples in the process of thawing. The analysis of these data leads to the following conclusions:

- ***S*** value grows in the process of thawing, that is water phase is expected to be absorbing radiation energy more actively than ice;
- Within time period ***t*** ≈ 300 s, which is much less than the time of full thawing of a sample (~ 1500 s), ***S*** value reaches typical value for water S_{max} ≈ 28 dB;

- Time of achievement S_{max} depends on availability of impurity ions in ice composition, it decreasing in the series of "distilled water > running water > NaCl solution".

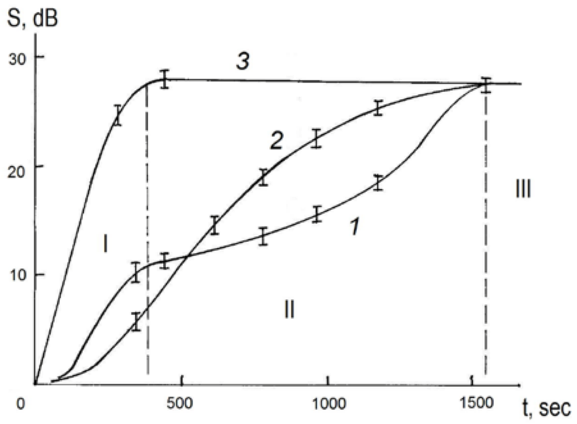

Figure 2. Microwave radiation energy attenuation by thawing ice on the base of: **1** and **2 d**istilled and running water, **3** − 1% NaCl solution

On kinetic dependence S of distilled water thawing ice (curve*1*) one can mark out three stages: I – accelerated absorption growth, II – slow progressing, III - limiting value S_{max} achievement. It is logical to suggest that stage I like in Figure 1 corresponds to uneven thawing of crystal phases of ice and forming boundaries between them on which radiation energy is absorbed more intensively. Monotonous absorption growth at stage II is associated with water accumulation in a cell. Critical amount of water corresponds to stage III at which absorption attains limiting value S_{max}. Curves 1 and 2 do not differ considerably since running water contains minor amount of impurity ions. The attention is drawn by the lack of stage I on curve 2 and a faster yield of constant value S_{max}. Curve 3 only after 70÷75 s from the beginning of ice thawing attains maximal value of absorbed energy.

Thus, freezing water conditions microwave radiation reflection growth by water screen and practically total loss of capacity to absorb EMR. Water solutions of salts are more efficient as screens but they do not work at freezing either. Therefore, the appropriateness of physical and chemical binding of water with other materials of electromagnetic screen has been obvious.

PVA hydrogels

Dissolving PVA in water, a partially crystalline polymer with crystallinity level 30÷70 % [6], in most cases do not result in forming true solution. The adopted in this work techniques of twofold heating PVA and water mixture is based on the following regularities. At first heating mixture up to 80 ˚ C in true solution with dissociated macromolecules, 100÷150 nm solid particles persist, they being fragments of the most perfect PVA crystallites, particles of the initial level. At cooling solution, they serve as nuclei of arising permolecular PVA structures of the second level in it. Repeated heating up to 95 ˚ C stipulates their dissociation and reducing. Further cooling initiates PVA crystallization leading to forming smaller structures of the second level in the solution [12]. Shear stresses arising at mixing solution accelerate crystallization.

Crystallization of solution leads to hydrogel formation. It corresponds to disperse system with water continuous phase, in which permolecular PVA formations joined in contact sections by intermolecular interaction forces, make structural space lattice. Its free volume is occupied with water, its considerable part of molecules being connected with macromolecules. Water phase gives to PVA radio transparent gel property to absorb EMR energy.

Instability of hydrogels' thermodynamic state in work [13] has been explained in the following way. PVA macromolecules dissociate in water with forming charged links and low-molecular counter-ions. Ions of one sign are within links, those of an opposite sign are in water phase in free state. Similarly charged links of macromolecules joined in the lattice push off from each other increasing gel volume. Counter-ions tend to occupy maximal volume in free space of a lattice, generating "bursting" osmotic pressure. Changing ambient conditions (temperature, pressure, environment pH) can significantly weaken the effect of these factors, this leading to gel shrinkage and displacement of inbound water. Uneven reduction (up to hundreds of times) of gel volume at minor external action corresponds to phase transition termed "gel collapse". Such possibility of cardinal structural readjustment had reasons to rating PVA hydrogels to the category of smart (intelligent) materials [13].

Hydrogels obtained from 10% PVA water solution are elastic constructional materials ($\sigma \approx 30$ MPa, $\varepsilon \approx 50$ %), possessing radio absorption property. Placed into 30 mm wide measuring cells, water and hydrogel demonstrate practically the same parameters of EMR absorption at 20 ℃ (Table 1).

Table 1. Attenuation of microwave radiation energy by water and hydrogel

Sample	**S (dB) at radiation frequencies (GHz)**				
	8	**9**	**10**	**11**	**12**
Distilled water	28.43	28.45	28.27	28.45	28.14
PVA hydrogel, 10 % mass.	28.61	28.48	28.39	28.03	28.04

Essential disadvantages of hydrogels as components of electromagnetic screens are low meltability ($T_{mlt} < 30 \div 40$ ˚C) and high evaporation rate of inbound water from them [~ 20 mg/(cm$^{2}\cdot$ 24 hrs)]. At drying hydrogels become rigid ($\sigma \rightarrow 100$ MPa, $\varepsilon \rightarrow 10$ %), value S decreases 4÷5 times. This forces to take additional measures to sealing hydrogels in electromagnetic screens compositions**.** The situation considerably simplifies at conversion of hydrogels into cryogel state.

PVA cryogels

Cryogels form in the process of freezing, exposure in this state and thawing of PVA water solutions. The compulsory condition of forming cryogel is the transformation of hydrogel water phase into ice. At this time cryogels space lattice sites form at the expense of coordination and ionic bonds and noncovalent interactions of macromolecules [7].

The first PVA cryogels were obtained in Japan at the beginning of 1970-s as base for aking fishing baits, then "discovered" again in 1990-s and entered materials science as biomaterials-carriers of immobilized protein molecules, cells, microorganisms designed to carry out medical and biotechnologies [14].

Figure 3 shows the diagram of PVA water solution state in the process of cryotrope gelation. Section AB conforms to cooling solution from initial temperature T_i till freezing , which can occur after overcooling up to T_u**.** On sloping section CD at temperature T_f hidden heat of ice crystallization is released. Curve DE conforms to reduction of frozen solution temperature up to given temperature T_s. For 10% PVA solution it is $(T_0 - T_f) \approx 0.3 \div 0{,}8$ ˚C. With PVA concentration growth value T_u decreases. Freezing out process goes through FG heating stages of a frozen sample up to T_f and GH stabilization of this temperature due to absorbing melting heat by a sample. On section HI a melted sample is heated up to initial temperature which remains stable on IK.

Scheme of cryogel structure formation is given in Figure 4. In initial state, colloid solution contains particles of permolecular formations and PVA true solution. At negative temperature, in true solution ice crystals form, they concentrating colloid polymer particles at the expense of a larger volume than that of water's. The latter ones come in contact, bind and form space lattice. Polymer matrix structure formed after drying a sample is shown in the picture, Figure 5. The matrix load-bearing member is walls of interconnecting micropores where there is a radio absorbing cryogel component – PVA water phase.

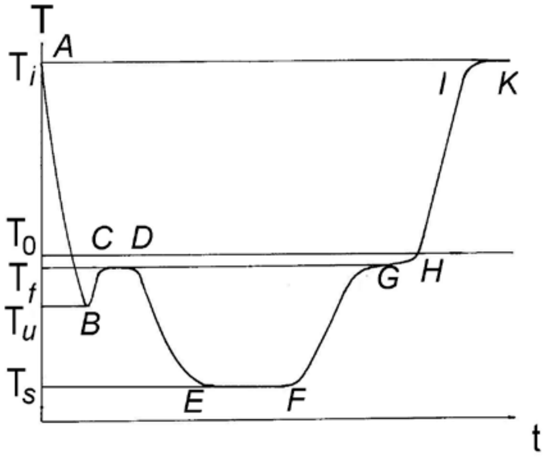

Figure 3. Kinetic dependence of PVA solution temperature at freezing-thawing. Temperatures: T_i − initial, T_0 = 0 ˚C, T_f and T_u − of freezing and overcooling solution, T_s − of a frozen sample exposure [7]

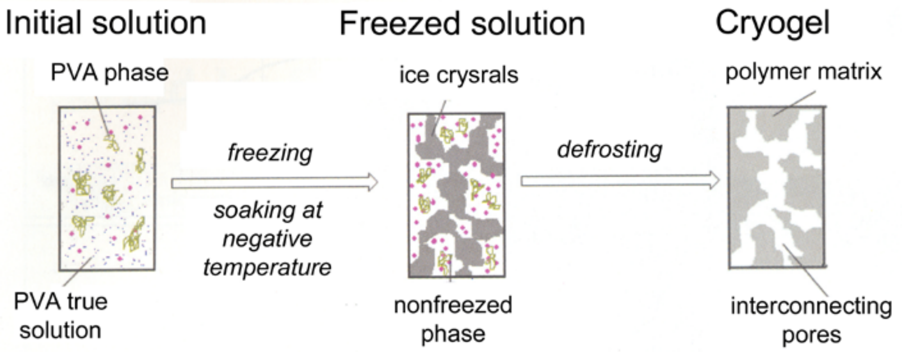

Figure 4. Scheme of cryotrope gelation [14]

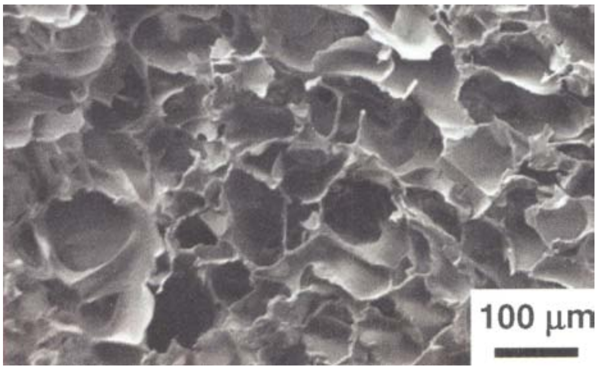

Figure 5. Surface structure of cryogel sample formed at T = –12˚C from 10% mass concentration PVA water solution.

Cryoformation is accompanied by the collapse of initial gel structure. This is seen on the dependence of a gel sample volume upon the time of exposure at negative temperature (Figure 6). The initial point of the curve corresponds to unfrozen sample volume consisting of true solution and PVA colloid particles. A sharp volume reduction of a sample within the period from the 12th up to the 36th minute including corresponds to PVA gel structure collapse. Shrinkage of hydrogel space lattice took place at negative temperatures within the period of overcooling the solution and conditioned displacement of overcooled liquid. Further cooling resulted in ice generation and cryogel matrix walls formation. Simultaneously, matrix porosity and pores diameter have grown from 44 up to 73 % and from 70 up to 84 mcm, respectively [14].

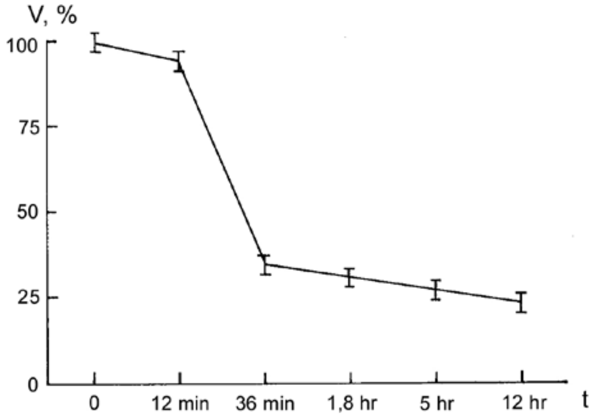

Figure 6. Volume dependence of 10% PVA solution hydrogel sample on thermostating time at $T = -12$˚C [14]

Experiments with PVA (10 %) water cryogels showed that compared to similar gydrogels they possess higher melting temperature (60÷80˚C), strength ($\sigma \approx 70$ MPa, $\varepsilon \approx 25$ %) and are characterized by low evaporation rate of inbound water [< 5 mg/(cm^2·24 hrs)]. This testifies the fact that cryotrope transformation of hydrogels is accompanied by changing physical and chemical structure of polymer matrix.

Figure 7 shows pictures of samples surface made with optical microscope as well as IR spectra of 10% hydrogel and cryogels formed from it by single and twofold freezing-thawing (at $T = -12$ ˚C with 30 min exposure). One can see in the pictures that subzero treatment stipulates enlargement of permolecular formations of the second level. This corresponds to the given above data about pore sizes enlarging in cryogels matrix with cryoprocessing time growth.

On IR spectra (*b*) attention is drawn by changes of fluctuations of the following links of PVA macromolecule. In the first place, a very strong absorption band 3340 cm^{-1}, corresponding to valent fluctuations of OH group, is increasingly intensifying in cryogels. Secondly, peak noticeably decreases at frequency 2910 cm^{-1}, it corresponding to CH_2 valent fluctuations. Thirdly, 1146 cm^{-1} band reinforces, characterizing molecules ordering [15]. This is the evidence of water molecules joining to hydroxyl groups of PVA macromolecule by means of hydrogen bonds and orientational ordering of cryogel polymer matrix walls due to the compression of walls by ice microcrystals .

The confirmation of the said is temperature dependences of heat absorption by gels in the process of heating taken by DSC method (Figure 8). Sloping peak at $T \approx 50$ ˚C on curve ***a*** corresponds to evaporation from hydrogel of inbound water. The latter one totally bonds with macromolecules and freezes out at threefold subzero treatment of hydrogel. At heating cryogel, a peak with maximum at $T \approx 120$ ˚C appears which is not available in hydrogels. One can imagine that heat absorbed at this temperature is spent on destroying hydrogen bonds by means of which water molecules are fixed in cryogel structure.

Physical and chemical binding of water stipulates a remarkable property of cryogels to preserve stability of radiophysical characteristics at negative temperatures. In Table 2, values of ***S*** index are given, they having been obtained in the process of thawing cryogel frozen samples (30 mm thickness, received from 10% hydrogel by means of freezing at –12 ˚C during half an hour). It is seen that by radio absorption parameters cryogels do not yield to water (see Table 1) but unlike it preserve this property even in frozen state. Minor decreasing ***S*** values after 16 hrs air exposure of samples is related to drying moist surface of a sample.

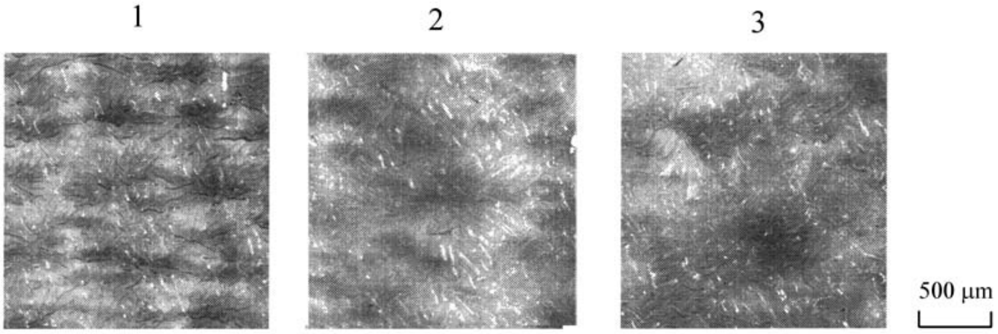

Figure 7. Surface structure (*a*) and IR spectra (*b*) of gel samples: **1** – original gel, **2** and 3 – cryogels obtained from it by means of single and twofold freezing

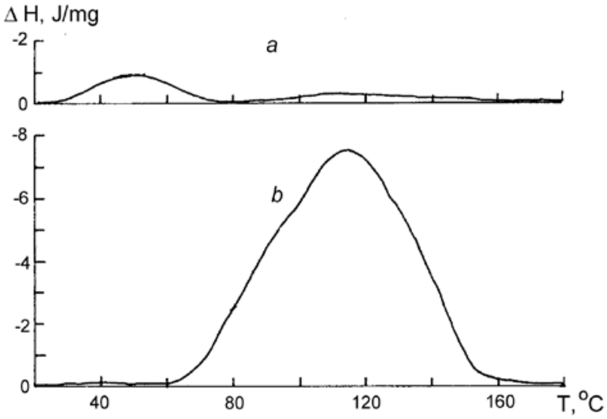

Figure 8. DSC curves of hydrogel (*a*) and obtained from it by threefold freezing-thawing cryogel (*b*)

Table 2. Attenuation of microwave radiation energy by cryogel samples at thawing

Thawing time of a sample, hrs	***S* (dB) at radiation frequencies (GHz)**				
	8	**9**	**10**	**11**	**12**
0	28.44	28.42	28.24	28.48	28.01
1	28.54	28.48	28.34	28.50	27.53
2	28.84	28.78	28.61	28.73	28.58
16	28.65	28.58	28.40	28.67	27.25

Improving radioabsorbing cryogels

Recommended in [7, 16] procedure of repeated manifold deep freezing (–10 ÷ –30˚C) and further thawing of gel system does not appear to be an optimal technology of cryogel radioabsorbing materials formation. The main phase transformations and restructuring original hydrogel structure are initiated by ice crystals formation in it, this taking place (taking into account overcooling of solution) in the area of so-called subzero temperatures (–1 ÷ –5)˚C. Deep freezing and the more so long exposure (up to 24 hrs) of hydrogel at temperatures lower than –20˚C makes sense unless there is aim to "freeze out" inbound water. Moreover, the main technological factor of cryogel formation from deeply frozen solution becomes kinetics of its thawing.

The following fundamental regularities of this process have been established [7]:

1) At higher rate of thawing $\upsilon > 10$ ˚C/min it is not cryogel which forms but a viscous colloid solution;
2) Decreasing $\boldsymbol{\upsilon}$ till 1.0, 0.1, 0.01˚C/min stipulates growth of elasticity and $\boldsymbol{T_{mlt}}$ and also reduces microinhomogeneity of cryogels structure;
3) The rate of thawing is of essential significance precisely at deep freezing of gels since it determines the time of staying gel system within subzero temperatures range at which key processes of cryotrope gelation occur.

Our experiments showed that cryogels formed at $\boldsymbol{T} = (-1 \div -5)$ ˚C with exposure to that temperature during 15 ÷ 25 min are characterized by high (like water's) index of microwave radiation energy absorption stable within ±30 ˚C temperature range and higher values of deformation and strength parameters: $\boldsymbol{\sigma} > 70$ MPa, ε up to 20 % [17]. Consequently, traditional methods of regulating service properties of radioabsorbing materials on cryogels basis, they being multiple deep freezing-thawing of original hydrogels, can be replaced by less energy and effort varying of time freazing gel system at subzero temperatures.

The task to intensify EMR energy absorption by cryogels modifying them with water solutions of ferroelectrics had been set. Ferroelectrics are crystal polar dielectrics possessing spontaneous polarization within a certain temperature range. At first being not numerous, the group of ferroelectrics had listed several hundred nominations by 1990 [18].

Methods of modifying PVA cryogels with ferroelectrics is to thaw frozen cryogel in saturated (54%) solution of Seignette salt. During this procedure, hydrates of Seignette salt diffuse into gel space lattice and are immobilized there, causing gel collapse. Separation of inbound water results in deposition of crystals of Seignette salt in microvoids of polymer matrix. When such material is in EMR field, an intensive polarization-depolarization of these crystals take place, it stipulating an additional mechanism of EMR absorption by cryogels. As a result, 30 mm thickness samples from 10% PVA cryogels modified by Seignette salt water solution have microwave radiation energy attenuation index $\boldsymbol{S} = 43 \div 49$ dB. Introduction of Seignette salt into PVA cryogel stipulates decrease of water evaporation rate from samples [$\boldsymbol{\upsilon} < 3$ mg/(cm^2·24hrs)], but is accompanied by cryogels strength drop up to values $\boldsymbol{\sigma} \sim 4$ MPa and elasticity growth $\boldsymbol{\varepsilon} > 200$ %. This limits a little bit the possibility to use such material preserving constructive distinctness in electromagnetic screens composition.

Radioabsorbing capacity of cryogels noticeably increases when PVA solution is filled in with disperse carbon sorbent before freezing. Collapse of a filled and frozen gel in Seignette salt solution is accompanied by absorbing solution by carbon particles. As a result the amount of bound water in a filled material increases. Carbon particles make their own contribution to radio absorption mechanism dissipating EMR energy at the expense of Foucault currents. In Figure 9 SEM-photograph of such radioabsorbing material structure is given. One can see elements of supramolecular formations making cryogel walls. They have the appearance of fibrillar fibres carrying absorptionally attached carbon particles which are saturated with Seignette salt solution. No wonder, that 30 mm thickness such material samples are characterized by index value $S = 53 \div 61$ dB and very low evaporation of inbound water, almost nothing of it remaining in cryogel structure.

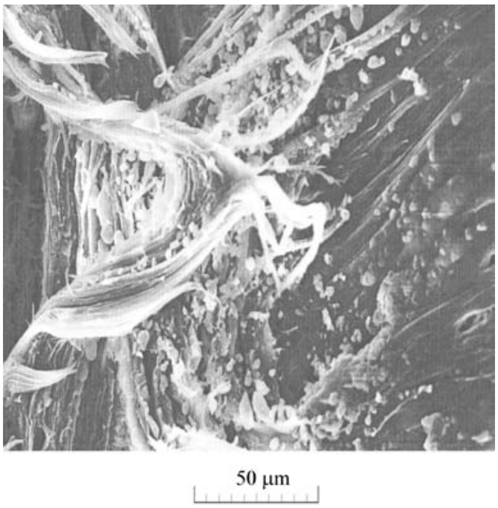

Figure 9. PVA (10 %) water cryogel structure modified by Seignette salt and filled in with active carbon (1.5 % mass.)

CONCLUSION

1. Polymer materials class for electromagnetic radiation screening containing water or water-salt solutions as radioabsorbing component has been developed and is intensively progressing. Water is structurally bounded with polymer basis of materials which stipulates their working capacity within electromagnetic screens composition at negative temperatures while inbound water becomes radio transparent transforming into ice. Cryogels formed by subzero treatment of PVA water solutions correspond to elastic constructive materials. They do not yield water as to specific (related to screen thickness) attenuation energy value but keep this index stability at negative temperatures.
2. Possibility to enhance drastically cryogels screening capacity by modifying them with Seignette salt water solutions has been established. In the process of thawing a frozen PVA gel in Seignette salt solution, the hydrates of the latter one diffuse into polymer phase causing gel structure collapse and deposit in the form of crystals on cryogel matrix walls. This stipulates material’s realization of additional mechanism of electromagnetic radiation energy attenuation at the expense of polarization-depolarization of ferroelectric crystals.
3. Cryogels are designed to be put as coatings on textile fabrics from which radioabsorbing clothes is manufactured. Cloth either in the form of cryogel sheets or glass fabrics impregnated with cryogels serve as means of ground machinery camouflage. Textile fabrics treated with cryogels are used to produce curtains to protect premises from news leak. Cryogel protective screens exceed metal ones by flexibility, elasticity and materials consumption.

REFERENCES

1. Grigoryev Yu.G., Ed.; Electromagnetic fields and human health; Russian University of Nation Friendship: Moscow, **2002**; 177 p.
2. Kovneristy Yu.K., Lazareva I.Yu.; Ravaev A.A. ,Materials absorbing electromagnetic radiation; Nauka [Science]: Moscow, **1982**; 164 p.
3. Lyn’kov L.M., Ed., Flexible constructions of electromagnetic radiation screens; Belarus State University of Informatics and Radioelectronics: Minsk, **2000**; 284 p.
4. Prokopovich D.N., Bogush V.A., Lyn’kov L.M., Petrova V.A., *Proc. of Belarus Engineering Academy*, **1999**, *1*, 195-197.

5. Kryzhanovsky V.K., Kerber M.L., Burlov V.V., Panimatchenko A.D., Manufacturing of polymer material articles; Profession: S.-Petersburg, **2008**; 464 p.
6. Nikolayev A.F., Mosaygina L.P. ,*Russian Plastics Technology Journal*, **2000**, *3*, 34-42.
7. Lozinsky V.I.,*Russian Chemical Reviews*. **1998**, *67*, 641-655.
8. Malenkov G.G., Yakovlev S.V., Gladkov V.A. In Russian Chemical Encyclopedia; Knunyats, I.L., Ed.; Grate Russian Encycl.: Moscow, **1998**; Vol. 1, pp 763-769.
9. Grudinskaya G.P.,Radiowaves propagation; High school: Moscow, **1967**; 244 p.
10. Belaya M.L., Levadny V.G. ,Molecular structure of water; Znaniye [Knowledge]: Moscow, **1987**; 64 p.
11. Malenkov G.G., In Russian Physical Encyclopedia; Prokhorov, A.M., Ed.; Soviet Encycl.: Moscow, **1988**; Vol. 1, pp 294-297.
12. Klenin V.I., Fedusenko I.V., Klokhtina Yu.I. ,*Polymer Science: Ser. A*. **2004**; *46*, 1754-1758.
13. Filipova O.Ye., *Nature [Russian Priroda]*. **2005**, *8*, 11-17.
14. Kumar A., Mishra R., Reinwald Yu., Bhat, S., *Materials Today*. **2010**, *13*, No. 11, 42-44.
15. Dechant J., Danz R., Kimmer W. ,Ultrarot Spektroskopische Untersuchungen an Polymere; Akademie-Verlag: Berlin, **1972**, 472 p.
16. Lozinsky V.I.., Savina I.N., Davankov V.A., *Russian Patent* 2,190,644; IPC C08L 29/04, 2002.
17. Bondarenko, P.I., Pinchuk L.S., Tsvetkova E.A., Goldade V.A., *Belarus Patent* 15,555; IPC C08J 3/075, 2012.
18. Levanyuk A.P., Strukov B.A., In Russian Physical Encyclopedia; Prokhorov, A.M., Ed.; Soviet Encycl.: Moscow, **1994**; Vol. 4, pp 477-481.