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BONDING OF POROUS STRUCTURE AND SOIL MOISTURE RETENTION IN MODIFICATION SURFACTANTS AND POLYMERS

SHAMURATOVA MOXINABONU

PhD, Institute of General and Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan
Phone.: (0891) 259-6941, E-mail.: shamuratovamr@mail.ru
*Corresponding author

GIYASIDINOV ABDUAZIZ

Associate professor, Namangan State Technical University, Namangan, Uzbekistan
Phone.: (0891) 180-8989, E-mail.: abduaziz_giyasidinov89@mail.ru

ABDIKAMALOVA AZIZA

Professor, Institute of General and Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan
Phone.: (0897) 501-7477, E-mail.: aziza.abdik@gmail.com

ESHMETOV IZZAT

Professor, Institute of General and Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan
Phone.: (0897) 448-2856, E-mail.: izzat.dusimbatovich@gmail.com

Abstract: In this paper, the relationship between the parameters of the porous structure and the moisture retention capacity of soils modified with a surfactant (sulfonyl) and polymer additive C9 was investigated. Water vapour sorption isotherms were obtained by excitatory method, and the parameters of the porous structure were calculated according to BAT theory. The infrared spectroscopy method was used to analyze changes in the chemical nature of soil surfaces after modification. It is shown that the introduction of organic additives leads to a significant increase in water vapour sorption compared with the original soil sample. Modification by sulfonyl mainly contributes to increase the number of hydrophilic centers of the surface and development of microporosity, which is manifested in the growth of the monolayer capacity of sorption and strengthening the absorption bands of O-H groups in IR spectra. At the same time, polymer additive K9 has a major influence on the structural organization of the pore space, contributing to the development of mesoporosity and increasing moisture retention in soils at medium and high relative pressures. Comprehensive analysis of infrared spectroscopy data, MET parameters and sorption isotherm confirms that the improvement in soil moisture retention under the action of surfactants and polymers is complex structurally-chemical. The results obtained are of practical relevance for regulating the water regime of soils and developing effective soil conditioners for arid regions.

Keywords: soil, sorption of water vapours, porous structure, PET method, infrared spectroscopy, surfactants, polymer additives, moisture retention.

Introduction. In the context of changing climatic factors and increasing impoverishment of territories, the problem of conservation and rational use of soil moisture is becoming particularly urgent. Soil moisture retention is a key indicator of their agro-ecological condition, productivity and resistance to degradation, especially in arid and semi-arid regions [1, 2]. The porous structure of the soil matrix plays a significant role in forming this property, especially the development of micro- and mesophores in which sorption and retention of water takes place [3, 4]. Modern representations of soil physics and chemistry indicate that the parameters of the porous structure are determined not only by the granulometric composition, but also by the chemical nature of the surface of the soil particles, as well as their interaction with organic substances [4, 5]. In this context, the application of surfactants (SAA) and water-soluble polymers that can purposefully change the energy state of the surface, pore space structure and water retention is a promising direction. It has been shown earlier that SAA can promote the formation of hydrophilic envelopes on the surface of dispersed particles and increase the number of active sorption centers, leading to an increase in single-molecular and multi-layer water adsorption [6, 7]. At the same time, polymer additives have a predominantly structuring effect, stabilizing soil aggregates and increasing the volume of pores responsible for moisture retention at elevated relative pressures [8, 9]. Water vapour sorption isotherms are widely used to quantify changes in the porous structure and moisture-holding properties of soils, followed by structural parameters calculation using BAT based on classical adsorption models for gases and vapours on porous bodies [3, 10]. Combining data from sorption measurements with IR spectroscopy results allows not only to characterize the pore space structure, but also to establish mechanisms of interaction of organic additives with the surface of soil particles [5, 6]. Despite the existence of some studies, the relationship between the parameters of porous structure and soil moisture retention capacity during modification of ABV and polymers remains insufficiently studied, especially for mesoterrestrial and saline soils in arid regions.

Therefore, the aim of this work is to establish a relationship between the structural characteristics of soils and their ability to retain moisture when introducing surfactants and polymer additives.

Methods of research. As objects of research were used samples of soil selected in the arid regions of the Republic of Uzbekistan. The soil samples were pre-dried to air-dry state, cleared of plant residues and sieved through a 1 mm mesh. Soil modification was carried out using the surfactant sulfonyl and the polymer additive C9. For this purpose, 1% aqueous solutions of additives were prepared, which were applied in the amount of 4 ml per 50 g of air-dry soil. After the solutions have been applied, the samples were thoroughly stirred to obtain a homogeneous mass and kept at room temperature to stabilize the structure. The sorption properties of soils in relation to water pairs were investigated by an excipient method at a constant temperature. Water vapour sorption isotherms obtained in a wide range of relative pressures generated by saturated solutions of electrolytes. Equilibrium is considered achieved if the mass of samples does not change over time. The amount of sorbed water was determined gravimetrically and expressed in mmol/g dry soil. The parameters of the porous structure were calculated on the basis of experimental water vapour adsorption isotherms using the BET method. Determined the monomolecular sorption capacity, surface area and total pore volume. The calculations were performed in the area of low relative pressures corresponding to the linear portion of BET-dependence. Changes in the chemical nature of surface soil particles after modification were analyzed by infrared spectroscopy. IR spectra were recorded in the range 4000-400 cm^{-1}, which allowed to identify functional groups and evaluate the interaction of organic additives with the mineral matrix of the soil. The experimental data were processed using standard methods of mathematical statistics. To establish the relationship between the parameters of porous structure and soil moisture retention, comparative analysis of results from sorption, structural and spectroscopic studies was carried out.

Results and discussion. The IR-spectroscopic studies of the ground soil modified with sulfonyl (4 ml 1% solution) revealed changes in the chemical nature of the surface and the interaction of the solid phase with water (Fig. 1).

The spectrum of the modified sample shows a wide absorption band in the region of 3396 cm^{-1}, corresponding to the O-H oscillations of the adsorbed water groups and hydroxyl groups of the soil mineral components. The increase in the intensity of this strip compared to the original sample indicates an increase in the number of hydrophilic centres and an increase in hydrogen bonds, which is directly related to the increase in moisture retention. The bands in the area of 1434-1468 cm^{-1} can be attributed to the deformation oscillations of C-H and associated oscillations of the functional groups of sulfonyl, as well as the carbonate impurities of the soil matrix. Their presence confirms the adsorption of VOC on the surface of soil particles. The intense band at 1003-1008 cm^{-1} is characteristic of the valence oscillations of the Si-O-Si and Si-O-Al bonds, typical for the silicate base of serovars.

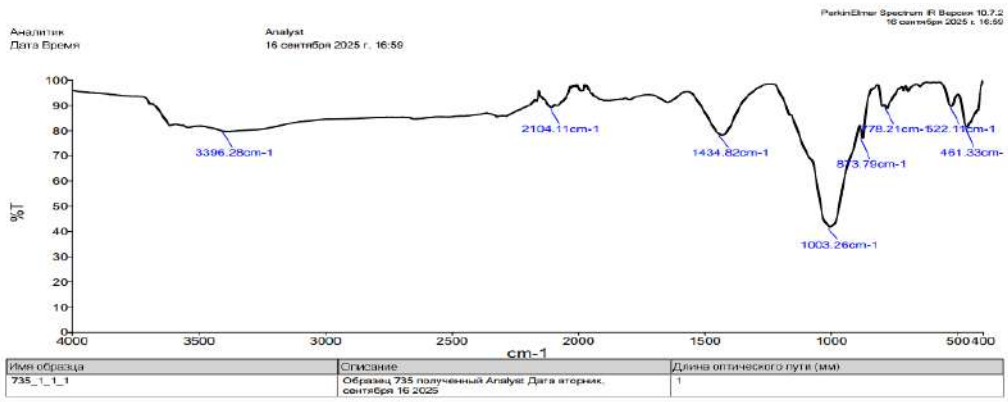

Fig. 1. IR-spectrum of sulfur soil modified with 1% sulphan solution

When modified with sulfonyl, the shape and depth of this strip change is observed, indicating the redistribution of electron density and the involvement of surface silanoic groups in interaction with organic molecules. The low frequency bands in the 873-878 cm^{-1}, 778 cm^{-1}, 523-532 cm^{-1} and 461-469 cm^{-1} correspond to the oscillations of the aluminosilicate framework and confirm the preservation of the soil mineral structure while changing its surface properties.

Thus, IR spectroscopy confirms that the introduction of sulfonyl leads to an increase in the number of hydrophilic functional groups on the soil surface, which creates conditions for increased sorption of water vapour and is consistent with the results of the analysis of adsorption isotherm and porous structure parameters.

When modified with C9 (4 ml 1% solution) in the IR spectrum, there are noticeable changes that indicate a transformation of surface properties (fig. 2). The band in the region of 3390-3400 cm^{-1} is becoming more pronounced and wider than the original sample, indicating an increase in the number of hydrophilic O-H groups and an increase in hydrogen bonds. This indicates the formation of an additional hydrophilic shell on the surface of the soil particles.

In the area of 1435-1470 cm^{-1} there is a strengthening of bands, which may be related to fluctuations of organic functional groups of K9 additives, as well as interaction of the organic phase with the carbonate components of the soil. The presence of these strips confirms the adsorption of additives on the mineral surface. Strip 1006-1008 cm^{-1}, corresponding to the silicate base of the soil, is retained but changes in its shape and depth, indicating the involvement of surface silano groups in interaction with organic molecules.

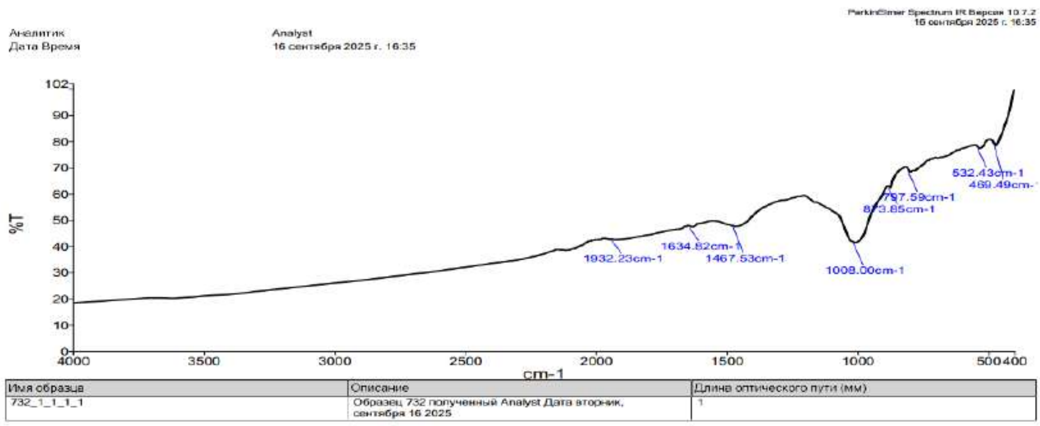

Fig. 2. IR-spectrum of sulfur soil modified with 1% solution K9

Low frequency bands (878, 778, 532 and 469 cm^{-1}) are retained, indicating that the mineral carcass has not been destroyed by modification. The IR spectrum of the original sulfur-earth sample is characterized by a set of bands, typical for aluminosilicate soil matrix (Fig. 3).

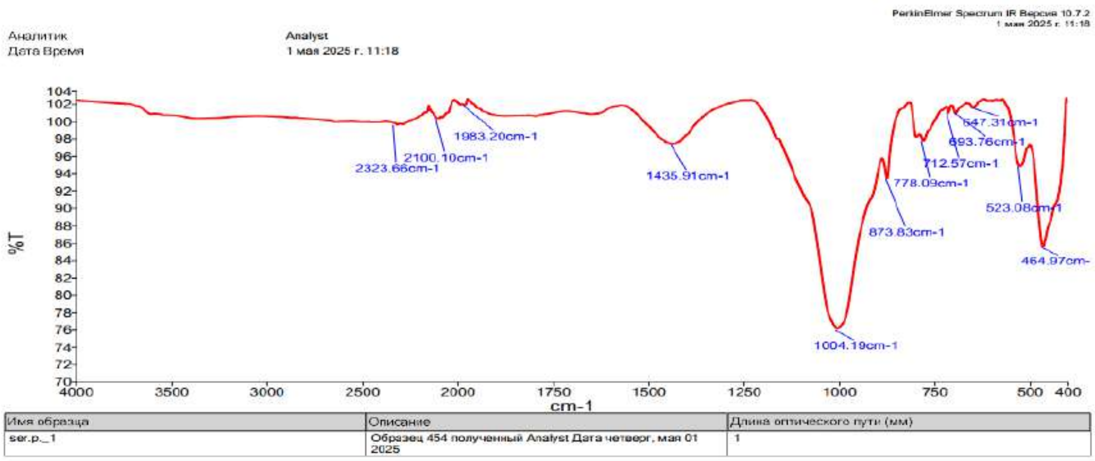

Fig. 3. IR-spectrum of the original sulfur soil

The broad band at 3400 cm^{-1} corresponds to the O-H group of hydroxyl minerals and physically adsorbed water. The moderate intensity of this stripe indicates a limited number of hydrophilic centers on the surface of the soil particles. The intense absorption band at 1004 cm^{-1} is associated with the valence oscillations of the Si-O-Si and Si-O-Al bonds, which are characteristic for quartz and clay minerals of the Mesozoic. The bands at 873 cm^{-1}, 778 cm^{-1}, 523 cm^{-1} and 465 cm^{-1} belong to the deformation oscillations of the aluminosilicate framework and confirm the preservation of the mineral structure of the soil. In general, the IR-spectrum of the initial serotonin reflects the predominance of the mineral phase and the relatively low degree of chemical activity of the surface relative to water. Water vapour sorption isotherms for the original serotonin and modified sulfonyl and K9 additive samples have a characteristic S-shape, typical of polydispersed porous systems. In the low relative pressure range, there is an area corresponding to mono-molecular sorption of water at active centres on the surface of soil particles, whereas with increasing relative pressure, the contribution of multilayer sorption and capillary condensation in mesophores increases.

For the reference serotype, the sorption of water vapour over the whole relative pressure range remains minimal, indicating a limited number of hydrophilic centres and a poorly developed microporous structure. The introduction of organic additives leads to a noticeable increase in the sorption capacity of the soil, and the extent of this increase depends on the nature of the modifier. The sulphenol-modified samples of serotonin are characterized by a significant increase in water sorption already at low relative pressures, indicating an increase in the number of energy-active centers and an increase in surface interaction with water molecules. At high relative pressures, there is an additional increase in sorption associated with the development of the mesoporous structure.

For C9, the increase in water sorption is less pronounced at low relative pressures but more pronounced at medium and high relative pressures. This indicates the predominant influence of K9 on pore space formation and water retention due to capillary effects.

Conclusion. In this paper, a relationship was established between the parameters of porous structure and moisture-holding capacity of sulfur soils when modified by surfactants and polymer additives. It is shown that the introduction of organic modifiers leads to increased sorption of water vapours and changes in the interaction of soil matrix with moisture. It was found that sulfonyl mainly increases soil moisture retention capacity due to surface chemical activation and increase in number of hydrophilic centers, which is accompanied by the growth of single-molecular sorption and specific surface. In turn, K9 has a more pronounced effect on the structural characteristics of the soil, contributing to the development of mesoporosity and increasing the volume of pores responsible for water retention at elevated relative pressures. Comprehensive analysis of IR-spectroscopic data, water vapour sorption isotherm and BAT parameters confirms that the increase in soil moisture retention capacity during modification of PA and polymers is structurally chemical. The results can be used to develop effective approaches for water regime management and soil resilience in the face of moisture scarcity.

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