Investigation of the effect of contamination with chemical elements on changes in the content of clay fraction in sandy-clay rocks

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Abstract. The reasons for soil pollution that causes deviations in the mineral composition are considered. It is noted that changes in the chemical composition of the soil lead to a change in various fractions. This process is considered on the example of clay fractions. The sandy-clay rocks of the Leningrad region in the Russian Federation are considered. Modeling of situations on taking samples of rocks for research has been performed. Comparison of the calculations with the results of express control of the state of rocks by other methods is carried out. The method for determining the content of clay fraction in sandy-clay rocks has been determined.

1. Introduction

Soil pollution is one of the topical environmental issues, since soil is a non-renewable resource [1-8]. The main anthropogenic sources of soil pollution are chemicals used or produced as by-products of industrial activities, household, livestock and municipal waste (including sewage), agrochemicals and oil products [1-3, 7, 9-16].

Chemicals can enter nature by accident, for example, as a result of oil spills or leaching from landfills, as well as deliberately, as a result of the use of fertilizers and pesticides, the use of untreated sewage for irrigation or the ingress of sewage sludge on the ground [1, 3, 4, 7, 8, 15-18].

Microelements and metals enter the body through food products in contact with the soil. Both the excess and the lack of chemical compounds negatively affect the health and well-being of people. Deviations in the soil from the full-fledged mineral composition lead to disruption of metabolic processes and to the formation of intermediate chemical compounds in the body, leading to endemic diseases [3, 4, 16, 19-25]. In sandy-clay rocks, that are located in the Leningrad Region of the Russian Federation in large amount, these processes are very noticeable. To predict such processes, it is necessary to correctly determine the content of the clay fraction in sandy-clay rocks. The clay fraction is a group of particles with a size of <0.002 mm that is part of loose soil. It is usually represented by clay minerals. Soils, consisting of clay particles, shrink when wet, absorb large amounts of water and swell when moistened, and are solid when dry. Has a pronounced ability to coagulate. Irreversible coagulation is weakened. With a high content in the composition of soils and soils in an uncoagulated state, it gives them a reduced water permeability, a high but slow capillary rise, swelling and stickiness in a wet state, shrinkage, fracturing and dry hardness. These "specific properties" of rocks are especially important in predicting hazardous engineering and geological processes. In addition, valuable fertile
lands are formed on clay rocks of alluvial fans and intermontane depressions, they have a good natural water content, millions of people live on them.

The penetration of chemically active substances into the soil and soil affects the entire complex of properties associated with the presence of clay minerals in the composition of soils and soils, which in turn can lead to undesirable consequences of various scales [26-31].

2. Contamination of sandy-clay rocks
The most common and dangerous type of soil pollution is chemical. Various substances actively penetrate into the surface layers of the soil, as a result, the physicochemical parameters of soils change, their fertility decreases [1-5, 30-33]. Studies have shown that more than 80% of hazardous pollutants are concentrated in the fine clay fraction.

Hydrocarbons are one of the priority environmental pollutants [30-36]. They enter the soil as a result of accidents and leaks at the enterprises of the chemical and petrochemical industries, as products and wastes of the activities of oil production and oil refineries, as well as from the atmosphere - during the combustion of oil products [9, 11, 16, 33-39]. Soil pollution leads not only to a change in the human environment, but also to a change in the state and properties of soils. In many cases, this reduces the bearing capacity of the subgrade, which entails emergency situations at oil refineries, in buildings and structures [1, 7, 8, 16, 30-35, 37, 38, 40].

The soil base of the pipeline is clayey soils with lenses and interlayers of sands of various sizes. The experience of operating oil pipelines shows that quite often emergency situations occur on them, which leads to oil spills on the earth's surface [2, 15, 19, 20, 30, 31, 40]. And this, in turn, entails a change in the properties of the base soils and, as a result, affects the stability of the pipeline.

When clay soils are contaminated with machine oil up to 2.5%, coagulation processes take place in them, and with an increase in pollution, dispersion occurs. These processes are most intense in clays. A change in the aggregate composition entails a change in their physical properties. With an increase in the content of hydrocarbons in kaolinite and bentonite clays to 10%, a decrease in the number of plasticity and moisture content at the yield point is observed. With increasing pollution, the opposite pattern is observed. In hydromica clays, the opposite pattern is revealed. Thus, when soils are contaminated with hydrocarbons, the processes of coagulation and dispersion of particles are observed. The nature of these processes is associated with a change in the energies of the solid and liquid components of the soil. A change in the interaction energies of particles entails not only a change in the physical properties of clay soils, but also mechanical ones.

Industrial effluents also cause changes in the properties of clay soils [40]. The action of alkali solutions on sandy-clayey soils leads to the destruction of silicates and the formation of new compounds, cement-like minerals, which have a large volume in comparison with the initial compounds [41-43].

When the acid acts on the clay component of the soil, the aluminosilicate core is destroyed along the \( \equiv \text{Si} - \text{O} - \text{Al} = \) bonds with the release of \( \text{Al}^3+ \) and \( \text{Fe}^3+ \) from the crystal lattice, followed by their binding with the acid anion. The action of acids on clayey rocks is also manifested in a decrease in the content of the clay fraction, a decrease in the number of plasticity, density of the soil and the density of its mineral part.

All these changes in the properties of sandy-clayey soils can lead to various soil deformation: landslides, floods, uneven precipitation, etc. This, in turn, leads to the destruction of buildings [1, 4, 7, 9, 16]. The destruction of the oil pipeline and the oil spill have a strong negative effect on the environment.

3. Measuring method
The way to measure the composition of the soil and its correctness are important points. If measured incorrectly, the composition of the soil can be measured incorrectly and, as a result, dangerous geotechnical situations may arise.

The hydrometric method is the most used laboratory method for determining the particle size distribution of sandy-clayey soils. It is based on measuring the density of the suspension prepared from
them during its settling and allows you to determine the content of fractions in the rock with a diameter of less than 0.25 mm.

To calculate the correct time from the end of agitation of the suspension to measuring its density, consider the Stokes formula, which allows us to determine the sedimentation rate of particles:

\[ v = \frac{2}{9} \cdot g \cdot r^2 \cdot \frac{\rho_s - \rho_t}{\eta} \]  

where \( r \) is the particle radius, \( \rho_s \) is the density of the mineral part of the soil, \( \rho_t \) is the density of water, \( g \) is the acceleration of gravity, \( \eta \) is the viscosity.

Note that such parameters as the density of water and its viscosity depend on the temperature of the suspension.

Also consider the formula for determining speed in terms of distance and time:

\[ v = \frac{H}{t} \]  

where \( H \) is the distance traveled by a particle, \( t \) is the time of falling particles.

Using formulas (1) and (2), we express the time of falling particles:

\[ t = \frac{18 \cdot \eta H}{g \cdot d^2 \cdot (\rho_s - \rho_t)} \]  

where \( d \) is the particle diameter.

This formula allows you to determine the correct settling time of particles in suspension, which will allow you to correctly determine the particle size distribution.

4. Results

To compare the results, the calculations were performed at a density of the mineral part of the soil equal to 2.68; 2.70; 2.72 g/cm\(^3\) and temperatures equal to 293.15, 295.15 and 297.15 K (table 1). The choice of temperature is due to the permissible values of the air temperature in the room according to GOST 30416-2012. The particle path is 30 cm, the particle diameter is 2\( \cdot 10^{-4} \) cm.

| \( \rho_s \) (g/cm\(^3\)) | T (K) | \( \rho_t \) (g/cm\(^3\)) | \( \eta \cdot 10^2 \) (cm/s) | t (hours) |
|--------------------------|-------|---------------------------|-----------------------------|---------|
| 2.68                     | 293.15| 0.99823                   | 1.005                       | 22.85   |
|                          | 295.15| 0.9978                    | 0.961                       | 21.85   |
|                          | 297.15| 0.99732                   | 0.916                       | 20.82   |
| 2.7                      | 293.15| 0.99823                   | 1.005                       | 22.5    |
|                          | 295.15| 0.9978                    | 0.961                       | 21.59   |
|                          | 297.15| 0.99732                   | 0.916                       | 20.57   |
| 2.72                     | 293.15| 0.99823                   | 1.005                       | 22.32   |
|                          | 295.15| 0.9978                    | 0.961                       | 21.34   |
|                          | 297.15| 0.99732                   | 0.916                       | 20.33   |

The calculation result showed that the average measurement time for particles with a diameter of less than 0.002 mm was from 20 to 23 hours (fig. 1).
Figure 1. The dependence of the sampling time on the suspension temperature.

The calculated results are in good agreement with the experimental data obtained as a result of soil studies.

5. Conclusion

Hydrocarbon pollution and leaks from drainage systems radically affect the state and physical and mechanical properties of sandy-clay soils, the development of hazardous processes in the underground environment and reduce the bearing capacity of soils at the base of structures. Changes in physicochemical conditions negatively affect the transformation of the type of structural bonds in sandy-clayey soils, the degree of their dispersion and, accordingly, hydrophilicity, which contributes to their transition into weaker and unstable varieties.

An incorrect determination of the content of the clay fraction leads to an incorrect classification of rocks, and, as a consequence, errors in calculations and the impossibility of predicting in advance the development of hazardous geological processes (swelling, swelling, shrinkage, fracturing). This is especially important when laying oil pipelines, since the destruction of the supporting structure can cause oil spillage, which will greatly harm the environment.

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