Research on high speed drilling technology and economic integration evaluation in Oilfield

Kun Wang\textsuperscript{1,2}, Hongjian Ni\textsuperscript{1}, Na Cheng\textsuperscript{2}, Jingbo Song\textsuperscript{2}

\textsuperscript{1}China University of Petroleum, Qingdao 266580, China
\textsuperscript{2}PetroChina Tarim Oilfield Company, Korla 841000, China

Abstract. The carbonate reservoir in the oilfield mainly formed in Ordovician System and Carboniferous System. The geology here is very complicated, with high heterogeneity. It gets much more difficult to control the well deflection in Permian system so that high accident ratio could be expected. The buried depth of the reservoir is large, normally 4600-6600m deep. The temperature of the layer is higher than 132 and the pressure is greater than 62MPa. The reservoir is with a high fluid properties, mainly including thin oil, heavy oil, condensate oil, gas and so on; the ground is very hard to drill, so we can foresee low drilling speed, long drilling period and high drilling cost, which will surely restrict the employing progress of the reservoir.

1. Difficulties in Speed Raising

1.1. Poor Drillability
The drillability is poor and block falling is easy due to that the permian system contains pebbly and igneous stratum, so that we can expect that the drilling and drill pipe-splicing get difficult or even a collapse there to seize the machine. Above the carboniferous system, there are mainly mudstone and limestone, which make it hard and slow to drill.\textsuperscript{[1]} At the bottom of silurian system and Sangtamu formation of ordovician system, there are a lot of brown mudstone and brown grey mudstone with high plasticity. In this area, the drilling pressure and speed don't work smoothly and parameter adjustment doesn't work so much either. The drill machine has to work in a low speed about 40-60min/m. Further more, at the bottom of silurian system, we can get fine sandstone layer with uneven thickness, low predictability and abrasiveness. For this area, PDC+screw drills will be worn heavily as soon as they meet 2-3m sandstone because of the irreconcilability between the displacement and the speed. As for the PDC drill, its footage is 170-230m and speed is 2.0m/h or so, however it can not run so much in deep intervals, which will obviously add drilling times and delay the finishing time.

1.2. Difficult to Control Well Deflection
The rocks of carbonate reservoir are very complicated, mainly formed by bioclastic sand-gravel limestone and algal bondstone; fault system has developed; the reservoir zones are mainly holes, crevice, hollows\textsuperscript{[2]}, which make it hard to control the deviation. Due to the particularity of carbonate rocks, the target region needs to be constricted. In the deep area, even if the deviation is very small, the target is still very easy to lose.
1.3. High Ratio of Complicated
Accidents From the complicated geology drilled: During the drilling progress, the most complication mainly occurs in the ordovician system. In the ordovician system, excellent crevice and karst cave reservoirs can be detected. Hydrocarbon shows are active, status such as overflow, killing, leakage, and so on can happen in the drilling progress; this will make the horizontal well restricted in the horizontal extension.

Accidents of drilled wells tell us: the accidents often include: Drills break, stage collar doesn't work, logging tools drop into the well, and so on. For the preventing part, we mainly work on the wearing down of drilling tools, solid particles' erosion to drilling tools, the quality of state collar, and so forth.

2. Evaluation on Adaptability of Drilling Speed -Increasing Technology
The block has tried 4 speed-increasing technology so far. They are: VSI drilling speed-increasing improving technology, Screw X-Treme in high temperature, adjustable pulse increasing tools, jet-flow increasing tools. And all of the above 4 tools are executed below the permian system. The experimental stratum is in the carboniferous system, devonian system, silurian system, and ordovician system.

2.1. Evaluation on VSI Adaptability in the Block
AS a "software" technology of improving drilling parameter, VSI is mainly used below the second interval of the 4 wells. Experiment layers are carboniferous system, silurian system, and ordovician system and experiment period is 2412-4013m. The average depth is 239.3m, while drilling speed is 3.74m/h. The drilling speed in progress is 3.23m/h, and for each well 1.42 days were saved. So the speed increasing is good.

The adaptability of VSI on drills and layers was also tested. The experiments tried many types of PDC drills, which showed that VSI totally adapts to carboniferous system and silurian system (mainly sandy mudstone), and hard ground of ordovician system (mainly sand and limestone). What's more, VSI also works well with many kinds of drills and parameters (drilling pressure: 30-60kN, spinning speed: 60-90r/min, pump pressure: 20-31M Pa, displacement: 30-38L/s). See table 1.

| Well number | Drill Type | Drill Size(mm) | Well Interval(m) | Stratum | Lithology               |
|------------|------------|----------------|-----------------|---------|-------------------------|
| W-01       | FX56SX3    | 215.9          | 3594-3935       | Carboniferous System | Mudstone, sandstone, limestone |
| w-H1       | FX56S      | 241.3          | 4702-4890       | Ordovician System   | sandstone, mudstone         |
| w-TH       | MS1952SS   | 241.3          | 4294-4564       | Silurian System     | siltstone, mudstone         |
| w-H2       | FX56SX3    | 241.3          | 4956-5135       | Silurian System     | Mudstone, sandy mudstone    |

2.2. Evaluation of Adaptability of High-Temperature Screw X-Treme in the Block
High-temperature Screw X-Treme was tried below the second interval of 6 wells. Stratum are carboniferous system, silurian system, and ordovician system. Well interval is 3788-5994m, and the average footage is 1235.5m. The machine speed is 4.04m/h, while the progressing speed is 3.09m/h. All of the above save one well 13.1 days, which excellently increased drilling speed.

The adaptability of high-temperature Screw X-Treme on drills and layers was also experimented. In the experiments, many types of PDC drills were used. And the results tell us that high-temperature Screw X-Treme totally suits carboniferous system and silurian system (mainly sandy mudstone), and hard ground of ordovician system (mainly sand and limestone). What's more, VSI also works well with many kinds of drills and parameters (drilling pressure: 40-60kN, spinning speed: 50-70r/min, pump pressure: 19-23MPa, displacement: 26-33L/s), which is the best speed-increasing tool for the
block. And its high-temperature resistance can work well with a well footage by one drill. A good lifespan of the Screw can be expected. Above all, it's effective.

2.3. Evaluation of Adaptability of Pulse Speed-Increasing Tool with Adjustable Frequency on Tazhong Area

Pulse Speed-Increasing Tool with Adjustable Frequency was used below the second interval of one well. The experiment stratum is the ordovician system. Well interval is 5448-5863m, and footage is 415m.

As for drills and stratum, its adaptability was also tested. In the experiment, PDS drill was adopted. For the conclusion, the tool completely suits hard ground of Sangtamu formation of ordovician system (mainly limestone) and adopted drilling parameter at that time (drilling pressure: 30-80KN, spinning speed: 60-90rpm, displacement: 28-30L/s, standpipe pressure: 18MPa). During the usage time, the tool didn't change normal parameter. So the tool can effectively improve the machine drill without changing drilling tool combination and drilling parameter. Frequency is adjustable. During the work time, no accidents happened. And floating inclination survey was also tested successfully, so the tool doesn't have any impact on floating inclination survey; the tool was put in the well for 180 hours, and the pure work time is 146.5 hours. When it was raised up, it was still 90% new, which proved that the tool can meet field operation. The tool is fully metal sealing, and its highest temperature is 220°C [3], which makes it have a long lifespan. It can meet long drilling requirements in a deep well, as well as the safety of working in wells. Screw drill can not match it. The pulse tool successfully solved the difficult problems of improving drilling speed in deep wells, so it's very helpful for deep wells.

2.4. Evaluation of Adaptability of Jet Speed-Increasing Tool in Tazhong Area

Jet speed-increasing tool was put into practice in the second interval of one well, and the experiment stratum is devonian system, silurian system and ordovician system. Well interval is 4640-5190m, while the average footage is 330.5m. The average machine drilling speed we got is 4.57m/h, and the average progressing drilling speed is 3.07m/h. Above all, this can save one well 3.91days, good result.

The adaptability of jet speed-increasing tool on drills and stratum was also tested in the area. In the experiments, two kinds of PDC drills were adopted. As for the conclusion, the tool totally adapts to carboniferous system, devonian system and silurian system (mainly sandy mudstone cross layer), and the hard layers of ordovician system (mainly limestone). It also suits the field drilling parameter (drilling pressure: 40-120kn, spinning speed 50-80rpm, displacement: 28-35L/s, standpipe pressure: 18-22Mpa). At the same time, the tool didn't change normal parameter while working, which testified that the tool can greatly improve machine drilling speed without changing drilling tools combination and parameter; During work time of the tool, no accidents occurred. And floating inclination survey didn't get any impact neither. So the tool is reliable and it can meet the requirements of field operation. The tool is fully metal sealing, and the highest temperature it can stand is 220°C, which makes it can work a very long time and meet long time drilling requirements of working in deep wells. It can also improve the well safety, which is incomparable for screw drills.

3. Integration and Optimization of Speed-Increasing Technologies

According to the evaluations of every single technology, the integration plans for the area are induced as the following:

3.1. Plan 1

- Above the Permian System8” High-temperature Screw X-treme + Efficient PDC;
- The Permian System and Below Torque percussion tool: Torkbuster+ U513M.

Expectation: saving cycle days: 7.26+30.46=37.72(days); Take the straight wells as examples, the drilling cycle is 119.3days. For one well, the cycle can be reduced by 31.62%, it's a good result.

Optimized drilling parameter and drilling fluid for the plan are as follows:
• Above the Permian System: Drilling pressure: 40-60kN, Spinning speed: 50+Screw, Pump pressure: 21-24MPa, Displacement: 30-45l/s, polymer drilling fluids, polymer sulfonate drilling fluids;
• The Permian System and Below: Drilling pressure: 80kN, Spinning speed: 60, Pump pressure: 18-25 MPa, Displacement: 31~37l/s, polymer sulfonate drilling fluids.

3.2. Plan 2
• Above the Permian System 8" High-temperature Screw X-treme + Efficient PDC;
• Below the Permian System: 6¾" High-temperature Screw X-treme + Efficient PDC;
Expectation: saving cycle days: 7.26+8.29=15.55 (days); For the straight wells, the average cycle is 119.3 days, it can save one well by 12.99%, which is remarkable.
Optimized drilling parameter and drilling fluids for the plan are as follows:
• Above the Permian System: Drilling pressure: 40–60kN, Spinning speed: 50+Screw, Pump pressure: 21–24MPa, Displacement: 30–45l/s, polymer sulfonate drilling fluids.
• Below the Permian System: Drilling pressure: 40–60kN, Spinning speed: 50–70+Screw, Pump pressure: 20–24MPa, Displacement: 28–35l/s, polymer sulfonate drilling fluids.

4. Economic Evaluation on Speed-Increasing Technologies of Drilling

4.1. Economic Evaluation on Integration Plan
Plan 1:
• Above the Permian System 8" High-temperature Screw X-treme + Efficient PDC;
• The Permian System and Below Torque percussion tool: Torkbuster+ U513M.

4.1.1. Economic Evaluation of Plan on Stratum above the Permian System. The "8" High-temperature Screw X-treme + Efficient PDC" plan was used in the upper stratum of 14 wells. The average footage is 3623.4m; The average machine drilling speed is 16.07m/h, 60.82% higher than the same well intervals of neighboring wells; The average Progressing drilling speed is 11.7m/h, 56.23% [4] higher than the same well intervals of neighboring wells;
According to the statistics, the plan in the experiments of 14 wells totally saved: 7.26*14=101.64(days). If the drill costs 150k each day, the plan will save 15.246 million yuan;
The “8” High-temperature Screw X-treme + Efficient PDC" plan will totally cost: 180.65*9.45=1707.1(17.071 million yuan);
14 neighboring wells cost 47 bits and 7 three-cone bits; The 14 wells cost 4239.94 hours with homemade screws, so the cost of neighboring wells is:
47*220000+7*18000+4239.94*1116=1519.78 (15.1978 million yuan);
So, the 14 wells with the plan will save totally: 1524.6-(1707.1-1519.78)=1337.28 (13.3728 million yuan). For one single well, it will save 955.2k, so the economic effect is obvious.

4.1.2. Economic Evaluation of Plan on Stratum below the Permian System. The “Torque percussion tool: Torkbuster+ U513M” plan was used in middle and lower parts of 9 wells in the area. The average footage is 1272.8m; The average machine drilling speed is 4.21m/h, 161.5% higher than the same well intervals of neighboring wells; The average Progressing drilling speed is 3.22m/h, 185% higher than the same well intervals of neighboring wells;
According to the statistics, the “Torque percussion tool: Torkbuster+ U513M” plan totally saved the 9 wells: 30.46*9=274.14(days). If the drills save 150k yuan every day, the total savings will be 41.121 million yuan; The plan will totally cost: 148.23*9.9=14.675 million yuan;
9 neighboring wells totally used 39 PDC bits and 34 three-cone bits; the 9 wells totally cost 773 hours with homemade screws. So the total cost of screws and bits:
39*220000+34*18000+773*1116=1005.5(10.055 million yuan);
Hence, the 9 wells will totally save: 4112.1-(1467.5-1005.5)=3650.1(36.501 million yuan). As for one single well, it will save 4.0557 million. The good result is remarkable.

So in the area, plan 1: Above the Permian System: 8" High-temperature Screw X-treme + Efficient PDC; The Permian System and Below: Torque percussion tool: Torkbuster+ U513M, the plans will save one single well for 405.57+95.52=501.1(5.011 million yuan) it's very economic.

4.2. Economic Evaluation on Integration Plan
Plan 2:
- Above the Permian System 8" High-temperature Screw X-treme + Efficient PDC;
- Below the Permian System: 6¾" High-temperature Screw X-treme + Efficient PDC;

4.2.1. Economic Evaluation of Plan on Stratum above the Permian System. As mentioned before, 14 wells totally save: 1524.6-(1707.1-1519.78)=1337.28 (13.3728 million yuan). For one single well: 955.2k yuan, so economic results can be obtained.

4.2.2. Economic Evaluation of Plan on Stratum below the Permian System. The "6¾" High-temperature Screw X-treme + Efficient PDC" plan was put into practice in 13 wells of the area. the average footage is 637.4m; The average machine drilling speed is 2.88m/h, 47.7% higher than the same well intervals of neighboring wells; The average Progressing drilling speed is 2.0m/h, 62.6% [5] higher than the same well intervals of neighboring wells.

According to the statistics, the plan totally saved the 13 wells: 8.29*13=107.77(days). If the drills cost 150k yuan each day, the plan will totally save: 1616.55 million yuan; The plan will cost totally:

172.6*9.45=1631.35(16.3135 million yuan);
13 neighboring wells cost 32 PDC bits and 24 three-cone bits; The 13 wells totally cost 321 hours with homemade screws, so the neighboring screws and bits cost totally:

32*220000+24*18000+321*1116=783(7.83 million yuan)

Hence, 13 wells totally saved: 1616.55-(1631.35-783)=768.2 (7.682 million yuan), as for one single well, the plan saves 591k yuan, excellent performance.

The results tell us: plan2: Above the Permian System: 8" High-temperature Screw X-treme + Efficient PDC; Belove the Permian System: 6¾" High-temperature Screw X-treme + Efficient PDC; the plan will save every single well: 59.1+95.52=154.61(15.461 million yuan).

5. Conclusion
- The combination VSI optimization drilling technology and screws can improve the load-bearing characteristics of hard rocks in stratum, as well as take full advantages of effectively breaking rocks of screws. It can further improve the speed of drilling.
- "High-temperature screw X-Treme" completely fix hard ground which mainly includes interbedded sandy mudstone and limestone. Its high-temperature resistance can work well and for every single bit the footage is large. Screws have long lifespans. The speed-increasing effect is obvious.
- Pulse speed-increasing tools with adjustable frequency successfully solved the speed-increasing problems for deep wells, and offered great help. Its adaptability to bits and ground is excellent, especially for deep soils.
- The integrated plans such as torque percussion tool: Torkbuster+ U513M and 8" High-temperature Screw X-treme + Efficient PDC and so on, performed very well in saving drilling cost.

References
[1] Wang Shengli, Wang Dong. Ultradeep Well No.1 Drilling Fluids Technology [J]. Oil Drilling & Production Technology, 2007(4): 83-86.
[2] Liu Juntian, Hu Qianze, Zhang Rigong, Tian Lin&Cui E.Discussion of Formation
Characteristics in Lucaogou of Sangtanghu Basin. [J]. Xinjiang Oil & Gas, 2013(3): 1-4.

[3] Ouyang Yong, Zhou Wenjun, Xu Ziqiang, & Huang Zhanying. Research and Application of Pulse Speed-Increasing Tools with Adjustable Frequency [J]. Oil Drilling & Production Technology, 2013(2): 6-8.

[4] Liu Wei, Li Li, Hu Daliang & Zhu Huayu. Application of New Drilling Technologies in middle and deep stratum in West Sichuan [J]. Oil Drilling & Production Technology, 2008(2): 120-122.

[5] Lv Xiaoping, Li Xingguo, Wang Zhenyu, Wang Shui & Han Yuping. Experimental Application of Torque Impactor in the Silurian System of Yashen No.1 Well. [J]. Oil Drilling & Production Technology, 2012(2): 99-101.