EFFECTS OF WATER-SOLUBLE POLYMERS AND ELECTROLYTES ON PERMEABILITY OF HEAVY CLAY SOILS

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UDC 620.168.34

A study has been made of the effects of water-soluble polymers on the filtration and chemical response of gypsum-bearing soils from the Hunger Steppe and takyr-like soils from the Karsha Steppe.

Measurements have been made [1-3] on the effects of water-soluble polymers and electrolytes on the permeabilities of rock-forming clay minerals (the natural and Na forms of montmorillonite and kaolinite), using the data filtration, adsorption, and electron microscopy, and a mechanism (physical model) has been defined for the interaction between the polymer macromolecules and the active centers on the clay minerals. Appropriate concentrations of these polymers can maximize the permeability, and functions have been defined for predicting the filtration coefficients as functions of polymer content and specific surface.

Detailed measurements are of considerable interest because current practice in soil improvement places particular emphasis on improved infiltration in heavy soils, i.e., means of controlling water transport.

We have examined the effects of water-soluble polymers on desalination of soils and infiltration improvement, which has defined the scope for using brackish waters for irrigation, on account of the improved filtration occurring in the soils.

We used genetic horizons I and III from soils in the Hunger Steppe (collective farm No. 5) and genetic horizons I and II from takyr-like soils in the Karsha Steppe. We used water-soluble polymers K-4, K-9, SMMA, PEM, SVAN, and SVAM, which were made at the Institute of Chemistry, Academy of Sciences of the Uzbek SSR. The infiltration fluids were saline waters whose chemical compositions were similar to that of the water in the southern Hunger Steppe canal and in the River Amu Dar'ya, in addition to 0.01 M aqueous potassium nitrate. Measurements were made to determine the initial salinity in the horizons, the gypsum content, the exchangeable sodium, and the total absorption capacity; x-ray analysis defined the mineral composition, while adsorption studies defined the specific surface. In addition, infiltration tests and electron microscopy were employed. The soils were examined in three states: 1) with the initial salt and gypsum contents, 2) freed from salts, and 3) modified by a mixture of subsoil water and irrigation water.

Table 1 gives the main results from the chemical and x-ray studies.

The effects of saline waters on the parameters were examined by tenfold treatment with aqueous solutions of salts present in the subsoil water and irrigation waters with solid–liquid phase ratios of 1:8, which was followed by repeated washing with distilled water until a negative reaction for chloride was obtained.

The salt concentrations in the solutions were made up 1/5 from the subsoil water and 4/5 from the irrigation water.

Table 2 gives data on the compositions of these waters.

Methods. The mineral compositions were determined from the x-ray patterns recorded with a DRON-2 diffractometer with CuK_α radiation.

Classical chemical analysis methods were used [4-6] (argentometric, EDTA, flame photometry, etc.).

Central Water-Resource Utilization Research Institute, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 34, No. 2, pp. 236-242, February, 1978. Original article submitted January 1, 1977.

TABLE 1. Mineralogical Composition and Chemical Characteristics

Material	Genetic horizon	Form of soil	Salt content dry residue, %	Gypsum, %	Absorption capacity	Exchangeable sodium, μ-eq/	Mineral composition
Hunger Steppe (collective farm No. 5)	I	with initial salt and gypsum contents	2,1	14,45	17,3	0,8	quartz, gypsum, calcite, hydromica, kaolinite, and montmorillonite;
		washed free from salts	—	6,8	17,0	0,7	
		modified by a mixture of subsoil water and irrigation water	—	6,54	16,8	0,75	
	III	with initial salt and gypsum contents	3,79	15,20	11,66	1,11	quartz, gypsum, dolomite, fedspars, hydromica, kaolinite, and montmorillonite
		washed free from salts	—	4,91	10,16	0,65	
		modified by a mixture of subsoil water and irrigation water	—	6,4	8,84	0,7	
Takyr-like soil, Karsha Steppe	I	with initial salt and gypsum contents	0,49	0,1	16,4	1,4	quartz, feldspars, calcite, gypsum, and a mixed-layer phase (transitional from hydromica to kaolinite), hydromica, and chlorite
		with initial salt and gypsum contents	0,35	0,2	18,3	1,2	
	II	washed free from salts	—	0,0	16,0	0,66	
		modified by a mixture of subsoil water and irrigation water	—	0,0	15,2	2,33	

TABLE 2. Salt Contents of Soil Water and Irrigation Water

Object	Water type	Ion contents, g/liter						
		HCO_3^-	Cl^-	SO_4^{-2}	Ca^{+2}	Mg^{+2}	Na^+	Dry residue
Hunger Steppe (collective farm No. 5)	Subsoil waters	0,43	2,34	11,7	0,4	0,22	4,21	19,26
	Irrigation water Southern Hunger-Steppe canal	0,15	0,13	0,56	0,081	0,043	0,052	1,037
Takyr-like soil Karsha Steppe	Subsoil waters	0,27	5,52	4,89	0,62	0,73	3,31	14,45
	Irrigation water Amu-Dar'ya	0,075	0,063	0,107	0,069	0,003	0,040	0,36

The specific surface was deduced by measuring the bound-water concentration and the density change of a dispersion medium mixed with the solid, which took up the adsorbed water [7]; thermal desorption by nitrogen was also employed.

The filtration studies were made with F-1m instruments by analogy with the method of [8], while the electron micrographs were recorded with an EM-9. Table 3 gives the particle sizes, as well as the main results from the filtration studies, while Fig. 1 shows the chloride content during washing for genetic horizons I and III in the Hunger Steppe for various levels of water content and water-soluble polymer.

Even a crude analysis of the results indicates the following:

1. The various water-soluble polymers accelerate the desalination from the initial level to the minimum level [9] by factors of 2-2.5.

2. These polymers increase the permeability factors for the highly saline soil in the natural porosity range by factors of 1.4-1.5, whereas the values for the washed state are virtually unaltered.

TABLE 3. Infiltration and Structure Parameters of Soils

Soil state	Polymer added	Permeability coefficients $K \cdot 10^{12}$ for given porosity coefficients ε				Mean microaggregate size, μ
Hunger Steppe, I soil horizon		$\varepsilon = 0,75$	$\varepsilon_T = 0,796$	$\varepsilon = 0,85$	$\varepsilon = 0,90$	
With initial salt content	Without polymer	0,024	0,055	0,095	0,136	0,611
	0,05% K-4, K-9	0,045	0,083	0,131	0,181	0,450
Washed free from salts	Without polymer 0,025% K-4, K-9, S MMA	0,045	0,083	0,131	0,181	0,410
Modified by irrigation water and subsoil water mixture	Without polymer	0,045	0,083	0,131	0,181	0,354
Hunger Steppe, III soil horizon		$\varepsilon = 0,50$	$\varepsilon = 0,55$	$\varepsilon_T = 0,63$	$\varepsilon = 0,65$	
With initial salt content	Without polymer	0,029	0,111	0,266	0,309	0,617
	0,05% K-4, K-9 0,025% K-4, K-9	0,121	0,212	0,383	0,429	
Washed free from salts	Without polymer	0,121	0,212	0,383	0,429	0,370
	0,025% K-9, S MMA, PEM	0,121	0,212	0,383	0,429	
Modified by irrigation water and subsoil water mixture	Without polymer	0,121	0,212	0,383	0,429	0,49
Karsha Steppe, II soil horizon		$\varepsilon = 0,90$	$\varepsilon_T = 0,97$	$\varepsilon = 1,05$	$\varepsilon = 1,10$	
With initial salt content	Without polymer 0,05% K-4, K-9	0,1032	0,1556	0,2238	0,2711	
Washed free from salts	Without polymer 0,05% SVAM, S MMA, SVAN	0,1532	0,2309	0,3320	0,4022	
Modified by irrigation water and subsoil water mixture	Without polymer	0,1032	0,1556	0,2238	0,2711	

Note. ε_T is the porosity of the soil in the natural state.

3. Accelerated elution of the gypsum from the soil is accompanied by an increase in the water permeability by a factor 1.4-1.5.

4. Modification of a soil by means of mixtures of irrigation water and subsoil water does not alter the filtration coefficient appreciably by comparison with salt-free soils, nor is the maximum swelling, gypsum content, or exchangeable sodium appreciably altered.

All of the results are explained by the measurements.

Soluble salts in any dispersed system tend to compress the diffuse layers around the particles and increase the water permeability; results of this kind have been given for monothermite [10].

It has been shown [1] that the macromolecules of a water-soluble polymer can regulate or adjust the behavior of a finely divided system, not only on account of particle coagulation but also because the exchangeable cations are partially bound; i.e., some of the exchangeable cations become localized within the pores rather than at the solid–liquid interfaces. The result is a material less resistant to external factors. This effect from a polyelectrolyte determines the increased transport of inorganic salts and accelerates the desalination during washing. Similar results have been obtained elsewhere.

For instance, it has been shown [11] that an initially takyr-like soil artificially treated with sodium chloride will yield up 52% of the salts during the first stage of washing after treatment, whereas only 26% of the NaCl is lost under the same conditions with an untreated soil, while the rate of elution is increased by a factor of 4.

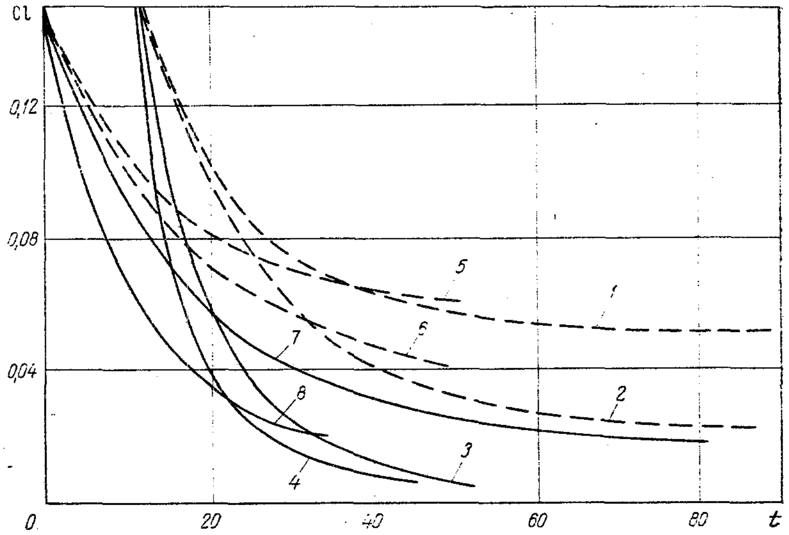

Fig. 1. Variations in chloride content during washing for Hunger Steppe soils in relation to water content (P %) and content of water-soluble polymers (C %). First genetic horizon: 1) P = 30, C = 0; 6) P = 34, C = 0; 7) P = 30, concentration of K-9 = 0.05; 8) P = 33, K-4 concentration 0.05. Third genetic horizon: 5) P = 17.8, C = 0; 2) P = 22.3, C = 0; 3) P = 22.5, K-9 concentration 0.05; 4) P = 18.7, K-4 concentration 0.05.

It has also been found [12] that the water permeability and salt loss are increased for a salt-march meadow soil in the presence of K-4; the accelerated salt loss and water transport go with a certain increase in the rate of gypsum loss in the presence of water-soluble polymers.

The gypsum crystals in a soil form clumps with the clay minerals, and these produce conditions for additional hydration, which ultimately reduces the water permeability. It has also been found [13] that gypsum adversely affects the physical parameters of soils. In particular, the shape of the gypsum clumps can affect the water permeability of an irrigated soil. An increase in the water content tends to enlarge the gypsum crystals, which itself reduces the permeability and blocks the pores. Accumulative salt-marsh soils show considerable difficulty in desalination due to the poor permeability, since some of the toxic salts are trapped in the gypsum crystals.

In our experiments, the permeability increased by a factor 1.4-1.5 on reducing the gypsum content from 15 to 7%.

Previous measurements [3] have provided a basis for generalizing the filtration and adsorption data to define the relative changes in the filtration coefficients for clay soils modified with polymers, where there is a specific effect on the particle surface for K-9, PAA, and K-4 water-soluble polymers.

These curves have been constructed for the modified soil at optimal polymer levels, and values were calculated for the mean porosity using the filtration coefficients for the unmodified soil with the appropriate porosity coefficients. The curves were monotonic functions, and the ratios of the filtration coefficients for the modified soil and unmodified soil for specific surfaces of 200-240 m^2/g were close to 1. However, the specific surfaces of medium-grained loams and clays in the Hunger Steppe and the takyr-like clays in the Karsha steppe lie in this range.

We have found [1-3] that K-9, PAA, and K-4 are adsorbed at free hydroxyl groups via their carboxyl groups, which tends to bind the particles into clumps and thus increase the permeability. The increase is determined by the number of adsorption centers (active groups) per unit length of the macromolecule as well as by the number of free hydroxyl groups, in addition to any effect from the exchangeable cations per unit surface area. There are thus strong interactions between the polymer and the solid, particularly for montmorillonite. Any excess content of carboxyl groups results in an additional content of charged particles when the pore space is at the natural level (in contrast to a suspension), which causes repulsion between the particles, and thus dispersal of the aggregates, which may reduce the permeability, as occurs in kaolinite clays.

The clay fraction in these soils in the main consists of hydromica with a little kaolinite and montmorillonite.

The concentrations of active centers in such systems are intermediate between those for montmorillonite and kaolinite, which means that the conditions are intermediate between those discussed above, where conflicting tendencies from the polymers make themselves felt.

Modification with a mixture of irrigation water and subsoil water involves the introduction of additional sodium ions; these are adsorbed by the active centers, which tends to disperse the particles and thus to reduce the permeability.

However, our measurements showed that the permeability factors were unchanged, as were the levels of exchangeable sodium in the washed and modified Hunger Steppe soils, which is ascribed to the effects of gypsum in the adsorbed complex.

The calcium in the gypsum is displaced by the sodium, which reduces the alkalinity of the soil and improves the physical properties, while causing irreversible coagulation of the colloids.

A somewhat different situation occurs with takyr-like soils.

There is an increase (Table 3) in the permeability of the washed specimens, namely, by 40% by comparison with the initial value, which is due to the elimination of gypsum and the partial dissolution of the calcite and dolomite.

However, the secondary processing with a mixture of salts during the modification and subsequent washing to negative chloride reaction results in the accumulation of exchangeable sodium (increased from 0.66 to 2.33 mg-eq/100 g, Table 1), with a reduction in the permeability coefficient by a factor of 1.4.

Modification of a takyr-like soil by subsoil water or any other combination of dissolved salts at high concentrations can increase the salt contamination of the soil and markedly reduce the water permeability.

Therefore, the salinity of water, obtained by mixing irrigation water and subsoil water in a ratio of 5:1, is such as to have no adverse effects due to the accumulation of exchangeable sodium in such a soil, and there is no appreciable deterioration in the water permeability, and therefore such a mixture can be used at periods when irrigation water is scarce.

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