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Design and Simulation of Gas Storage Caverns from Underground Rock Salt Solution Mining

Classification: Salt Manufacture Technologies

Abstract: Brine mining from underground rock salt deposit can be used in chemical technology and edible, in addition, the rest dissolution space after brine mining can be used as underground storage. The rock salt dissolving properties are the key factors in the mining of rock salt and building underground rock salt repository. By conducting research in underground rock salt dissolving laws, the influence of the underground rock salt dissolving process upon rock-salt cavity shape and the quality of brine extraction is discussed. On the basis of the experiment, a mathematical model is set up and water lava salt dissolving process simulation research is carried out, in order to establish a mechanism for the vast salt water solution aiming at the coordinated control of the underground salt water dissolved cavity and the ground water soluble concentration. Stability analyzed, the research of underground rock salt mining and the safety of rock-salt cavity are of important practical significance.

Key words: underground rock salt; underground storage; halite dissolving; solution mining for gas storage caverns

1. Introduction

Brine mining from underground rock salt deposit can be used in chemical technology and to produce edible salt. In addition, the space that remains after brine mining can be used as underground storage. Underground salt caverns are recognized as some of the best places to store energy related materials, such as oil, gas, and compressed air [1–4]. The main reasons are that rock salt when compared to other rock materials has four particular advantages [5–7]. (i) Low permeability. The permeability of rock salt is about 10^{-21}–10^{-24} m^2, which can ensure the excellent sealing of salt cavern. (ii) Good mechanical properties. Damage self-recovery capability of rock salt can ensure the safety of salt caverns even with frequent changes of gas pressure. (iii) Solution in water. Rock salt is easily dissolved into water, which facilitates the construction and shape control of salt caverns. (iv) Abundant resources. Rock salt resource is a very rich mineral resource with wide distributions and large reserves.

Underground gas storage (UGS) is widely used as an effective method to balance gas supply and demand [8,9]. It is an important aspect of competitive natural-gas markets [10]. UGS usually can be established in depleted oil or gas reservoirs, aquifers, salt caverns, and abandoned mines [11]. Among these, salt caverns are safe and stable options since salt rock has rheology, low permeability, and capabilities of self-healing of damage [12]. In addition, salt cavern UGS has high injection-production ratio, less cushion gas and low construction cost, because of which salt caverns are widely used for gas storage [13]. Salt cavern UGS is mainly constructed by water solution mining, using one or more drilled wells to dissolve the salt and leach a cavern with water. Since the whole leaching process is deep underground, it is difficult to control the development of the salt cavern. Cavern shape irregularities usually occur as a result of an inappropriate mining process design, downhole failure or water-insoluble interlayers in the salt formations [14]. As a

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key technology in the construction of salt cavern gas storage, the control of salt cavity is directly related to the stability, sealing and safety of gas storage. Thus, it is of importance to study the control of cavity morphology.

The rock salt dissolving properties are the key factors in the mining of rock salt and building underground rock salt repository. In this paper, the experiment is carried out to study the dissolution of underground rock salt, which is of great significance to the control of salt cavity. Currently, most studies focus on the mechanical properties and constitutive model of salt rock, with emphasis on storage security [15,16]; but there are almost no data for rock salt dissolving properties.

2. Materials and method

The static upward solution and lateral solution rates of salt rocks of different compositions in different concentrations of NaCl solution at 55 ℃ were studied. Salt rock was mainly mined in Hubei, Yunying area in China, as shown in Figure 1. By analyzing the composition of the salt rock though a large number of experiments, it was found that it mainly contained soluble salt and insoluble matter, in which the soluble salt was mainly NaCl, Na_2SO_4, $CaSO_4$ and so on, and the insoluble matter was including sediment, insoluble salt and so on. Although the salt rock mining was in the same area, its composition was quite different, especially the content of NaCl. For example, the mass percentage of NaCl were distributed from 4% to 97%, while the mass content of Na_2SO_4 and $CaSO_4$ were both below 16 %.

Fig. 1 The core sample of the salt rock mining

According to the analysis of composition of the salt rock, salt rocks with high variation in components were selected for measurement of dissolution rate. The concentration of NaCl in the solution was in the range of 0-300 g / L and the temperature is kept as 55 ℃. The dissolution manner includes: upward solution (the dissolved surface was horizontal and faced down, dissolution angle was 180 °) and lateral solution (the dissolved surface was vertical, dissolution angle was 90 °).

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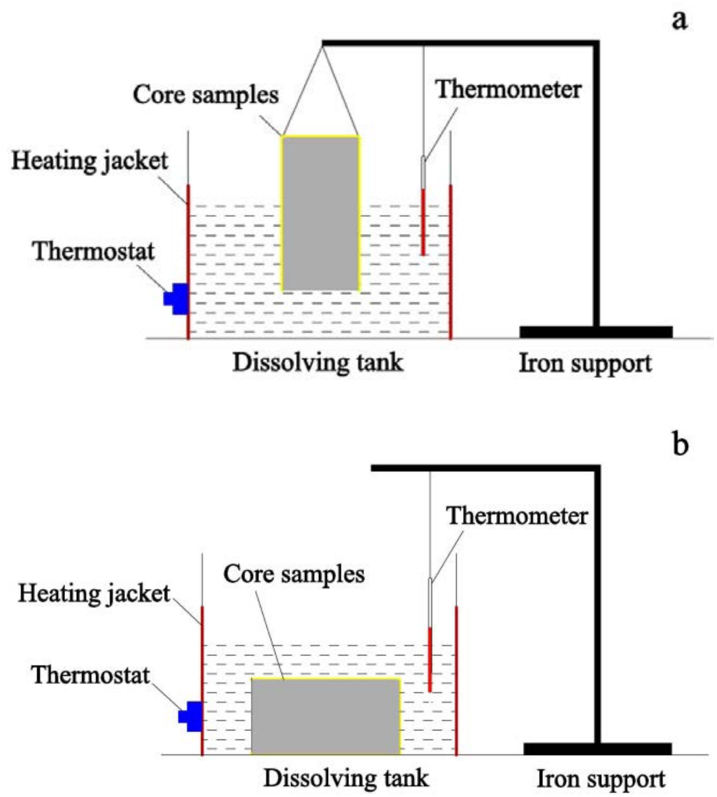

Fig. 2 Schematic diagram of experimental equipment for salt rock dissolution (a - upward solution, b - lateral solution)

In order to determine the dissolution rate of the salt rock under the conditions above, an experimental apparatus was designed and the scheme is shown in Fig 2.The salt rock was cut and sealed by wax to make sure that only the cutting surface dissolved and the surface area remained constant during the experiment As indicated in Figure 2, 10L NaCl solution of a certain concentration was put in the dissolving tank, a temperature regulator was applied to maintain the temperature of the solution at 55 ℃. Next, the prepared salt rock specimen was dipped into the solution for a certain time. Finally, the dissolution rate of salt rock was calculated through the formula 1 by measuring the ion concentration before and after the dissolution of the specimen.

$$v = \frac{C_2 V_2 - C_1 V_1}{S \cdot t} \quad (1)$$

Where v is the salt dissolution rate, C_1 is the concentration before the dissolution of the rock specimen, C_2 is the concentration after the dissolution of the rock specimen, V_1 is the liquid volume before the dissolution, V_2 is the liquid volume after the dissolution (The volume change of solution in the experiment can be ignored. $V_1 \approx V_2$), S is the salt dissolution area, t is the salt dissolution time.

As the composition of salt rock is of large difference, it's not easy to find two core samples of the same composition at all. Thus, single factor experiments can't be performed. In this case, a

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large number of experiments, approximately 500 sets, under a few factors were carried out to measure the dissolution rate of salt rock. Results were analyzed though the artificial neural network in MATLAB software. Finally, the dissolution laws of salt rocks under different conditions were predicted through the trained artificial neural network.

3. Results and discussion

Through a large number of experimental data training, the artificial neural network model was established. And the static upward solution and lateral solution rates of salt rocks of different compositions in different concentrations of NaCl solution were predicted. As a result, the dissolution characteristics of different composition of salt rock in different concentrations of NaCl solution were obtained.

3.1 Effect of the content of NaCl in salt rock on dissolution rate

The upward solution and lateral solution rates of salt rocks of different compositions (Na_2SO_4 and $CaSO_4$ content of 5%, different content of NaCl) in the NaCl concentration of 100g / L at 55 ℃ were studied, as shown in Figure 3.

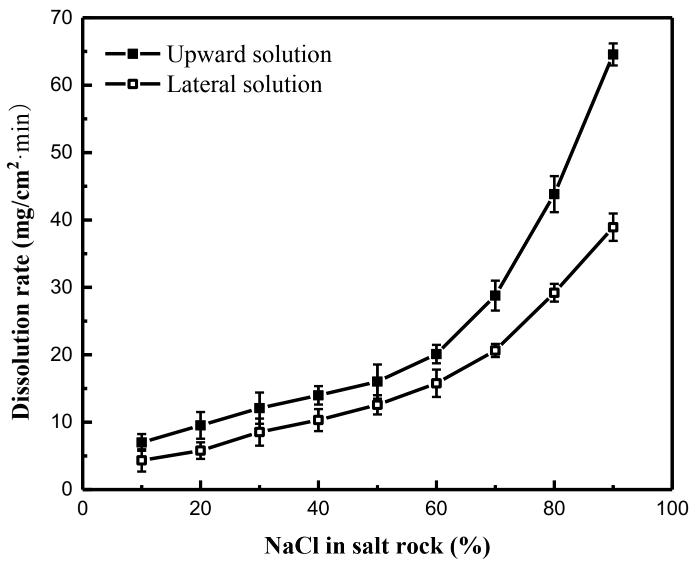

Fig. 3 Effect of the content of NaCl in salt rock on dissolution rate

It can be seen from Fig.3 that the content of NaCl in salt rock has an obvious effect on the dissolution rate of salt rock. Whether it is upward solution or lateral solution, the dissolution rate of salt rock increases with the increase in the content of NaCl in salt rock. Under the same conditions, the upward dissolution rate of 90% NaCl in the salt rock is 9.22 times than that of 10% NaCl; and the lateral dissolution rate of 90% NaCl in the salt rock is 8.99 times than that of 10% NaCl. When the content of NaCl in salt rock is10%, the upward dissolution rate is 7.00 mg / (cm^2 · min) and the lateral dissolution rate is 4.33 mg / (cm^2 · min). This is due to the reason that the soluble salt is mainly NaCl. Under the same conditions of other soluble salts, the proportion of relative soluble salt area in the same dissolved area increases, with the increase of NaCl content

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in salt rock. And thus, it increases the probability that the soluble salt of solute contact with the solution. Consequently, the results contribute to an increase in the total dissolution rate of salt rock.

3.2 Effect of the content of Na_2SO_4 in salt rock on dissolution rate

The upward solution and lateral solution rates of salt rocks of different compositions (NaCl content of 60%, $CaSO_4$ content of 5%, different content of Na_2SO_4) in the NaCl concentration of 100g / L at 55 ℃ were studied, as shown in Figure 4.

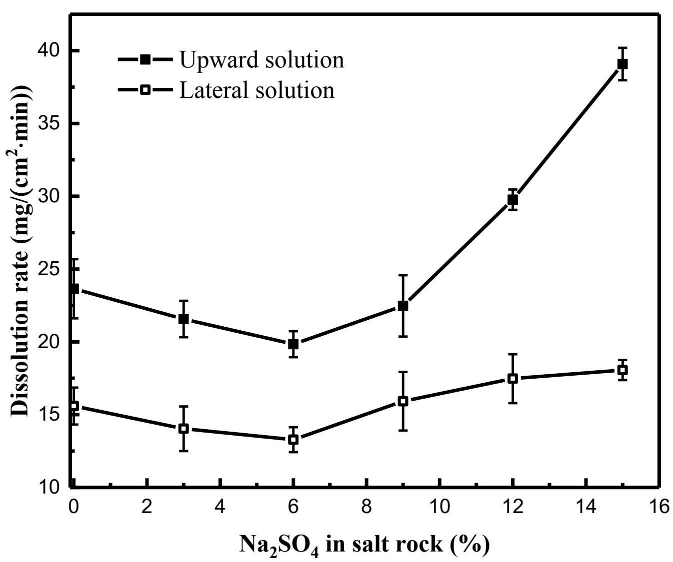

Fig. 4 Effect of the content of Na_2SO_4 in salt rock on dissolution rate

It can be seen from Fig.4 that the content of Na_2SO_4 in salt rock has an obvious effect on the dissolution rate of salt rock. Whether it is upward solution or lateral solution, the dissolution rate of salt rock decreases first and then increases with the increase of Na_2SO_4 content in salt rock. And the lowest point reached the same place, the Na_2SO_4 content in the salt rock of 6%, where the upward dissolution rate is 19.84 mg / (cm^2 · min) and the lateral dissolution rate is 13.28 mg / (cm^2 · min). This is mainly due to the reason when the Na_2SO_4 content in the solution increases, the solubility of NaCl solution will be slightly reduced. For example, the solubility of NaCl decreases from 26.8% to about 24.2% as the content of Na_2SO_4 in the solution increases at 55 °C. When the content of Na_2SO_4 in the salt rock increases, the concentration of Na_2SO_4 in the solution increases with the dissolution of Na_2SO_4 in the salt rock. And thus, the solubility of the main soluble salt, NaCl (60%), in the salt rock is slightly decreased. So that the dissolution rate of NaCl in salt rock decreases. But because of the low content of Na_2SO_4, Na_2SO_4 dissolution rate can't make up the decrease of the dissolution rate of NaCl. Consequently, when the content of Na_2SO_4 in salt rock is less than 6%, the total dissolution rate of salt rock decreases with the increase of Na_2SO_4 content; when the content of Na_2SO_4 in salt rock is more than 6%, the dissolution rate of Na_2SO_4 in salt rock is sufficient to compensate for the decrease of NaCl

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dissolution rate due to the decrease of solubility. Therefore, the total dissolution rate increases with the increase of Na_2SO_4 content in salt rock.

3.3 Effect of the content of $CaSO_4$ in salt rock on dissolution rate

The upward solution and lateral solution rates of salt rocks of different compositions (NaCl content of 60%, Na_2SO_4 content of 5%, different content of $CaSO_4$) in the NaCl concentration of 100g / L at 55 ℃ were studied, as shown in Figure 5.

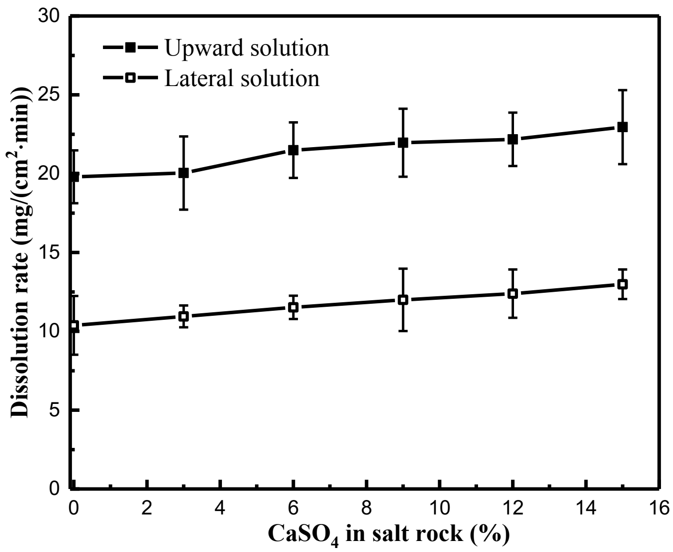

Fig. 5 Effect of the content of $CaSO_4$ in salt rock on dissolution rate

It can be seen from Fig.5 that the content of $CaSO_4$ in salt rock has little effect on the dissolution rate of salt rock, and the dissolution rate is almost constant. In the same case of other soluble salt composition, the upward solution and lateral solution rate of salt rock are slightly increased with the increase of $CaSO_4$ content, but the change is not significant. This is mainly due to the reason that the solubility of $CaSO_4$ is pretty small. As a result, the dissolution rate of $CaSO_4$ in salt rock is small, almost close to zero. Therefore, with the increase of $CaSO_4$ content, the total dissolution rate of salt rock is almost unchanged, but slightly increases.

3.4 Effect of the concentration of NaCl solution on dissolution rate

The upward solution and lateral solution rates of salt rocks of different compositions (NaCl content of 60%, Na_2SO_4 content of 5%, $CaSO_4$ content of 5%) in different NaCl concentration (0 ~ 300 g/L) at 55 ℃ were studied, as shown in Figure 6.

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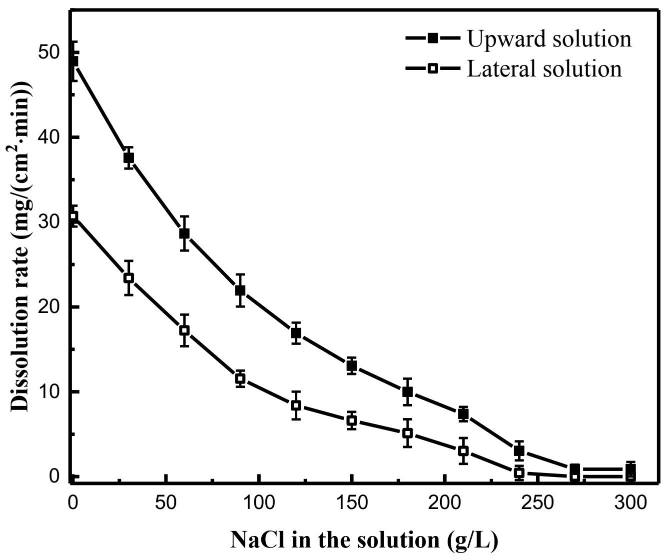

Fig. 6 Effect of the concentration of NaCl solution on dissolution rate

It can be seen from Fig.6 that the concentration of NaCl solution has an obvious effect on the dissolution rate of salt rock. Whether it is upward solution or lateral solution, the dissolution rate of salt rock decreases with the increase of the concentration of NaCl solution. In fresh water (NaCl concentration of 0 g / L), the upward dissolution rate is 48.95 mg / (cm^2 · min) and the lateral dissolution rate is 30.70 mg / (cm^2 · min). While the NaCl concentration is more than 250g / L, the upward dissolution and the lateral dissolution rate are both close to zero. From the perspective of chemical kinetics, the driving force of dissolution of the salt rock is the gap between the actual solution concentration and the saturated concentration. When the concentration of NaCl solution increases, the gap gradually reduced, and the dissolution rate decreases. When the concentration of the solution reaches a certain level, the dissolution manner and the salt rock composition can affect little on the dissolution rate, constraint to too low driving force of the dissolution, and can be negligible.

4. Conclusions

In this paper, the artificial neural network (ANN) was established by training with the experiment data of upward dissolving and lateral dissolving rate of about 500 groups of salt rocks. Through the established artificial neural network, the upward dissolution and lateral dissolution of different salt rocks in different concentrations of NaCl solution were predicted. And the effects of salt rock composition and dissolved concentration on the dissolution rate of salt rock were studied. It is found that the increase of NaCl content in salt rock will promote the dissolution of salt rock, which is mainly related to the probability of collision between NaCl solute and solution; The dissolution rate of salt rock decreases first and then increases with the increase of Na_2SO_4 content in salt rock, this is mainly related to the effect of Na_2SO_4 in solution on the solubility of NaCl, and the dissolution rate of Na_2SO_4 in salt rock may make a difference, too; The content of $CaSO_4$ in salt rock has little effect on the dissolution rate of salt rock, which is mainly due to the small

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solubility of $CaSO_4$; The increase in the concentration of NaCl in the solution will inhibit the dissolution of the salt rock, which is mainly related to the dissolution driving force. The dissolution mechanism of salt rock is mainly proved in this study, which provide a theoretical basis for the synergetic control of the formation of groundwater rock and the formation of brine concentration on the ground. Combined with the stability analysis, the study has important practical significance to underground rock salt mining and underground rock salt cavity safety.

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