

Structure Formation of the Surface Layer of Soil as a Way to Prevent a Wind and Water Erosion

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Abstract

The present work describes the results of a study of structuring ability of water-soluble polymers such as polydimethyl diallyl ammonium chloride, saponification product of polyacrylonitrile (uniflok) and their interpolymer complex. On the kinetics of growth of Reh binder's plastic durability of coagulation structure of soil concentrated suspensions the effect of water soluble polymers and interpolymer complexes on the structure formation in the dispersions was studied. It was determined that the process is a two-step process which was caused by the adsorption step process: the binding of macromolecules with the soil surface by the random segments and conformational changes of macromolecules in the adsorbed layer. It was found that the soil stability structured by polymers against wind and water erosion increased with the concentration of water-soluble polymers. This is due to the increase of the structure formation in concentrated suspensions of soil in the presence of water soluble polymers. On the basis of the results it can be concluded that the treatment of mineral dispersions by water-soluble polymers alone or in the form of the interpolymer complex leads to a significant reduction of dust-and run-off of soil particles. The PDMDAAC/uniflok interpolymer complex in comparison with polymers reduces intensively the deflation which has a great economic and ecological importance.

Introduction

Special situation of the soil is determined by the fact that being located on the boundary of a contact and an interaction between the lithosphere, hydrosphere, atmosphere and it fulfills global functions: the regulation of the chemical composition of the atmosphere and hydrosphere, biosphere regulation processes, the active accumulation of organic matter and etc.

At present with the environmental degradation caused by unsustainable human use of pedosphere and unfavorable natural phenomena soil turns into non-renewable resources of the earth.

To prevent the soil erosion is possible by various methods and techniques [1-4].

One of the possible solutions of the problem of the soil erosion can be the use of water-soluble polymers for structuring of the soil surface [3-5].

In connection with this study structuration of brown soil with water soluble polymers such as polydimethyldiallyl ammonium chloride, saponification product of polyacrylonitrile (uniflok) and their interpolymer complex.

The selection of polymers as research objects is due to the fact that on the one hand, polydimethyldiallylammonium chloride is a well studied polyelectrolyte and has many practical applications. For example, it is an effective flocculant for the water treatment. On the other hand, uniflok is easy to get from waste products and from widely available polymers.

In addition, the features of the interaction of uniflok with polydimethyldiallylammonium chloride are also important to create modified forms of uniflok.

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Experimental Procedure

Materials

Soil from Kyzylorda city (Kazakhstan) is used as the object of the study and in this region soil is brown and alkaline. A profile of brown soil is characterized by a clear differentiation of the genetic horizons, humus, carbonate and salt. Due to the formation of complexes with solonetz, solonchaks and takyrs, brown soil is characterized by lack of humus in the structure and strong salinity. The thickness of the soil layer on the described area is very small (2-10 cm).

As the soil structure formers the following water-soluble polymers are: saponification product of polyacrylonitrile - uniflok with molecular weight $M_n = 3 \cdot 10^5$ ("Navoi-nitrogen" plant Uzbekistan), polydimethyldiallylammonium chloride $[-C_8H_{16}NCl-]_n$ with $M_n = 5 \cdot 10^6$ ("Carbokam" Russia) and their interpolymer complex.

The aqueous polymer solution with a concentration of 0.001-2.0 mol/l was used.

Uniflok concentration was constant and equaled to 0.5 mol/l in the PDMDAAC/uniflok complex.

Methods

The measurement of plastic durability of the soil structure was carried out by Reh binder's conical plastometer [5]. The plastic durability was calculated by the formula:

$$P_m = K_a (F/h_m^2) \quad (1)$$

K_a – constant depending on the apex of the cone,

$$K_a = 1/P \cos^2 \alpha/2 \operatorname{ctg} \alpha/2 \quad (2)$$

F – number of grams taken from the counterweight cone, g; h_m^2 – immersion value dL.

The anti-deflation strength of soil was studied in a wind facility [6]. For this study soil samples were placed in trays placed in the chamber device. Then the air flow was supplied at a rate of 21 m/s, which was acted on the surface of the soil sample. Thus there was a separation of the individual soil particles which were picked up and carried away by the flow of the duct to the cyclone. Then the particles, drawn thread, had the effect of centrifugal force, the action of which they were pushed to the sides of the cyclone. As a result of soil particles in the cy-

clone were moved in a spiral near the walls and accumulated in the pan. Turning off the unit for 10-15 minutes for the equilibration the tray were removed from the chamber, are weighed, and the rest of soil were compared to the initial weight of the sample.

The intensity of the deflation was calculated as follows:

$$J = (m_x - m_0)/m_0 \cdot 100\% \quad (3)$$

m_x – the mass of the soil sample after the experiment, g; m_0 – mass of the original soil sample, g.

For the investigation of the soil erosion V.B. Gussak's small erosion tray was used. It is open a tray with parabolic bottom in the test section equipped with a silencer and screws for the establishment of a strictly horizontal tray [6].

The choice of this pan is due to the fact that this device allows to capture accurately the end of the experiment. Studied soil samples were placed in a process chamber previously plugged in the output of the device. To give a form for the sample that can persist after the removal of the plug, soil was soaked with a known amount of polyelectrolyte solution or polycomplex providing of the sample connectivity. Before wetting of the sample surface the groove of filter paper was placed which covered the entire surface of the soil sample in the chamber. Then the measured volume of the polymer solution (or polycomplex) on groove was poured by pipette trickle. When the sample was completely wet the filter paper and the cover were removed.

The value of erosion resistance of soil sample was measured by amount of water needed to flush the soil sample with the volume of 160 cm³ at a flow rate of 13 ml/s.

$$Q = T * q \quad (4)$$

Q – water amount required for flushing of the soil sample, l., T – the duration of the experience, min.; q – specific consumption of water, l.

All experiments were carried out at three times and the average of these three measurements were taken for the calculation.

Experimental Results

The structure formation in the concentrated suspensions of soil is different that due to the high concentration of the dispersed phase and the short distance between the particles, the conditions are

formed which have good influence on the interaction of macromolecules with a large number of particles, the formation of supramolecular structures of the particles at relatively low concentrations of polymer. In the process of drying these supramolecular structures are compacted and "gummed up" the particles of the dispersed phase.

Thus, the structure of the air-dry soil suspension "laid" in the process of structure formation in the concentrated aqueous suspensions of soil. Therefore in this paper the selection of water-soluble polymers and their interpolymer complexes were carried out after studying of the features of structure formation in these systems to enhance the erosion resistance of soil [7].

The kinetics of the process is showed the similarity of kinetic curves for individual polymers and their complexes (Fig. 1). At small t a little growth of plastic durability (P_m) values is happened. This indicates a structuring of disperse system by polymers and their interpolymer complex. The increase of drying time leads to the stabilization of disperse systems, i.e. yield curves $P_m = f(t)$ on the plateau. Such behavior is typical for the coagulation structures. This phenomenon can be explained by the conformational changes of macromolecules in the adsorption layers. Macromolecules of water-soluble polymers and their complexes are adsorbed on the several particles of soil and are formed between them the polymer "bridges", resulting in a gain of soil structure.

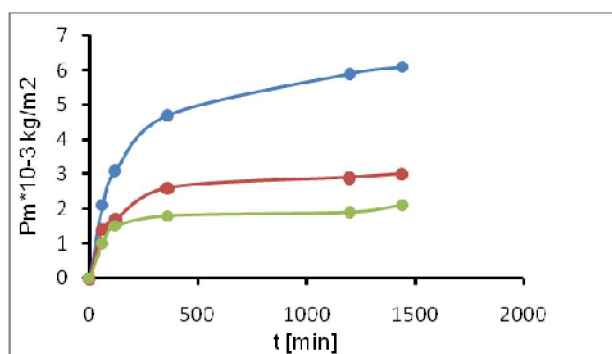


Fig. 1. Kinetics of the plastic durability of the soil suspension structured by polydimethyldiallyl ammonium chloride (1), uniflok (2) and polydimethyldiallyl ammonium chloride/uniflok complex (3).

The sharp increase in the structuring of the reagent at the relatively low concentrations of solutions is due to the binding of the structural and kinetic units of polymer by soil particles. A further increase in the high concentration is due to the adsorption of solid particles by polymers and their

interpolymer complex. Moreover the similarity of isotherm curves of PDMDAAC, uniflok and PDMDAAC/uniflok complex on soil indicates that the wetting of the surface of sorbent particles by water is preceded to the adsorption and structural and kinetic units of polymers diffuse from the bulk solution to the wet surface of the solid phase. According to the polymer adsorption theories of (Fler's, Hesselink's theory) the adsorbed polymer or polycomplex binds to the adsorbent surface by the small number of cooperative bonds where most of the macromolecules is in free state in the form of "loops" and "tails" near the adsorbent surface, structuring effect of which can be interpreted as the possibility of adsorption of "loops" and "tails" [7].

This is confirmed by the studies of the effect of reagents concentration on the plastic durability. Increasing of the concentration of polymer (C) and molar ratio of polymer complex ($n = C_{\text{PDMDAAC}}/C_{\text{uniflok}}$) leads to an increase in P_m suspension of soil (up to $6 \cdot 10^{-3} \text{ kg/m}^3$ for the complex, $3.5 \cdot 10^{-3} \text{ kg/m}^3$ for PDMDAAC, $4.6 \cdot 10^{-3} \text{ kg/m}^3$ for uniflok). In addition, there is a synergistic effect in increasing the plastic durability. For example, for a complex uniflok/PDMDAAC P_m 0.41, while P_m^{ad} was 0.75. The observed phenomenon is explained by the formation of the compacted layer adsorption of the macromolecules from the concentrated polymer solutions and probably the formation of supramolecular structures that enhance the structuring.

The discovered effects in the study of plastic durability of soil suspensions are confirmed by using the data of polyelectrolytes to improve the suspension erosion resistance of soil at the wind erosion. The growth of the polymer concentration decreases deflationary of soil particles, which indicates the formation of stable soil aggregates [8-11].

Since the adsorption of water-soluble polymers and interpolymer complexes on the solid surfaces proceeds practically irreversible, the growth of the concentration C (n) of the polymer on the surface of the adsorbent leads to the saturated adsorption layer formation, which is a stabilizer of the disperse system. These assumptions are confirmed by the kinetic data of soil structure formation which are treated by polymers and interpolymer complexes (Figs. 2, 3).

Figure 2 shows that in the case of unstructured soil the deflation rate (J_{def}) equaled to 100% is observed at 2 minutes, for soil structured by water the total weight loss of soil sample occurs at $t = 20$ minutes. For soil samples structured by PDMDAAC, uniflok and interpolymer complex the

deflation intensity is $\approx 0.4\text{--}1.5\%$ even in 180 minutes (Fig. 3). This comparison confirms the high efficiency of the studied structuring agents.

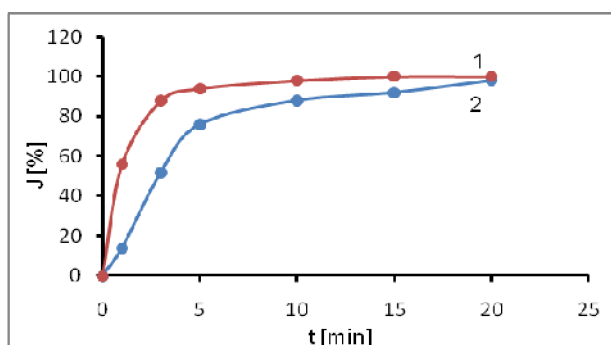


Fig. 2. The kinetics of changes of the deflation intensity of untreated soil particles (1) and soil structured by water (2). Water flow equals to 21 ml/cm^2 .

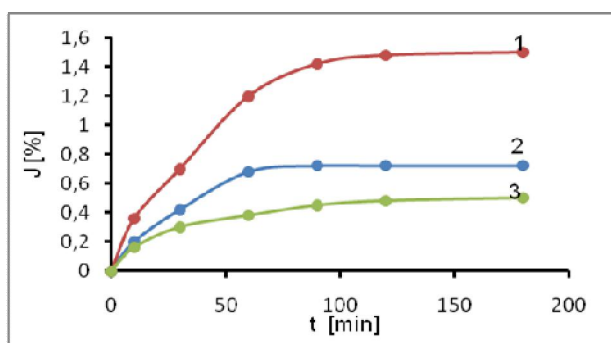


Fig. 3. The kinetics of changes of the deflation intensity of soil particles structured by polydimethyldiallyl ammonium chloride (1), uniflok (2) and polydimethyldiallyl ammonium chloride/uniflok acomplex (3). Water flow equals to 21 ml/cm^2 .

A significant decrease of the deflation intensity with using the complex additives is due to the new formations at fixing of soils. The observed process is the chemical adsorption of the polycomplex with surfaces of elementary mineral particles which results very thin but quite strength polymer film formed by ion-exchanging process between the absorbing complex of soil and water repellent groups which are capable to the ion exchange reaction.

The action of the composite former is interpreted by the formation of reinforced links between soil aggregates consisting of interpolymer complexes. Note that the structuring of the soil dispersion by interpolymer complex is realized by associates as a result of Coulomb and hydrophobic interactions, van der Waals forces and the coordination and hydrogen bonds. The existence of the interpolymer complexes in two states in the form of a complex and in the form of a gel-like hydrophilic associate

supposes the interaction of the latter mainly with the soil surface layer which forms a waterproof crust. The action of the hydrophilic associate is reduced to the electrostatic interactions with not only the soil surface but also the penetration into the interior of the polydisperse system, the binding of the soil colloids of the hydrophobic interactions and hydrogen bonding. As a result of which a strong soil structure with anti-erosion properties is formed.

Water-retaining capacity of the soil is one of the most important factors of the soil erosion resistance. High antierosion resistance is associated with its high structuring [12-13]. However, in some cases, the durability of the soil structure in water does not provide high antierosion resistance. Antierosion activities in the case of water erosion should be economically viable and marketable. From this position one of the problem solution of the aqueous soil erosion is the use of water-soluble polymers and polycomplexes that can inhibit deflation and prevent the water erosion.

Antierosion soil resistance at the water erosion is defined by the water amount which is sufficient to flush the soil sample. The bigger it is the greater the resistance of the given disperse system.

The increase of the water amount needed to flush the soil samples at the water erosion (Fig. 4) confirms the idea that the polymers are not only able to adsorb at the surface of soil particles but also can form new formations, which are located in the structure, and can link the aggregated particles with their flexible chains of macromolecules.

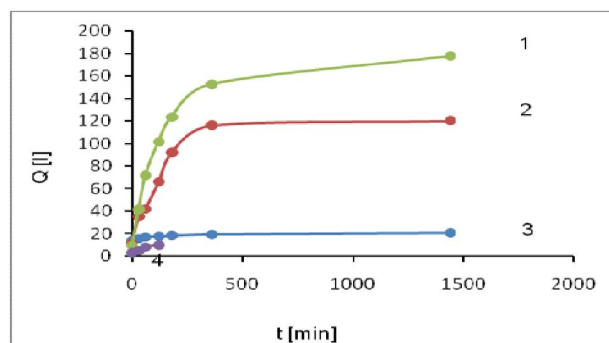


Fig. 4. The water retaining capacity of the soil suspension treated by polydimethyldiallyl ammonium chloride (1), uniflok (2), polydimethyldiallyl ammonium chloride/uniflok complex (3) and water (4).

Analysis of the results showed that the treatment of soil by uniflok and PDMDAAC leads to more robust aggregates formation which can withstand the effect of large amount of eroding water and reduce the intensity of blowing of soil particles by

50-60% higher in comparison with other polyelectrolytes. Since the most of the finely ground soil has a negative charge, the effect of cationactive PDMDAAC is explained by the strong electrostatic interaction between polycations active groups and a negatively charged backbone of soil.

The aggregative effect of uniflok is due to his polyampholyte nature and the adsorption of hydroxyl and amine groups of the polymer on the soil surface.

The results of the study of water erosion of soil suspensions treated by interpolymer complex had a correlation between plastic durability and water resistance which is characterized by the water amount needed to flush the soil samples (Fig. 4).

The experimental results shows that PDMDAAC/uniflok complex has less structuring ability than the original polymers. This is most likely due to the waste of reactive functional groups on the formation of the polymer complex.

Analysis of physical and chemical parameters of structure formation of real disperse systems soil by water-soluble polymers and interpolymer complexes showed an increase of plastic durability from 0.2 to 6.0 kg/m³, decrease of the deflation of soil particles by 94-98% and raise of the water resistance 2-8 times [14].

On the basis of these results it can be concluded that the treatment of mineral dispersions by water-soluble polymers alone or in the form of the interpolymer complex leads to a significant reduction of dust-and run-off of soil particles. Note that the PDMDAAC/uniflok interpolymer complex in comparison with polymers reduces intensively the deflation, which has a great economic and ecological importance.

Conclusion

On the kinetics of growth of Reh binder's plastic durability of coagulation structure of soil concentrated suspensions the effect of water soluble polymers and interpolymer complexes on the structure formation in the dispersions was studied. It was determined that the process is a two-step process which was caused by the adsorption step process: the binding of macromolecules with the soil surface by the random segments (Stage 1) and conformational changes of macromolecules in the adsorbed layer (Stage 2).

It was found that the soil stability structured by polymers against wind and water erosion increased with the concentration of water-soluble polymers.

This is due to the increase of the structure formation in concentrated suspensions of soil in the presence of water soluble polymers.

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