THE APPLICATION OF DIRECTIONAL BUTTED WELL TECH USED IN THIN AND LOOSE GYPSUM SALT BED

Yun-hong NA

Qiao-hou Salt Mine of Yunnan Salt Chemical Co., Ltd.

Abstract: In November 2007, with directional drilling butted connective water-soluble exploitation salt-rock technology, selecting drilling fluid rationally and controlling the dissolution rate according to the stratum situation, Qiao-hou Salt Mine successfully drilled a pair of directional butted wells in the complex thin and loose gypsum salt bed. It is the first success of butted well technology in such a complex stratum.

Keywords: Directional butted well, thin layer, Loose and soft, salt bed

PREFACE

At present, directional butted, connective water-soluble mining rock salt technology is an advanced technology at home and abroad. Normally, the butted method is: one-vertical and one-deviated wells directional butt; there are also three wells butt and old well transformation butt connectivity, etc. Comparing with other drilling technologies, directional butted connective well technology has following big advantages: high recovery rate (above 30%), stable quality of brine, high concentration of brine, big production capacity, easy mining management, fewer accidents in the well, fewer fixed number in the mine; protecting pillar can be pre-reserved to avoid subside of land, with fewer safety and environment problem; meanwhile, it takes less time to build slots, with lower construction cost, longer service life of well and lower brine-mining cost, etc. But this technology is confronted with many obstacles in complex thin, soft and loose salt bed; during the period of drilling, any technical faults may result in well-jam or even cause well-rejection. During the two years since June 2006, due to complexity of the stratum, Qiao-hou Salt Mine experienced twice failure of well-drilling, three times trying to operate well-jam, three times whipstocking butt and well-maintenance when constructing the stratum of Qiao-Salt 1-1# well and Qiao-Salt 1-2# well. By summing up experience and reasonable choice of drilling liquid as well as controlling dissolution speed according to actual stratum situation, our company succeeded in constructing the directional butt of a pair of one-vertical and one-deviated wells. This paper aims to introduce the experience during the construction as a reference to the readers.

GEOLOGICAL STRUCTURE OF THE MINE

The mining area of Qiao-hou Salt Mine has a complex geological structure which is metamorphic ore deposits by lagoon phase deposition. The stratum situation from above to below is as follows:

The Quaternary alluvium, residual deposit, colluvium deposit, abundant in pore water; the Tertiary riverbed phase conglomerate, clays, silt rock, being aquitard; Cretaceous, J_3 sandstone, conglomerate, dolomitic limestone; permeable layer; J_2^3 is sandstone, shale, limestone, phyllite, being aquifuge; J_2^{2-3} is fibrous gypsum shale conglomerate aquifuge; J_2^{2-2} is NaCl halite, meltable layer. J_2^{2-1} is cloddy limestone shale conglomerate aquifuge; J_2^1 is dolomite limestone aquifuge; J_1 is sandstone, conglomerate aquifuge; M layer is phyllite schist, with abundant crevice water.

Mining area lies in southern part of asymmetric synclinorium basin between Dali-Lijiang virgation and Mesozoic Lanping-Simao depression tectonic unit. The landform is altiplano denudated accumulation, with landform gradient of 4.5 grades, and its hydrological geology is relatively simple.

Being controlled by bottom basin, ore-body appears inerratic lamina, between the apical plate and floor gypsum layer; The strike is from east towards west, and eastern part is a bit higher than western part, with dip angle of 30-40 degree and thickness of 4-120m and buried depth of 150 to 500, with. The coefficient of thickness variation is 105.41%, coefficient of grade variation is 36.91%, average grade is 55.5%, and geographic condition of forming mine is complex. The data sheet during the process of drilling also proves the complexity of geographic structure:

Qiao-Salt 1-1# well stratum (vertical well)

0-114.68 meter deep: yellow calcium argillaceous siltstone, yellow-purple calcium fine sandstone. Stratum undergauge, mud making, landslide takes place during drilling.

114.68-467.19 meter deep: 26 meter thickness, gray or gray-black phyllite or phyllite with carbon. Stratum undergauge, mud making, collapse, and landslide take place and well inclination is hard to control during drilling.

467.19-480.49 meter deep: light grey brecciaous mudstone with gray silica. The bottom is grey-white brecciaous dolomite and light grey brecciaous mudstone interbed. Stratum undergauge, mud making, collapse, and landslide take place and well inclination is hard to control during drilling.

480.49-508.39 meters: black-grey brecciaous mudstone with plaster. Stratum undergauge, mud making, collapse, and landslide take place and well inclination is hard to control during drilling.

508.39-628.00 meters: thickness of 41.40 meters, clastic halite rock. The halite appears grey-white, fine crystalline structure and boulder clay tectonic. Scraps are mainly grey-black boulder clay and a small quantity of gypsum fragment. During drilling stratum oversize should be prevented. Among, 577 m--585 m has phacoid red sandstone layer with dip angle of 30 degree. Salt bed is black-gray rock salt, with average grade of 67%; the rest 30% is water insoluble matters, which is mainly conglomeratic mudstone, with inflation coefficient reaching 1.5, f < 2. The laboratory test result shows that the content of sand is 16.8% as well as 17% for mud when rock salt grade reaches 61%. That is to say that when the content of NaCl reaches 304 g/l, the salt rock contains 84.89g/l mud and 84g/l sand. That means the saltbed is loose and soft with too much mud, lower weight bearing ability, bigger coefficient of expansion.

628.00-635.52 meter: black grey conglomerate sandstone with plaster and a small quantity of fine crystalline boulder clay.

635.52-637.52 meter: light green quartzite.

Qiao-Salt 1-1#2well (deviated well)

0-64.83 meter: grey white thin-layered phyllite and calcareous phyllite. There are mud making, undergauge, collapse and landslide in the stratum and well inclination is hard to control when drilling.

64.83-103.21 meter: grey, gray-white dolomite limestone with sandy mudstone.

There is mud making, undergauge, collapse and landslide taking place in the stratum and well inclination is hard to control when drilling.

103.21-455.09 meter: black, grey-white phyllite interbed. There is mud making, undergauge, collapse and landslide taking place in the stratum and well inclination is hard to control when drilling.

455.09-468.29 meter: grey and black mudstone conglomerate with plaster. There is mud making, undergauge, collapse and landslide taking place in the stratum and well inclination is hard to control when drilling.

468.29-691.58 meter: clastic halite. Stratum oversize should be prevented.

Such complex stratum is very hard to see; there is only some simple introduction in the paper" Application of Obstacle-Avoiding Horizontally Butted Wells in the Exploitation of Hugely Thick Rock Salt Stratum", which is embodied in the collected papers of 17^{th} National Well and Rock Salt Scientific Seminar. The stratum dip angle of Shuang-he Mine area in Sichuan Changning is big and the geological situation is complex; when No.5 well is butted with No.1 well, drilling can not continue at the position of 1309m because of hole straightening; then backfilling to 900m and adopting new technology the drilling and butt was achieved.

STRUCTURE OF QIAO-SALT 1-1# WELL (VERTICAL)

Using Φ311mm cone bit, drill well to 250.93 m once, and Φ219 mm surface casing was laid down 250 m to achieve well cementing. After drilling into 579.49 m with Φ250mm cone bit, the initial way of well completion have to be used to lay down Φ140 mm technical casing pipe to 554 m, because of the long open hole interval and drilling risk as well as incorrect geological data. Then use Φ110 mm drill bit to do the core drilling, proving that there is salt layer with a thickness of 74m below, and finally penetrate the floor through.

Cavity construction situation of Qiao-Salt 1-1# well: Φ76 mm central casing pipe is laid down to 627 m, close to saltbed floor, 72 m away from the two holes. According to the ore compositions, high discharge and normal circulation cavity construction is adopted; the color of brine produced appears black grey; after 21-day continuous operation, it brings out 43 m^3 muddy sand, with 869 m^3 for cavity space and 216 m^3 for wet body. It forms a calabash-like cavity in the red sandstone; down cavity has a maximum diameter of 8 meter, which can fulfill the need of butted target.

THE SITUATION OF BUTTED WELL CONSTRUCTION

Drilling way of Qiao-Salt 1-1# well:

First spud-in (from 0 to 251.93 meters): first use Φ311 mm insert cone bit to drill, then use J55Φ219 mm surface casing pipe as well as P.032.5R ordinary Portland cement to cement well, and also clean doors to do the pressure test in and out of the pipe.

Second spud-in (from 251.93 to 579.49 meters): first use Φ190 mm insert cone bit to drill, then lay down Φ139.7 mm technical casing pipe to 553.58 meters; next, use G medium sulfate-resistance oil well cement for well cementing, and also do the pressure test inside and outside the pipe.

Third spud-in (from 579.49 to 637.52 meters): use Φ95 mm core-taking tube for core drilling; after well completion to lay Φ73 mm cavity-constructing central pipe.

Drilling way of Qiao-Salt 1-2# well:

First spud-in (from 0 to 160.36 meters): first use Φ311 mm inserted cone bit to drill, then lay down the J55Φ219 mm surface casing pipe as well as P.032.5R ordinary Portland cement to cement well, and also clean doors to do the pressure test in and out of the pipe.

Second spud-in (from 160.36 to 435.42 meters): first use Φ190 mm inserted cone bit andΦ190 mm PDC bit to drill wells, then lay down Φ139.7 mm technical casing pipe to 435.42 meters; next, use G-Type medium sulfate-resistance oil well cement for well cementing, and also do the pressure test inside and outside the pipe.

Third spud-in (from 435.42 to 691.58 meters): use Φ95 mm screw drill for angled drill (bit diameter Φ118 mm). After well completion, layΦ108 mm protective casing pipe down to 437.13 meters.

CHOOSING DRILLING FLUID CORRECTLY

Drilling fluid is also called slurry, which helps to entrain cuttings, prevent leaking, prevent hole diameter reduction as well as to balance downhole pressure. Due to not adjusting slurry performance according to actual stratum characteristics, as well as small mud pump power, we used to fail to drill straight wells twice; sticking and drill-burying accidents were caused sometimes. Buy many trials and improvements, selecting following drilling in

fluid in different stages guarantees the success of drilling construction:

1. Formula of drilling fluid in the first spud-in for two wells: 8-10% sodium soil powder, 0.5% KPAN, 0.1-0.2%CMC, 10-15% barite.

2. Formula at second stage of drilling for two wells: well mud, 1% amine salt, 05% potassium polyacrylate, 0.5% filtrate reducer.

Requirement of slurry performance for First and second spud-in: Gravity 1.2-1.35 g/ml, viscosity: 60-120s, PH value: 10-11, water loss 4-6ml/30min, thickness of earth layer: 0.5 mm.

3. Formula of drilling fluid in two-well cross-salt layer: saturated saline mud.

4. Drilling parameters:

Drilling pressure dropped from 4-5t in the first spud-in to 1-2t in the second drilling; pumping pressure increased from 2-4 MPa in the first spud-in to 5-9 MPa in the third stage, keeping discharge rate at 15-20 L/s.

During the construction, slurry pump was adjusted, and glue liquid was made from KPAM, NH_4PAN and HV-CMC to guarantee performance stability and security; keep low drilling pressure and low drilling speed; strengthen desanding and redressing, and conduct slurry management and cuttings, rock core, drilling time, drilling pressure and mud logging well; measures should be taken timely when abnormity takes place to try our best to prevent well accidents. Anyway, suitable slurry is the key factor to guarantee whether drilling will be successful.

CONSTRUCTION OF BUTTED WELLS

From 435m to 470m of the salt bed in Qiao-Salt 1-2# well is conglomerate mudstone with plaster, 35 m thick, drilling starts from 470m of salt bed. The height of Qiao-Salt 1-2# well is 38.4m lower than that of Qiao-Salt 1-1#. The linear distance between two wells is 172 m. According to the technical requirement that the whipstocking height should be higher than 150m, the Φ140mm technical casing pipe of 1-2# well can only be laid down to 335m for well cementing, where whipstocking starts. Finally, 1-2# well was butted with 1-1# well along with the mine tendency and dip angle. To decrease accidents in the well and meet the production demand, a Φ108mm technical casing pipe has to be set in the position from 435m to 470m to isolate conglomerate mudstone with plaster.

The whipstocking starts 375m of 1-1# well, with an angle of 134.25° from Qiao-Salt 1-1# to Qiao-Salt 1-2#, using 1.75° screw drilling wired MWD to drill, whipstocking gauge 680m, and connect 1-1# well successfully at the point of 620m; while vertex angle is $\geq 80^0$, the well is horizontal part, and by calculation, the length of horizontal well section of Qiao-Salt 1-2# is 61.4 m.

The second whipstocking of butted channel: After the butted wells are connected, because of the interference of outer factors, 400 cubic meter water had to be pumped from the deviated well by mud pump; butted channel is blocked, so we have to adopt high pressure to protect well. Meanwhile, construction team was asked to do the second whipstocking for the butted channel.

The first plan is to dredge the former butted channel with screw drill, but due to the failure of drill-burying, the only thing that can be done was the second whipstocking docking after cementing well. After two wells are butted, the crystallization is not enough, so the drill was buried by grits; with some drills abandoned, the third whipstocking docking was carried out.

PROBLEM NEED TO BE PAID ATTENTION DURING TRIAL PRODUCTION

The reasonable operation mode

Considering the material composition of salt rock and that horizontal well section is too long, after both of wells are connected, the only way to ensure the underground safety is to put them into operation with high discharge capacity. According to the well structure and well maintenance, one set of 586-meter Φ89 mm casing in the vertical well just penetrated into the red sandstone by 1 meter, and Φ108 casing of the inclined well just went into the salt formation by 4 meters; therefore, if the water comes from the inclined well too early, the gypsum conglomeratic mudstone at the section of 435-470-meter will be exposed too early, consequently resulting in the collapse of roof plate and affecting the normal production. In the early stage, the production can only be done in the way of continuously injecting water from vertical well and discharging brine from inclined well. The pressure when discharging brine should keep a relatively constant value of about 0.3MPa±, and a thin air cushion will be naturally formed on the top of cavity to slow down the speed of upper dissolution.

In the early stage of production, the brine is relatively muddy and slightly red, containing the average shale about 8g/l, so the enlargement of underground cavity and horizontal tunnel should be more focused on and the flow rate of 30-40m³/h is recommended for smooth and stable running. In addition, the lenticular salt-bearing red sandstone of 8-meter thickness has certain plane distribution range at 577-585 meters section in Qiao-Salt 1-1# well; therefore, the hindering effect of red sandstone to upper dissolution should be made full use of to realize side dissolution and enlarge the volume of cavity as far as possible so as to create conditions for stable production and high production as well as the production of clear brine.

Rationally control the way of influent and the shape of cavity

Water was injected from the vertical well and brine was discharged from the inclined well in the early stage, and the underground cavity is horn-shaped, therefore, the diameter of cavity is the largest at vertical well, that of horizontal roadway is the second largest and that of inclined well the smallest. Water won't be injected from the inclined water until the space of cavity reaches 40,000 m³。 At present, the quality of brine has exceeded the design requirement, 305g/l, and the content of shale is reduced to 5-8g/l from 30-40g/l during the period of cavity construction.

Thanks to large amount of water insoluble matters including shale and gravels with different sizes that are deposited underground, frequent well changing should be avoided, and the flow should be increased gradually from small to large in the emergency start-up of pump to reduce harm of water hammer. Otherwise, the underground sediments will be stirred by the jet action of water column, resulting in clogging. Once the operation of changing well is conducted impatiently because a wrong judgment is made, the sediment deposited and suspended under the well will be forced to be taken out of the well due to sudden release and impetus of pressure; the large gravel in sediments will block up the brine extraction casing with fixed inner diameter, causing man-made accidents.

CONCLUSION

The successful butt between Qiao-Salt 1-1# well and 1-2# well marks the directionally butted well technology can also be applied in the crumbly gypseous rock salt mine with adverse topography, complicated geological conditions and inclined, loose thin layer. What is more, this successful butt makes Qiao-hou salt mine that has a 50-year history of drilling water-soluble mining under adit well break through the ground mining. The experiences of success are:

1. The speed of upper dissolution of ore in Qiao-hou salt mine is 2-3 times that of side dissolution, and the expansion coefficient of insoluble matters is 1.3-1.5; therefore, in the early stage, only the stable running with large discharge and high flow rate can be beneficial to the continuous production, which is contrary to the trial production with small flow rate of mirabilite rock salt.

2. The routine management of brine extraction technology is of great importance, including start-up and shutdown of brine extraction pump, controlling of flow rate and pressure, brine concentration (Content of NaCl) and changes in water color, switching frequency of brine entering and leaving, production period, production injection ratio, and the content of shale in the brine. In the meantime, strengthen the training of brine extraction worker for basic knowledge and skills.

3. Pay attention to hold certain pressure and pressure balance underground; slow down the collapse time and scope of gypsum layer roof plate and salt formation in the red sandstone and inclined well section. A check valve should be installed on the pipe and wellhead to ensure that certain pressure can be held underground in the abnormal cases and reduce the possibility of clogging in the case of sudden pressurization or depressurization.

In the future running, the following problems should be concerned:

1. Observe the pressure variations of pressure gauge on the technical casing installed on Qiao-Salt 1-1# well to judge the situation of ore dissolution in the upper and lower cavity.

2. The maximum flow rate of brine extraction pump can reach 85 m^3/h, and the flow rate in the actual running should be controlled around 30-40 m^3/h to ensure that brine-extraction capacity has a surplus y. In addition, the motor power is up to 160kw, with a large power consumption, and after installing transducer, the power can be saved by 30kw · h.

3. The mining zone is adjacent to villages; therefore, it is required to observe the displacement of ground settlement for long to ensure the safe production and security of people's lives and properties.

References

Zheng Mao-quan, Chen Guang-bin. Application of Obstacle-Avoiding Horizontally Butted Wells in the Exploitation of Hugely Thick Rock Salt Stratum (C). Proceedings of the 17th Symposium of China Well and Rock Salt. May, 2005.