

Investigation of salt migration in the ground saturated with a chloride-sulphate sodium-magnesium solution in freezing-thawing cycles**

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Abstract. Among the variety of objects in the permafrost zone, soils are encountered, including cryopegs – highly mineralized solutions that have excessive pore pressure. Generally, they have a negative impact, reducing the load-bearing capacity of the ground and causing corrosion of concrete and metal constructions. The study of cryopegs does not receive enough attention from Russian and foreign researchers, not least because of the peculiarities of the thermodynamic state they exist in, therefore detailed investigation of this cryologic object is required in the field and in laboratory conditions. In the presented research the authors study the mechanism of the migration of salt ions in pore water in an enclosed volume of ground during the freezing front movement. To do this, the authors developed an experimental unit and created a measuring unit where the studied moist ground is inserted. Temperature can be set on the opposite sides of the measuring unit. Controlling the extent and speed of temperature change provides a means to regulate freezing front movement (directed from top to bottom). After a number of freezing-thawing cycles salt compositions and concentrations are checked and measured in four intervals of sampling. As a result of the experiments a significant increase in concentration was found at opposite sampling points, and in particular at the beginning of the freezing front movement.

1 Introduction

Permafrost is important for human industrial activity. A considerable part of it has a high salinization level. Generally, this part is represented by coastal lowlands, large rivers' valleys and technogenically contaminated areas. The development of the permafrost is accompanied by the destruction of the active ground layer, the erection of residential and industrial structures, thermal and mineral pollution of the surrounding areas.

As a result of the annual seasonal thawing, the accumulated highly soluble mineral salts migrate to the border of the permafrost, facilitating the concentration of the pore solution in enclosed areas and leaving the pore solution in liquid form during the winter season [1]. These highly mineralized solutions surrounded by the permafrost having an excess pore pressure, are called cryopegs.

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The formation of cryopegs can occur as a result of alterations of ice ages and sea’s cyclical impact on coastal lowlands, while processes connected with technogenic impact and seasonal mass-transfer of mineral salts reach a much greater scale [2, 3].

When the mineralized waters of a cryopeg are exposed to the frozen ground, the ice contained within it dissolves, resulting in the frozen ground’s cooling [4, 5]. High mineralization of waters contained in cryopegs is the reason of increasing the corrosion activity towards reinforced concrete and metal structures [6, 7].

The diversity of the chemical composition of natural saline solutions and thermobaric conditions, that cryopegs exist in, make it difficult to experimentally study the processes of cryogenic metamorphism in the field [5]. This calls for laboratory research which is necessary to reconstruct the formation conditions of cryopegs; studying the processes of mass-transfer and local accumulation of salt ions; establishing equilibrium factors within the “ice-solution-salt crystals” system and the “frozen ground-cryopeg” border.

The purpose of this investigation is to create a methodology and carry out experiments to study the migration of salt ions in pore water during the freezing front movement – the causes of the formation of increased salt concentration zones in the pore solution as the main factor in the formation of cryopegs.

2 Experimental unit description

In order to study the migration of salt ions in pore water during the movement of the freezing front, an original experimental unit was developed. It allows setting and regulating the movement of the freezing front inside moist ground. The unit contains a measuring unit with the investigated ground, a thermocouples cold junction temperature maintaining system and a cryochamber.

The measuring unit (Fig. 1) is a cylinder inside which the investigated ground is placed.

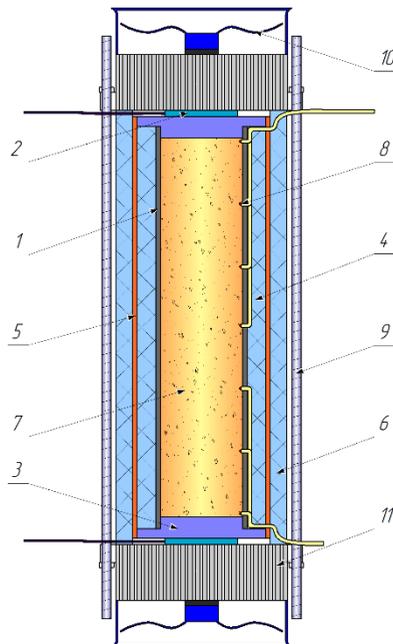


Fig. 1. Structure of the measuring unit: 1 – cylinder for the ground; 2 – Peltier elements; 3 – aluminum disks; 4, 6 – thermal insulation; 5 – copper casing; 7 – ground; 8 – T-type thermocouples; 9 – studs; 10 – fans; 11 – radiators.

On its ends the cylinder is bounded by two aluminum disks, their outer sides are connected to the corresponding Peltier element for setting the desired positive or negative temperature. Since different voltage polarities lead to one side of the Peltier element being heated and the other being cooled, radiators with fans for venting or supplying heat are provided in the unit. The cylinder has a double thermal insulation with a temperature gradient stabilizer over the surface. The entire structure is tightened by the studs, which ensures a tight contact on the contacting surfaces.

3 Preparation for the experiment

To monitor the freezing front movement of the ground, a preliminary experiment was conducted to determine the freezing temperature of the ground type used (loam). It was saturated with a chloride-sulfate sodium-magnesium solution with a 40 g/l concentration. During the experiment, the freezing temperature of the solution used was also determined. The air temperature inside the cryochamber was gradually decreased from 2.5 °C below zero to 10.0 °C below zero, which prevented abrupt subcooling of the ground. The results of the experiment are shown in the form of a graph (Fig. 2).

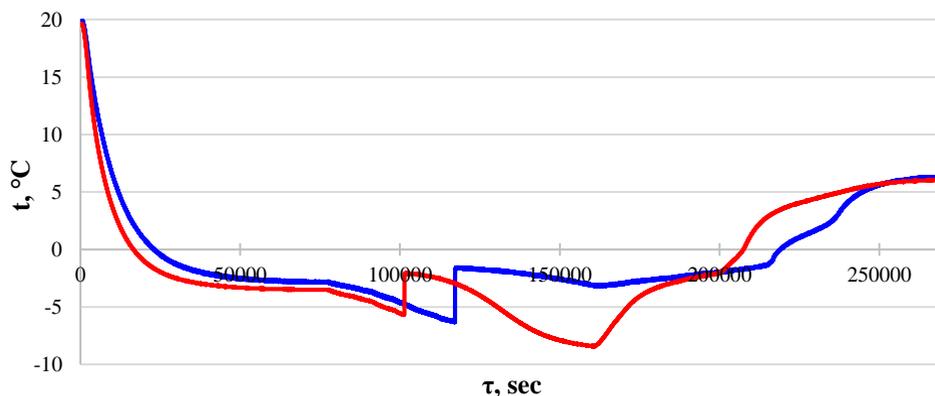


Fig. 2. Freezing-thawing curve of the ground saturated with chloride-sulfate sodium-magnesium solution with a concentration of 40 g/l: red line – ground temperature; blue line – solution temperature.

Based on the graph, the following conclusions were drawn:

1. The freezing point of loam saturated with a chloride-sulfate sodium-magnesium solution with a concentration of 40 g/l is 2.1 °C below zero.
2. The freezing point of a chloride-sulfate sodium-magnesium solution with a concentration of 40 g/l is 1.6 °C below zero.

4 Experimental procedure

The experiment was carried out in the following sequence:

1. Preparing ground and salt solution with a concentration of 40 g/l.
2. Assembling the measuring unit and the experimental unit.
3. Setting the initial voltage value on the Peltier elements.
4. Setting the time interval and the value of voltage increase at the "cold" Peltier element within a single freezing cycle.
5. Tripping the "cold" Peltier element off until the ground's complete thawing.

6. Repeating the freezing-thawing cycle 6-7 times.
7. Disassembling the experimental unit.
8. Extracting the ground from the measuring unit and dividing it into 4 equal parts.
9. Obtaining the water extract from the ground samples and conducting a chemical analysis of the solution.

5 Experiment on salt migration in the ground saturated with a chloride-sulphate sodium-magnesium solution

Prior to the experiment, the moisture of the ground was (31.17 ± 0.06) %, the mineralization of the pore water was (21.42 ± 2.36) g/l. The ion content in the pore water before the start of the freezing-thawing cycles is given in Table 1.

Table 1. The ion content in the pore water before the start of the freezing-thawing cycles.

Anion content, g/l			Cation content, g/l			
HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
< 0,10	$1,96 \pm 0,24$	$11,29 \pm 2,26$	$0,86 \pm 0,09$	$1,21 \pm 0,12$	$5,95 \pm 0,60$	$0,06 \pm 0,01$

After a series of freezing-thawing cycles, a sample with a height of 210 mm was extracted and divided into 4 parts, each 50 ± 5 mm high. 5 mm thick ground's interlayers between the separated sections were not considered while analyzing the chemical extract from the sample.

Table 2 contains the values of ion concentrations in the pore water after the completion of a series of freezing-thawing cycles.

Table 2. The values of ion concentrations in the pore water after a series of freezing-thawing cycles.

Sampling depth, mm	Anion content, g/l			Cation content, g/l			
	HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
0-49	< 0,11	$4,12 \pm 0,51$	$12,76 \pm 2,55$	$1,37 \pm 0,14$	$1,34 \pm 0,13$	$6,76 \pm 0,68$	$0,06 \pm 0,01$
54-99	< 0,10	$3,53 \pm 0,44$	$11,17 \pm 2,23$	$1,16 \pm 0,12$	$1,26 \pm 0,13$	$6,02 \pm 0,60$	$0,06 \pm 0,01$
104-155	< 0,11	$2,94 \pm 0,36$	$9,89 \pm 1,97$	$0,89 \pm 0,09$	$1,02 \pm 0,10$	$5,72 \pm 0,57$	$0,06 \pm 0,01$
160-210	< 0,11	$2,52 \pm 0,31$	$12,04 \pm 2,41$	$1,07 \pm 0,11$	$1,36 \pm 0,14$	$6,54 \pm 0,65$	$0,04 \pm 0,01$

Table 3 contains the values of the total mineralization of the pore water, which are the sums of all the corresponding values from Table 2. It should be noted that the ions presented in Table 2 do not make up the complete list of all the ions present in the ground water, therefore the real values of the total mineralization differ slightly from the ones presented in Table 3 to the higher side.

Table 3. Total mineralization of the pore water.

Sampling depth, mm	Ground's moisture, %	Total mineralization, g/l
0-49	$28,61 \pm 0,05$	$26,52 \pm 2,69$
54-99	$30,71 \pm 0,05$	$23,31 \pm 2,36$
104-155	$27,90 \pm 0,04$	$20,62 \pm 2,09$
160-210	$28,99 \pm 0,04$	$23,68 \pm 2,53$

6 Conclusions

After conducting the experiments with a chloride-sulfate sodium-magnesium solution, it was found that the maximum salt concentration in the pore solution was contained in the sample taken from the side of the "cold" Peltier element, from which the freezing front started its movement each cycle, the second maximum of concentration was observed near the "hot"

Peltier element. The concentration of salts in the upper sampling interval increased by 24 %, in the lower interval – by 11 %.

This can be explained by the type of the ground: mass-transfer of the concentrated solution to the crystallization centers is observed due to osmotic powers in clayey silty soils that have a large active surface area and a high unfrozen water content. Concentration in the lower part is possible due to the mechanism of squeezing out the excess solution during the crystallization of water in the ground's pores.

In the subsequent experiment, it is necessary to provide some compensation the growth of pore pressure in the lower part of the measuring unit, which occurs when most of the solution is crystallized. It is important to evaluate the results for the solution's migration in an enclosed and open volume.

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