Negative impact modeling on the Baltic Sea in the production of underground gas storages

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Abstract. The technology of construction in salt caves based on the erosion of salt layers of underground gas storages facilities has been considered. The main technological processes, leading to wastewater pollution have been determined. The main pollutants that were formed during the production of UGS facilities, which have a negative impact on the water environment, have been identified. The necessary hydrochemical, morphometric, hydrological and hydrometeorological characteristics of the Baltic Sea section in the area of wastewater discharge through the scattering outlet have been determined, the necessary cartographic material has been prepared in the system of geographic coordinates. The parameters were substantiated and mathematical models were constructed for wind currents and convective-diffusion transport of pollutants for a section of the Baltic Sea in the area of wastewater discharges from the Kaliningrad’s UGS facility. The zones of negative impacts of pollutants from wastewater discharges in the Baltic Sea area have been calculated.

Underground gas storage facilities (UGS) serve to ensure energy security, gas supply development and gasification for the country. Kaliningrad UGS facility is located in the rock salt deposits, which are more than 230 million years old. The salt domes are not only impermeable to gas - salt has the ability to independently «heal» cracks and faults. During the construction of UGS facilities, wells are drilled in rock deposits in a salt layer on a suitable height, through which water is being supplied to the salt layers to wash out the cavity of the required volume.

Development technology of underground reservoirs requires preparatory work for the construction of facilities for a water-brine complex. Water from the Baltic Sea will be used as wash water for the production of the Kaliningrad UGS facility, and polluted wastewater will also be discharged into the Baltic Sea.

The construction of the water-brine complex (WBC) facilities allows following reductions:

- creation time of working-capacities of underground reservoirs in rock salt;
- consumption of fresh water, drinking water for technical purposes;
- energy consumption and costs of maintaining subsoil in the ability to receive brine.
The process of underground dissolution of rock salt during the construction of working-capacities is a combination of the most complex physicochemical and heat-mass exchange processes, for the joint solution of which specially developed software systems are used [1-2]. The technological scheme is shown in figure 1.

![Figure 1. Technological scheme.](image)

Seawater from the Baltic Sea through a conduit enters the site of the water-brine complex (WBC). From the reservoirs, water under natural pressure enters the suction manifold of the pumping station and then comes through solvent injection pipelines into three wells to mine underground reservoirs in rock salt. In the brine degassing and filtrating unit, the brine is degassed and filtered from solid inorganic impurities, the filtered brine is directed to the brine tanks, in which the brine level required for the technological equipment is provided. Simultaneously with the supply of brine, seawater is supplied to the brine tank for the primary dilution of the brine with a concentration of 310 g/l to a concentration of 250 g/l.

From the brine tanks under natural pressure, the brine enters the section manifold of the brine pumping station. The brine pumping station provides pumping of primary diluted brine with a concentration of 150 g/l through the brine pipeline to the unified pumping station located on the Baltic Sea coast. At the unified pumping station there is an additional dilution of brine with seawater up to 170 g/l and the release of the diluted brine into the Baltic Sea through a scattering outlet. Insoluble suspended and solid inorganic impurities from the brine degassing and filtration unit and from the water and brine tanks are being discharged into the appropriate receiving wells, from where they are pumped into the sludge tank by submersible pumps.

With regard to the intensive washing of the prepared trench in the coastal zone of the construction of water intake and water conduit for the water-brine complex, it is necessary to build a cofferdam. The cofferdam is a temporary structure erected during the construction of the water intake and water conduit onshore crossing. Cofferdam protects the trench and laid pipelines from unfavorable wave effects. The estimated service life of cofferdam is one navigational season. Upon completion of the construction and installation work, cofferdam is dismantled. Control over the content of pollutants in wastewater is carried out using modern automated systems using geographic information systems [3-4].
Based on the performed analyses, it was found that the main pollutants in wastewater are chlorides and sodium ions. The assessment of the negative impact of chlorides and nitrates in the environment was carried out on the basis of the developed mathematical model of the Baltic Sea area. Wind currents modeling is a complex multifactorial process that depends on individual morphometric and hydrodynamic conditions [5-7]. In the place of wastewater discharge, Baltic Sea is a shallow body of water, which made it possible to use the mathematical model of total flows, developed by P.S.Lineykin and F.I.Filsenbaum [9]. The computation area was a square with size of 1.5x1.5 km.

The coastline of the computational area was modeled based on the cartographic material, which was cut out from Google maps, using the SasPlanet program in a geographic coordinate system. The depth values were obtained based on the sailing directions, wind speed and directions were taken from the data of the Roshydrometeocenter.

The mathematical model of wind currents was implemented in MS Excel. Entire computation domain was divided into cells with a face size of 30 m, the total number of cells was 2500 pieces (50x50 cells). Since the number of calculated cells significantly exceeds the number of depth values in the sailing directions – interpolation methods were used to obtain intermediate values (1).

\[ Y = Y_2 + \frac{Y_4 - Y_2}{X_4 - X_2} (X - X_2) \]  

where X – unknown cell number;  
X_1 – first cell number;  
X_2 – last cell number;  
Y – required cell depth, m;  
Y_1 – first cell depth value, m;  
Y_2 – last cell depth value, m.

The first approximation of total flows was calculated by the formula:

\[ \bar{\Psi}_0 = \frac{1}{4} (f_0(1) + f_0(2) + f_0(3) + f_0(4)) - f_0 \]  

where \( \bar{\Psi}_0 \) – first approximation of total flows;  
f_0 – support function [4];  
f_0(1), f_0(2), f_0(3), f_0(4) – support function for cells 1-4.

For subsequent approximations, the used formula is (3):

\[ \bar{\Psi}_0 = \frac{1}{4} (\bar{\Psi}_1 + \bar{\Psi}_2 + \bar{\Psi}_3 + \bar{\Psi}_4) - f_0 \]  

where \( \bar{\Psi}_1, \bar{\Psi}_2, \bar{\Psi}_3, \bar{\Psi}_4 \) – subsequent approximations of total fluxes for cells 1-4.

The calculations continued until, within the given one, two consecutive patterns would match.

To ensure that an error does not exceed 5%, 140 fields of total flows were calculated. The function of total flows was calculated by the formula (4):

\[ \psi = \bar{\Psi} \cdot H \]  

The current velocity vectors along the x-(u_0) and the velocity vectors along the y-(v_0) were calculated using formulas (5) and (6):

\[ u_0 = \frac{3 \cdot (\psi_4 - \psi_2)}{4 \cdot h \cdot H} + \frac{T_x \cdot H}{4 \cdot A_z} \]  

\[ v_0 = \frac{3 \cdot (\psi_3 - \psi_1)}{4 \cdot h \cdot H} + \frac{T_y \cdot H}{4 \cdot A_z} \]  

where \( A_z \) – coefficient of turbulent exchange of momentum in the vertical direction;  
h –greed spacing, equals 30 meters.

The calculated current velocity field is shown in figure 2.
According to the results of the calculation, the prevailing directions of currents are north-western currents, with velocities not exceeding 5 cm/s. The prevailing current velocities along the coastal zone do not exceed 1 cm/s.

Based on the calculated values of wind currents at different wind directions, process modeling of convective-diffusion transfer of pollutants was carried out. The modeling results showed that in control sections, that were located 500 meters from the wastewater discharge, none of the pollutants will exceed the MPC. The zone of negative influence from the discharge of chlorides will not exceed 160 meters, and the zone of negative influence of sodium ions will not exceed 136 meters.

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