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DILATATION OF THE METHOD OF THE FIXATION OF MOVEABLE SANDS

Summary. A new method of physicochemical blocking deflation of movable sands has been developed that represents their fixation in a wet state with binders. It is proposed to carry out sand-fixing works during rainy periods or after preliminary moistening of the sandy surface in order to intensify and reduce the cost of sand-fixing works. The substantiation is carried out on the example of some of the approved and recommended binders based on the express method of studying the possibility of their application to obtain a polymer sandy protective crust on wet sand. The emerging defensive hull is characterized by resistance to wind-sand stream and evaluated by plastic quality and thickness. The impregnation of damp sand with a smaller sum of cover than dry sand is related to an alteration within the nature of impregnation from gravity to capillary. With a decrease in the specific surface of the bulk material and an increase in the pore space, gravitational forces are predominant. The process of wet sand impregnation is associated with the acceleration of the adsorption of the dispersed phase and a reduction in the hole covered due to the partial occupation of the interpore space with water. As a result, in wet sand, the depth of sand impregnation with the binder increases at a lower consumption per unit volume of sand. The following has been established: the possibility of impregnation of approved and recommended binders into wet sand, the inverse dependence of the binder concentration in emulsion forms on the humidity of the sandy surface, the time of application of various binders after moistening the sand and the possible savings of binders.

1. INTRODUCTION

Mobile and partially overgrown sands in Uzbekistan occupy an area of over 13 million hectares. Significant areas of the territory of Uzbekistan adjacent to desert zones are historically under the threat of shifting sands (the Amu Darya delta, part of the Kyzylkum, Alat, Karakul, Dzhandar, Kagan, Rometan, and Karaul-Bazar districts of the Bukhara region, which border the sands of Sundukli; Mubarek, Bakhoristan, Nishan, and other areas of the Kashkadarya region; and the lands of the Jizzakh region, which border the Kyzylkum desert and the Surkhandarya region) [1].

In all arid regions, a person has to expend much effort in order to prevent the threat of the onset of shifting sands. The construction of new roads is accompanied by a significant technogenic impact on the natural environment. The entire construction process is carried out in a short time. The period from the beginning of construction to the commissioning of the road is characterized by a high concentration of machinery and an intense impact on the environment. The rate of technogenic change in the surface layer is much higher than the rate of the self-recovery of landscapes [2, 3].

The practical need to protect railway tracks from sand drifts is associated with the widespread occurrence of this phenomenon. The deployed length of the republic's railways exceeds 6500 kilometers, including more than 3000 km of railways that run in sandy deserts and semi-deserts [4, 5]. These areas are threatened by the eolian movement of sands, dust storms, and dry winds. The

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construction and operation of railways in these areas should be carried out without damaging the environment using natural and climatic features to benefit both the construction and the ecological state of these territories.

The construction and operation of industrial facilities in sandy deserts in specific railroads and streets are carried out in troublesome physical, geological and climatic conditions [4, 6]. Issues are caused by the negative impact of the wind on the free sandy surface, causing the free sand stores to collapse, which leads to sand transport and the arrangement of sand floats. Sand floats harm the unwavering quality of normal and specialized frameworks within the setting of the security of the development of ground vehicles. The damage they cause to railways and roads is usually significant. Skids sharply worsen the technical and operational performance of roads; lead to the premature failure of rails, pavement, and vehicles; and increase maintenance costs.

Damage from drifts is also imposed on conduits, hydro-reclamation system abilities, and pasture lands. The beginning stages of shifting sands is a serious threat that requires a lot of effort to mitigate. Therefore, reducing the negative effects of wind is critical to the reliable operation of natural and engineered systems in deserts.

Works to protect production and technical systems from sand drifts in sandy desert conditions are carried out by fixing and delaying, respectively, the blowing of sand towards the object. Such measures, known as sand fixing works (SFW), are, in a broad sense, a form of quicksand recycling [6, 7].

Based on their historical development, materials used, and technological features, existing methods of protecting engineering objects from moving sands are categorized into four groups [4, 8]: phytomelioration (forest belts of tree and shrub plants, grass cover, etc.); mechanical protection (clay, wooden shields, reed cage protections, etc.); physicochemical consolidation of sands with binders (water-soluble and water-insoluble); and combined (cells in combination with planting seedlings and seedlings of plants, sowing psammophyte (sandy soil plants) seeds in combination with the device of an astringent sandy protective (anti-deflation) crust, etc.).

Phytomelioration (hereafter, “the biological method”) is a relatively cheap option for fixing sands that is also the most environmentally safe, reliable, and common available method. It has some disadvantages, such as a small percentage of plant survival in arid desert conditions and low efficiency.

At the beginning of the 20th century, a physicochemical method (PCM) was proposed to address the need to intensify SFW and make it cheaper [4, 8]. This method significantly reduces the cost of protecting objects from sand drifts, makes it possible to replace labor-consuming reed cages with comprehensively mechanized ones and increases the effectiveness of phytomelioration works. Treating one hectare of a sand surface with a chemical ameliorant (for example, bitumen emulsion) using various types of tractor sprayers is 20 times cheaper than mechanical protection from sawn timber [1, 8]. The main disadvantage of protective crusts obtained from binders is their short service life of one to two years; however, this disadvantage is completely overcome by combining SFW with phytomelioration. The anti-deflation layer of sand created by SFW increases the survival rate of sand-loving plants by up to 80% [4, 6]. At the same time, some authors believe that PCM protects the surface from blowing out for three years [9, 10, 11]. At present, there are many PCMs for fixing sands. However, their implementation is limited to the dry season, which narrows the scope of the method and leads to irrational use of resources.

Introducing a layer of sand fixed with a chemical ameliorant to ensure the immobility of a sandy surface creates favorable thermal and humidity conditions in the initial period of plant survival and growth. In the summer, the upper layers of sand, which are exposed to direct sunlight, heat up to 70 °C and lose most of their moisture. Obviously, the wet season is favorable for sowing seeds and seedlings. However, at the end of the rainy season, moisture in the upper layers of sandy soils remains for a very short period, which is insufficient for the growing season of sand-loving plants; thus, the germinated plants die from a lack of moisture. There is a need to prolong the moisture retention in the upper layers of sand. A longer preservation of moisture and a lower heating temperature in the upper layers of the soil are possible with the use of binders and the formation of a protective bindery sand crust. At a temperature above the crust (25% HE) of 30 °C, the moisture content of the sand under the crust decreases by only 3–6% in 100 hours and, subsequently, decreases only slightly [8, 9].

Thus, it is necessary to research the most economically viable options—namely, the possibility of impregnating wet sands with binders and obtaining a protective crust that satisfies the operating conditions.

It is well-known that in sandy soils, as in other soils, the water is bound and free. Mineral soil particles are negatively charged, and water molecules are dipoles with a positive charge (one oxygen atom) at one end and a negative charge (two hydrogen atoms) at the other end. Due to electromagnetic effects, water dipoles are attracted to mineral particles with great force, thereby forming a layer of strongly bound (adsorbed) water. Electromolecular forces work together at the surface of mineral particles to order several hundred MPa. Therefore, water molecules close to mineral particles with a thickness of one to three rows cannot be separated by external pressure or the action of water pressure. The following layers of water, as they move away from the surface of soil particles, are bound by smaller interaction forces and form a layer of loosely bound water. Water molecules that are outside the field of the electromolecular forces of interaction form a layer of free water.

It can be assumed that the fixation of moving wet sands will expand the scope of the methods within the PCM and increase the duration of the working season. Therefore, the use of technical and human resources will be more comprehensive throughout the year and, importantly, save the binder. Therefore, this is a resource-saving method of obtaining material.

2. MATERIALS AND METHODS

The physicochemical and technological properties consist of several compositions based on grain and dispersed materials. The number of contacts between solid particles depends entirely on the size, shape, and microrelief of the particles. The strength of individual contacts depends on the contact area, the chemical nature of the components, and their energy state. The facility of the binder-sand protective crust to perform its function depends entirely on the physical and mechanical properties of the sand consisting of the physic-chemical properties of the binder. Grain size characteristics and mineralogy are important characteristics for identifying the nature and origin of sand deposits [9–13].

The medium is an astringent in the protective layer in the form of a dispersed system, the phase of which is grains of sand. The study of their properties for a deeper disclosure of the mechanism of formation of a resource-saving protective anti-deflationary crust is an important research task.

A common feature of desert sands is a noticeable or sharp predominance of particles less than 0.25 mm in size and up to 0.1 mm of various shapes; such sands are also fine-grained and well-sorted [14, 15]. The granulometric composition of the sand was determined using sieves with hole sizes of 0.5, 0.25, and 0.1 mm and laboratory scales [10, 11, 12]. The module of the size of the sands of the deserts of Uzbekistan is not larger than 0.25. Thus, the studied sands are referred to as fine sands (i.e., they are the result of a long rewinding and grinding), due to which the grains of sand are rolled, and light and small fractions are carried away by the wind. An X-ray diffraction quantitative analysis of the mineral structure of the studied Kyzylkum sand was made on the Empyrean diffractometer with data processing (Fig. 1).

The purpose of this study is to substantiate the possibility of obtaining a polymer sandy protective crust of a given quality on sands of a wet state. Justification was carried out using the example of some of the approved and recommended binders based on an express method for studying the possibility of their application to obtain a polymer sandy protective crust.

Emulsions are obtained by emulsifying bitumen and gossypol resins. A viscous bitumen resin obtained at the Tashkent asphalt concrete plant was used to obtain the emulsion. Gossypol resin is a waste product of cottonseed petroleum production produced by oil and fat factories. In areas where these hazardous wastes are accumulated and stored, sanitary conditions are deteriorating. Specifically, the territory is contaminated, toxic fumes are released into the atmosphere, and an unpleasant odor is created [1]. Therefore, the issue of cleaning the environment from its negative impact will be solved using resin.

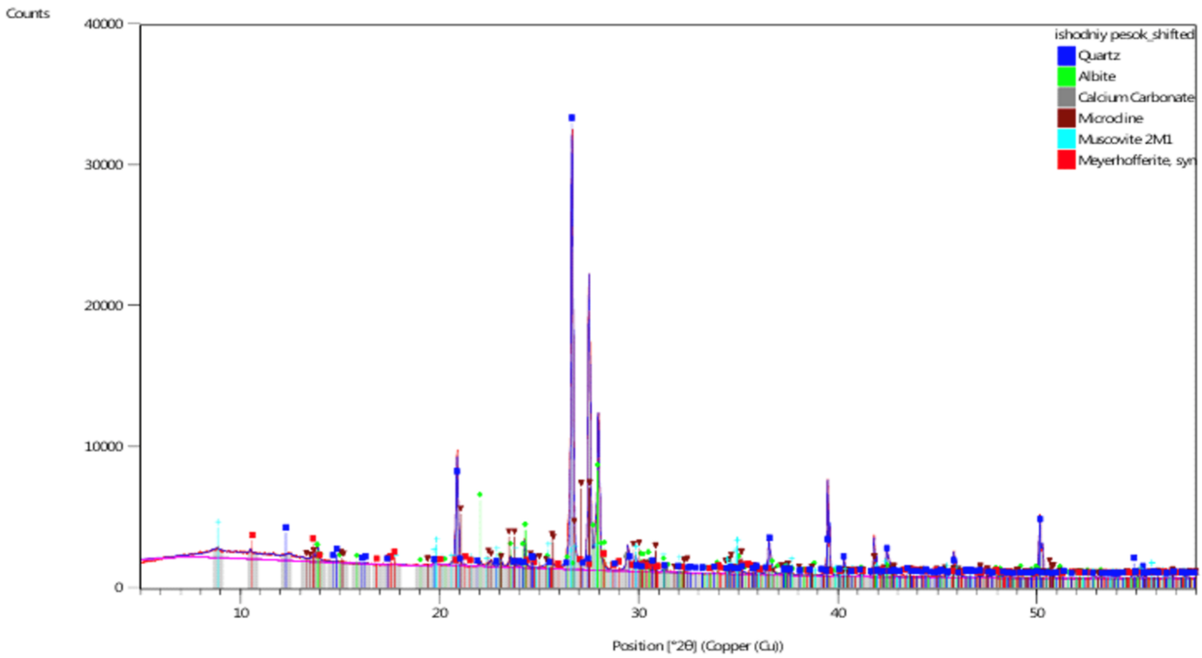


Fig. 1. X-ray diffraction structural analysis of the Kyzylkum sand

A quantitative mineralogical analysis of the sand of Kyzylkum was performed under a binocular microscope BM-2. The X-ray diffraction patterns on the Empyrean diffractometer with data processing software (Fig. 1) confirmed the results of the mineralogical analysis.

The method for determining the chemical and mineralogical composition of the substrate is as follows:

- quartering a sample of 0.2 kg of thoroughly mixed initial sand;
- washing it in water to a gray concentrate;
- isolating the heavy fraction by separating the entire concentrate in the form of brome.

The heavy fraction is separated using a Sochnev magnet into magnetic, electromagnetic and non-magnetic heavy fractions. The original sands and isolated heavy fractions were examined under a BM-2 binocular microscope. The main and minor minerals were identified and estimated visually (semi-quantitatively) as a percentage of the volume.

The results of the mineralogical analysis are listed in Tab. 1.

A universal permanent magnet of the Sochnev system was used to separate minerals according to their magnetic properties. Minerals were separated by magnetic properties into the following groups:

- highly magnetic minerals (attracted by an ordinary permanent magnet;
- electromagnetic minerals (separated on an electromagnet with a current strength;
- non-magnetic minerals.

Fractions were weighed with an accuracy of 0.001 kg.

The impregnation of wet sand with solution was studied using a new binder—polymer glue PG-001. The chemical composition of the PG-001 glue was obtained by spectrographic on a Nicolet iS50 infrared Fourier spectrometer.

The IQ spectrum presented above shows that the absorption signals caused by the functional groups OH, -NH2 were observed in the analyzed substance. The broad and intense signal in the region of 3000–3500 cm^{-1} was caused by the valence vibration of the –OH group. The broadened appearance of this signal occurred due to intermolecular and intramolecular hydrogen bonds. Also, an absorption signal due to the valence vibration of the –NH2 group can be observed in this area. The absorption signal in the region of ~1600 cm-1 was caused by the deformation vibration of the –OH and –NH2 groups. These functional groups are highly reactive and can connect to organic and inorganic substances in the soil via intermolecular and intramolecular hydrogen bonds and Van der Waals forces.

The components of the polymer adhesive are unsaturated monomers: acrylic acid and esters of methacrylic acid with methyl, stearyl, cyclohexane, isobornyl, isodecyl, and dimethylaminoethyl alcohols (Fig. 2). The water-solubility of the monomers that make up the adhesive determines their hydrophilic properties.

Table 1

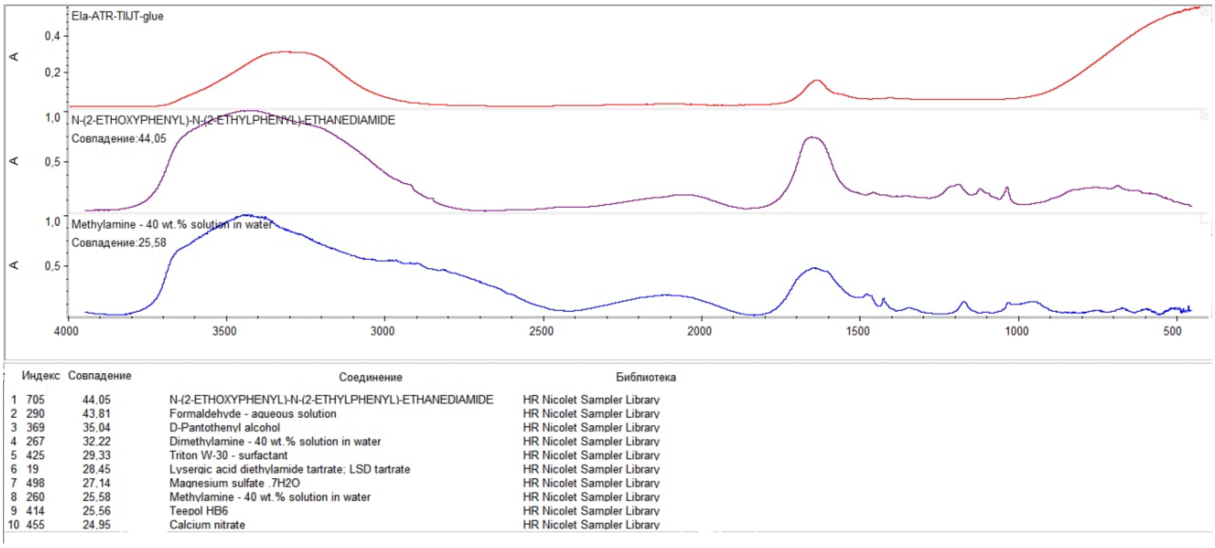
Quantitative mineralogical composition

Composition	Sand source, 200 g	Including the heavy fraction, g (0.2%)		
		Highly magnetic fraction	Electromagnetic fraction	Non-magnetic heavy fraction
		0.032	0.35	0.014
1. Minerals, %		Heavy fraction, %		
Quartz	62.5			
Feldspars	24.8			
Amphiboles	2.2		30	
Biotite	0.13			
Muscovite	0.048			
Calcite	7.3			
Magnetite		100		
Martit			2	
Ilmenite			6	
Sphene				59
Apatite				32
Tourmaline			0.5	3.5
Epidote			42	
Zoisite				
Rutile			15	
Zircon				0.5
Pomegranate			2	
Pyrite oxide			0.5	
Leucoxene			2	3
Barite				2
2. Other materials, %				
Organic and other impurities	2.65			

The systemic comprehension of cognitive activity is accompanied by the logic of science. Based on the idea that there are two levels of logic in science, logical means are used to obtain knowledge. Thus, a retrospective analysis of the available information on the methods of protecting objects from moving sands was used to substantiate the relevance of the research topic, confirm the existing problem, and select the key method (physicochemical) of the fixation of moveable sands as an object of research.

The algorithm of random search in subspaces was applied to study changes in sand moisture over time and at different depths from the sand surface. According to the method offered by Adylkhodzhaev A.I., the impregnation of the depth water and binder in the sand was determined using a moisture meter with a probe fixed at a depth of up to 100 mm [4, 8]. Humidity measurements were carried out at different time intervals until a constant humidity of 5% was established (i.e., until the sand reached an air-dry state in natural conditions).

Valuation changes in the protective coating were made by measuring the plastic strength of the protective coating P_m and its thickness h. Currently, weights and a metal ruler are used to measure the plastic strength and lever conical plastometer system at Moscow State University. The principle of operation of the plastometer is based on measurements of the load required to immerse a cone with an apex angle of 45° into the test mixture (crust) to a depth of 5 mm [1, 4].



	Индекс	Совпадение	Соединение	Библиотека
1	705	44,05	N-(2-ETHOXYPHENYL)-N-(2-ETHYLPHENYL)-ETHANEDIAMIDE	HR Nicolet Sampler Library
2	290	43,81	Formaldehyde - aqueous solution	HR Nicolet Sampler Library
3	369	35,04	D-Pantothenyl alcohol	HR Nicolet Sampler Library
4	267	32,22	Dimethylamine - 40 wt.% solution in water	HR Nicolet Sampler Library
5	425	29,33	Triton W-30 - surfactant	HR Nicolet Sampler Library
6	19	28,45	Lysergic acid diethylamide tartrate; LSD tartrate	HR Nicolet Sampler Library
7	498	27,14	Magnesium sulfate .7H2O	HR Nicolet Sampler Library
8	260	25,58	Methylamine - 40 wt.% solution in water	HR Nicolet Sampler Library
9	414	25,56	Teepol HB6	HR Nicolet Sampler Library
10	455	24,95	Calcium nitrate	HR Nicolet Sampler Library

Fig. 2. PG-001 polymer glue on a Nicolet FT-IR spectrometer

3. RESULTS

The change in the moisture content of the sand must be known to determine the possibility and threshold of the beginning of the binder impregnation. The results of studies of changes in sand moisture over time are presented in Tab. 2.

Table 2

Changes in sand moisture in a layer with a thickness of 15–20 mm

Time t [min]	Sand moisture W [%]
0	32–22
10	20
20	19
30	17
40	15
50	13
60	11.5
70	10
80	8
90	6
100	4

The formation of a polymer-sand protective crust resistant to the impact of stream wind-sand in air-dry sand occurs in a layer up to 10 mm thick [8]. Bearing in mind the possibility of increasing the thickness of the fixed layer in wet sand at the same consumption of the binder, changes in the moisture content of the sand were investigated in a layer up to 20 mm thick. Based on the graphic interpretation of the tabular data (Tab. 2), the linear fit gives the formula for the change in humidity over time, which was obtained with the value of the accuracy of the approximation $R^2 = 0.965$ (the uncertainties of the obtained parameters were 0.75 and 0.013, respectively):

$$W = 23.75 - 0.201t \tag{1}$$

Knowing the information about changes in the moisture component of the sand over the period and the moisture threshold (in %) at which the sand is impregnated, it is possible to determine the time at the commencement of the impregnation of the sand with binders in the period after rain or after artificial sprinkling (Tab. 2).

In the first minutes after complete moisture saturation, the pore space of the sand is filled with water, making impregnation with a binder impossible. However, after a certain time (after the end of rain or artificial humidification with full moisture saturation), the moisture content of the sand in the surface layer decreased due to the evaporation and penetration of water into the lower layers. This process caused freeing up of a part of the space between the sand grains and created the possibility of impregnating the binder. In this regard, the moisture threshold was determined at which impregnation with binders is possible (Tab. 3).

Considering this, it is advisable to investigate the possibility of using binders on sands of various states (air-dry and wet) in two stages. It is important to identify the maximum moisture content of the sand at which it is possible to implement the proposed methods, as well as the minimum necessary and sufficient precise ingesting at working structure of the binder according to aggregated physical and mechanical indicators. Then, upon receipt of a positive result, more detailed studies can be carried out.

The resins are emulsified to overcome their hydrophobicity. Emulsions are well impregnated by dry and wet sand. For a multicomponent binder, this is apparently due to its hydrophobic property. Therefore, impregnation is possible only at a moisture content below 17%. Due to the hydrophobicity of some binders, such as oil and resins, they are concentrated in the upper layers of the crust. This leads to the production of a crust with an uneven distribution of the structuring over the thickness and a decrease in the strength properties of the crust protective in the minor layers. When impregnated with IPG-001 and sulfite-yeast mash (SYM) glue solutions, the filtering process occurs more intensively. Solutions, in comparison to emulsions and resins, are more active, more easily miscible with aqueous compositions, and easier to manufacture [1, 4, 8].

The permeability of sand with different moisture contents containing binders was investigated, and the threshold moisture content of each of them was revealed (Tab. 3).

Table 3

Impregnation method of moisture limits to use in technological feasibility

Polymer glue solution concentration [%]	Dzharkurgan petroleum	Emulsions of bitumen (EB) and gossypol resins (GR) concentration [%]					Sulfite-yeast mash [%]
1.5–2.5		5	10	15	20	25	14
W [%]							
22	17	32	32	32	24	24	24

An X-ray diffraction structural analysis of knitted-sandy crusts obtained on air-dry and wet sands (Fig. 3) was performed with data processing by software on an Empyrean diffractometer.

The costs of binding materials for impregnating air-dry and wet sands were determined. The resource-saving costs of binding materials were obtained by impregnating wet sand with an assessment of the quality of the protective crust by the express method. The moisture content of the sand was taken according to the impregnation method of moisture limit to be used to assess technological feasibility (Tab. 4).

4. DISCUSSION OF EXPERIMENTAL RESULTS

Tab. 1 presents the main mineral in the substrate of quartz. The quartz of the feldspars makes up more than 80% of their content. The heavy fractions—whose content in the sample is about 0.2% and contain 50% sphene, 27% apatite, 15% rutile, 3% leucoxene, 2% tourmaline, and 1% barite—of desert sands are classified as well-sorted and fine or quartz-feldspar (63% and 25%, respectively) substrates.

Shape of the grains led to the idea that roundness is probably a more important characteristic than sphericity regarding their effects on sands [1].

The chemical structure of the substrate is represented generally by silica SiO_2 (63 %), solid solutions of the ternary system of the isomorphic series $Na[AlSi_3O_8]$ (25 %), salts of carbonic acid and calcium $CaCO_3$ (7 %), potassium mica $KAl_2[AlSi_3O_{10}](OH)_2$, and magnetites $FeO \cdot Fe_2O_3$.

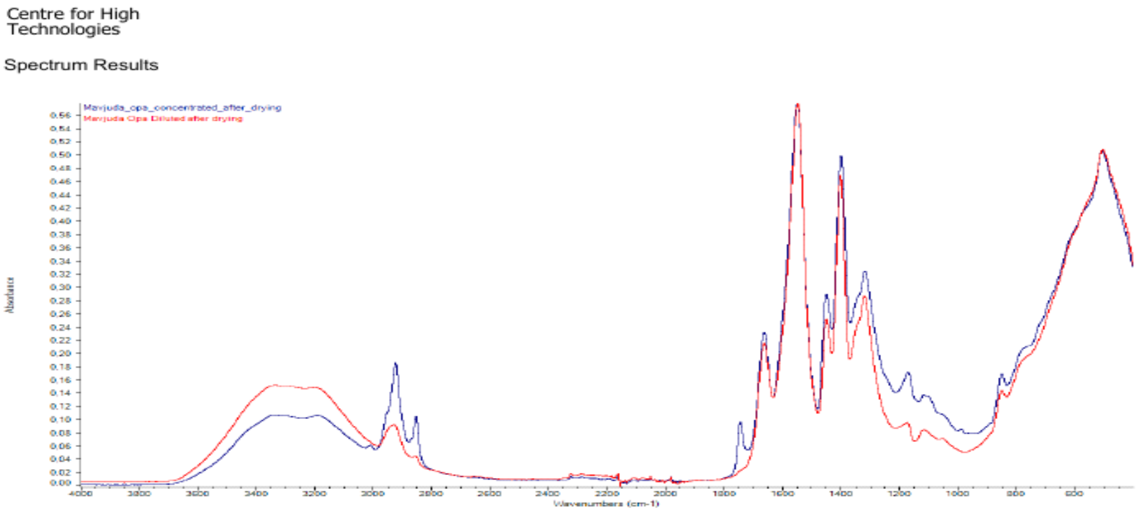


Fig. 3. Comparison of structural diffraction patterns of binder-sand crusts obtained by impregnating an air-dry and wet substrate with an adhesive solution with a concentration of 2.2%

Table 4

Consumption of the binder according to the conditions of the demands for the operation of the protective crust ($P_m \geq (2.5 \div 2.7) \times 10^3\ Pa,\ h\ \geq 5\ mm$ [1, 3]))

Binder type	Binder consumption, q [l / m ^{2}]		Plastic strength P_m 10^3 [Pa]		Protective shell thickness h [mm]	
	Air dry sand	Wet sand	Air dry sand	Wet sand	Air dry sand	Wet sand
Gossypol emulsion concentration (sand moisture 32%): 10% 15%	2.7 2.8–3.0	1.0–1.5 1.5–2	3.5 4.0	3 3.6	6 5	7.5 6.0
Bitumen emulsion concentration (sand moisture 32%): 10% 15%	2.7 2.7	1.0 1.5	5 7	3.5 4	5 5	8 7
Dzharkurgan petroleum (sand moisture 17%):	1.3–1.7	1.2	4.5	3	5	7
Polymer glue solution concentration 2.2% (polymer glue solution concentration 22%):	3.0	1.5	4	7	5	6

The authors of earlier studies on the consolidation of mobile sands of a dry state noted that when porous bodies are impregnated with binders, the classical concept of wetting, which is caused only by surface tension, is incorrect. In the case of multicomponent sand from particles that exhibit different surface activities, selective wetting is observed, the nature of which is very complex. In this case, the accepted model of sand represents a capillary-porous body in which particles are stacked with different degrees of "packing" density. The degree of density depends on the shape and size particles.

During the process of sand moistening, complete moisture saturation is achieved. At the same time, the maximum humidity at a depth of 15–20 mm is equal to 24–32%. Sprinkling water from the upper layer moves downward under the action of a field of two forces: gravity and capillary suction. During the first 10 to 15 minutes, the humidity drops to 20%. Further, as a result of the evaporation of water in the upper layer of sand and gravity, the moisture content decreases. Subsequently, both internal forces (gravity and capillary absorption) and external forces (solar radiation, heat and wind) act on moisture in the upper layers. In the upper soil layer, the moisture change occurs more noticeably than in the lower layer (more than 10 mm from the ground surface), as this lower layer is protected from direct exposure to sunlight and wind. Further measurements of humidity showed its constancy, with a decrease in a layer of 15 mm from the soil surface to an air-dry state.

Thus, the impregnation of wet sand with emulsions is possible after the end of rain or artificial sprinkling (subject to maximum saturation of the sand with water), with solutions after 10–15 minutes and with petroleum after 30 minutes.

Under the protective crust, the moisture content of the sand does not decrease to less than 5–6% of the weight of the air-dry sand. In this case, water cannot move any further or evaporate since it remains in the form of disconnected accumulations at the junctions of sand particles. This phenomenon is associated with the possibility of coexistence in the sands of menisci and the force of unsticking pressure. At a certain thickness of the water film, these forces are in equilibrium, and water does not evaporate. When the air temperature above the protective crust rises to 60–65 °C after 120 hours of continuous heating, no significant changes occur in the 5–15 cm horizons. The 0- to 4-cm layer is subject to sharp evaporation. Due to subsequent heating, the layer at a depth of 1–3 cm almost dries up; by 300 hours, the moisture line is almost evened out. A 3- to 5-cm-thick layer of dry sand forms under the crust, which impedes the diffusion of water vapor. Water vapor is retained by the difference in capillary pressures at the low and upper meniscus surfaces of the grains of sand. With a sand moisture content of 10–30%, the temperature under the crust is 15–300 °C lower than above the open surface.

An inverse dependence of the concentration of the binder used in the form of emulsions on humidity has been established. Specifically, the higher the humidity, the lower the concentration of the binder should be. So, for emulsions with a concentration of 20–25%, the moisture content of sand should not exceed 24%; for concentrations of 5–15%, the moisture content should not exceed 32%. Binders used in the form of solutions of various concentrations can impregnate sand with 24% moisture. Apparently, this is due to the cork-like mechanism of emulsion impregnation during the impregnation process, which occurs due to its disintegration and the fusion of emulsified binder particles in the upper layers of the impregnated sand and preventing the penetration of the binder into wet sand.

X-ray diffraction structural analysis of knitted sand crusts was obtained on air-dry and wet sands (Fig. 3). Data processing by software on an Empyrean diffractometer showed the absence of chemisorption bonds. The obtained infrared spectra with three main repeated peaks indicate the physical nature of the formation of the structure of the binder-sand crust under the influence of physical adsorption. Therefore, the peaks have a similar character in the diffraction patterns of the lower and upper layers of the protective crust (Fig. 3). Consequently, there are no qualitative changes in the mineralogical composition of the sand. However, on the diffraction patterns of the protective crust substrate on the wet sand of the state, significant changes in the intensity of the peaks of these phases are observed (peaks at 2° angles of 13.68 and 13.90, 23.58 and 24.24, 27.50 and 27.96, and almost all peaks between 29.69° and 32°). This corresponds to the mica-muscovite phase.

In conclusion, the solution, including water, mainly interacts with the microcline and albite phases. The latter is characterized by layering. Probably, the interlayer space is saturated with water and the solution. This confirms the assumption that an increase in the colloidal layer of water absorbed on the surface of sand particles causes the pore space to decrease. At the same time, the size of the channels through which the binder penetrates into the sand decreases to sizes less than 10^2 mm, which results in a change in the predominantly gravitational nature of impregnation to the capillary.

In wet sand, this process occurs before impregnation with a binder. In the case of impregnation of wet sand with a binder, we believe the above interaction is already completed; that is, the micromica layers are filled with moisture. Consequently, this explains the decrease in the consumption of the binder and the increase in the depth of its impregnation with the achievement of the required quality parameters of the protective crust: plastic strength $P_m \geq (2.5 \div 2.7) \cdot 10^3 Pa$, crust thickness $h \geq 5\ mm$.

The decrease in solution consumption on wet sand is 1.5–2 times ($q = 1.0\ \div 2.0\ l/m^2$) less than on dry sand. The need to impregnate wet sand with a smaller amount of binder than dry sand is apparently also associated with a change in the nature of impregnation from gravity to capillary. With a decrease in the specific surface area of the bulk material and an increase in the pore space, gravitational forces are predominant. Thus, their role in the process of wet sand impregnation decreases, which is probably associated with the acceleration of the adsorption of the dispersed phase and, as a result, a decrease in the pore space. As a result of the partial occupation of the interposed space with water in wet sand, the depth of impregnation of the sand with the binder increases since its consumption per unit volume of sand decreases.

5. CONCLUSIONS

1. The possibility of fixing wet sands with their preliminary moistening (natural and artificial) with the previously proposed binders has been confirmed.
2. The changes in the moisture content of the sand in time were investigated, and the time of applying the binder after the wetting of the sand was established.
3. Due to the consolidation of wet sands with PCMs, the data related to technological solutions have been expanded, and the saving of binders has been achieved (i.e., the consumption of binders per square meter has been reduced).

Thus, it is possible to draw conclusions about the technical and economic feasibility of transferring the start of sand-fixing works in rainy periods of the year. Moreover, it is possible to carry out the SFW in a short time after the end of the rain or artificial sprinkling, which will significantly increase the efficiency and effectiveness of the SFW and, in general, the main biological method.

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