Mass transfer in the zone adjacent to the contour of an underground cavern

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Various processes of mass-transfer induced by hydrodynamic forces in the zone adjacent to an underground cavern are discussed on the basis of: (1) the physico-chemical mechanics regarding the phenomena occurring at the contour surface, (2) the theory of boundary layers and flows around the contour and (3) a geomechanical approach for the boundary zone of rock salt deposit.

1. Mass-transfer at the surface of an underground cavern.

Physico-chemical mechanics, postulated by P.A. Rebinder, is concerned with the investigation of surface phenomena. B. Derjagin was one of the first among other scientists who discussed the mechanism of splitting pressure of sodium chloride water solutions (concentrated electrolytes) in thin films on hydrophilic surfaces [1], which was predicted by W. Hardy.

Physico-chemical mechanics describe the Rebinder effect in the earth's crust [2]. It can be used to establish a correlation between mechanical properties of mountain formations and physicochemical processes occurring at the phase boundary. The studies of underground cavern surfaces carried out in real conditions and of salt samples lead to the suggestion of a mass-transfer mechanism that causes the formation of rough and ripply surface, ribs and craters under influence of hydrodynamic forces together with Taylor-Goertler vortices [3].

In general, mass-transfer on a surface depends on the interaction between a solid material and a liquid. The basic concept of dislocation theory states that, among other various mechanisms of plastic deformation, translation slipping predominates in the direction and in the plane, in which the atomic density is maximal [4]. If a surface-active medium interacts with a single crystal, then the rate of slipping and the number of actual slipping systems will increase (according to E.D. Tstchukin due to lowering of activation energy, which prevents the transport of dislocations to the surface). Many important properties of ionic crystals are associated with the presence of charged boundary dislocations and point defects that interact with the latter. Reduction of the surface energy, decrease of the strength and accelerated plastic deformation [2] are associated with the Rebinder effect. In the process of plastic deformation, the self-ordering of dislocations and all other defects of crystal lattice takes place [5]. At ambient conditions, the contact area on the surface of rock salt is presumably ripply and rough. ($40^0 < \alpha_{av} < 80^0$, where α_{av}, is an average slope angle of lugs). The rupture of ionic crystals under stress, occurs in the plane of the minimum surface energy - i.e. plane (100). When hydrodynamic forces act at a contour of an underground cavern, the initial smooth surface comes into contact with saturated rock salt solution

The initial smooth rock salt surface in underground cavern is characterized by the minimum value of surface energy. During contact with a concentrated salt solution the hydrodynamic forces act onto contour area of underground cavern, which results in the deformation and rupture of the surface and the formation of a new ripply and rough structure. The surface is getting covered with cracks, the number of which is higher than that and the pristine material [6], which reduces mass-transfer coefficient to a value less than 10^{-5} cm^2/s [7]. It was found that the creep rate of a sodium chloride sample is equal to 6.3 micron/hr after treatment with NaCl water solution [2]. This value is larger than that for contour creep movement in underground cavern at similar conditions, (except higher temperature) which is equal to 3.65 mm/month (5.1 μm/hour) [6]. The thickness of the intergranular layer is around 0.1 μm. The actual influence of splitting pressure become evident when this value becomes less 0. 1 μm (according to B. Derjagin) and the pressure increases rapidly as the thickness of the layer decreases.

2. Flow of non-homogeneous liquid near crooked surfaces.

J.I. Taylor studied flow stability of a viscous liquid between two coaxial cylinders, one of which, the internal, rotates. A stable division of the system into layers was observed which was due to centrifugal effect acting liquid particles located close to the internal wall, causing them to move outside. This phenomenon is similar to that arising from the density variations (density dividing) during flow of homogeneous liquid in vertical direction along the wall (G. Shlikhting).

G.Goertler showed that near concave walls, the effect of centrifugal forces results in instability similar to that for flow between rotating coaxial cylinders.

Laboratory determination of mass-transfer coefficient was carried out using rock salt samples from the deposit where an underground reservoir is situated. The cylinder salt sample was put vertically in a glass vessel filled with water. Subsequently, the formation of ripply rough surface and craters with Goertler vortices was observed. When magnetic stirrer brought liquid between the two cylinders (between side walls of the vessel and the sample) into rotation, screw longitudinal ribs were formed similar to screw-like interfering H. Ludwieg vortices. This indicates the decisive role of the liquid flow for shaping the surface characteristics as well as the possibilities of various relief transformations.

Fig. 1 shows the horizontal underground reservoir at Khodzha-Mumynsk field range. The upper part presents the surface with craters and Goertler vortices [3]. Ribs and Taylor vortices characterize the lower part. Cross section A-A shows ratio between different surfaces. One can see also a surface covered with linear ribs, which are perpendicular to the well, then ripply salient surface of the bottom of the underground reservoir at an angular direction to horizon (r).

Fig. 2 represents the form of the underground reservoir built up using a solvent. Evidently, there is a similar distribution of surfaces covered by Goertler and Taylor vortices and their various combinations in vertical and contour directions, which were formed in pristine condition [9], as in the laboratory experiment. The relief built up by the craters and ribs has a regular morphology.

Mass-transfer phenomena induced by hydrodynamic force lead to release of insoluble admixtures and gas encapsulated in rock salt deposit. These processes participate as well in the formation of salt surface in an underground cavern.

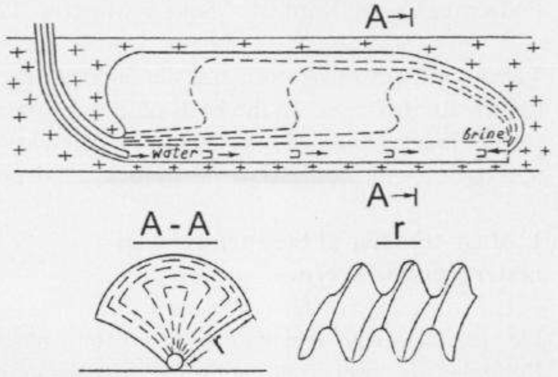

Fig. 1 Underground horizontal reservoir. Longitudinal and vertical section. Cross section A-A, r – ridged surface.

3. Characterizing of brine infiltration process in the contour rock salt deposit by kinetical rupture theory

The main difference between underground caverns and excavations arising from mine works at rock salt deposits is the influence of a liquid on mass transfer processes, which occur on salt surface and in the zone of contour rock salt massive.

In salt mines, the amount of cracks in the contour area increases hyperbolically with the approach to the contour, while the infiltration occurring in underground caverns decreases that value when moving off the contour.

The additional crack formation in the contour zone takes place during brine infiltration into the salt deposit. This resembles phenomena, which proceed on a contour surface in the mass-transfer process.

Crack formation is defined as a process of rupture accumulation. The volume of injected liquid is an index for degree of rupture.

The rupture of near contour massive during infiltration is a multistep kinetical process.

On the basis of result obtained by P. Desgree and J. Durup, and kinetical rupture theory approach, different critical values of tangential strain (threshold strain values) were found for various

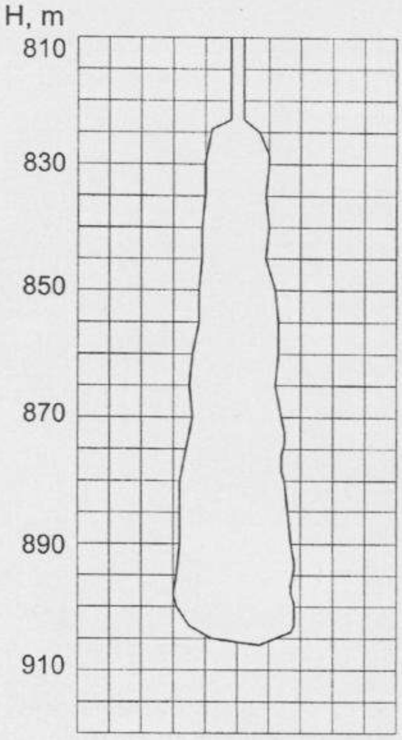

Fig 2. The shape of an underground cavern created by dissolution

stages depending on the amount of infiltrated brine into rock salt. The obtained results are practically the same as the gradient of pressure values for intermediate points during brine infiltration into the zone adjacent to the contour massive of an underground cavern.

4. CONCLUSIONS

1. Mass-transfer induced by hydrodynamic force takes place on newly formed granular surfaces of rock salt at the boundary contact with sodium chloride solution - the surfaces of minimum surface energy with rough texture, craters and ribs.

2. The flow of non-homogeneous liquid around crooked surfaces in underground caverns is accompanied by the formation of craters with Goertler vortices and ribs with Taylor vortices. Mass transfer is controlled by combination of various relief depending on convexity or concavity of the surface.

3. Pressure values were determined for intermediate points of different stages of the process on the basis of kinetical rupture theory, which are practically coincide with the gradient pressure values for infiltration into near-contour massive of rock salt.

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