APPLICATION OF OBSTACLE-AVOIDING HORIZONTAL WELL-BUTTING IN THE MINING OF HUGE THICKLY-BEDDED ROCK SALT DEPOSIT

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Abstract: Changning Well No. 5 in Changning County, Sichuan Province is the first well in huge thickly-bedded salt deposit, in which the technology of obstacle-avoiding horizontal well-butting is applied in China. The drilling of horizontal well is done with DST cabled while-drilling inclinometer. The wellbore of Changning Well No. 5 avoids the bottom of the cavity of Changning Well No. 3 and is successfully butted with the old cavity of Changning Well No. 1. This communication of wells has greatly enhanced extraction and quality of brine and the recovery rate is also increased.

Keywords: Huge thickly-bedded rock salt deposit, cabled while-drilling inclinometer, obstacle-avoiding Horizontal Well-Butting, brine extraction

1. DEPOSIT GEOLOGY

The Changning anticlinal structure is located at the southern edge of Sichuan Basin, belonging to a belt of transition between Sichuan Basin and Yunnan-Guizhou Plateau. The Shuanghe rock salt mine is located in the vicinity of the middle section of the Changning anticline. The strata met during drilling include Douposi formation, Longwangmaio Formation, Canglangpu Formation, Qiongzhusi Formation and Maidiping Formation of the Middle Series of Cambrian System, and Dengying Formation of Sinian System. There is a big dip at the mine area with complicated geological conditions. Rock salt deposit is rich in the second sub-member of the first member of Dengying Formation of Sinian System ($Zbdn^{1-2}$), being one of the oldest rock salt deposits in the world. The deposit is buried at a depth of about 2,500m. The thickness of the single layer of rock salt is 160~370m. The ore grade of NaCl averages over 94%.

2. FORMER CONDITIONS OF BRINE EXTRACTION

2.1 Conditions of brine extraction

This mine was put into operation in 1994 with a production capacity of 100,000 tpa of brine (converted into salt). Four wells of two well pairs were put into brine extraction. The process applied is solution mining with single-well convection. Wells were completed with Φ177.8mm casing set at 40~60 m into the top of salt seam and Φ89mm tubing set at about 100m below the casing shoe. Brine production is 30~50 m^3/h with a salinity of about 300g/l. For an individual well, the production capacity is 30,000 tpa of brine (converted into salt). Several well accidents took place, causing disability of brine production in well pair of Changning Well Nos. 2 and 4 though scientific management and reasonable technical schemes were drafted.

2.2 Problem area

(1) Small production capacity of a single well. The restriction of the well bore structure caused small amount of injection flow and brine flow. In addition, miscellaneous reasons led to more time of non-effective production.

(2)Easy roof collapse. The fast speed of upward dissolution enabled the roof to be exposed fast due to the process of solution mining with single-well convection. Along with the progress of brine extraction, the roof collapsed when the area of roof exposed exceeded the span limitation, resulting in tubing and casing failures.

(3)Serious water hammer impact. The extraction depth was over 2,500m. Large pressure difference existed between the tubing and the annulus. Spiral bending effect of tubing was severe. This was especially true at the instant when pump was started up, which easily led to tubing bending and breaking.

(4)Large amount of investment for well repair and treatment. For well repair, investment would be at least several hundred thousand yuan or at most over several million yuan because of the depth of the wells. The fact proved that the economic efficiency of the mine was greatly decreased because of the investment for well repair and treatment.

(5)Low recovery rate. In view of the safety of the wells, only the top section of the huge thickly-bedded rock salt deposit can be mined by solution mining with single well convection. The middle and bottom sections have to be abandoned. What is more, the speed of upward dissolution was fast and the speed of lateral dissolution was slow. Therefore, the rock salt recovery rate was less than 5%.

3. ENGINEERING DESIGN

3.1 Design requirement

(1)At the place of 637.7m distant from Changning Well No. 1, Changning Well No. 5 is to be drilled with horizontal well-butting technology. It is required that Changning Well No. 5 avoids the cavity of Changning Well No. 3 and is butted with Changning Well No. 1.

(2)Data of butting target: Directional position—3255.72 degrees, horizontal displacement—637.7m, vertical depth—2,531.40m

(3)The horizontal section when drilled to the bottom cavity of Changning Well No 3 is more than 150m. Drilling is completed if Changning Well No. 3 is connected.

3.2 Cross section design of Changning Well No. 5

3.2.1 Selection of obstacle-avoiding schemes

Changning Well Nos 1, 3 and 5 are almost located along a straight line with Changning Well No. 3 in the middle. Changning Well No.3 has to be avoided if Changning Well No. 5 is to be butted with Changning Well No. 1. There are two options for avoiding the obstacle: one is that drilling avoids the lateral side of the cavity of Well No.3 and the other is that drill avoids the bottom of the cavity of Well No.3. In the former case, the direction of well bore orbit changes greatly, and it is required that the wall of the bore must be regular and smooth, which facilitates the directional drilling. However, it is very difficult to have regular and smooth wall because the salt deposit at the well bore section is soft and soluble. In the latter case, the main thing is to control the dip angle of well bore when the direction of well bore orbit of Changning No. 5 is corrected. Difficulties during drilling are comparatively less. After analyses, it was decided the latter option was selected.

3.2.2 Well bore orbit design

Well Section	Inclination Depth (m)	Vertical Depth (m)	Visual Displacement (m)	Dip (deg)	Azimuth (deg)	Full Angle K (deg/m)
Straight	0~2170.70	2170.70	0	0		
Slant	2737.29	2531.40	360.70	90	325.72	0.16
Level I	2887.29	2531.40	510.70	90	325.72	0
Level II	3014.29	2531.40	637.70	90	325.72	0

3.2.3Well bore structure

(1)Order of bits: Φ444.5mm bit×46.0m + Φ311.1mm bit×342.0m + Φ215.9mm bit×2706.0m + Φ152mm bit×3014.29m.

(2)Order of casings: Φ339.7mm casing×45.0m + Φ244.5mm casing×340.0m + Φ177.8mm casing×2704.0m

4. WELL BORE ORBIT CONTROL

4.1 Straight section (0~2,328.0m)

This section mainly contains limestone, shale and carbonaceous shale with large dip angle. The drillability is not desirable. During drilling, the drilling speed is low and a slant well is easy to occur. The incline angle was 27.3°when drilled to the depth of 872 m after the outer casing was set. Refilling to the depth of 375m had to be made so as to re-drill after correcting the slant.

In order to control the inclination, pendulum assembly with EMS inclinometer was applied to correct the inclination during drilling. When drilled to the depth of 1,309m, drilling was stopped due to the complicated conditions caused by frequent corrections of inclination, resulting in complicated well bore orbit in carbonaceous shale easy to collapse with large dip. Treatments with cement were unsuccessful. After careful study, it was decided to refill to the depth of 900m and drill again. Inclination was corrected with DST cabled while-drilling inclinometer and single bending screw pipe was used to control the inclination. The drilling results show that this technical scheme effectively controlled the inclination and eliminated the complicated well bore orbit. The inclining point at the depth of 2,328m was tapped with high quality of well bore. Solid foundation was laid for further drilling.

4.2 Inclination increase section (2,328.0~2,622.0m)

The strata under the inclining point are dolomite, limestone and anhydrite of the second and first members of Dengying Formation of Sinian System. Changning Well No. 5 is the first horizontal well drilled in this region. The accuracy of inclination of the directional compound drilling assembly is difficult to predict. Analytical prediction and timely correction were applied during drilling.

Inclination drilling assembly: Φ215.9mm bit+Φ172mm single bending screw +directional joint+Φ177.8mmnon-magnetic drill collar+Φ127mm heavy wall drill pipe×200m+Φ127mm drill pipe+HP rotary circulating head; Drilling parameters: drilling pressure—100~130kN, displacement—30~35 l/s, pump pressure—7~8Mpa. The most important thing at the initial stage during directing well bore is to correct the orientation of well bore and increase the inclination. When drilled at the depth of 2,380m, the azimuth was adjusted from 10° to 315° and the inclining angle from 2.1° to 17°. To this point, the correction of the orientation was completed and inclination increase began.

When drilled at the depth of 2,431m in salt deposit, the inclination angle was increased to 40.5° and the azimuth was maintained at 315° to 321°. The inclining capacity of screw pipe: K=0.3°~0.85°/m. Due to the fact that the built-up rate was far more than designed and in order to adjust the well bore orbit, slightly increasing compound driller was used to drill to the depth of 2,501m with the inclining angle increased to 47.1°. The orientation was stable.

After the inclining angle increased to 45°, friction in well increased obviously. It was difficult to bring the sand up and to transmit pressure due to the existence of rock debris deposit. In order to ensure the safety in well and smooth drilling, proper measures were taken. Firstly, mud was transformed into anti-salt oil-mixed polymer. Secondly, driller was lifted up once at every 20m drilling progress, and thirdly, the mud was purified to at least "Class III".

Drilling continued in salt deposit after the proper adjustment. When drilled to the depth of 2,622m, the inclining angle was increased to 87.5° and the azimuth was maintained at 317° to 324°. The inclining capacity of screw pipe in salt deposit: K=0.2°~0.65°/m. At this stage, the major inclining section of well bore was completed. Φ177.8mm casing was set at the depth of 2,617.21m. Well cementation

completed when cement grout returned to surface.

4.3 Drilling in the horizontal obstacle-avoiding section (2622.0~2831.26m)

Drilling assembly: Φ152mm bit+Φ120mm single bending screw +directional joint+Φ120mm non-magnetic drill collar+Φ88.9mmdrill pipe×260m+Φ88.9mm heavy wall drill pipe+200m+Φ120mm drill collar×110m+Φ88.9mm drill pipe+HP rotary circulating head; Drilling parameters: drilling pressure—80~110kN, displacement—20~25 l/s, pump pressure—8~10Mpa. In order to achieve the designed goal that drilling would avoid the bottom of the cavity of Changning Well No.3, starting from the depth of 2,662m, the scheme of decreased inclining drilling with inverted drilling assembly followed by increased inclining drilling was decided. When decreased inclining drilling conducted to the depth of 2,712m, the inclining angle decreased to 80.7° and the orientation was stable. The decreased inclination rate: K=-0.13°~-0.3°/m. Then, when increased inclining drilling was conducted to the depth of 2831.26m, the inclining angle was increased to 94°. The increased inclination rate: K=0.2°~0.4°/m. This position is just below the cavity of Changning Well No.3. The vertical depth of the bottom of the cavity of Changning Well No.3 is 2518.8m. The vertical depth of the newly drilled well is 2533.66m. This shows that the newly-drilled well bore successfully avoided the cavity of Changning Well No.3. The obstacle-avoiding distance is 209.26m which meets the technical requirement of Target A at least 150m.

4.4 Drilling in the cocked horizontal section (2831.26~2960.0m)

The point where wells are to be butted is under the cavity of Changning Well No.1, i.e. Target B. The predicted vertical depth is 2,518m with a closing distance of 638m. Therefore, the well bore should be drilled upwardly. The drilling assembly and drilling parameters remained unchanged. Difficulties were the pumping of the seat of DST cabled while-drilling inclinometer, the positioning of tools and boosting of drilling pressure. During the drilling, increased inclining drilling and screw-pipe compound drilling were applied in accordance with the change of well bore orbit. The positioning of tools and boosting of drilling pressure were realized with large movement of drilling assembly. The well bore gradually progressed toward Target B as expected. Eventually, the newly-drilled well was butted with Changning Well No. 1 at the depth of 2,960.0m on May 19, 2004. The vertical depth at which wells were butted was 2,517.62m with a closing distance of 638.53m and a maximum upward inclination of 100.65°.

4.5 Main well completion technical indexes

(1)Depth of drilling: 2960.0m
(2)Vertical of drilling: 2517.62m
(3)Closed horizontal displacement: 638.53m
(4)Closing azimuth: 325.85°
(5)Depth at which inclination began: 2328.0m
(6)Maximum inclining angle: 100.65°
(7)Length of horizontal drilling: 338.0m
(8)Depth in salt deposit: 529.0m

5. PREDICTION OF RESULT OF BRINE EXTRACTION AFTER WELLS BUTTED

After wells were butted with drilling assembly lifted up, there was no need to set tubing in the well. Flushing of well and expansion of sump with small displacement were done once the well head was installed. A large displacement DG150 pump was used for brine production after a period of time. The brine extraction process was that water was injected through horizontal well and brine was pumped out from Changning Well No.1. (Injection pressure: 10~10.4Mpa, injection flow: 160m^3/h, brine flow:~ 160m^3/h, salinity of brine: 300~310g/l)

Prediction of result of brine extraction after wells butted:

(1)Large capacity. A pair of horizontal wells can produce 350,000~400,000 tpa of brine (converted to salt), several times more than the former wells.
(2)High and stable salinity
(3)Fewer underground accidents with longer production duration
(4)Longer service time

(5)Higher recovery rate. The predicted recovery rate is over 25%, favorable for the development and protection of mine resources.

6. SOME CONSIDERATIONS

(1)It is feasible to extract brine in horizontally-drilled wells in huge and deep thickly-bedded salt deposit. This technique is the most advanced used in the same kind of salt deposit. It is worth whiling popularizing.
(2)Well logging data of the target well must be mastered when drilling horizontally and the selection of place where wells are to be butted has to be made in accordance with the history of mining and the development patterns of the cavity
(3)There exist some demerits when cabled while-drilling inclinometer is used. Non-cable inclinometer may be tried.
(4)The drift in the upper section of well bore and the directional section must be analyzed, summarized and controlled. This is the base for the smoothness and success of butting.
(5)The length (338m) of the horizontal section of this well indicates that it is feasible to drill medium and long distances in the horizontal section in huge and deep thickly-bedded salt deposit, which will facilitate the increase of brine production, brine quality and recovery rate, and the decrease of brine production cost with higher economic efficiency.

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