ANALYSIS ABOUT THE FORMATION MECHANISM OF OPPOSITE-WELL CONNECTIVITY MINING CAVITY IN THE THIN-LAYER AND MULTI-LAYER SALT MINE

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Abstract: On the basis of the basic theory of rock mechanics and basic method of opposite-well connectivity mining, this article puts forward the mechanism of cavity formation, the stages of cavity formation and the prospect of cavity reutilization by a comprehensive study, concerning with the laboratory model testing and the recording datum of water-soluble fracturing mining in salt mine.

Key words: salt mine, mining, cavity mechanism of formation

INTRODUCTION

The thin-layer and multi-layer salt mine is the main mode of occurrence of ancient saline lake deposit in our country. The main mining technique is water-soluble fracturing oppositewell connectivity mining. Because of the limit of testing method, the research about cavity shape and formation mechanism by water-soluble fracturing butted wells connectivity mining is still a virgin field. The traditional view of cavity shape is through theoretic calculation. It is thought that a nearly ellipse horizontal cavity shape which takes the two wells as the center and has a 75-meter dissolving radius is formed in salt bed, then the cavity dissolves upwards layer by layer after the thin layer roof collapsed. But, judging from the mining practice over the past 20 years, there are many differences between actual conditions and ideal morphology. Rediscovering the basic forms of this kind of cavity in different developmental stages is of great significance for designing the distance between brine wells and the layout of the mining areas scientifically, constructing the cavity rationally, raising the utilization rate of resources and the recycle of the cavity.

RESEARCH METHODS

According to the basic theory and method of rock mechanics and water-soluble fracturing

mining in salt mine, the dynamic data recordings of hydrologic project in drilling construction, the prospecting and measuring data of cavity, the relevant parameters of brine-extraction production of salt well, the achievements of laboratory model testing in the opposite-well connectivity mining area in Hubei Yun-ying salt mine are analyzed and summed up. Making a comparative research for the achievements of the following three aspects: theoretic calculation, production practice and laboratory model testing, a new understanding on cavity shape and formation mechanism of water-soluble fracturing mining in salt mine have been summed up; and the object and method of water-soluble mining of the thin-layer and multi-layer salt mine can be evaluated scientifically, which can guide the further water-soluble fracturing mining design and brine-producing in salt mine.

SHAPE AND CLASSIFICATION OF CAVITY

Type of cavity shape

The cavity shape of drilling water-soluble mining in rock salt deposit depends chiefly upon the multi-factors, such as the feature of rock salt deposit, buried depth, mining method, the quailty of well construction, mining strength and production and management level. The cavity shape can be classified into two categories: regular forms and irregular form.

When conducting the water-soluble mining for huge thick rock salt and salt dome deposit, the "Oil Cushion" and "Air Cushion" of single well convection are widely used. There is no connection among the wells in the period of pre-production and during the production. The drilling technology in directional horizontally-butted wells is often used in recent years. The cavity shape can be manually controlled in the process of brine extraction to the utmost extent and the cavity shape is rather regular.

The thin-layer and multi-layer salt ore deposit under the inland rock salt geologic ore-forming condition is usually mined by hydraulic fracturing directional opposite-well connectivity method, rather than the technology of "Oil Cushion" and " Air Cushion". The upward dissolution is often obstructed naturally by interlayer in the salt mine. The shape of cavity formed by water-soluble salt mining is mostly irregular, and this kind of irregular cavity is the focal point of this paper.

The characteristic of cavity shape

The irregular cavity shown by laboratory model testing and production practice has three characteristics. Firstly, the upward solution of cavity is intense. An irregular upward columned cavity taking each well tube as the center is formed. Secondly, the speed of side dissolution and horizontal washing dissolution in the passage between two wells is more slowly than that of upward solution. When the upward dissolution of cavity reaches the intercalated bed or roof, the speed of side solution will increase. Lastly, there is no downward dissolution along the fracture passages basically. Without artificial control, this kind of cavity is a nearly cylindrical or inverted dome-shaped cavity, which upwards dissolve along the well tube, taking the two tubular wells as the center and having a 30~50 meter side solution radius. The height of the cavity is higher than the radius of cavity. The cavity height/radius ratio is 1.5~2.5/1. The cavity looks like an asymmetry saddle shape on the longitudinal section of the two-hole axis. The inside of the cavity is marked by indentation. The inner structure of cavity is a cavity, skeleton or honeycombed structure, with the remnants like coral reef.

SIMPLE ANALYSIS OF THE FORMATION MECHANISM OF CAVITY

Analysis of cavity stress-strain

In the salt mining area which having non-connectivity geological tectonic, the cavity of water-soluble fracturing mining in salt mine can be considered as mined-out area filled with salt brine. Under closed conditions, from the water-injecting well to underground cavity, then to brine-extracting well, the uplift force of salt

brine in the cavity and stress of roof subsidence and deformation is in a state of equilibrium, due to the incompressibility of salt brine and transitivity of the stress. When the closed environments are destroyed (including the situation that some parts of brine is absorbed by the rock around the cavity), there exists the constant corrosion of rock salt and new spaces, or the brine loss connects other subterranean passages because of well tube leakage. These factors will weaken the holding power from brine against roof subsidence, causing the collapsing and deformation of the weak part of roof and releasing the stress. Then a new equilibrium emerges. The roof of the cavity collapsed gradually according to this iteration. As a result, the roof gradually collapses. Therefore, without the interactive of other factors, the collapse of roof is a long process; while the land subsidence causing by this collapse is a longer process.

The physic-chemical conditions of cavity formation

This experiment chose typical rock samples, simulated different mining methods and carried out many tests on the formed cavity. According to the analysis of production practice, there comes a conclusion that the factors which affecting the formation of cavity are both geologic factors and artificial factors in the mining process. The main contents can be summarized as follows: 1. The main body of cavity is determined by stratum-structure; 2. The configuration of the inner cavity is determined by ore deposit structure; 3. The growth speed of cavity is determined by the types of ore; 4. The height of upward dissolution cavity is determined by the fractionation of brine self-weight; 5. The sedimentary transition of the salt mine causes some difference in different horizontal levels in the same cavity; 6. The development degree of dissolution passage around the cavity is controlled by the structure of ore deposit likes joints and fissures; 7. The symmetric of the cavity is determined by the method of well water-injecting ;8. The size of the cavity is determined by the way of water-injecting; 9. The shape of upward flow of the cavity is determined by the quality of salt well cementing; 10. The dissolution range of the double-well and the shape of horizontal projection areas are determined by the original passage of fracturing connectivity.

THE DEVELOPMENT STAGES OF THE CAVITY

Each cavity has its own morphological characteristics, but there are some regularities existing in each unit, which provides a reliable basis for the research of the cavity morphological characteristics. Based on the hydraulic feature of the hydraulic fracturing water-soluble mining technology in every period, this paper classifies the process into hydraulic fracturing stage, cavity constructing stage and brine-extracting stage. These three stages, in essence, are the whole process of the generation, incubation, growth, formation and development of the cavity. The morphological characteristics of the cavity development are different in different stages.

Generation and incubation of the cavity

In normal circumstances, the vertical stress gradient of the ground stress is about 0.25 MPa/100 m, and the horizontal stress gradient is about 1.1 MPa/100 m. The fracturing stress gradient is always 2.4~2.6 MPa/ 100 m in the process of hydraulic fracturing connection the in salt mine of Yun-ying, Hubei. Since the steady stress gradient is 1.2~1.4 MPa /100 m, it is proved that the double wells are connected by vertical cracks. A group of radiating cracks is generated on the upper of the ore layer which is in the open-hole section of water-injection wells, when carrying out hydraulic fracturing of water-infecting wells. The appearance of this group of radiating cracks marks the generation of the micro-cavity; at the instant of its generation, it had a circular distribution taking the water-injection wells as the center, and then had a sectorial distribution with the injection well as the focal spot. The distribution of the cracks nearing the water-injection wells is dense

and wide; which is also sparse and narrow nearing the back-brine well. Once the fissures communicates with back-brine well, the comm.unicated fissures will determine the general direction of the future development of cavity. The process from the generation of fissures to the formation of communication fissures is the incubation process of the cavity. The development of cavity is on the basis of the communication fissures.

This group of communication fissures may not on the link of the opposite wells. Sometimes, this group of communication fissures can connect the two wells, even deviating from the link of the opposite wells. As for the multi-layer salt mine with many interlayer, the development of fissures formed by hydraulic fracturing are generally the extension of longitudinal crack along horizontal direction. This is mainly because of the reasons that mechanical damage (hydraulic fracturing) and the compressive strength are higher than the obstruction from the interlayer of the salt bed.

The expansion of the cavity

This stage aims to expand the communication fissures and augment and strengthen the water-carrying sections. The characteristic of the cavity development is more complex than the generation of the cavity. First of all, there will form a small original cavity in the bottom of the well because the completely well washing should be carried out before the completion of the drilling. This small cavity, on one hand, is convenient for receiving the conduction of hydraulic fracturing fissures of another well and forming a larger target; on the other hand, is beneficial for the sediments inside the well tube depositing in the bottom of the well. Because of the self weight-differentiation of the brine well, the density of injected fresh water is relatively small , about 1. But the brine in the small cavity is almost saturated and its density is 1.2. Therefore, with the help of density difference, fresh water bears an upward buoyancy force to make the injected water rising along the exit of the casing pipe. Its function is to dilute the brine in the upper of the small cavity and make the flowing direction of brine along the outer wall of the casing pipe, then flow around when getting the top, and next flow downward along the well wall, and lastly flow towards another well along the hydraulic fracturing fissures in the bottom of the well. In this course, the density of brine is increasing gradually; the speed of upward development of cavity is faster than that of horizontal development; while the speed of horizontal development of cavity is faster than that of downward development. Finally, there will form a cylindrical cavity or inverted dome-shaped cavity near the casing pipe of each well.

The formation of the cavity

With further extending of the passage between the opposite wells, the small cavity caves in the two wells are expanding continuously and making the cylindrical cavity dissolving upwards. When meeting the roof or the insoluble rocks, there will be a strong side solution and there will form a round plate shape centering on the well tube. At that situation, the cylindrical cavity will dissolve sideward along the insoluble rocks and the structural interface of salt bed. The communication fissures of the two wells under the hydraulic scour and dissolution will expand according to the rule of fast upward dissolution, slow side dissolution and almost no downward dissolution. At the early and middle stage, the liquid is a turbulent flow; at the late stage, the liquid is a laminar flow. The horizontal projection of the passage of the connected two wells resembles winding river course. At this stage, some parts of insoluble substances are taken out of the surface by fast flowing liquid and another part of the insoluble substance is deposited in the bottom or two sides of the passage, which segregate the rock salt and the solution again. The ores in the under-part of the cavity are mainly contacting with the pore water of the deposits in the bottom wells and the contacting area is small. With the influence of gravity differentiation, the concention of the brine is high; therefore, the development of the lower cavity is quite slow. As the thickening of the deposits or large scale collapsing of the top rock layer, the deposits in the bottom are compacted constantly and the

porosity is reduced; therefore, the downward development of the cavity slows down or even creases growth and the rock salt in the bottom doesn't dissolve any more basically. Besides the solution cave, the cavity also includes the pores of the deposits that are insoluble in the bottom water and fissures formed when the surrounding rocks are destructed. All these form an integrated and complex cavity, which haves hydraulic connection in different ways in the bottom well, and it is these different hydraulic connections that determine the future development of the cavity.

The development of the cavity

The top cavity and the surrounding rock always keep a good contraction with the water solution. The direction of the dissolution will expand to horizontal direction when meeting the insoluble roof. In this situation, the development speed of cavity in the same direction is relatively stable and there is no remarkable change within a short period of time. Just the speed of development in different directions is different; for instance, the dissolution speed along the upward direction is faster than that in the downward direction. The range of the cavity is constantly increasing when dome-shaped roof meets the insoluble rock; its diameter is become larger and larger. When the load of the upper rock layer exceeds the strength of top rocks, due to the double actions of corrosion and loading, the roof rocks will undergo a transformation even fracture. Then there will generate caving zone and fracturing zone in the upside of the cavity and the final collapsing of the roof may happen, which lets the light brine enter the last salt bed for further solution. In addition, the larger the span of the cavity is, the larger the height of the cavity development is. Therefore, the upward development of cavity speeds up and generate new solution caves constantly in the upper of salt bed so that the solution cave group comes into being in longitudinal section. The actual reserves of the rock salt when mining are not the salt quantity in the artificially designated mining layer, but the mining production from non-industrial salt groups during the upward solution of rock salt. The formation of the salt rock cavity is affected by several factors; they are ultimately an irregular, extremely complicated solution cave aggregation that has different types, multi-layers, and multi-structure and is filled with brine.

DESTABILIZATION PATTERNS AND DETECTION METHODS OF THE CAVITY

Destabilization patterns of the cavity

No matter what kind of method for the drilling water-soluble mining of rock salt mine is adopted, it is bound to go through the process of mining empty, the change of crustal stress, the deformation of roof, the collapsing of the roof and overlying strata and land subsidence. Because after the water-solution mining, the mining-out area, that is, all the spaces of the cavity has been filled by the brine, the roof of cavity is supported by a balanced uplift force; this kind of uplift force is a beneficial factor for stabilizing the cavity roof when the salt well and cavity is under a closed condition. At the same time, salt mine is a soluble substance. The water-solution effect on the ore in the roof and the hydration of insoluble rocks weaken the mechanical and physical strength of the salt mine. This is an adverse factor for the collapse of cavity roof. It is this pair of contradictions that control and seek balance in the unity of opposites. With the salt layer mined, this balance is broken, and then there is a new balance. By repeating this process, the roof of salt rock will collapse, be stable, and then develop to the ground surface; in the end there will a ground deformation. As a result, geological disasters will be likely to happen, what will cause the destruction of farms, buildings and environment. Therefore, several factors affecting the stability of the cavity are the depth of mining, the upper solution height and the shape and area that the roof of the cavity exposes. If the mine is designed scientifically, mined rationally and restricted the height of mining, with the insoluble rock of enough thickness on the roof, the stability of the cavity is proved relevantly good.

Detection methods of the cavity

Since land subsidence occurred in 1980s in salt brine mining area in Xiang-Li, Hunan Province, the engineering technicians of geology and mining has been looking for economical and practical methods for detecting the cavity by opposite-well connectivity mining. In the last twenty years, the detection methods used for this kind of cavity in succession are high-resolution seismic method, sonar method, electrical method, geophysical prospecting well logging method, and so on. Judging from the standard of science, economy and practicality, each method has its own features and limitations. According to the actual situation, choosing the reasonable methods of cavity detection is a right way without question.

THE PROSPECT OF THE SALT ROCK CAVITY REUTILIZATION

Basic conditions of available underground cavity

The cavity formed by mining salt is a kind of underground space. According to its own situation, cavity has two properties, either reutilization or harm. Designs must be carried out according to certain requirement before mining salt and technological measures must be taken to control the process of salt mining. In this way, the formed cavity can be used as the underground storage space. There are two factors to measure the basic conditions for the reutilization of cavity. The first factor is physical conditions, including the stability, pressure resistance, sealing and scale property. The physical condition chiefly refers to the cavity depth, the physical features of surrounding rocks and the shape of cavity construction. The second factor is geological conditions. The zone which has the features of heavy-thickness, high stability and strong continuity, hasn't been destroyed by fracture structure and has good protection cap rock is suitable for constructing specific underground cavity.

The prospect of the cavity reutilization

On the premise of meeting the basic conditions stated above, the underground spaces formed through rock salt mining can be used as a storage cavern for mud of calcium and magnesium, oil and natural gas. By computation and analysis, it is shown that the buried depth of the cavity which is used as oil storage cavern should be 600~1000 meters and the ratios of the safe distance between the cavity diameter and protecting pillar among the adjacent cavities is 2.1~2.5. The buried depth for the storage cavern of natural gas should be more than 1000 meters. It is more safety when the buried depth of natural gas is more than 1500 meters, with the diameter ratio of cavity and protecting pillar of 2.8~3.

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