TEMPERATURE DEPENDENCE OF ELECTROMAGNETIC RADIATION ATTENUATION BY WATER-CONTAINING MATERIALS WITH DISPERSED STRUCTURE

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ABSTRACT

Electromagnetic radiation (EMR) and water interaction features are used in medicine, microwave measurement of moisture, radiometrology, remote sensing etc. At that the object of EMR impact is often not the bulk water, which is quite well studied, but structures containing materials (substances) in different aggregation states – solid, liquid and gaseous (e.g. moisture measurement, non-destructive inspection). Properties of these heterogeneous systems containing dispersed water depend on many factors – dimensions and structure of fractions, physical and chemical compounds etc. Characteristics of thin layers of bounded water being close to solid surfaces (density, solvability, electromagnetic properties) differ from that of bulk water. Thus description of interfering mechanisms of EMR and heterogeneous systems, containing both bounded and bulk water, is very complicated but important for many purposes.

Aim of the work is exploration of electromagnetic radiation attenuation in the temperature range of -18..+70°C by the heterogeneous structures based on water fixed in organic capillary-porous matrix. For that ultrathickened machine-knitted fabric of 1,6 mm thickness with maximum pore diameter 2 μm was impregnated with liquid. Characteristics of dispersed water and aqueous solutions were explored in frequency ranges 8..12, 27..36 and 80..115 GHz applying panoramic indicators of VSWR and attenuation and waveguide lines.

Because of temperature dependence of water dielectric permeability the attenuation of EMR varies with temperature change. Cooling to -18°C causes complete water crystallization, at that attenuation by heterogeneous structure is close to zero which is caused by water transfer into solid aggregation state. When heating samples to -15°C attenuation rises (to 7 dB in the frequency ranges of 8…12 and 27…36 GHz and 13 dB at 80…115 GHz) because of formation of liquid non-freezing layers on the surface of organic matrix. Their temperature of crystallization is lower than that of bulk water and they possess dielectric losses for penetrating electromagnetic radiation. Temperature increase leads to thickening this water boundary layers and further attenuation rise. Addition of organic compounds preventing ice formation results in attenuation increase at the temperatures below zero. Application of aqueous solutions of metal salts decreases water freezing point in dependence of salts concentration. This results in retaining of EMR absorbing properties of water even at temperature down to -18°C. Heating samples to +70°C causes intensification of molecules thermal motion and leads to decrease of dielectric permeability and losses of water and aqueous solutions of organic compounds. On the contrary EMR attenuation by aqueous solutions of metal salts dispersed in porous matrix increases to 17 dB (in the frequency range of 8…12 GHz) with rising temperature up to +70°C. This can be explained by ionic conductivity increase caused by temperature rise. Measured characteristics are repeated in all explored frequency ranges. Heterogeneous structure containing water and aqueous solutions provide larger attenuation and smaller reflection in higher frequency range (80…115 GHz). It is produced due to geometrically non-uniform surface of EMR absorbing material, formed by capillary forces on the boundaries liquid – gas (air) – solid material. It causes additional dispersion of the incident electromagnetic radiation by the surface of material and multiple reflections inside it. Thus electromagnetic properties of dispersed water and its solutions depend on dimensions and shape of forming organic matrix and liquid composition.

INTRODUCTION

Electromagnetic radiation (EMR) and water interaction in microwave frequency range is connected with relaxation process of water dipoles orientation polarization and is described in Debay's theory. At lower and higher frequencies in Debay's relaxation region the real part of water dielectric permeability steadily decreases from static permeability value (=80) and, according to this theory, tends to constant minimum value ε_∞. At frequency $12{,}3\cdot10^{14}$ Hz measured values of

water dielectric permeability amount ε'=4,33, ε''=2,8 at the temperature 20°C [1]. Special properties, different from bulk water, are possessed by thin mono- and polymolecular water layers (so called bounded water), formed as the result of moisture adsorption on solid materials surfaces. Their characteristics strongly depend on surface attractive forces and layer thickness. Bound water has increased density (at moisture content in material 1,64% density of bound water is 1,74 g/cm^3), its specific resistance is very high, which is caused by very low solvent ability, dielectric losses of such kind of water are lower [2]. EMR and water interactions features are widely used in medicine, microwave measurement of moisture, radiometrology, remote sensing etc. [3]

Materials having capillary-porous structure (e.g. fibrous materials) possess a high ability to moisture adsorption from air due to their very developed surface. Moisture content increase results in capillary condensation of liquid and heterogeneous structure forming. It contains solid fibrous matrix, gaseous phase and both bulk and bounded water forming in capillaries and pores a dispersed structure. Its properties depend much on shape and dimensions of pores of material. Heterogeneous structures with dispersed liquid possess special features of interfering with electromagnetic radiation, depending on liquid composition and capillary-porous system parameters. Complicated dependences of heterogeneous systems parameters and different mechanisms of electromagnetic radiation interaction with materials having different characteristics makes studying and description of the processes of such interfering very difficult [4].

The aim of this paper investigations is determination of electromagnetic radiation attenuation features by liquid dispersed in organic porous matrix at different temperatures. Temperature variation causes change of electromagnetic radiation absorption by water. The most significant difference is observed on transfer of water from one aggregation state to another. At that crystal structure of water (ice) is almost transparent for EMR. Water molecules in gaseous state also possess capability for EMR absorption, though in less degree [5]. As it was mentioned above, heterogeneous systems containing solid fibrous matrix, gaseous phase and both bulk and bounded water possess complicated dependences of their electromagnetic characteristics on temperature.

EXPERIMENTAL

Ultrathickened machine-knitted fabric, made on original technology, was used for exploration of radiation attenuation by liquids having dispersed structure. Knitted material is a complicated capillary-porous structure with moderate degree of anisotropy. Maximum pore dimension of fabric is 2 µm, air permeability – 6 dm^3/m^{2}c. Fabric samples were impregnated with liquid and after sealed with polymeric films. As impregnation liquids were used water and aqueous solutions of NaCl in different concentrations, mineral brine (Gomel deposition) and aqueous solution of organic compound (glycerin) (5:1). Samples thickness was 1,6 mm.

Measurements were carried out in frequency ranges of 8…12, 27…36, 80…115 GHz. Panoramic indicators of VSWR and attenuation and waveguide lines were used for electromagnetic energy attenuation observation. The measurement inaccuracy is not higher than 1,5 dB. Samples were cooled to -18°C and heated to +70°C. Samples temperature was checked *in situ* by mercurial thermometers. Before measurement of attenuation, samples water saturation was estimated by weighing.

RESULTS AND DISCUSSION

Attenuation provided by liquid dispersed in organic matrix strongly depends on its amount. So measured moisture content of samples was 75%±1% by weight. Attenuation characteristics of described four samples in temperature range -18°C...+70°C are given in Fig. 1.

Measured EMR attenuation by investigated liquids with dispersed structure at the temperature of 0…+20°C come to 13…16 dB in the frequency range 8…12 GHz. It was shown, that attenuation by water dispersed in organic porous matrix tends to zero at temperature down to -18°C. This can be explained by complete water transfer from liquid into solid state. When heating the sample thin non-freezing water layers appear at the boundaries of organic material causing incident electromagnetic radiation attenuation. The freezing point of this bounded water is lower than that of bulk water and they possess dielectric losses at the temperature of -15°C already. This results in attenuation by water-containing sample amounted as 5 dB. Further heating causes thickening this bound water layers and attenuation increase. Liquid freezing point lowering using organic compounds causes moderate increase of EMR attenuation by heterogeneous structures. Glycerin and NaCl aqueous solutions used for preventing liquid from freezing provide 6 dB attenuation at -18°C because of retaining liquid phase properties of the solutions depending on the concentration of additives. Mineral

brine (Gomel deposition) has a very high concentration of metal salts, which EMR attenuation varies within 13…15, 14…20, 23…28 dB, possess the most stable characteristics in the frequency range 8…115 GHz on temperature change from 0 до –18°C and moderate decrease of attenuation (down to 13 dB) when temperature lowering. Temperature rise results in increase of water dielectric losses impact on total abatement of liquid-containing heterogeneous structure.

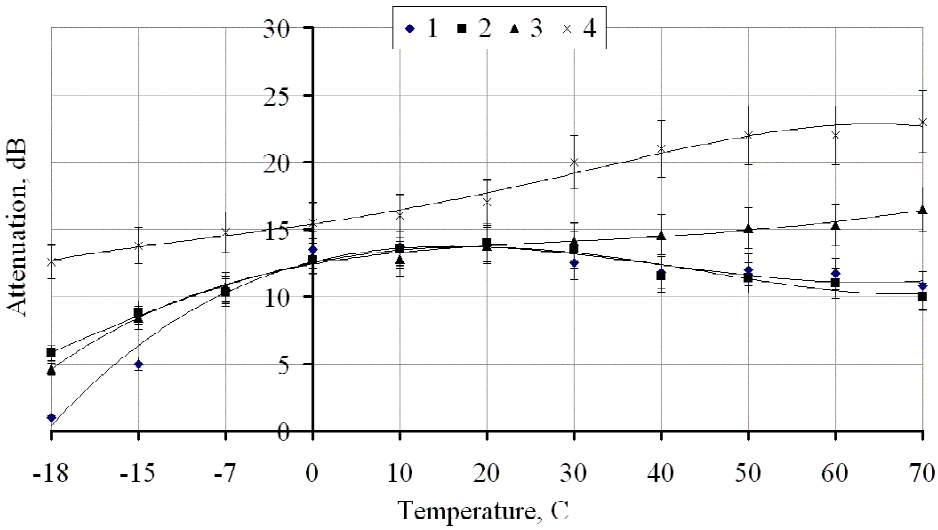

Fig. 1. EMR attenuation as a function of temperature for heterogeneous liquid-containing materials in the frequency range 8…12 GHz, moisture content 75 %: 1 – water; 2 – aqueous solution of glycerine 5:1; 3 – aqueous solution of NaCl 20 %; 4 – mineral brine

Heating samples containing water and glycerin up to +70°C leads to attenuation decrease down to 10 dB because of acceleration of thermal motion of water molecules and dependence of liquid dielectric permeability on temperature. Thus glycerin (and as additional measurements showed many other organic liquids) don't possess dielectric losses itself and can be used just for broadening of temperature range of the solution EMR absorption in the temperature span under 0°C. Fibrous materials impregnated with mineral brines with high concentration of metal salts, provide higher attenuation which rises up to 23 dB with heating to the temperature of +70°C. This can be caused by metal salts ionic conductance increase, which is repeated by the sample containing NaCl aqueous solution but in lower degree (5 dB increase when heating from 20 to +70°C).

EMR attenuation characteristics nature of liquid impregnated fibrous material at different temperatures are repeated in all explored frequency ranges (Fig. 1, 2, 3).

Analysis of measured attenuation characteristics in different frequency ranges shows that cooling causes decrease of attenuation provided by water and its solutions having dispersed structure in all frequency ranges 8…12, 27…36, 80…115 GHz, at that reduction degree is defined by composition of the solution. Water is almost transparent for electromagnetic radiation at low temperatures (to –18°C) in explored frequency ranges. Non-freezing layers of water on organic material boundaries appearing after heating to –15°C provide stronger attenuation of 6…14 dB (Fig. 2).

Electromagnetic radiation reflection on the mediums interface is the result of difference of their wave resistance. In their turn wave resistance of a medium is defined as ratio of its dielectric and magnetic properties. So temperature decrease causes reduction of EMR reflection by water-containing samples at –9…–10 dB as dielectric permeability of such a medium is low. When heating samples reflection of electromagnetic radiation increases. In different frequency ranges samples possess different reflection levels — at frequencies 8…12 GHz reflection by water-containing samples is equal to –4 dB at 0°C. With frequency growth reflection decreases to –10 dB at frequencies 80…115 GHz. It is caused by shortening of electromagnetic radiation wavelength and increase of electromagnetic energy scattering by dispersed liquid structure.

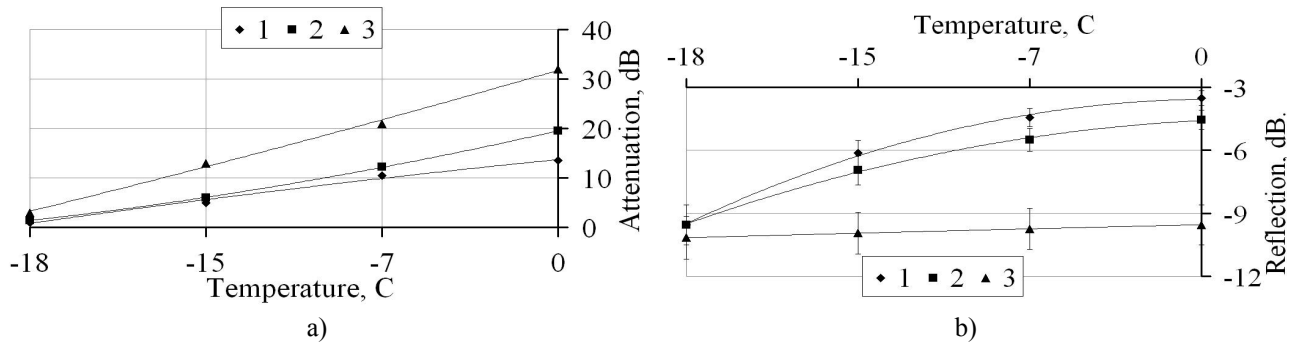

Fig. 2. Attenuation (a) and reflection (b) of EMI by heterogeneous water-containing materials (moisture content 75 %) as a function of temperature in the frequency ranges: 1 – 8…12 GHz, 2 – 27…36 GHz, 3 – 80…115 GHz

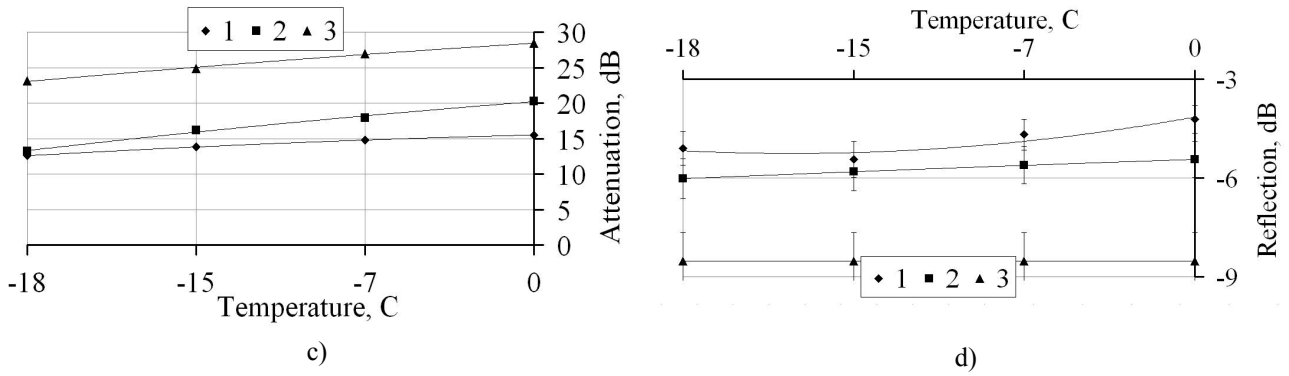

Fig. 3. Attenuation (a) and reflection (b) of EMI by heterogeneous mineral brine containing materials (moisture content 75 %) as a function of temperature in the frequency ranges: 1 – 8…12 GHz, 2 – 27…36 GHz, 3 – 80…115 GHz

As is shown in Fig. 3 EMR reflection by mineral brine containing samples doesn't vary with temperature lowering and possess about –4,0…–5,0 dB in frequency range 8…12 GHz, –5,5 dB in 27…36 GHz, and –8,5 dB in 80…115 GHz. It is explained by retaining dielectric properties of liquid even at temperature –18°C. Mineral brine reveals higher reflection comparing to other liquid-containing samples which is the result of its higher conductivity.

CONCLUSION

The EMR attenuation characteristic of water dispersed in capillary-porous matrix at the temperatures lower than water freezing point strongly depends on liquid boundary layers formation, their characteristics being defined by solid material surface parameters. Aqueous solutions of organic compounds prevent ice formation and attenuation is provided due to dielectric losses of water liquid phase. Solutions synthesis based on metal salts leads to the heterogeneous structure attenuation increase due to freezing temperature lowering, additional resistive losses in the material and increase of ionic conductivity with temperature rise.

REFERENCES

1. V.I. Gaiduk, B.M. Libermann, V.N. Apletalin, et al., "Molecular model of "above-Debay" radiation absorption in water and aqueous solution of nonelectrolyte", Radiotechniques and Electronics, vol. 44, N2, pp.234–242, 1999. (In Russian)

2. B.V. Derjagin, N.V. Churaev, F.D. Ovcharenko, et al., "Water in dispersed systems", 288 pp, 1989. (In Russian)

3. Fang Lu, Seichi Okamura, "Determining moisture content in a broad range of sawdust from microwave transmission measurement using microstrip line", Proc. of SPIE, vol. 4129, pp. 82–87, 2000.

4. L.M. Lynkov, V.A. Bogush, N.V. Kolbun, et al., "New materials for electromagnetic radiation shields", Doklady BSUIR, vol. 2, N5, pp.152–167, 2004. (In Russian)

5. Libermann B.M., Gaiduk V.I. // Radiotechniques and Electronics. 1999, **44**, N1, pp.97–103. (In Russian)