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The Casing Programme and Completion Technology of Reinjection Well in Porous Sandstone Reservoir in Tianjin, China

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ABSTRACT

It is quite early to make a study and test on reinjection into porous sandstone reservoirs in Tianjin, and make a certain extent of success, as focusing on the casing programme and completion technology of reinjection wells in porous sandstone reservoirs has just occurred in the latest five years. Different casing programmes have been designed for different types of porous sandstone reservoirs in the Tianjin area, including the single open large-diameter borehole with gravel packing, the second open monolayer strainer, and the reinjection wells changed from abandoned oil wells. This last programme is accomplished through analysis of the reservoir's structure, reservoir simulation, practical application in the well, and reinjection testing. On the side of completion technology, we adopted a series of techniques consisting of improving the mud capability, well-passing and wall-breaking before running casing, and joint well-washing. Practice shows these methods have good effects worthy of further application.

1. INTRODUCTION

Tianjin has a long history of porous geothermal resource development and utilization in Tertiary reserviors. The wells drilled here have many advantages: simple casing programmes, short construction periods, large well yields, low drilling costs, small risk, and so on. Its exploitation amount each year has exceeded 50% of the gross exploitation amount; it is widely applied to space heating, washing, and aquiculture greenhouses, and has obvious social and economic benefits. At present, the prominent problems are that geothermal reservoir pressure declines over time and running cost increases. These are disadvantages to sustainable development and utilization of geothermal resources. To solve these problems, Tianjin administration sections and research institutions reached a unanimous agreement to use tail water for reinjection. Therefore, many studies and analyses have been performed on ground filter systems for reinjection, service regulations, casing programmes, and completion technologies and have achieved some results. This paper focuses on the casing programmes and completion technologies.

2. THE TEXTURE CHARACTER OF POROUS GEOTHERMAL RESERVOIR

The porous exploitation reservoirs in Tianjin mainly include the Minghuazhen (Nm) and Guantaozu (Ng) formations. Their lithologies are mainly of sandstone and mudstone and they show nonuniform thickness type interbeddings with buried depths between 500 and 2000 m. The fluid temperature in these geothermal reservoirs is low to medium. The dissimilar palaeogeomorphologies controlled by tectonic elements caused a difference in physical resources and depositional dynamic conditions and finally led to the vertically and horizontally non-homogeneous reservoir lithologies and physical properties.

Nm is widely distributed in the plains area of Tianjin with an area of 9181 km^2. Its grain size is fine that builds up in a series of normal cycles with grey-green siltstone, silt-fine sand and brownish-red mudstone. Nm can been further divided into two segments, the upper segment (Nm2) and lower segment (Nm1), which have normal consolidation. Ng mainly distributes on the depressions and its depositional thickness is larger. On areas of high uplift, its thickness is smaller, or even thin out. Ng can distinctly be divided into three normal strata. From top to bottom, they are NgI, Ng□ and Ng□. Of them, the NgⅢ sandstone grains are the coarsest, sandstone layers concentrate, The sand-mud ratio (the ratio of sandstone thickness to gross stratum thickness) generally exceeds 40-50%, sometimes even reaching 60-80% in local areas. NgⅢ has good connectivity and large well yield characteristics, and it is the main segment of Ng for geothermal development.

The basic characteristics of Nm and Ng are shown in Table 1. This type of porous reservior has broad representation among China's sedimentary basins. The study of casing programmes and completion technologies concerns not only drilling engineering safety, but also reinjection effects.

Table1 The Basic Characters of Nm and Ng in Tianjin

Resevior character	Minghuazhen formation (Nm)	Guantao formation (Ng)
Buried depth of roof (m)	300-520	590-1990
Thickness(m)	230-1300	228-755
Sand-mud ratio	0.24-0.46	0.2-0.64
Porosity(%)	26	18-36.6
Permeability coefficient(m/d)	0.38-1.8	0.28-1.71

3. THE REINJECTION WELLS OF NM

There are two types of casing programmes used in Nm reinjection wells. When the well depth is less than 1000 m, the completion technology of one open large-diameter borehole is adopted, and the annular space is filled with gravel after the strainer is in place. Its advantages are simple technology, low cost, little water resistance, and good reinjection effects; but its disadvantage is that the sidewall may collapse during drilling because of too long open hole. When well depth is over 1000 m, the completion technology of two open holes with double-decked strainers is adopted. The advantages of this technology are a short construction period, safety, and easy sidewall maintenance. Its disadvantages are as follows: first, there is no support between strainer and sidewall, which can easily cause the sand layers to become unstable and have disorderly arrangement; second, the pore space among artificial packing is partly filled with sand from stratum and causes seepage during reinjection.

3.1 One Open Drilling Borehole with Large-Diameter

After a Φ550 mm borehole was drilled to the target stratum, the Φ339.7mm surface casing strings, Φ177.8mm intermediate casing strings, and strainers were connected and put into the borehole at the same time. The silt-fine sand grains in the Nm target stratum were between 0.1 to 0.2 mm. If D_{50} expresses the wire winding intervals of porous strainer, d_{50} expresses the median grain size in the reservior. Laboratory tests indicated that the well yield would be largest with little sand content when D_{50} was 6-7 times larger than d_{50} (D_{50}/d_{50}=6-7), resulting in wire winding intervals of 0.7-0.15mm.

Generally, filling gravels should adopt Φ2-4mm quartz sands with good roundness and hard texture, and the unilateral thickness of filling gravel should be 75-100 mm. The amount of fill should be calculated according to the practical well structure before filling. In sand segments, the borehole diameter often happens over-gauge hole phenomena, so the amount of filling gravel should exceed 10% of the calculated value.

The gravel filling method requires certain hydrodynamic conditions. After connecting the top casing with mud pump pile, they should be sealed, and the mud pump's discharge amount and mud returning rate should be less than the filling amount and dropping rate of the gravel through the annular space to avoid the gravel clogging that will affect the reinjection well quality.

3.2 Second Open Drilling Borehole with Double-decked Strainers

Casing programmes with double-decked strainers were adopted. One open borehole was drilled with a Φ444.5 mm drill bit to a depth of 350 m, after which Φ 339.7 mm surface casing strings were run (also as pump chamber). A second open borehole was then drilled with a Φ311mm drill bit to the target depth, after which Φ117.8mm casing strings and Φ260-265mm double-decked strainers were run. According to the results of ground simulation tests of double-decked strainers, optimal wire winding intervals of 1.5mm in the inner net and 2mm in the outer net should be observed, and the unilateral thickness of Φ4-6 mm filling gravel should be more than 40 mm. After running the casing, the drilling fluid should be replaced by clear water, followed immediately by the well-washing.

4. THE REINJECTION WELLS OF NG

Because the Ng reservior reaches great depths, Ng wells usually reach 1800-2100 mm. In these cases, the second open casing programme with single-deck strainer is usually adopted. One open borehole was drilled with Φ444.5mm drill bit to a depth of 350-400m, after which Φ 339.7mm surface casing strings were run(also as pump chamber). Because the water level declines over time, the pump chamber needed to be longer than 350 m in order to be used for a long time. The second open borehole was drilled with a Φ241.3mm drill bit to the target depth, after which Φ117.8mm casing strings and a single-decked strainer were run. The gravel diameter of Ng in a state of natural consolidation usually is 0.5-1.25 mm and the grains are not easy to move with groundwater flowing. Tests confirmed that the optimal wire winding intervals were Φ0.75-1 mm to allow fluid to pass through it easily. All the casings were seamless oil casings conformed to API standards, because of their simple construction technology and low cost, so a few of wells have been drilled in Tianjin. It can be infrred from practice that this type of casing programme and construction technology are successful and mature. Sketches of the structures of each well for porous reservoir reinjection in Tianjin are shown in Figure 1.

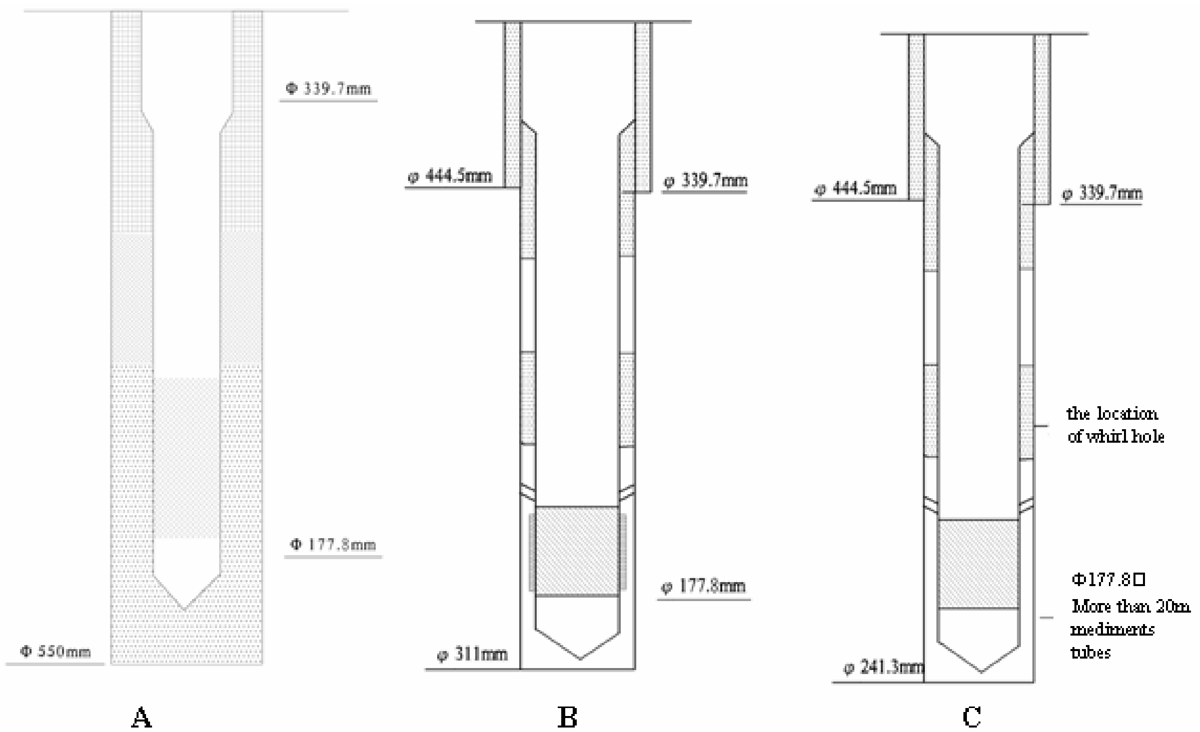

Figure 1 The Well structure sketch map of the porouse reservoir reinjection well in Tianjin

A The well structure of the first drilling with large caliber filling gravel of in the Minghuazhen formation

B. The well structure of the twice second drilling with a double layersed filter in the of Minghuazhen formation

C. The well structure of the twicesecond drilling with a single layered filter of in the Guantaozu formation

The major steps of well-washing of Ng reinjection wells are as follows:

(1) Replace mud in well casing with clean water.

(2) Pump 10-15 m^3 of 1% sodium tripolyphosphate into hole to immerse strainer part for 24 hours. (Tests with 1%, 1.5% and 2% concentration show that 1% concentration is best.)

(3) Send down the high pressure jet nozzle to wash the strainer part. This generates vibrations and pressure waves that remove clogging or mud caking.

(4) The well-washing programme of air compressor should be used: suspend the drill pipes from the wellhead to 450 m, then use the method of gas lift to achieve negative pressure relative to the reservoir and induct the reservoir water into the well and to be discharged. The air lift should last until the well water is clear with no sand, after which the well-washing is complete.

5. REINJECTION WELLS TRANSFORMED FROM ABANDONED OIL WELLS

5.1 Transformation Mechanism

There were a lots of abandoned oil holes in the North China Plain. Although useless for oil exploitation, they still have value as geothermal resources. So oil hole perforating technology was introduced to transform the abandoned oil holes into geothermal wells. After perforating, the kone shots thrust the casing into the strata to form pore paths whose internal walls formed a seepage section, and a turbulent flow of groundwater gushed out. However, the process to form pore paths can exert a great influence on the surrounding stratum, primarily causing agglomeration and compaction that greatly decreases the porosity. According to the sandstone target perforation experiment by R·J·Sanucier, the porosity in the cracked compaction zone within 12.70 mm of a borehole is only 10% of the original porosity. Thus, when transforming abandoned oil holes into geothermal wells, reservoirs with good water-bearing capabilities, coarse gravel grains and excellent permeability rates must be chosen.

5.2 Influence Factors

The major factors of influencing perforation effects are the geological and hydrogeological characteristics of reservoirs including lithology, grain size, sorting and roundness, cementation, porosity, and permeability. Sandstone layers in Ng are better developed in the Tianjin area, as their thickness can reach 40-60% of the total Ng thickness. Each sandstone layer can reach 10-20 m, totaling 80-120 m. The permeability rate through this sandstone is usually $500\text{-}1200\times10^{-3}\mu m^2$. Due to the superiority of Ng over Nm and the agglomeration during perforation, the mass sand outflow from the strata is no longer a problem. The abandoned oil holes T38, T36-1, T38-2 in Tianjin area had favorable effects after perforation transformation, and the reinjection rate of geothermal tail water exceeded 90%. Through correlation of more than 10 wells having similar conditions in the North China area, it is concluded that choosing advantageous segments of Ng can lead to highly successful reinjection rates.

The secondary factor influencing perforation effects is the optimization grouping of perforation parameters. In the North China area including Tianjin, the following parameter values are usually chosen: 89 gun - 89 bullet or 127 gun - 127 bullet, a gun length of 2-4 m, a density of 16-20 holes/m, a hole diameter of 12 mm, and a spiral arrangement of the holes.

5.3 Major Technological Transformation

This perforating technology is quite mature, but its application to the transformation of abandoned oil holes to geothermal wells is novel. The major technological transformations include: making well-passing and mud fluid displacement; making an artificial borehole bottom; confirming the cement bond and cement top and checking the depth of each casing using magnetic location and amplitude logging; chopping up the small diameter casing and removing it to guarantee the pump chamber length; cementing the overlap part of the new casing; making perforations; detecting the sand surface and flushing the sand out of the well; and making well-washing and pump water. Generally, strainers do not need after perforating, but properly lengthen the deposition space. A sketch of the casing programme of the geothermal well transformed from an abandoned oil hole is shown in Figure 2.

6. CONCLUSIONS

According to theoretical analysis of the characteristics of porous reserviors in Tianjin, reservoir simulations, and many years of experience, the casing programmes and completion technologies for different well depths and different reserviors should be different:

(1) Nm reinjection wells with depths less than 1000 m should adopt the single open casing programme with a large-diameter. The wire winding intervals of the strainer should be 6-7 times the median grain size, and the gravel filling method should adopt hydrodynamic conditions.

(2) Nm reinjection wells with depths greater than 1000 m should adopt the second open casing programme with double-decked strainers. The wire winding intervals of the strainer should be 1.5 mm in the inner net and 2 mm in the outer net, and the unilateral thickness of the filling gravel with Φ4-6mm should be greater than 40 mm.

(3) Ng reinjection wells that adopt the second open casing programme with a single-decked strainer should have wire winding intervals of Φ0.75-1mm. The comprehensive method of well washing should be used until the well water is clear with no sand. The reinjection rate of geothermal reinjection wells transformed from abandoned oil holes can exceed 90%.

In summary, the reinjection effects are key to deciding if porous reserviors can be developed further, and the casing programmes and completion technologies are major factors in this. Solving these problems can accelerate the development of geothermal resources.

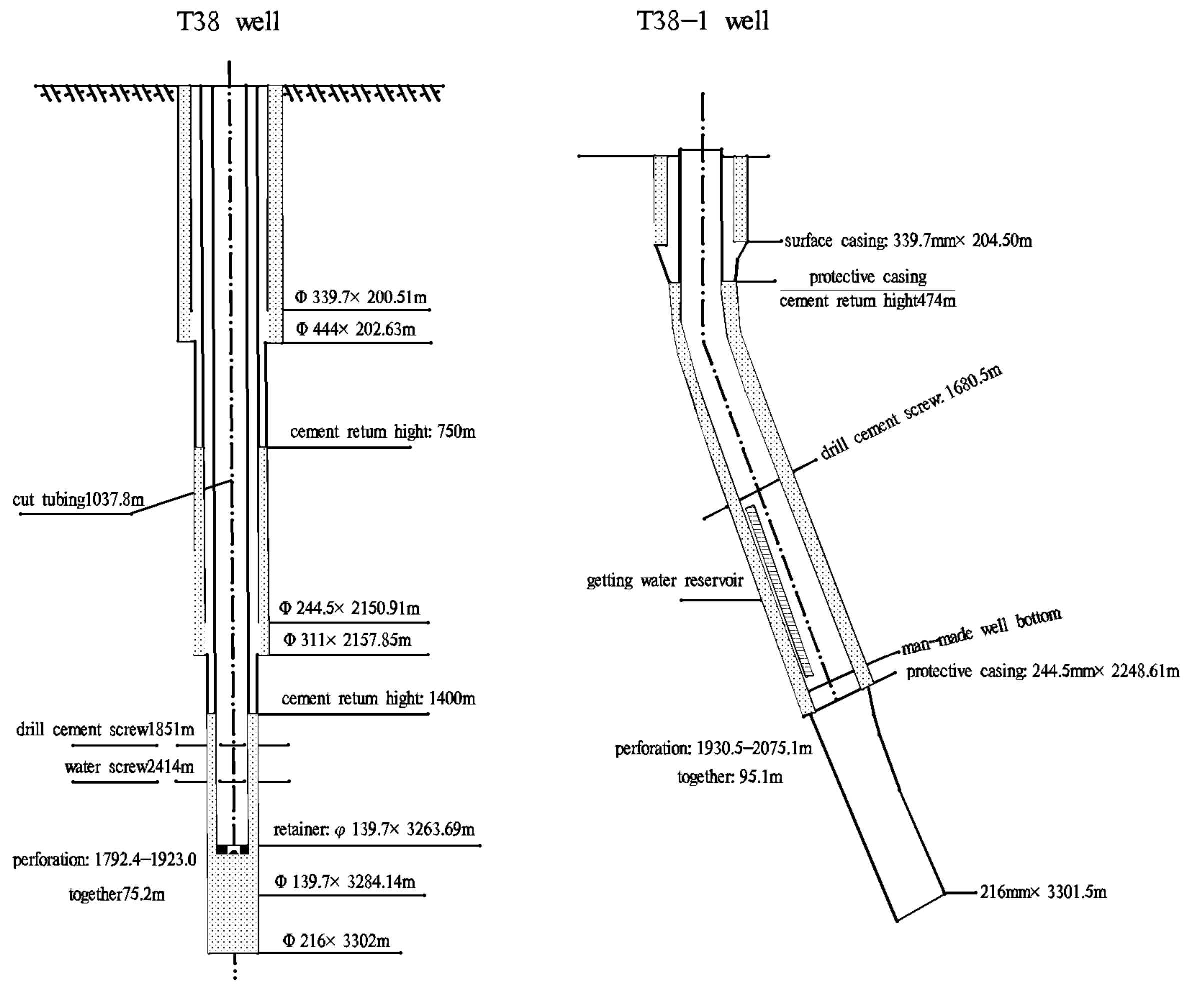

Figure 2 Sketch of the T38 and T38-1well structures for rebuilding them as geothermal wells