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# A Method for Preventing Infiltration of Oil and Oil Products into Sandy Soils

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**Abstract—**A method for preventing infiltration of oil and oil products into sandy soils was developed. The method is based on soil treatment with aqueous solutions of sodium polyacrylate. Experiments showed that treatment of samples with a 2 wt % sodium polyacrylate solution completely prevents oil infiltration into sandy soils.

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## INTRODUCTION

Oil, oil products, and their transformation products, as well as synthetic additives are among the main sources of biosphere pollution. Faulty technology and transportation and storage management (spills, evaporation) have a great environmental impact.

The method for protection of sandy soils, considered in the present paper, makes it possible to prevent infiltration (leakage) of oil and oil products into soil layers. This method consists in forming on soil surface of the hydrophilic layer of a highly viscous aqueous solution of sodium polyacrylate. The solution is applied on soil surface to form a 0.5–1.0-cm thick film impermeable to oil, even in the case of large spills of liquid hydrocarbons. Such protective film is applied using standard fire-fighting or public water distribution equipment.

The polymer-treated soil layer of up 10 cm in thickness can be mechanically removed after completion of emergency, engineering, and repair works.

After treatment with water in a conventional apparatus with a stirrer, the soil–hydrocarbon mixture can fractionated into oil products, aqueous polymer solution containing oil residues, and purified soil.

The soil is returned to the natural cycle. The separated oil products after treatment and quality assessment can be used for the intended purpose, and the aqueous solution can be either discharged into natural waterways (provided the polymer level is no higher than the maximum allowable concentration) or purified by coagulation of the polymer and oil residues. To reduce discharges of sodium acrylate solutions, they can be recycled many times.

The technology based on the proposed method is expedient to use for soil protection during planned repairs of oil and oil-product pipelines, protection of wells of ground collectors for draining unpumpable oil products, soil protection in the regions of oil exploration and repair works at oil extraction facilities, and in other cases where spills are probable a fortiori. Of particular interest is protection of river, lake, and sea shores from migrating oil spots formed by accidents with oil tankers.

The most important factors that determined whether the hydrophilic layer formed on treatment of sandy soil with aqueous solution of sodium polyacrylate will be impermeable to oil products are the layer thickness and the polymer concentration in the solution.

In the present work we have studied infiltration of oil products into sandy soil, both untreated and pretreated with solutions of sodium polyacrylate of varied concentration, with the aim to choose polymer concentrations for creating the protective layer.

## Physicochemical and Hydrodynamic Characteristics of the Infiltration of Oil and Oil Products into Sandy Soil

The rate of infiltration of oil and oil products into sandy soil depends on the composition, structure, and humidity of the soil. The distribution of oil and oil products in soil is affected by their viscosity, capillary processes involved in the water–oil displacement process, surface properties of soil mineral particles, etc. [1].

The process of infiltration of oil and oil products into surface layers of soil essentially differs from the well-known process of oil filtration in reservoirs [2]. The atmosphere–soil interface forms a potential barrier for oil infiltration into soil, and, therewith, this process is much dependent on hydrophilic components of soil.

In attacking the problem of protection of sandy soils from oil and oil products of different viscosities, one can rely on the accumulated experience on surface solidification of soil by means of binding agents, because in both cases a bound dispersion is formed.

The transformation of sandy soil from a free to a bound dispersion system is underlain by intermolecular interactions between the surface of sandy soil particles and structural kinetic units of binder solutions (ions, molecules, their associates, supramolecular structures); as a result, depending on the type of the binder, structures different in nature and strength are formed.

The dispersion systems of binders for mobile sandy soils include true solutions of organic and inorganic salts, acids, bases, surfactants, polyelectrolytes, colloid polymer solutions, aqueous suspensions of clays, aqueous emulsion of latex, bitumen solutions in oil products, etc. Among polyelectrolytes, the widest acceptance has been gained by water-soluble polyacrylate polymers.

When applied on sandy surface, the polyelectrolyte solution having a fairly high viscosity penetrates sandy soil layers to an inconsiderable depth. As a result, a sandy soil–dispersion medium–polymer dispersion system is formed, where structuring processes take place. The mechanical strength of the forming system is increasing as water evaporates. On the other hand, owing to its hygroscopicity, the polymer film still remains plastic, and this reduces the probability of cracking of the resulting coating.

The strength of contact between sand grains in the bound dispersion system and, therefore, strength of the surface film depends on the nature of the surface of solid particles, as well as the type and degree of structuring of the binder dispersion. The structuring kinetics is associated with the rate of binder–substrate interaction, in particular, adsorption and adhesion processes.

To find the rational consumption of binders and conditions for application of a fixing (oil-isolating) layer one should know the physicochemical properties of binders, dependence of their properties on concentration, temperature, etc. Thus, if polyelectrolyte solutions are used as binders, it is expedient to know the concentrations of the solutions, which favor association of macromolecules (fibrils), association of fibrils, aggregation of associates, and formation of a 3D structure.

A spill of oil products is accompanied by their spreading over the surface, evaporation, and infiltration into soil. This downward motion of the liquid can be hindered or stopped by three reasons [3]: (1) if the residual saturation of soil with oil reaches levels below a threshold value; (2) if soil contains a layer impermeable for oil products; and (3) if oil reaches the groundwater table.

The residual saturation is defined as the minimum threshold level of oil products in soil, above which motion of a liquid in a porous (granular) medium is initiated. The residual saturation can be described by a dimensionless retention capacity factor $R$:

$$R = V_{\mathrm{OP}}/V_{\mathrm{soil}},$$

where $V_{\mathrm{OP}}$ and $V_{\mathrm{soil}}$ are the volume fractions of oil products and soil, respectively.

Typical retention capacity factors for different soils are listed in Table 1.

The maximum infiltration depth of oil products ($D_{\mathrm{MI}}$) into soil can be calculated by the equation:

where $V_{\mathrm{spill}}$ is the volume of spilled oil products, m$^3$;

$$D_{\mathrm{MI}} = \frac{V_{\mathrm{spill}} - V_{\mathrm{evap}}}{V_{\mathrm{spill}} R \zeta_V}, \tag{1}$$

$V_{\mathrm{evap}}$, volume of evaporated oil products, m$^3$; $\varsigma_{\mathrm{spill}}$, spill area, m$^2$; and $\varsigma_V$, parameter related to the liquid viscosity. The $\varsigma_V$ values for certain oil products are listed in Table 2.

Let us use Eq. (1) to estimate the depth of infiltration of certain oil products into sandy soil. The area of a spill of diesel fuel (a typical oil product) in

**Table 1.** Retention capacity factors for different soils [4]

| Soil type | $R$ |
|---|---|
| Gravel | $5 \times 10^{-3}$ |
| Coarse sand | $8 \times 10^{-3}$ |
| Medium sand | $15 \times 10^{-3}$ |
| Fine sand | $25 \times 10^{-3}$ |
| Silt | $40 \times 10^{-3}$ |

the absence of leakage at room temperature is estimated by the equation $S_{\text{spill}}$ (m$^2$) = $V_{\text{spill}}$ (m$^3$) × $10^3$ (m$^{-1}$) [5, 6].

According to [6], the intensity of evaporation of diesel fuel at room temperature is $9.45 \times 10^{-6}$ kg m$^{-2}$ s$^{-1}$. Under conditions, when oil spills penetrate to soil within a few minutes, the evaporation volume $V_{\text{evap}}$ can be neglected. Under this assumption, Eq. (1) takes the form

$$D_{\text{MI}} = \frac{1}{10^3 R \zeta_V}\,. \qquad (2)$$

The infiltration depths for certain oil products, estimated by Eq. (2), are presented in Fig. 1. As seen from the figure, the depth of infiltration of oil products into soil is much dependent on the porosity of the soil and on the viscosity of the liquid and varies of a wide range: from 1 mm (oil infiltration into silt) to 40 cm (gasoline infiltration into gravel).

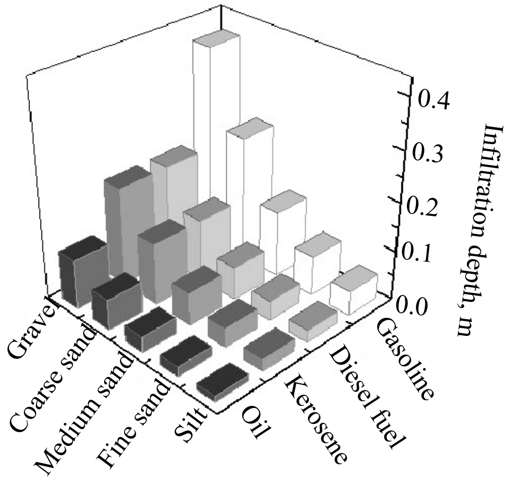

**Fig. 1.** Infiltration depths of oil products into different soils. Calculation by Eq. (2).

**Table 2.** Parameters $\varsigma_V$ for oil products [4]

| Oil products | $\varsigma_V$ |
|---|---|
| Gasoline, motor fuel | 0.5 |
| Kerosene, gasoil, diesel fuel | 1.0 |
| Fuel oil | 2.0 |

There are other approaches to theoretical and semi-empirical considerations of processes associated with oil spills [7, 8]. However, no theoretical models that would allow one to find out the mechanism of liquid motion in soil with account on the structure and humidity of the latter, presence of one or another components as impregnating substances or additional layers, etc. As a result, the most adequate results are obtained in experimental studies on these processes [7].

## EXPERIMENTAL

To study protective properties of a hydrophilic layer we chose sandy soil as the most penetrable and uniform in mineral composition. The characteristics of the used sample of a river sandy soil were as follows:

- particle size <1 mm;
- total bulk mass 1.61 g/cm$^3$;
- relative humidity up to 15%;
- total volume of infiltration pores up to 0.198 cm$^3$/g.

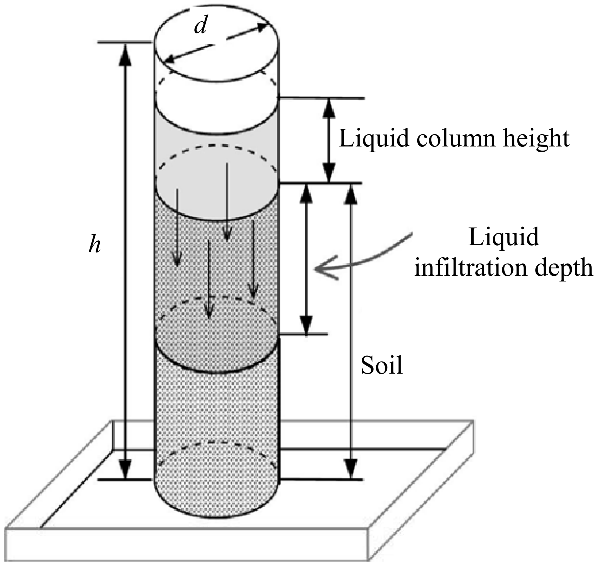

**Fig. 2.** Glass cylinder with a tray for studying protective properties of a hydrophilic layer.

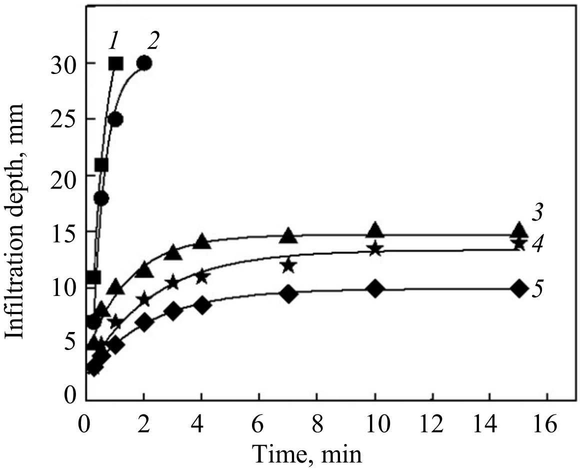

**Fig. 3.** Time dependence of the infiltration depth into sandy soil of sodium polyacrylate solutions. Polymer concentration, wt %: (*1*) 0.25, (*2*) 0.5, (*3*) 1.0, (*4*) 1.5, and (*5*) 2.0.

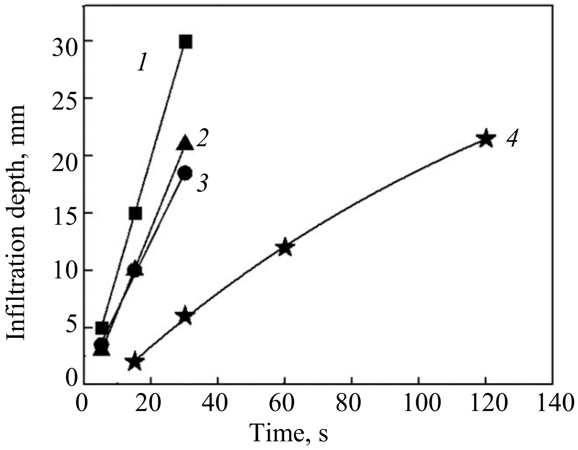

**Fig. 4.** Time dependence of the infiltration depth of oil products into untreated sandy soil: (*1*) A-80 gasoline, (*2*) diesel fuel (winter), (*3*) TS-1 kerosene, and (*4*) oil.

The experiment was performed on a laboratory device constructed of a hollow glass cylinder (Fig. 2) mounted vertically on a tray to exclude the effect of barrier layer and mimic free infiltration of liquid into sand. Sand was poured into the cylinder (height 300 mm, diameter 35 mm) and on the tray. The solutions of polymer and oil products were added from a dropping funnel at a rate of 0.2 mL/s to the center of the sand bed to exclude the wall effect.

To choose the concentration of the aqueous solution of sodium polyacrylate, optimal for forming a stable protective layer on the surface of sandy soil, we determined the depth of infiltration into soil of the polymer solutions with concentrations of 0.25, 0.5, 1.0, 1.5, and 2 wt %. The infiltration depth was measured in time as the liquid front moved through the sandy soil. The resulting data are shown in Fig. 3. As seen from the figure, as the concentration of the polymer solution increases, the time required for the polymer to penetrate completely into the sandy soil increases, and the infiltration depth (thickness of a fixed surface layer) decreases.

The infiltration depths of the polymer solutions with concentrations of 1.0, 1.5, and 2.0 wt % asymptotically reach the limiting values of 15, 14, and 10 mm, respectively, within the time shorter than 8 min. Such shape of the curves can be explained by that the residual saturation of soil with the solution at the propagation front of the viscous liquid has not yet reached its threshold values [Eqs. (1) and (2) with minor corrections can be used to estimate the infiltration depth into porous materials of viscous aqueous polymer solutions [4]).

For testing the performance of the protective film of sodium polyacrylate, the following oil products were used: A-80 motor gasoline, TS-1 aviation kerosene, diesel fuel (winter), and oil. Before experiments on infiltration of oil products through polymer-treated soils we studied the infiltration of oil products into untreated soil. The resulting data are shown in Fig. 4. Initially, the infiltration rate is quite high, and it scarcely changes until depths of 20–30 mm. The highest infiltration rate is characteristic of gasoline. As to oil, its infiltration rate gradually decreases with depth; however, as judged from the curve, the residual saturation can reach threshold values within a very long time period.

To assess the properties of sandy soil treated with sodium polyacrylate solutions of different concentrations, we measured the thickness of the protective surface film and the infiltration stop time.

The strength and performance of the sodium polyacrylate protective film on the sandy soil surface in laboratory conditions were evaluated by the height of the column of oil products, held on the treated surface. Hollow cylinders (see Fig. 2) were mounted on a 100-mm bed of sandy soil pretreated with polymer solution, and the cylinders were filled with oil products. Because oil hydrocarbns tend to spread over soil surface, the column height in the cylinder was brought to the height of 50 mm, which is many times higher than the layer of oil products in real spills.

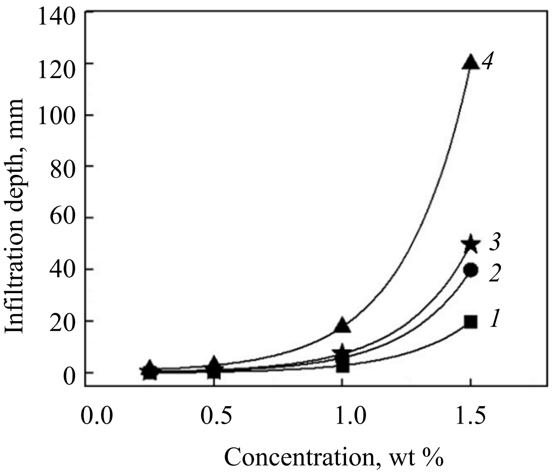

**Fig. 5.** Dependence of the infiltration time of oil products into the sandy soil treated with sodium polyacrylate on the concentration of the polymer solution: (*1*) A-80 gasoline, (*2*) diesel fuel (winter), (*3*) TS-1 kerosene, and (*4*) oil.

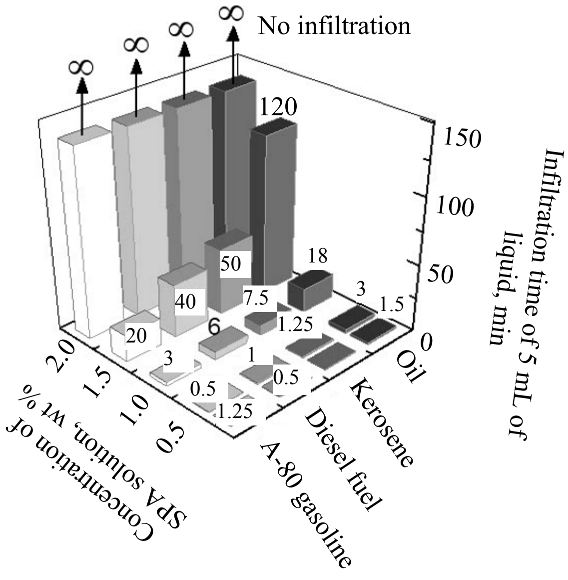

**Fig. 6.** Infiltration time of oil products into the sandy soil treated with aqueous solutions of sodium polyacrylate (SPA) of different concentrations.

The experimental results (Figs. 5 and 6) show that the highest performance is characteristic of a 2 wt% polymer solution which produces an impermeable protective film no more than 10 mm in thickness at the consumption of the working solution of 5 L/m$^2$.

The hydrophilic film formed by the 2 wt % solution of sodium polyacrylate becomes impermeable for oil and all the oil products, i.e. the soil infiltration time becomes indefinite. These data are fairly difficult to present in the curves in Fig. 5. More illustrative is a 3D presentation of the dependences of infiltration time on the type of oil product and on the concentration of sodium polyacrylate (Fig. 6).

The dependences of infiltration time on concentration for all the oil products in the 0–1.5 wt % range are nearly exponential. Extrapolation of such dependence for, for example, oil to the concentration of 2 wt % predicts the infiltration time of 900 min (15 h). Obviously, the theoretical infiltration times for oil products are shorter. However, the experimental times for all the tested oil products are at least longer than 5 days, and, as judged from visual observations, they are infinite. This fact can be explained by the formation in soil of a wet or dry sodium polyacrylate gel substance impermeable for oil products.

Under the experimental conditions, the mechanical loads of hydrocarbon column (see Fig. 2) for all the tested oil products (gasoline, kerosene, diesel fuel, and oil) are close to each other and span the range 18.76–21.60 g/mm$^2$. The level of the liquid column did not decrease throughout the entire experiment (5 days), providing evidence for a satisfactory performance of the protective film.

## CONCLUSIONS

The method for preventing infiltration of oil and oil products into sandy soils, involving impregnation of soil with an aqueous solution of sodium polyacrylate provides reliable protection, if the concentration of the polymer solution is 2 wt %. The consumption of the solution is no more than 5 L/m$^2$ (no more than 100 g of sodium polyacrylate per 1 m$^2$ of soil).

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