The influence of gas appearance on the construction of underground tanks in rock salt

V P Malyukov
Peoples' Friendship University of Russia (RUDN University), Moscow, Russia
E-mail: v.malyukov@mail.ru

Abstract. The article describes the influence of gas bubbles released during the underground dis-solution of rock salt during the construction of underground tanks for storage of petroleum products on drilling, oil borehole drilling, operation of tanks, and acceleration of the construction of underground tanks in rock salt with a significant gas content. It is revealed that complex use of oil and salt layers of the oil field allows to obtain a mineralized solution to intensify the extraction of oil from the reservoir and to create an underground reservoir in the salt reservoir for underground storage of associated petroleum gas (APG), i.e. to create an underground gas storage (UGS) in rock salt.

Keywords: rock salt, underground production-capacity, salt dissolution, solvent, borehole, non-solvent, gas, insoluble inclusions, flotation processes.

1. Introduction
The construction of underground workings-tanks for hydrocarbon reserves in rock salt is carried out by supplying a solvent and dispensing brine through a borehole [1-7].

The construction of underground workings-tanks in rock salt is largely determined by mass transfer processes in the marginal zone. When the solvent is supplied through a borehole with hydrodynamic effects at the “rock salt-fluid” boundary, mass transfer processes take place, which characterize the speed of construction of the underground production capacity and its shaping.

The mass transfer coefficient for dissolving rock salt determines the total amount of movement of the interphase boundary into the bulk of the mass when dissolving rock salt per unit time.

The mass transfer coefficient of rock salt (K) is determined by the formula:

\[ K = \frac{\Delta G}{S_{cp} \cdot t \cdot (C_n - C_0)} \]

where \( K \) – is the mass transfer coefficient of rock salt, m/s; \( G \) – weight loss of the sample, g; \( S_{cp} \) – average surface dissolution; \( t \) – duration of dissolution, s; \( C_n \) – maximum concentration of a solution of NaCl in water.

The mass transfer coefficient of the sample with rebounding of salt plates and gas evolution is 30% more than that of rock salt samples without rebounding of salt plates and gas evolution.

The method of underground dissolution of rock salt in the Leykovskoye field, taking into account the significant value of gas, built in 10 volumes of mineral resources in the amount of 50 or 75 thousand m³). At the Leikovsky salt stock with a significant gas content in the intercrystalline space of rock salt and impurities, a factor was found to increase the mass transfer coefficient of rock salt by dissolving by about 30% and faster con-struction of workings-tanks (about 10%) compared with the calculated parameters.

2. Materials and methods
At the Tuz Galu field in each crystal of rock salt is a pore filled with gas.
In the process of dissolving rock salt from the Tuz Galu deposit, when the rocky partition is thinning in a salt crystal, in which gas is under pressure, plates of rock salt rebound and gas is released (micro-discharge).

The micro-discharge of gas from the salt crystal with the rebounding of salt plates in the process of dissolution is a continuous process of the separation of salt particles (destruction of the contact zone of the rock).

The value of the mass transfer coefficient during the dissolution of rock salt with a high gas content increases, compared with the dissolution of the traditional salt.

The mass transfer coefficient of the sample with rebounding of salt plates and gas evolution is 30% more than that of rock salt samples without rebounding of salt plates and gas evolution.

The method of underground dissolution of rock salt in the Leykovskoye field, taking into account the significant value of gas, built in 10 volumes of mineral resources in the amount of 50 or 75 thousand m³). At the Leikovsky salt stock with a significant gas content in the intercrystalline space of rock salt and impurities, a factor was found to increase the mass transfer coefficient of rock salt by dissolving by about 30% and faster construction of workings-tanks (about 10%) compared with the calculated parameters.

In Figure 1 the vertical sections of the 4T production capacity, built on the Leykovskoye field, are presented (based on sound-location materials).

According to the intensity of gas evolution when the salt of the Leukovsky deposit is dissolved, the mass transfer process is characterized mainly by gas evolution: from rock inclusions and from the intercrystalline space. During the dissolution of core samples from the Leykovskoy site, gas bubbles with a diameter of 2 to 15 mm were noted.

A non-solvent (diesel fuel, gas) is used to control the underground dissolution process. Diesel fuel was used as a non-solvent in the Leykovskoye field.

**Figure 1.** Vertical cross sections of underground excavation 4T according to sound colocation materials: sections: ·-------· south-north; x ------ x west-east.

On the right side of the figure, processes of gas evolution from the intercrystalline space and particles of insoluble rocks are shown when salt is dissolved with a high gas content (typical of salt dissolution at the Leukovo field). On the left side of the figure, the process of gas extraction from salt crystals (typical for the dissolution of salt in the Tuz-Galu field) and particles of insoluble rocks during
the dissolution of salt with a high gas content is presented. Gas bubbles stand out from the rock, and gas bubbles stand out from the water supplied to the production capacity.

3. Results

Tables 1 and 2 present the values of the mass transfer coefficient of the vertical surface of rock salt in water under conditions of natural convection at a temperature of 200°C, identified in core samples of SLE. UGS 1 Tuz Galu and UGS 2 Tuz Galu (d – core diameter, h – core height, ρ – density of the salt sample, G1 – is the initial weight of the sample, G2 – is the weight of the sample after dissolution).

Table 1. Value of the mass transfer coefficient in vertical surface of rock salt in water under natural convection at a temperature of 200°C, identified in core samples of SLE. UGS 1 Tuz Galu

| Sample number | Sample’s depth, m | d, cm | h, cm | ρ, g/cm³ | G1, g | G2, g | K, m/h |
|---------------|------------------|------|-------|---------|-------|-------|-------|
| 10P | 1048.0-1048.2 | 9.44 | 10.01 | 2.20 | 1541.40 | 1273.54 | 0.0596 |
| 15P | 1077.0-1077.3 | 9.40 | 10.01 | 2.17 | 1510.00 | 1223.36 | 0.0643 |
| 25P | 1083.6-1084.0 | 9.45 | 9.95 | 2.23 | 1558.66 | 1290.31 | 0.0598 |
| 36P | 1105.4-1105.6 | 9.41 | 9.96 | 2.12 | 1472.80 | 1297.79 | 0.0387 |
| 42P | 1108.0-1109.0 | 9.38 | 10.08 | 2.19 | 1524.77 | 1262.70 | 0.0583 |
| 45P | 1151.0-1151.35 | 9.41 | 10.0 | 2.12 | 1471.15 | 1167.69 | 0.0685 |
| 52P | 1154.2-1155.0 | 9.44 | 9.87 | 2.11 | 1458.74 | 1126.41 | 0.0761 |
| 64P | 1203.0-1204.0 | 9.47 | 9.91 | 2.18 | 1520.63 | 1324.51 | 0.0644 |
| 74P | 1250.0-1251.0 | 9.44 | 9.96 | 2.24 | 1559.35 | 1298.09 | 0.0584 |
| 82P | 1275.5-1275.8 | 9.51 | 9.96 | 2.15 | 1524.45 | 1186.93 | 0.0759 |
| 86P | 1301.0-1302.0 | 9.47 | 9.97 | 2.20 | 1524.90 | 1223.35 | 0.0682 |
| 93P | 1308.0-1309.0 | 9.50 | 9.90 | 2.18 | 1533.20 | 1247.39 | 0.0640 |

Table 2. Value of the mass transfer coefficient in vertical surface of rock salt in water under natural convection at a temperature of 200°C, identified in core samples of SLE. UGS 2 Tuz Galu

| Sample number | Sample’s depth, m | d, cm | h, cm | ρ, g/cm³ | G1, g | G2, g | K, m/h |
|---------------|------------------|------|-------|---------|-------|-------|-------|
| 27P | 962.6-963.0 | 9.46 | 9.99 | 2.17 | 1523.45 | 1249.60 | 0.0610 |
| 33P | 956.6-966.0 | 9.50 | 9.97 | 2.10 | 1486.72 | 1206.60 | 0.0624 |
| 44P | 972.0-972.7 | 9.52 | 9.98 | 2.24 | 1590.15 | 1362.98 | 0.0499 |
| 52P | 978.0-929.0 | 10.16 | 10.29 | 2.22 | 1854.22 | 1568.78 | 0.0489 |
| 55P | 1033.0-1034.0 | 9.52 | 9.92 | 2.18 | 1540.99 | 1262.71 | 0.0620 |
| 68P | 1044.0-1045.0 | 10.15 | 9.92 | 2.24 | 1800.70 | 1538.84 | 0.0540 |
| 68P | 1044.8-1045.0 | 10.16 | 10.05 | 2.25 | 1828.75 | 1568.7 | 0.0532 |
| 74P | 1049.8-1050.0 | 10.17 | 9.92 | 2.21 | 1783.33 | 1512.98 | 0.0553 |
| 80P | 1105.0-1105.5 | 10.08 | 11.1 | 2.25 | 1990.21 | 1707.2 | 0.528 |
| 84P | 1107.4-1108.0 | 10.16 | 10.05 | 2.23 | 1816.97 | 1544.2 | 0.0558 |
| 90P | 1112.0-1112.5 | 10.15 | 9.90 | 2.23 | 1782.36 | 1508.0 | 0.0572 |
| 96P | 1116.0-1117.0 | 10.16 | 10.05 | 2.25 | 1837.87 | 1590.2 | 0.0502 |
| 98P | 1118.0-1118.4 | 10.15 | 10.05 | 2.26 | 1838.54 | 1574.59 | 0.0537 |
| 99P | 1118.4-1119.0 | 10.17 | 10.02 | 2.25 | 1831.95 | 1561.0 | 0.0551 |
| 101P | 1181.0-1181.5 | 10.14 | 9.74 | 2.20 | 1731.7 | 1474.4 | 0.0533 |
| 107P | 1185.5-1186.0 | 9.46 | 9.93 | 2.18 | 1519.85 | 1263.44 | 0.0574 |
| 110P | 1188.0-1189.0 | 9.46 | 9.99 | 2.10 | 1530.17 | 1261.82 | 0.0586 |
| 112P | 1251.0-1251.25 | 9.53 | 9.98 | 2.21 | 1573.71 | 1318.17 | 0.0563 |
| 120P | 1255.0-1256.0 | 9.49 | 9.98 | 2.21 | 1564.90 | 1315.85 | 0.0550 |
| 127P | 1259.0-1260.0 | 9.48 | 9.83 | 2.22 | 1539.33 | 1284.74 | 0.0573 |
| 131P | 1323.0-1323.4 | 9.52 | 10.02 | 2.25 | 1607.75 | 1417.28 | 0.0413 |
| 139P | 1327.0-1327.4 | 10.02 | 8.65 | 2.11 | 1436.19 | 1180.07 | 0.0612 |
Average values for the mass transfer coefficient of vertical surface of rock salt, under conditions of natural convection at temperature 20°C for core of the field Tuz Galu compose for SLE. UGS 1 Tuz Galu – 0.063 m/h; SLE. UGS 2 Tuz Galu – 0.0582 m/h.

In the process of dissolving salt samples with rebounding of salt plates and gas evolution, thin plates of rock salt ~ 1-2 mm thick and ~ 2-3 mm in diameter fall out (plates of ellipsoidal shape, sometimes larger ~ 4 mm). During the entire time of sample dissolution, salt plates “bounce off” the core surface to a distance of 5 cm. When the core samples are dissolved from the Tuz-Galu field, gas bubbles from salt crystals, ~ 2 mm in diameter are released.

4. Discussion

The study of gas in a mass transfer and its influence on the process of building workings-tanks at the creation of underground storage in salt Lachowska stock was developed. Gas occurrences from rock salt are considered for various technological operations throughout the entire period of construction of workings-tanks, while gas occurrences of different intensity are recorded on a number of boreholes.

During the drilling of the 9T borehole from a depth of 502 m, there was a significant gassing of mainly methane with the release of drilling equipment to the surface. Gas composition: CH₄ – 94.38%; C₂H₆ – 2.5%; C₃H₈ – 0.27%; C₄H₁₀ – 0.11%.

A similar significant gas emission with the release of drilling equipment to the surface occurred during the drilling of a borehole in the Tuz-Galu field.

Laboratory setup to determine the coefficient of mass recovery of rock salt during dissolution is shown in Figure 2.

With the determination of mass transfer coefficient of rock salt core samples from the laying-excavation-tanks interval, a high content of gas in the rock was found on the Leikovsky stock (Ukraine) and the Tuz-Galu de-posit (Turkey).

The studies were performed for rock salt containing gas in crystals (Tuz-Galu field) and for rock salt with a high gas content, mainly in the intercrystalline space and impurities (Leikovsky salt rod).

Furthermore, studies of the hydrodynamics of gas bubbles in a liquid are of great practical importance not only for the processes of drilling and cementing boreholes, but also in the construction of underground workings-tanks in rock salt by dissolving through boreholes, as well as for use in various mining technologies oil, for example, in the operation of boreholes jet pumps and the water-gas impact on the reservoir. Experimental studies of the coalescence of gas bubbles in aqueous electrolyte solutions [8, 9] showed, in particular, that there are areas of rational salt composition and concentrations in which the coalescence of gas bubbles is suppressed, which contributes to the creation of stable gas-liquid mixtures with foamy structure.

The definitions on the core material of the Leykovsky stock from the intervals of underground workings-capacities of the mass transfer coefficient of the vertical surface of the rock salt in water under conditions of natural convection revealed gassing containing mainly methane (~ 99%).

Figure 2. Diagram of the laboratory setup to determinate the mass transfer coefficient of rock salt during dissolution: 1 – tank; 2 - core; 3 - solvent; 4 - gas bubbles; 5 - salt plates; 6 - particles of insoluble inclusions; 7 - support; 8 - precipitated insoluble particles and salt plates; 9 - floating light particles of impurities; 10 - insulating coating of core ends.
In the process of mass transfer, gas, particles of insoluble inclusions and particles of salt are released from rock salt (when gas is included in salt crystals). Depending on the stratification of the solution, insoluble heavy particles sink to the bottom of the mine, and light particles together with gas microbubbles rise up, resulting in a significant amount of particles entering the non-solvent (diesel), significantly changing its properties.

It has been found that at the roof of the production capacity, which is constructed in rock salt with a significant gas content and with the use of diesel fuel as a non-solvent, a foam layer is formed [10]. The foam layer at the roof of the mine at the Leikovsky field is represented by a cluster of gas bubbles evenly distributed between thin layers of solid mineral particles and rocks of small size with diesel fuel and mortar. Suspended particles of rocks of different densities and sizes, like gas bubbles, are in the entire volume of the solution.

**Conclusions**

The use of mineralized water can reduce the hydration of formation clays, but it is desirable to select the composition of water that is most compatible with the formation components of the productive formation.

The use of mineralized water obtained by dissolving the salt layer of the oil field can largely solve the problem of compatibility of pumped mineralized water with reservoir water and mineral composition of the reservoir.

When developing a salt formation with a capacity of several tens of meters with the supply of solvent through the drilling well, according to the technological regulations, an underground production is created - a container in rock salt (vertical or horizontal) for storage of petroleum gas along the way.

Complex use of oil and salt layers of the oil field allows to obtain a mineralized solution to intensify the extraction of oil from the reservoir and to create an underground reservoir in the salt reservoir for underground storage of associated petroleum gas (APG), i.e. to create an underground gas storage (UGS) in rock salt.

At Talakan oil and gas condensate field (Republic of Sakha) the implementation of combined development of oil and salt layers of oil and gas condensate field with the creation of an underground gas storage in rock salt and the use of mineralized solution for the intensification of oil extraction was started.

**References**

[1] Sousa R L 2010 *Risk analysis for tunneling projects* PhD Thesis (Massachusetts Institute of Technology, USA)

[2] Yufin S, Lamonina E and Postolskaya O 2007 Estimation of strength and deformation parameters of jointed rock masses *Proc. 5th Int. Workshop on Applications Computational Mechanics in Geotechnical Engineering* (Guimarães, Portugal) pp 3-15

[3] Menezes A T, et al 2007 Geomechanical studies for a road tunnel in volcanic formations *Proc. World Tunnel Congress* (Prague, Czech Republic).

[4] Goodman R and Shi G 1985 *Block theory and its application to Rock Mechanics* (Prentice-Hall, USA)

[5] Cafofo P and Sousa L R 2007 Innovative underground works at Madeira Island, Portugal *Proc. 11th ACUUS Conference on Underground Space: Expanding the Frontiers* (Lavrios, Portugal) pp 137-143

[6] Eclaircy-Caudron S, et al 2007 Inverse analysis of two geotechnical works: a tunnel and a cavern *Proc. 5th Int. Workshop on Applications Computational Mechanics in Geotechnical Engineering* (Guimarães, Portugal) pp 125-142

[7] Miranda T, Sousa L R and Correia A G 2008 Bayesian framework for the deformability modulus updating in an underground structure *Proc. 42nd US Rock Mechanics Symposium* (San Francisco, USA)
[8] Lemos J V 2010 Modeling rock masses in large under-ground works *Proc. Int. Conference on Hydroelectric Schemes in Portugal* (Porto, Portugal)
[9] Elegbede C 2005 Structural reliability assessment based on Particles Swarm Optimization *Structural Safety* 27 pp 171–186
[10] Castro A T, et al 2002 *ISRM News* 7(2) pp 24–32