ANALYSIS ON RELATIVE STABILITY OF THE CAVITY TOP PLATE IN THE MID AND LATE PERIOD OF ROCK SALT SOLUTION EXPLOITATION

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Abstract: Taking Changshan salt mine in Weixi as an example, this paper mainly analyzes expansion capacity and maximum collapse height of the collapsing rock in the top plate, homeostasis process and block size of collapse, etc. It is concluded that the top plate is in condition of relative stability in the mid and late period of rock salt exploitation. This paper provides scientific basis for confirming the well-repairing and producing scheme, and will also increase the productive capacity for brine and the technical level for exploitation.

Keywords: Rock salt solution exploitation; mid and late period; top plate of cavity; stability analysis

SUMMARY

Adjoining the southeastern fracture zone and being the upper part of faultage, Changshan salt mine is affected greatly by the regional tectonic stress and traction of faultage, which cause the cranny development of the stratum structure above the top plate of salt layer. Among the top plate of terranes, the unstable parts are thin, and the stable parts are thick. In the stable terranes, the anhydrite has strong flexibility but no cranny development, and it is not very thick and easy to hydrate; porphyroblast terranes are in strong rigidity, with undeveloped cranny and small thickness. In the unstable terranes, with upright the cranny, the broken terranes which grow with the seam and are cut into irregular blocks belong to very unstable terranes; the argillaceous limestones which are in big thickness, have cranny development and bad mechanical intension, and are good at slurry with water also belong to unstable terranes. In the section of 60 m-- 80 m of the well above the top plate of the rock salt in the salt mine, the thickness of the stable terranes is only 8 m～9 m, and others belong to unstable terranes, which is the important factor to lead to the collapse. Furthermore, in the process of rock salt solution exploitation, it's difficult to control and inspect the underground solution cavity, and there is no treatment to backfill, so it's a kind of natural state of affusion solution. Usually the production is required to be continuing, so the cavity enlarges constantly and the distortion of wall rock (destabilizing

state) gradually aggravates. When this distortion above exceeds the capacity (intensity) what it can support, the damage will happen, and when the serious collapse accident happens, the production will be stopped. Therefore, in the process of rock salt exploitation, the collapse of top plate is absolute, but in the mid and late period of rock salt solution exploitation, the top plate is relatively stable. The particular discussion on this issue is as follows.

CALCULATE THE HEIGHT OF THE COLLAPSE OF TOP PLATE

The underground empty cavity of the brine well is filled by the nature collapse of the terranes of top plate; therefore, the collapse height which can satisfy the full filling of the underground empty cavity is called limit height of the collapse of top plate. The collapsing rocks possess expansion capacity. During the blasting of mine, the expansion coefficient of rock is 1.2～1.8; the top plate inside the brine well will naturally collapse, and expansion coefficient of the rock is not less than 1.1～1.3. As is shown from the following analysis, empirical data is consistent with the actual expansion capacity. When the terranes of the cavity's top plate collapse down, the cavity can be filled with the expanding rocks fully. At this time, the top terranes are in a new stable equilibrium state. The collapse height of the top plate of solution cavity in Changshan salt mine can be discussed from the two following aspects.

Theoretical calculation on the collapse height of top plate of solution cavity

The collapse of top plate of the rock can be divided into three zones from the top down, including irregular collapse zone, cranny sedimentation zone and no-cranny sedimentation zone. The collapse height of top plate of solution cavity can be calculated through the formula below:

$$h = \frac{m}{(k-1)\cos\alpha}$$

In the formula:

h—collapse height;

m—salt mine thickness;

α—rake angle of salt bed ;

k—rock expansion coefficient

Then according to that the unstable terrane height of top plate is 2～3 times larger than collapse height, the unstable terrane height of the cavity top plate of can be calculated. The theoretical collapse height of each brine well of Changshan salt mine is shown as table 1.

Table1. The Theoretical Collapse Height of Brine Well in Changshan Exploitation Area

Well Group	Well Number	Salt Thickness (m)	Stratum Slope angle (°)	Collapse Height (m)	Influencing Zone Height (m)
I -7	128	14.8	4	49.33	149.99
I -9	133	17.50	2	58.33	174.99
	134	16.90	2	56.33	168.99
II -1	201	16.01	2	53.37	160.11
	202	15.50	2	51.67	155.01
II -3	206	16.40	2.5	54.67	164.01
	207	16.00	2.5	53.33	159.99
II -4	209	12.25	2	40.83	122.49
	210	13.62	2	45.4	136.20

Judge the collapse height of top plate according to documents of repairing brine well

Though there are many reasons for the accidents in brine well, the main reason is that the oil pipe and bushing pipe distort and

rupture because of the collapse of top plate so that the high salt water can't be produced.

The accidents of the brine well in mine area happen frequently. For instance, the small distortions and minor repair of the oil pipes are very common. Some wells which have serious accidents, such as serious distortion, bend or break of the oil pipes and bushing pipes need heavy repairs, because they make oil pipes difficult to be lifted, well canisters jammed seriously and cause affusion or brine production to be difficult. The collapse part of the salt terranes of top plate should be near to the section of wells which have serious distortion of the oil pipes and bushing pipes. Because the instantaneous extrusion force produced by the collapse of the terranes of top plate greatly exceeds the bearing strength of the bushing pipes, the serious distortion, rupture or break of the bushing pipes may occur, and the similar accidents may happen to the oil pipes. It can be inferred that the opening window position of the well repaired greatly is the place where oil bushing pipes distort seriously and stress is the most intensive, which is thought to locate above the collapse part. The maintenance data of wells in our mine area indicate that the collapse of brine wells increases gradually (one reason is that the top plate collapses gradually; another reason is that the relative stable top plate is destroyed by the workers who repair wells by opening windows). And the height is usually 50 m; even the highest one is up to 100 m. The opening window position of some brine wells in Changshan salt mine is showed in table 2. As is known from the analysis above, theoretical calculation on the collapse height of top plate is quite consistent with the actual collapse height.

Table2. The Opening Window Position of Some Brine Wells in Changshan Salt Mine

Well Number	Date for Repairing the Well		Well Depth of Top Plate of Salt Bed (m)	Depth below Technical Bushing Pipes (m)	Opening Window Well Depth (m)	Depth from Window Position to the Top of Salt Bed (m)
	From	To				
207	1987.12.5	1988.3.3	1008.74	1010.85	972.64	36.10
	1989.6.15	1989.9.13	1008.74	1010.85	959.47	49.27
	1989.10.26	1989.12.31	1008.74	1010.85	930.53	78.21
206	1990.11.20	1990.12.16	1012.44	1014.59	901.55	110.89
	1991.6.15	1991.7.30	1012.44	1014.59	896.99	115.45
203	1988.8.18	1988.12.14	1007.63	1009.40	920.61	87.02
202	1991.9.13	1991.11.3	989.89	989.08	930.00	57.89
133	1989.3.1	1989.4.4	964.33	966.04	864.62	99.71
	1990.2.19	1990.4.5	964.33	966.04	858.53	105.80
	1990.10.27	1990.12.3	964.33	966.04	847.81	116.52
209	1988.9.23	1989.1.20	1017.54	1024.62	920.00	97.52
210	1989.4.22	1989.9.8	1019.02	1021.05	946	73.02
130	1989.8.21	1989.10.4	1018.98	1023.98	1006.38	12.60
128	1990.6.3	1990.6.16	888.36	891.89	815.76	72.60
201	1989.5.19	1990.2.13	985.49	987.12	915.55	69.94

The homeostasis process of the top plate Of solution cavity

From the view of rock mechanics, on one side, the collapse of top plate results from the salt cavity development and wallrock destabilization; on the other side, the collapse of top plate actually is an adjustment function leading to wall rock transiting from

destabilization to new balance (relative stabilization). It tends to natural balance arc with relative stabilization, and also due to the limit of collapse height, when the collapse height reaches the limit height, the cavity of top plate is in a relatively stable state, and the cavity comes into being and develops with the process of production. From the viewpoint of the stability of the wallrock in top plate, it is a homeostasis process from stability to instability to relative stability. There are so many influence factors, which include the geological structure, shape and thickness, embedding depth, mechanical properties, original ground stress, redistribution stress of the salt bed and terranes of the top plate as well as hydrodynamics, the shape and size of cavity etc which are related to well construction and production process. However, many of these factors are variable parameters themselves, so this is a complicated homeostasis problem. However, according to the production practice of our mine and related scientific knowledge, the complicated dynamic process can be simplified.

As a whole, the homeostasis process of the top plate can be divided into three main phases: The first is the stable phase of the top plate in the well construction period; the second is the destabilization, collapse and adjustment phase of the top plate in the early period of production; the third is the relatively stable phase of the top plate in the mid and late period. The dividing line between the first and second phase is the early destabilization and collapse of the top plate (which is similar to the first collapse accident in the production). When other conditions are certain, the destabilization and collapse of the top plate mainly depend on the span of the cavity (upper diameter), which can be called the minimal span of the collapse of the top plate or the maximal span of the stability of the top plate. That is to say, when the cavity extends to this span, the collapse of the top plate probably happens at any moment. As is discussed above, the collapse also indicates the adjustment from the stress state to new balance. Therefore, the second phase can be called as the destabilization collapse and adjustment phase of the top plate. The dividing symbol between the second and third phase is when the collapsed rock from the top plate can fill the solution cavity fully in the range of local fault-blocks in the mid and late period of the production of brine well. Then the original empty cavity of this fault-block is filled fully, and the upper terrane of the top plate turns to stable estate.

The influence of the collapse fragmentation on the distortion degree of oil casing pipe

The severity degree of the collapse of top plate cavity influences directly the distortion degree of the oil casing pipes. The severity degree of the collapse is not only related to the height and volume of the collapse, but also to the break fragment (collapse fragment) of the rock when collapse happens, which is not usually paid much attention in the previous analysis, so much as neglected. Actually it is a very important factor. The bigger the collapse fragmentation is, the more serious the influence on the distortion of the oil pipes and bushing pipes of the brine well and rapture accidents is. The rock collapse fragment size when top plate collapses is decided by two sides; one is the natural structure and construction of the terrane of the top plate and the developing state of the crack; the other is the water solution mining process and the manual cracks which form in the early period of the top plate collapse.

The research analysis on the core-taking documents of NO.29 production well in mine area: the cranny in the middle of mashed terrane develops, the rock core usually cracks along layer surface to the shape of thick pie, whose length is commonly less than 10cm, and the shape likes the leaf after weathering, with bad mechanical strength, easy disintegration and argillization; the original rock solution and cranny of upper terrane don't develop. But after the top plate collapses gradually, many manual cranny will be generated; the phenomenon of dissolving rust of the cracked rock is obvious, and the secondary vertical crack (structure) and the seam line develop

with skew cranny, and many of the rock cores rupture along the crack surface and seam line with the shape likes block and low yield. Therefore, with the continuous collapse of the top plate, the collapse fragmentation size of the collapse reduces continuously and the destructiveness to the oil pipes and casing pipes also reduced gradually.

According to our main well-constructing process, the high pressure state doesn't happen inside the wells and the natural cranny and block size of the terrane of the top plate are basically kept by using single-well convection and oil underlay well-constructing connected method, but if the fracturing connected method is adopted, the terrane of the top plate will certainly form manual cranny after the inner of well experiences high pressure state, which makes the rock falling down so small and reduces the severity degree of destroying the piping when the collapse of the top plate happens, and the safety production period will increase greatly. This point is also proved by our producing fact. 104 well-105 well-106 well is a well group with connected method by fracturing, 106 well has been used for 30 years, and it is also our main brine-producing well at present.

The top plate is in the relatively stable state in the mid and late period of the exploitation of rock salt

As is shown from the discussion above, the collapsing rocks of the top plate possess expansion property and the collapse height of the top plate is limited. Besides, the cranny of the rock cavity of the top plate of rack salt develops, and with the collapse of the top plate happens gradually, the secondary crannies increase continuously, and the collapse fragment size reduces gradually. Therefore, the top plate of the solution cavity has a relative stable state. Now this issue will be further explained this issue by the production practice in our mine.

NO.210 well which was put into production in 1983 has a long history of 20 years exploitation till now, and it has been in the mid period of rock salt exploitation. In 1989, this well was heavily repaired by opening window, and the structure of each kind of oil pipe is comprised of an oil pipe (d=□127 mm, l= 914.78 m), an drill pipe (d=□114 mm, l=112.27 m) and a naked aperture with the length of 79.58 m. This well didn't stop production until 1999 due to the reduction of the brine salty. Aiming at this situation, this well was conducted some testing. The result is that there are holes and crannies in oil pipes, but the distortion is small and there is no rupture and cast, etc; the water in the well cavity is high saline water. According to this result and combining to the production situation and the discussion above, it can be concluded that the top plate of the solution cavity is in the relative stable state. In order not to artificially destroy the stable state of the top plate, the repair by opening window repair to wells is not feasible. So the scheme of repairing the well has to be modified. Through the joint effort of the design and research institute, well team, production department and the second brine exploitation workshop, the effective well-repairing scheme is established, which is to put oil pipe with the inner diameter of □63. 5 mm inside the oil pipe with outer diameter of □127mm. And it is estimated that it is difficult to do this in the pipe below the naked aperture, because the inner diameter of drill and oil pipe is 95mm and 63.5mm respectively; the outer diameter of them is 114mm 73 mm respectively; the holding hoop is □89 mm; and also the brine well is a little inclined. But the process of pipe-setting is very successful. Therefore, the top plate of the solution cavity is proved further to be relatively stable.

NO.118 well which has been exploited for about 30 years till now was put into use in 1974, and it has been in the late period of rock salt exploitation and inside the of large-area connected exploitation area. It stopped production for the reduction of the brine salty in 1999. In April 2000, the production test on this well was carried out. The result is that: it is smooth when connecting pathway; there are holes in oil pipe; but the distortion is small and there is no rupture and dropping; the water in

well cavity is highly saline. According to this result and analysis above, this well is in the relative stable state.

NO.144 well that is drilled in 1990 is a remedy well in the large-scale connected exploitation area and put into production in September, 1990. It stopped production for the reduction of the brine salty in 1994. The result of the first production test is that: there are holes in oil pipe, but the distortion is small and there is no rupture and droppings. As for the repairing of the NO.115 well, the original circulation path for water is changed; the 114 well restarted production in July, 1998, while it stopped production again for the reduction of the brine salty in March, 2000. The second production test was conducted in June, 2000, with these following results: it is smooth when connecting pathway; there are big holes in oil pipe, but the distortion is small and there is no dropping; the water in well cavity is highly saline. According to these two test results and analysis above, the top plate of this well is also considered to be in the relative stable estate.

To sum up, after collapsing the rocks have expanding property, and the salt bed is thin with small limitation collapse. When the rock salt exploitation is in the mid and late period, there are many collapses at top plate of solution cavity, which lead to the development of rock's secondary cranny of the top plate and the reduction of the collapse block size. At this time, with the continuous exploitation of rock salt, the degree of the collapse reduces and the influence on the oil pipes and bushing pipes also reduces (nearly no influence). Therefore, the top plate of the solution cavity is in relative stable state; that is to say, the brine well is in relative stable state. It provides scientific basis for establishing well- repairing scheme and production technology scheme. When the well is being repaired, the stability of the top plate should be assured in order to prolong the safe production period after repairing the brine well and provide the essential guarantee for increasing the brine exploitation capacity. When the production technique scheme of the large-area connected exploitation area is established, production in low pressure should be considered because the top plate is in relative stable state. It can not only increase the exploitation rate and resource utilization rate, but also reduce the unit cost and realize the purpose of effective production.

CONCLUSION

1. The collapse of the top plate of rock salt cavity is absolute, but there is collapse limit height; the limit height in our mine is small, which is commonly 50 m while the maximum is more than 100 m. Therefore, it is impossible to lead to the geological disaster such as sinking of the ground and landslide, etc.

2. The collapse of the top plate of cavity is a homeostasis process that includes three stages: stability→ instability → relative stability. Therefore, oil pipes of the brine wells which are in middle and late maintenance period should possess anticorrosion performance in order to prolong the safe production period of brine well.

3. As for the three main processes of well construction including single-well convection, oilunderlay and fracturing, the wells group connected by fracturing method have slight man-made cranny development and small collapse rock block size; these wells have smaller influence on the oil bushing pipes and longer safe production period. (Much longer than the other two well construction processes).

4. It is firstly brought about and proved that the top plate in the mid and late period of rock salt exploitation is in relative stable state, that is to say, the brine is in relative stable state, which provides precious scientific support for establishing well-repairing scheme and production technique scheme.

5. When the brine well is repaired in the mid and late exploitation period of rock salt, the top plate should be protected from destruction in order to provide necessary

guarantee for prolong the safe production period after repairing the brine well.

6. Low pressure production should be suggested in the mid and late exploitation period of rock salt, because it can not only increase the brine productive capacity and resource utilization rate, but also reduce the cost and achieve the effective production.