APPLICATION OF HYDRAULIC FRACTURING METHOD IN PINGDINGSHAN MINING AREA

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Abstract: In this paper, applications of hydraulic fracturing method in Pingdingshan mining area and relevant points for attention are introduced.

Keywords: Hydraulic fracturing method; Application evaluation; Points for attention

INTRODUCTION

Salt Mine in Pingdingshan area from the 1988 started the scale-mining, with single well convection method adopted in the initial stage of exploitation. Some inherent shortcomings of single well convection method are widespread in the mining area, such as low yield, low brine concentration, the high rate of accident single well convection methods, etc. As a result, hydraulic fracturing method began to be exploited and tested in the mining area in 1991. Ever since the success was achieved, this method has always been adopted as a major mining method.

HYDRAULIC FRACTURING METHOD OF MINING TEST

Hydraulic fracturing method has many advantages, such as high-yield, high concentration of brine, low cost of brine mining, high recovery rate, low accident rate, manageable, long service life of brine wells and so on.

By the end of 1991, the construction of well 601-2 which belongs to Pingdingshan Federation of Trade Union has finished as the major killing well. It formed the well group with well 601-1 (a single convection well put into use in 1990) together to do fracturing tests, which is about 80 meters away from well 601-2 in the south. The two wells both located in the south of geological structure of mining area—south of Wuyang depression area. With the depth of more than 1200 meters, they were suitable for fracturing wells; exploited layer was produced like thin layers, with gypseous mudstone produced as the form of multilayer or interbed; Salt formation belonged to monoclinic structure, with the dip angle of 8°~10°; Without cavity and faultage development, two wells located in the direction of formation dip; the two wells possessed the basic conditions that the hydraulic fracturing method need. During the process of test, water pressure reached 15Mpa and the whole process lasted more than 5 hours. Water appeared in well 601-1 at one time, but due to the fracturing equipment errors, fracturing was forced to be stopped. The test was not successful.

In June 1992, well K2 of Pingdingshan

Science and Technology Commission is completed, which formed the hydraulic fracturing test well group with well K1 that was put into use for the single well convection production in January 1991. With the well depth of 1611.8 m, the technological casing of well K1 was laid up to 1514.8 meters underground, which was located at the top of the 14th salt-layer group, and five salt-layer groups in all including NO.14,15,16,17,18 were exposed. The distance between two wells was 80 meters, with the bottom distance of 78 meters. The two wells located between the rock layer direction and dip direction. Water pressure during the test reached up to the 18Mpa. In the constant pressure stage, water was injected continually with the pressure of 14 ~ 16Mpa maintained, and dripping water was also produced in well K1. The process of the trial lasted a total of 35 days, with the direction-changing back pressure carried out in the middle stage and a total of 1200 m^3 water injected, but unluckily two wells connection were not achieved in the end.

Fracturing tests failed twice, a viewpoint "Pingdingshan mining area is the forbidden area of the fracturing trial" came into being. Those who hold this view believed that the salt bed in mining area was too thick and the number of salt layers was too large. They also thought there was no difference in terms of compressive strength between the salt bed and the top plate or interlayer, and even the compressive strength of some salt beds was smaller than that of the top plates. All these reasons determined that hydraulic fracturing was inappropriate in this mining area, therefore the failure of the two experiments should be reasonable.

After analyzing the two fracturing process, it is found these two fracturing tests themselves have some shortcomings: the first failure is because fracturing equipments can not inject water continually and the main pressure well and subnormal pressure wells have excessive rocks exposed; and both of the two tests existed some problems of lack of experience or insufficient preparations; for example, when operating back pressure, the pressure of water injection well was first released totally and then water was injected into the subnormal pressure well; as a result, the crannies formed are easy to close; the buried depth of objective salt bed was a little bigger during the second test, and although the salt layer weighing 17 tons in the sub-pressure well was passed through, it may be covered by cuttings when singlewell convection happened. Therefore, the failure of two tests can not show that this mining area is not suitable for brine mining by hydraulic fracturing method.

Early in 1994, hydraulic fracturing exploitation test was carried out in the well group Y4 for designing fracturing test in Pingdingshan salt mine. In the well group Y4, Y4-1 was the main-pressure well. Y4-2 and Y4-3 as the subpressure wells formed a shape of triangle with well Y4-1 in the dip direction and tendency of salt respectively. The three wells had the 17 salt group-salt layer exposed as the objective fracturing layer by using perforation method, with the buried depth of 17 salt group-salt layer between 1485 ~ 1495m. The distance of any two wells of the three wells Y4-1, Y4-2, and Y4-3 was about 100m, with the bottom distance of less than 150m.

In the process of fracturing, the highest water injection pressure could reach up to 19Mpa; the pressure in the stable pressure stage was 16.8 ~ 17.8Mpa, with the water injecting time of 12 hours; In the formation dip direction, there came into being brine in wells L3-2 and L3-3 which are 300 m away in the south of Y4-1. After shutting down the two brine wells, water was injected continually and the pressure remains didn't decline. Then through several well pouring, water injection and slot extension, the water injected was a total of 5500m^3 in ten days. Then the water injecting pressure began to decline. Finally, Y4-1 and Y4-2 realized the fracturing connectivity.

This test is well-prepared, with effective measures and methods as well as fracturing equipment in good condition, the whole process of fracturing proceed quite well. It shows that: in the direction of salt layer dip direction in mining area fracturing connection

is easy to achieve; the time of the fracture stage and regulated pressure stage is relatively short when fracturing happened; during the slot-expansion phase, the pressure declined slowly, time lasted long and the operation was difficult to control. The successful trial proved the hydraulic fracturing exploitation is feasible in Pingdingshan mining area.

In November 1995 and May 1998, the fracturing connection of well groups D2 and L3 was implemented in Pingdingshan salt field well. Well group D2 was mainly large-caliber multi-layer single convection well, which was put into use for more than a year with single well convection method before fracturing. The mining layers were salt-group salt-layers 14, 15, 16 and 17; among them, salt group 14 had a buried depth of 1390 m. Wells D2-1 and D2-2 were in the direction of salt-layer trend, with the well space of 100 m and bottom hole spacing of 85 m. As for well group L3 that was designed to be single well convection naturally connected wells, salt-group salt-layer 17 planed to be mined, but No.18 salt-group salt-layer had also been exposed when drilling wells, and salt group 17 was also buried with the depth of about 1390 m. Well L3-2 was 80m away from L3-3, with the bottom hole spacing of 75 m; the two wells were also located in the direction of stratum tendency. The twice fracturing was carried out in the old wells, which belong to technical reform of old wells.

Fracturing In the old wells has many factors detrimental fracturing connectivity: the quality of cementing is relatively poor comparing to well group Y4; salt layer is excessively exposed; well D2-1 and central pipe L3-3 can not be extracted because of being locked; the fracturing connection along the direction of stratum connectivity has never succeeded; the roof may have collapsed; due to the big caverns, it is difficult to inject fresh water to the cracks of salt layer when fracturing happens, etc. However, because of the successful fracturing of well group Y4, as well as the well-organized construction, the two fracturing trials are successful.

During the two fracturing, the fracture pressures were 19.5Mpa and 19Mpa respectively. Due to the existence of caverns, it needed a long time from starting injecting water to reaching the fracture pressure, nine and half hours for well group L3; the time from the salt layer fracture to the stage of stable pressure is relatively short, only 40 minutes for well group L3. In the stage of stable pressure water injection pressure were 18 ~ 19Mpa and 15 ~ 16Mpa. Entered the phase of the slot expansion, water injection pressure had no evident decline, sometimes higher than the stable pressure; the stage of slot expansion lasted a relatively long time and had big operation difficulty. Two constructions both made use of some measures like limited pressure and flow rate, dual well water injection by turns. In the entire process of fracturing, well group D2 and L3 spent 10 days respectively, with the total water injection rate of 6300 m^3 and 13,500 m^3, respectively. The success of fracturing provided successful experience for fracturing in the direction of stratum tendency and transformation of old wells.

In 1992 after the failure of fracturing of wells K1 and K2, technological casing of well K2 were perforated at the same time in the salt groups 14, 15 and 16, and the two wells continued to be used in single well convection production. On April 13, 2000, Pingdingshan Salt Plant of Nutrition and Health Care carried out the hydraulic fracturing of well groups K1 and K2 for the second time, with K2 as the main pressure well. This fracturing learned from the successful experience of fracturing of Pingdingshan Salt Plant, so the process of fracturing went well and achieved success finally.

During the process of fracturing, the fracture pressure was 17Mpa; it took 7 hours from beginning injecting water to finishing fracturing, with 15Mpa for the stage of pressure stability; the phase of the slot expansion needed longer time, with about 38 days spent if excluding man-made break time; and the water injection pressure declined too much, generally between 12.5 ~ 13.0Mpa. They were largely different from well groups Y4, D2 and L3; the possible reasons are as

follows: first, single well convection of well K1 and K2 needs more time and well spacing and cavern spacing are smaller; second, the roof of salt-group 14 may have collapsed, and the caverns have been uplifted to the upper side of salt layer, so the actual targeted layer is the upper salt layer, and also the buried depth is shallow; third, the two wells have been used for many years, technology casing pipe may have been seriously eroded, when fracturing the upper part of the technology casing pipe may have been punctured and then a channel is formed in the upper salt layer; fourth, although the caverns of two wells are near, but the caverns are large, so fresh water is difficult to inject into the cracks; despite the small slot-expansion pressure, the time for slot-expansion is very long.

Well K1 is located in the southeast 145°of well K2, between the tendency and dip direction of the formation. From the ground surface and initial orientation of brine well bottom, the mine will be a new fracturing orientation. However, because the well spacing between wells is originally very small and each cavity is relatively big, the well head of the ground surface and orientation of bottom hole are not very meaningful any more.

THE APPLICATION OF HYDRAULIC FRACTURING METHOD FOR BRINE EXTRACTION

After the 3 groups of hydraulic fracturing wells of Pingdingshan Salt Plant and hydraulic fracturing wells of Pingdingshan Nutrition and Health Care Salt Plant are put into operation, the running conditions are better than before. Now, the two plants are mainly depend on fracturing wells for producing brine, with the brine concentration of 300 ~ 315 g/L, the output of 50 ~ 60 m^3/h. Comparing to the single well convection method, hydraulic fracturing method has obvious advantages, which are shown in Table 1.

Besides the items listed in Table 1, the hydraulic fracturing method also shows some characteristics like simple management method and small accident rate. But this brine extraction method is most prone to this accident: the lower part of the brine-extracting well is plugged by cuttings, salt particles. Insisting on switn switching out brine wells and water injection wells regularly can prevent the occurrence of this blockage.

Table1. Comparison of parameters between the single well convection and fracturing

Item Classes	Production (m^3/h)	Concentration (g/l)	Slot-building period/ month	Recovery rate/%	Brining Cost Yuan/m^3
Single-well convection	20×2 = 40	285～305	12	10～15	5/7
Double-well fracturing	65	305～315	1～2	20～45	3/4

Prior to 2001, except that in the place of cementing casing shoe of well Y4-2 of well group Y4 technological casing was forced to be cut a few meters off , there was no other serious accidents. In October, 2002, in the mining area well group L3-3 ~ L3-2 appeared serious fault. Specifically speaking, water was injected from well L3-3; when the amount of injected water kept the same or increased, the production of brine declined from 80 m^3/h gradually; until sunk panel water injection, the amount of brine was almost 0; Continued injecting water from well L3-3, and two months later, well L3-2 well didn't produce brine any longer. After this breakdown, analyze and judge by logging and other technical means, it is confirmed that casing of well L3-3 was seriously damaged in the part of 1000 ~ 1200 m, and a lot so difficult to repair this well group that there is still no suitable

scheme so far.

Although the success rate of fracturing can not reach 100%. However, even if the fracturing fails, whether the old well or new well, main-pressure well or subnormal-pressure well can be well used for single well convection production. It should be noted that the application of hydraulic fracturing in Pingdingshan mining area is successful.

NOTICE OF HYDRAULIC FRACTURING METHOD

In the future, the design and implementation of hydraulic fracturing method i should be paid more attention to in terms of the following questions:

1. The depth of the Fracturing wells should not be too big in order to enhance the success rate of fracturing; at present, it is better not to large-scale design fracturing wells with the depth of more than 1500 m. There are some records of successful fracturing to wells with the depth of about 2000 m, but the wells of our mine are 1500 m during several successful fracturing. The condition of well K1 and K2 may be related to the depth difference of actual objective layers. Of course, it needs further discussion if the fracturing test is implemented in deep wells.

2. Fracturing wells had better be designed along the stratum dip direction, supplemented by the well pattern along the tendency of formation, because the fracturing along the dip direction is relatively easy.

3. The well spacing should be controlled to about 100 m, and should not be too far, because of thick salt layers in the mine; if the fracturing is achieved in the depth of 100 m or, the brine wells have been able to ensure sufficient service life

4. The quality of cement should be quite good; if necessary, after cementing the method of perforating can be used to expose the salt layers.

5. The targeted salt layer of fracturing can not be exposed too much, and selecting only one salt layer is the best. Exposed excessively, if the fracturing pressure can not be controlled well, it is likely that any salt layers or parts form cracks at the same time, which is harmful to the success of fracturing.

6. If the targeted layer of the fracturing is relevantly thin, it can be exposed entirely from the interface with the roof to the interface with floor; otherwise, it can be exposed from the middle part to the bottom plate.

7. Hydraulic fracturing method needs continuous back pressure, so the brine-producing wells and water injection wells should be similar in respect of design of well body.

8. Prepare fully and take everything that may happen into account before fracturing; the fracturing equipments should also be prepared in a good condition in order to ensure that water can be injected continuously for a long time in the process of fracturing.

9. When fracturing, pay attention to the conditions of the brine wells around to prevent the connection of untargeted well in the distance.

10. fracturing ago to clean up the bottom of the well, fracturing the Old Well, if a halogen-purpose wells in the lower part of the caverns, it is necessary to pay special attention to this point.

11. During the fracturing process, if water injection stops by some errors, the valve between water and well must be closed in time to prevent water from returning or spraying, and also to ensure the fracturing cracks of the salt layers are not closed; so is the water injection of sunk panel. The original water-injecting valve should not be opened until there is clear connectivity.

12. Control the total amount water injected of fracturing stage and pressure stability stage; don't blindly inject water. As for the old wells, as a result of the influence of Cavern Effect, more water will be needed from injecting water to the fracture of salt layer. Moreover, because it is mainly saturated brine that enters into the cracks, so the process of expansion slot will be longer and more water needs to be injected. The stage of stable

pressure needs less water. As for the newly-designed fracturing wells, each stage need less water, especially the stage of stable pressure. If during the process of fracture the total amount of injected water is large, but there is no sign of connectivity, other possibilities can be considered to carry out the next step. Of course, when controlling the amount of injected water, many factors should be taken into account, such as the thickness of layer of salt, well spacing, the size of caverns. As for the Pingdingshan mine, the amount of injected water in the stage of stable pressure varies generally from tens of cubic meters to hundreds cubic meters. Considering the different situations, it can be limited in the range of 1000-2000 m^3.

13. All stages of fracturing demand appropriate water flow and pressure; don't go off at half cock. In this way the formation and stable development of fracturing cracks will be ensured, without channeling, roof breakdown and cracks that are harmful for connectivity.

THINKING ABOUT THE APPLICATION OF HYDRAULIC FRACTURING METHOD IN THE FUTURE

Hydraulic fracturing mining method has prominent advantages, which should be promoted in the mine area. However, this mining method demands higher technology requirement at all stages, especially in the early stage of fracturing connectivity. The success of fractuing is related to the quality of well completion, well pattern arrangement, and the choice of fracturing position, as well as buried depth and many other factors. Based on the characteristics of our mining area, single-well convection mining method can not be denied totally. In addition, the butted well technology has also been widely used in the mining area, which has great advantages. The combination of various mining methods should be selected according to different circumstances in order to maximize the resource utilization ratio and obtain the best economic benefit.