Staged Fracturing Technologies of Open Hole Horizontal Wells

Science & Technology Management Department

2013

CHINA NATIONAL PETROLEUM CORPORATION

The best choice for staged fracturing treatment of horizontal wells with open hole completion!

Contents

China National Petroleum Corporation (CNPC) is a state-authorized investment agency and a state holding company. On July 1998, with the implementation of the Institutional reform of the State Council, CNPC was reorgnized to become an integrated oil company of cross-regions, cross-industries and cross-countries, it adopts modern enterprise system to realize the integrations of upstream and downstream operations, internal and external trade, production and marketing. CNPC's business covers six main sectors: oil and gas operations, petroleum engineering service, petroleum engineering construction, petroleum equipment manufacturing, financial services and new energy development. In 2012 CNPC produced 110 million tons of crude oil and 79.82 billion cubic meters of natural gas, while crude processing volume reached 191 million tons. The total revenue of RMB 2,690 billion with a profit of RMB139.1 billion had been achieved the same year.

CNPC was ranked 4th among the world's largest 50 oil companies and 6th in Fortune Global 500 in 2012.

CNPC strictly follows by the combined strategies of increasing resource capacity, expanding market shares and consolidating the international role, and persists in regarding technical innovation as a key framework to advance technological progress. To develop its core businesses, focuses will be placed on the solutions of key bottleneck technologies and key proprietary technologies. Thanks to continuously improving of the technical innovation system, optimizing the configuration of technological resources and strengthening the construction of strong talent teams, CNPC's technological creativity has been considerably upgraded. Consequently, a large number of technologies have been developed independently, with its own intellectual property.

Staged Fracturing Technologies of Open Hole Horizontal Wells is one of representatives for major innovations of CNPC.

CLEAN ENERGY SUPPLY FOR BETTER ENVIRONMENT

1 INTRODUCTION

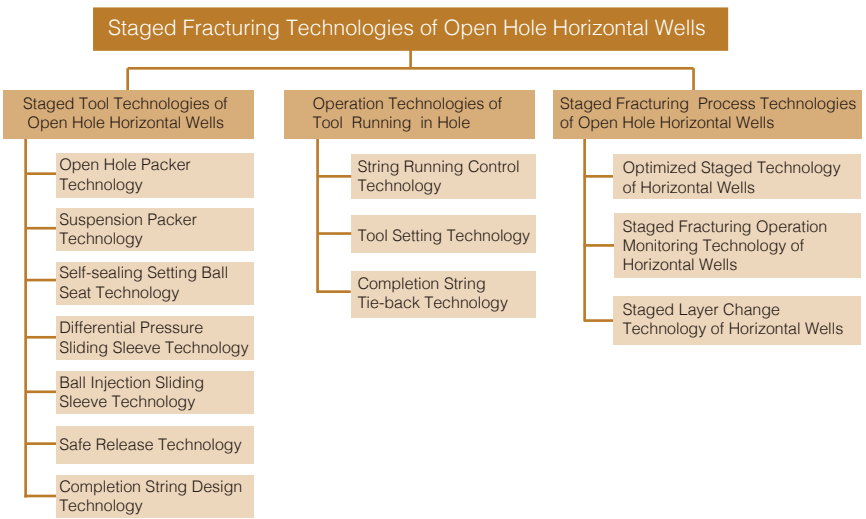
Horizontal well development is one of important means for increasing the production of oil and gas wells. Compared with vertical wells, horizontal wells expose reservoirs to a larger extent, and greatly increase the productivity of a single well, and finally improve the recovery ratio of a whole hydrocarbon reservoir.

CNPC is long committed to studying how to effectively stimulate the reservoirs focusing on the whole horizontal section. Due to being limited by the integral matching technologies for horizontal well fracturing technologies and especially by horizontal well stage fracturing tools and string technologies, horizontal well stimulation technologies develop slowly. Therefore, staged fracturing tools and string technologies for horizontal wells are the bottleneck of scale applications of horizontal well development technologies.

The successful development of staged fracturing technologies of open hole horizontal wells (CES-TopFrac) is a key breakthrough in the key technology field of oil and gas exploration and development and has provided powerful technical support and guarantee to large-scale high-efficiency economic producing of low grade reserves and greatly enhanced the comprehensive service capacity of CNPC.

Since the field applications of staged fracturing technologies of open hole horizontal wells, totally 699 intervals of fracturing and acidification of 106 open hole horizontal wells have been successfully performed. The operation success ratio is 100% and field application and stimulation effects are remarkable.

The staged fracturing technologies of open hole horizontal wells were independently developed by CNPC, including 13 unique technologies.



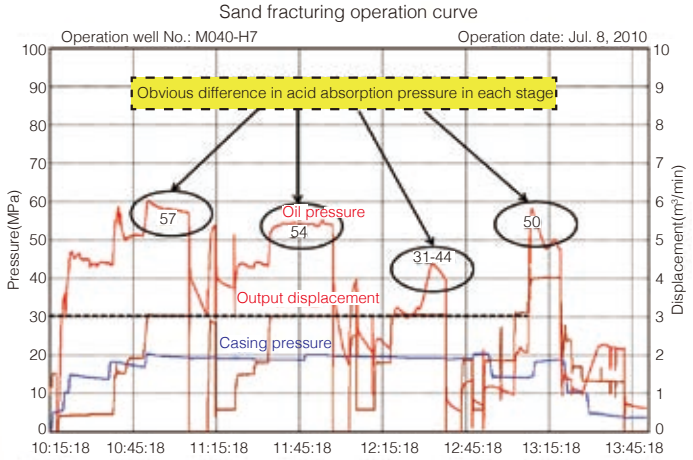
2 UNIQUE TECHNOLOGIES

2.1 Staged Tool Technologies of Open Hole Horizontal Wells

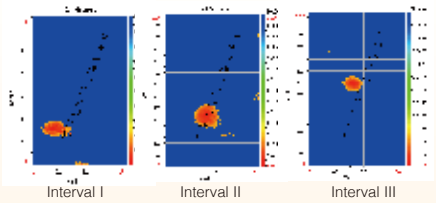
According to the requirements of staged stimulation technologies of open hole horizontal wells and the structure features of tools and strings, the components have been studied and designed, including open hole packers, suspension packers, self-sealing setting ball seats, differential pressure sliding sleeves, etc. so as to achieve the purpose of packer setting, reservoir separation, staged operation and layer conversion, etc.

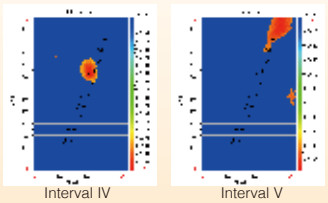
The dual reverse presetting compression sealing technology is used in the design of the open hole packer, thus improving the reliability of setting and sealing of the open hole packer in open hole sections and ensuring reliable separation of pay formations and highly effectively staged stimulation operations.

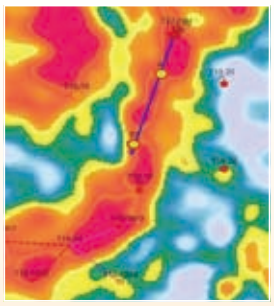
Open Hole Packer Technology



Pressure curve after open hole packer action







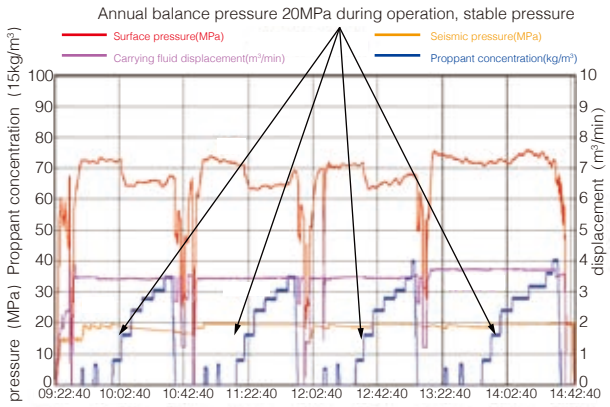
Wellbore azimuth and reservoir distribution of well T7-17-19H

Micro-seismic monitoring showed: The energy generated in each interval was monitored during formation fracturing.

Good sealing of T7-17-19H open hole packer through testing suspension packer technology

Suspension Packer Technology

The suspension packer uses split two-way slips and the two-way sealing design with “outburst prevention” mechanism and has advantages such as easy RIH, high safety and reliable sealing and pressure bearing property.



Pressure curve after suspension packer action

Self-sealing Setting Ball Seat Technology

Adopted internal closing type channel technology, the self-sealing setting ball seat technology can realize circulated liquid replacement after tool lowering, packer setting and two-way plugging of the end of the completion string after packer setting, which has advantages such as controllable and adjustable liquid displacement and pressure.

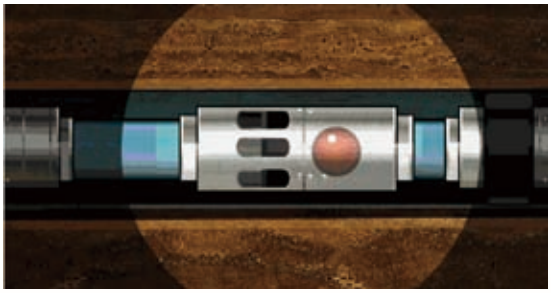
Differential Pressure Sliding Sleeve Technology

The two-hydraulic cylinder opening design is adopted. By opening any hydraulic cylinder, the sliding sleeve can be opened, thus improving the reliability of differential pressure sliding sleeve opening action, which has advantages such as adjustable pressure and large opening channel.

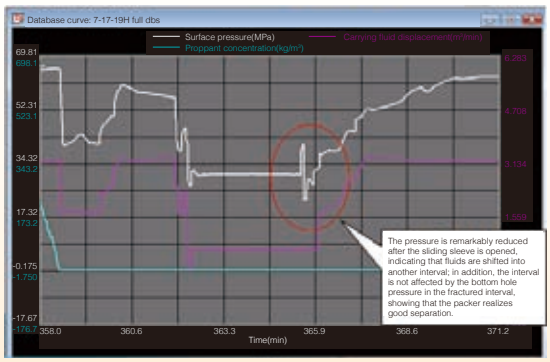
Differential pressure sliding sleeve opening

Ball Injection Sliding Sleeve Technology

The fracturing channels are opened through ball injection and pressurization. The check and anti-rotation mechanism design in the technology can prevent the sliding sleeve from unexpected closing after opening and has features such as reliable opening and adjustable pressure.



Ball injection sliding sleeve opening



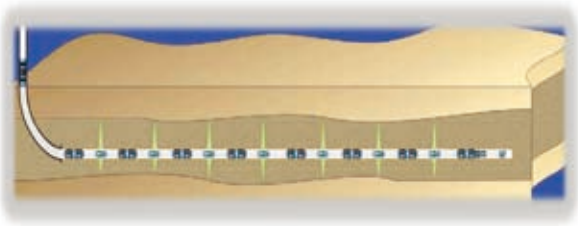
Sliding sleeve opening—operation pressure response

Safe Release Technology

According to different inclination positions of the suspension packer and the use of kill fluid, an auxiliary release constant pressure valve is set up; using the three modes such as integral pressure-out in the string, ball injection pressure-out and mechanical back-off, realize unlocking and releasing and improve the stability and reliability of releasing.

Completion String Design Technology

According to different well trajectories, geologic interpretation and target stimulation requirements, the suspension packer and the open hole packer are used in mechanical separation. In cooperation with various models of sliding sleeves, the packers can realize staged stimulation, combined measurement and combined production. The technology is characterized by convenient lowering operation, reliable setting and sealing, stable releasing and obvious staged sliding sleeve opening.



Schematic of the tool string for staged stimulation of a horizontal well with open hole completion

2.2 Operation Technologies of Tool Running in Hole

The technology has formed a set of complete and mature tool running operation processes through field practice based on the design and structure principle of tools, thus affectively ensuring favorable RIH of tools and avoiding complex conditions and downhole tool accidents.

Photo of tool RIH

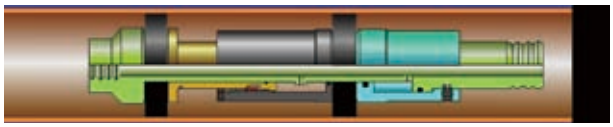
String Running Control Technology

The technology is an auxiliary guarantee technology that can ensure that a string is safely run to the predetermined position and that the friction increase value can be maintained within a permissible range.

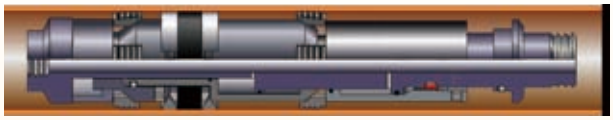
Combination structure of the pipe string to be runing in hole

Tool Setting Technology

The technology can ensure that all packers in the tool string act reliably, and set and effectively separate target intervals.



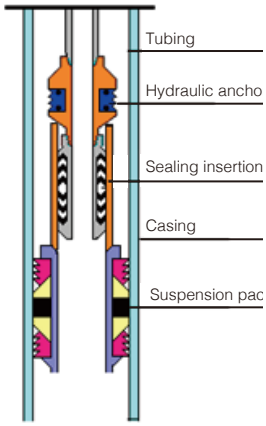
Open hole packer setting schematic



Suspension packer setting schematic

Completion String Tie-back Technology

Effective connection and sealing can be formed between production tubing and suspension packer. The application of the technology can make the tie-back action easily judged and form reliable sealing.



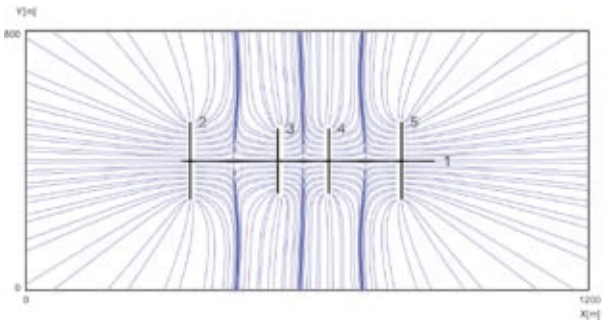
Completion string tie-back principle

Tie-back tool schematic

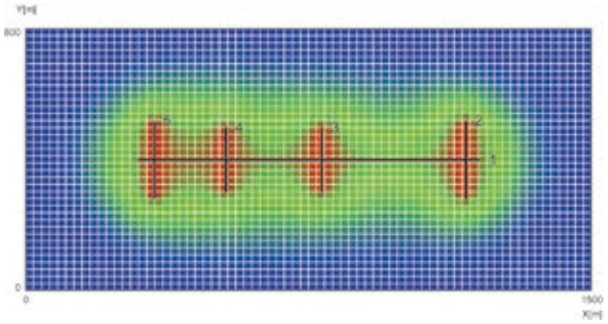
2.3 Staged Fracturing Technologies of Open Hole Horizontal Wells

Optimized staged technology of horizontal wells

The technology is used to simulate the fracture layout scheme for horizontal wells “many times”, which optimize the staged fracturing scheme and carry out dynamic prediction of production and formation pressure based on numerical reservoir simulation. The horizontal well plus numerical reservoir simulation model is established, The artificial fractures are treated using the methods such as grid density increasing plus equivalent flow conductivity, etc. The regularity of the impact of the shape, number, length and flow conductivity of fractures on the post-fracturing effect of a horizontal well is investigated, and thus the optimization result of the above parameters is determined.



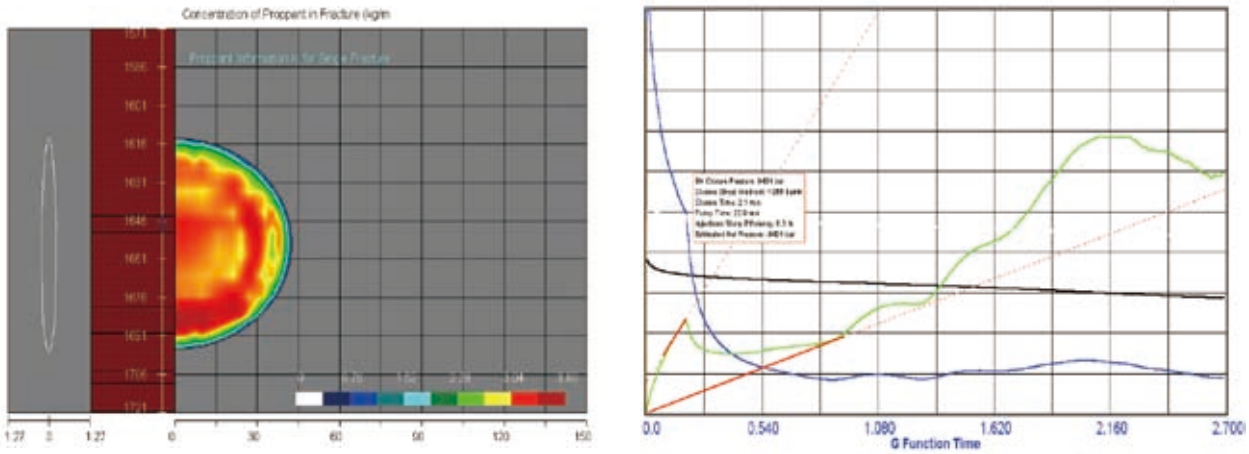
Fracture number and percolation form



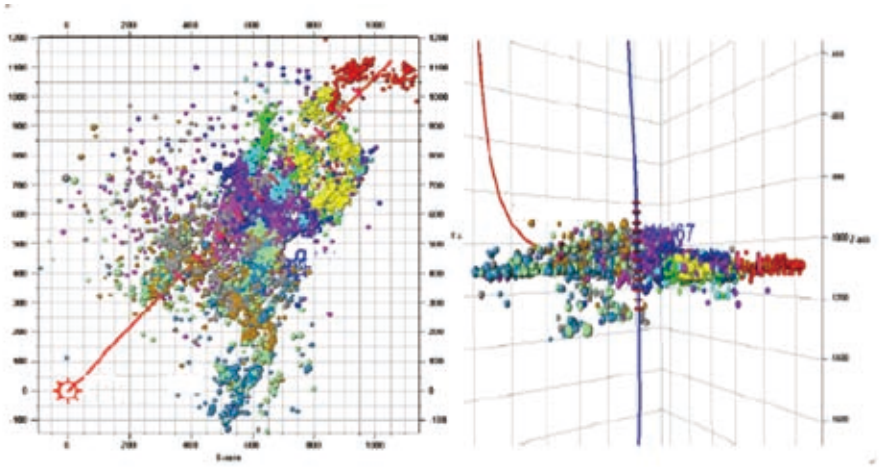
Fracture—reservoir percolation pressure field

Staged fracturing operation monitoring technology of horizontal wells

With the Fracpro-PT fracturing software, the variation of operation pressure and net fracture pressure are monitored in real time, with which judges whether the staged fracturing sliding sleeve is opened, the staged fracturing intervals are separated and fracture extension is abnormal, thus providing visual real-time fracturing operation monitoring technologies for fracturing operation decisions. The variation of the net pressure of fractures are monitored in real time using the Fracpro-PT fracturing software based on the double logarithmic curve characteristic chart of the classic model for different fracture extensions. The engineering scheme is timely adjusted according to the monitored variation trend of the net pressure of fractures and the abnormal variation of the net pressure of fractures in the operation process, thus increasing operation success ratio and effective rate. Under mature matching conditions, the microseism method is used to monitor the extension and distribution of staged fractures. Real time adjustment of operation parameters is a more visual monitoring means.



Operation pressure fitting analysis and judgment



Microseism monitoring, analysis and judgment

Staged layer change technology of horizontal wells

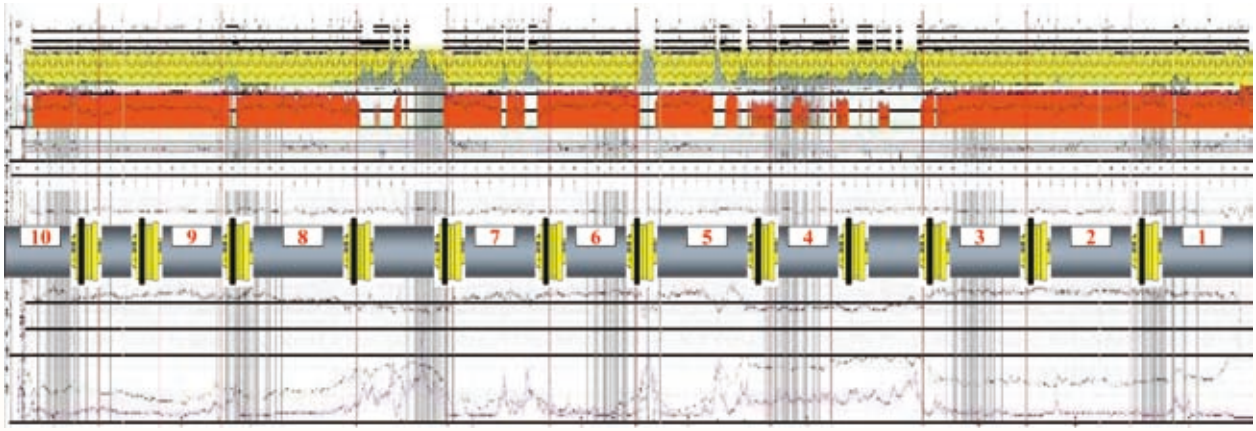
The technology can be used to effectively optimize the surface ball injection process, control the ball injection and safely complete layer change in horizontal wells with high quality.

Pipeline drawing of staged layer change site

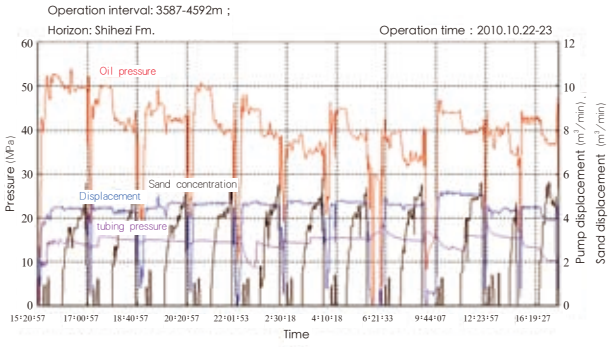
3 TYPICAL CASES

3.1 Staged Sand Fracturing of Open Hole Horizontal Well with Low Permeability Sandstones

Well S75-70-6H is located in the northwest of Sulige gas field. The vertical depth of reservoirs is 3402m, the reservoir temperature 105℃, the horizontal section length 1005m, the drilling ratio of reservoirs 80.1%, the average permeability of reservoirs 0.16mD, and the average porosity of reservoirs 8.3%. According to the lithologic difference between mudstones and sandstones in the horizontal section, 12 open hole packers were used in combined single-sealing and dual-sealing horizon determination, thus controlling the fracture starting point and fully exposing reservoirs. The exposure ratio of reservoirs was 99.4%. According to the operation curve, the obvious difference in the operation pump pressure in the stages shows good separation effect of the open hole packers and successful staged layer change fracturing. After fracturing, the test production was $20\times10^4m^3/d$, the stable test casing pressure 20.7MPa and the AOF $316.2\times10^4m^3/d$.



Logging curve and staged description of well S75-70-6H

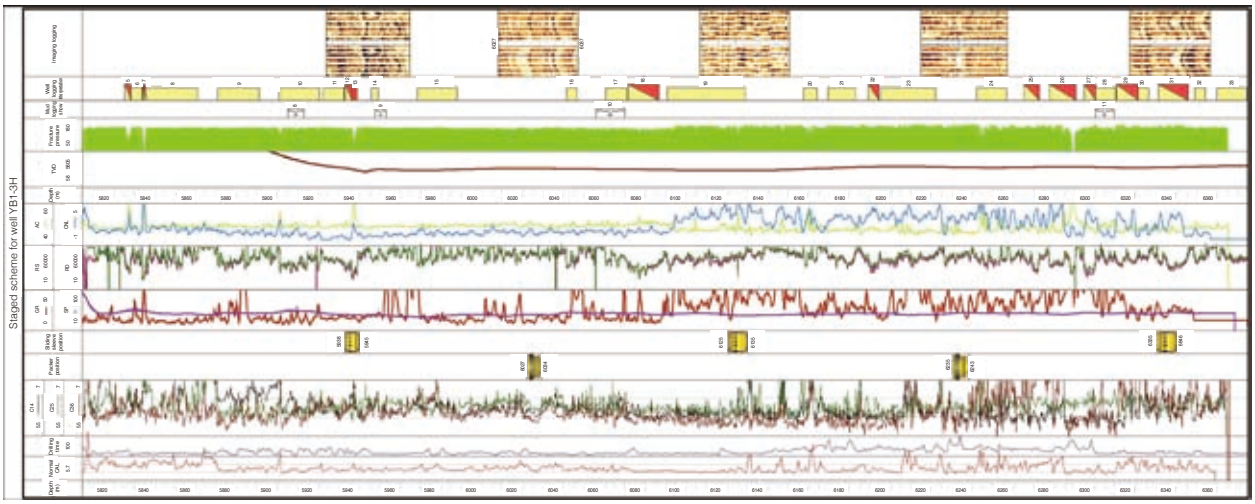


Staged fracturing operation curve of well S75-70-6H

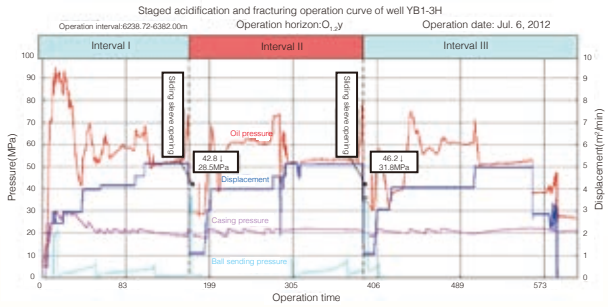
Field operations of well S75-70-6H

3.2 Staged Acidification and Fracturing of open Hole Horizontal Well with Low Permeability Carbonate Rocks

Well YB1-3H, located in the southwest depression area of Tarim basin, is a development appraisal well of Northwest Petroleum Bureau, Sinopec. The vertical depth of reservoirs is 5809m, the inclined depth of reservoirs 6382m, the reservoir temperature 144℃ , the horizontal section length 428.07m, and the average vertical permeability of reservoirs 0.37mD. The $9^5/_8″$ in casing of the well can bear only 34.5MPa pressure. The 7″ in casing suspension section was deformed, and blockage was encountered many times during drifting. As determined finally, 3 open hole packers were used in acidification and fracturing in 3 intervals. Totally 196.4m^3 slippery water, 880m3 fracture fluid, 140m^3 steering acid and 1010m^3 high temperatures gelled acid were injected into the strata during operations. The analysis of the operation curve shows that the operation pressure in the intervals was obviously different, indicating that the open hole packers played an effective role in separation and the pressure response of opening of the two ball injection sliding sleeves was also very obvious. Through the test with a 4mm choke after fracturing, the daily oil production was 96t and the tested stable tubing pressure 27MPa.



Logging curve and staged description of well YB1-3H



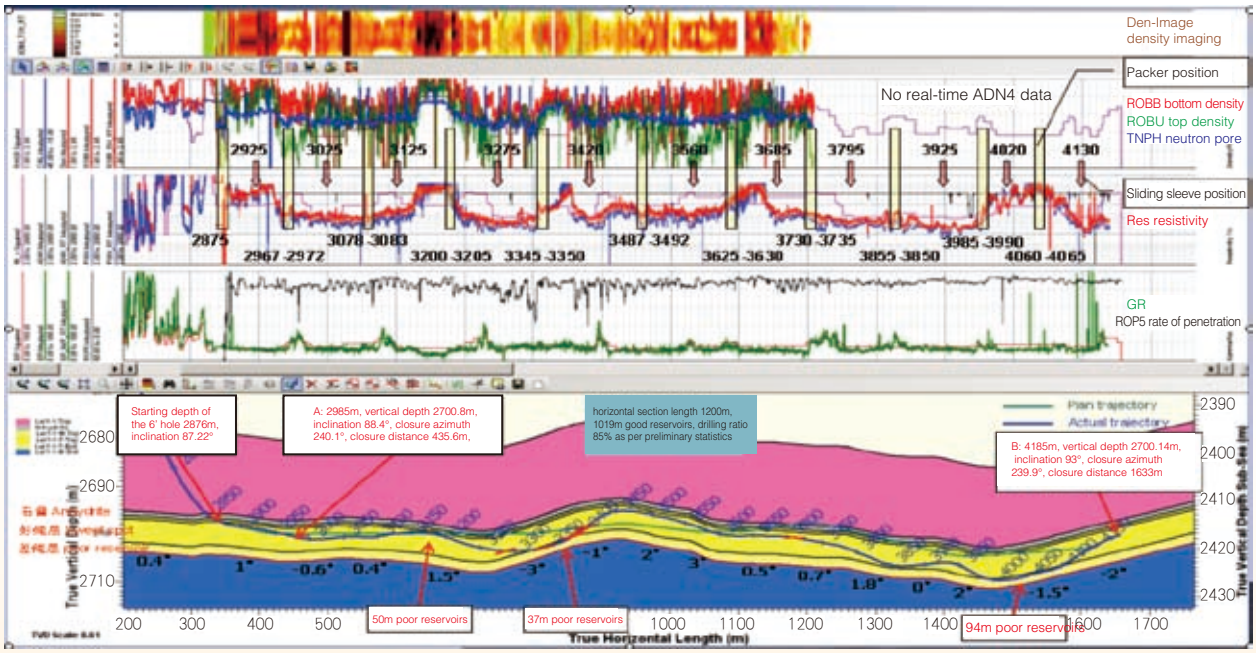
Staged acidification and fracturing operation curve of well YB1-3H

Field operations of well YB1-3H

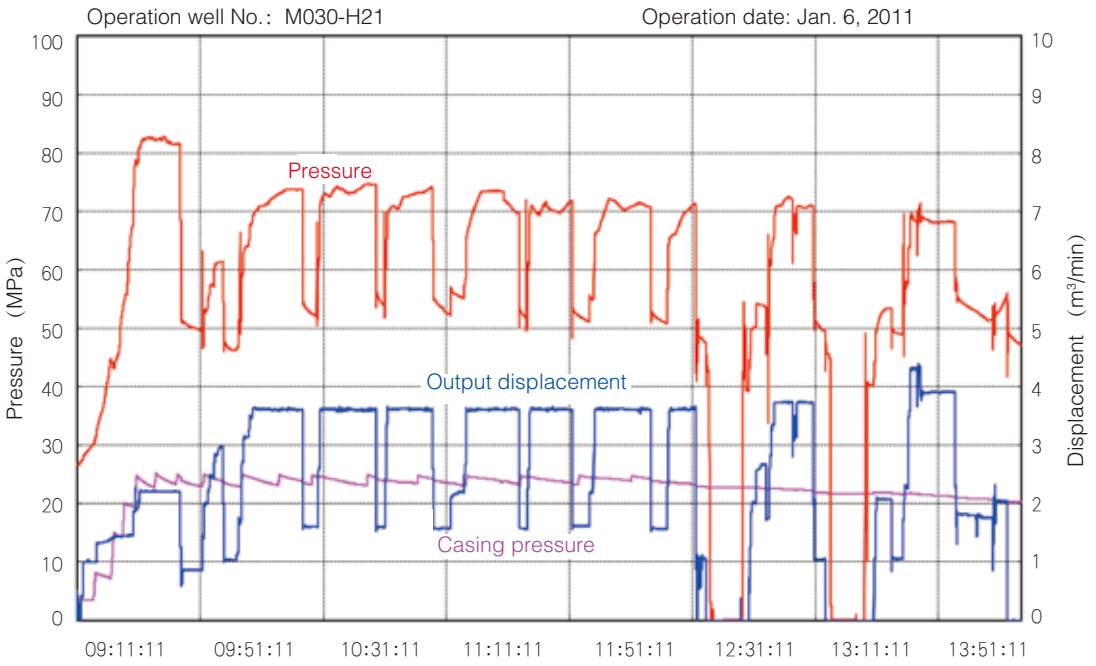
3.3 Staged Acidification of Horizontal Well with Low Permeable—Heterogeneous Carbonate Rocks

The total length of the curve section of well M030-H21 is 1309m, the length of the open hole section 1309.46m, and the total length of interpreted good reservoirs 1019m. By calculation from 2985m at point A, the drilling ratio of good reservoirs is 84.1%. The maximum hole inclination of the well is 96.31°. When the pay formation—L1 middle sub-member was drilled using the mud of 1.36~1.50g/cm^3 in density and 45~48s in viscosity, six times of gas logging anomaly shows and four times of gas cut shows were found. The porosity of the reservoir intervals is 3%~15.9%. The interpreted interval was 2876~4166m and there were totally 47 sections/1099.4m effective reservoirs, including 14 sections/196.3m type I reservoirs, 23 sections/807.1m type II reservoirs and 10 sections/96.0m type III reservoirs.

Open hole packers were used in acidification of 11 sections, and 860m^3 surfactant steering acid was injection. After operation, the obtained gas test production was 20×10^{4}m^3/d.



Logging curves and staged description of well M030-H21



Staged acidification and fracturing operation curve of well M030-H21

Field operations of well M030-H21

3.4 Achievements from Applications

The successful study of staged fracturing technologies of open hole horizontal wells has greatly promoted the application of horizontal well technologies and is a key breakthrough made in the key technical field of oil and gas exploration and development. From the successful development of staged fracturing technologies of open hole horizontal wells to now, fracturing and acidification of totally 669 intervals of 106 open hole horizontal wells have been successfully performed. The operation success ratio is 100% and field application and stimulation effects are remarkable.

Field operations

Field open flowing and test

4 R&D EQUIPMENT

The Downhole Service Company of CNPC Chuanqing Drilling Engineering Company Limited has a nearly 50-year history of downhole operations, downhole tools and oilfield chemical product development and production and field services for oil and gas wells. The Downhole Service Company has 8 well-configured fracturing and acidification operation teams, totally 140000HHP fracturing pumping equipment and 3 coiled tubing operation teams and has imported over 700 sets of units including HQ2000 and FC2251 fracturing units, HR10M coiled tubing units, etc. with the original value of 1.5 billion Yuan. The Downhole Service Company has built advanced tool production and detection equipment and oilfield chemical product production and synthesis units. The annual operation capacity of the Downhole Service Company reaches 3000 wells-times. The Downhole Service Company has created and renewed industrial records in China and even Asia.

The Downhole Service Company has developed and manufactured over 60 downhole tools and has over 30 downhole tool technology patents. The products of the Downhole Service Company have passed API certification. The Downhole Service Company is the designated downhole tool manufacturer of CNPC. The representative products of the Downhole Service Company include liner hangers, staged cementers, various models of completion and operation packers, bridge plugs, hydraulic jet tools, various sliding sleeves, etc.

Operation equipment

Tool machining plant

Tool assembling machine

Chuanqing Downhole Service Company has 2 experts of CNPC and 3 experts of Chuanqing Company. The fracturing and acidification technical personnel of the Downhole Service Company include 24 senior engineers, 85 engineers, 35 masters, 4 doctors and 1 post doctor. The Downhole Service Company has prefect fracturing and acidification—coiled tubing design software representatively including FracproPT, StimPT, WinGohfer, Cerberus, etc., Solidworks 3D mechanical design software, perfect liquid and engineering evaluation laboratories and over 50 sets of test equipment including RS6000 rheometers, FDS-800-10000 dynamic filter presses, independently developed horizontal well visualization simulation test units, etc.

RS600 Rheometer

FDS-800-10000 Dynamic filter press

In recent years, the Downhole Service Company has performed over 200 wells-times of staged fracturing and acidification operations in horizontal wells with multiple technologies including mechanical staged, jet staged, bridge plug stated and sand filing staged opens. The Downhole Service Company has staged fracturing and acidification technologies with complete independent intelligent property rights of open hole horizontal wells.

Horizontal well visualization simulation test unit

5 QUALIFICATIONS &STANDARDS

5.1 Enterprise Qualifications

The Downhole Service Company of CNPC Chuanqing Drilling Engineering Company Limited is a specialized enterprise that provides special fracturing, acidification, coiled tubing workover and cementing engineering services for oil and gas exploration and development and develops and produces downhole tools and oilfield chemical additives. The Downhole Service Company has been certificated by HSE, ISO9001 (Standard 2000), ISO14001 and API systems.

Qualification Certificates of the Downhole Service Company

5.2 Patents

The staged fracturing technology series of open hole horizontal wells have declared 14 national patents, including 6 patents of invention already published. The Downhole Service Company has obtained 8 utility model patents. The staged fracturing tools of open hole horizontal wells have been awarded by CNPC as important self-innovative products.

Certificate of important self-innovative product awarded by CNPC

Patents of staged fracturing tools and technologies of open hole horizontal wells

5.3 Standards

The following relevant standards are carried out for staged fracturing technologies of horizontal wells:

No.	Standard No.	Standard name
1	SY/T 5861—1993	Fracturing Wellhead Protector
2	SY/T 6120—1995	Technical Regulations for Blowout Control of Downhole Operations
3	SY/T 6334—1997	Acceptance pecification code for Acidification Design and Construction of Oil and Water Wells
4	SY/T 6283—1997	Health, Safety and Environment Management System Guideline for Oil and Gas Drilling
5	SY 6355—1998	Safety Mark Special for Oil and Natural Gas Production
6	SY/T5289—2000	Oil Well Fracturing Effect Evaluation Methods
7	SY/T 5127—2002	Specification of Wellhead Equipment and Christmas Trees
8	Q/SY 31—2002	Technical Supervision and Acceptance Code for Fracturing Engineering Quality
9	Q/SY 32—2002	Technical Supervision and Acceptance Code for Acidification Engineering Quality
10	SY/T 5211—2003	Complete Sets of Fracturing Equipment
11	SY/T 6566—2003	Technical Requirements for Safety of Hydraulic Fracturing
12	SY/T 5587.5—2004	Code for Conventional Workover Job—Part 5: Preparation of Wellbore for Downhole Operation
13	SY/T 5087—2005	Recommended Methods for Safety Drilling in Sour Wells
14	SY/T 5225—2005	Technical Specifications for Safety Production, Fire Control and Explosion Proof in Oil and Natural Gas Drilling, Development, Storage and Transportation
15	ST/T 6137—2005	Recommended Practices for Oil and Gas Producing and Gas Processing Plant Operations involving Hydrogen Sulfide
16	SY/T 6426—2005	Specification for Well Control Technology of Drilling
17	SY/T 6610—2005	Recommended Practice for Oil and Gas Well Servicing and Workover Operations Involving Hydrogen Sulfide
18	SY/T 6631—2005	Recommended Practice for Hazard Identification, Risk Evaluation, Risk Control
19	SY/T 6277—2005	Regulations on H_2S Monitoring and Personnel Safety Protection in Sour Oil and Gas Fields
20	Q/SY 1002.1—2007	Health, Safety and Environment Management System
21	SY/T 5587.9—2007	Specification for Conventional Workover Operations
22	SY/T 5727—2007	Safety Rules of Downhole Services
23	SY/T 6203—2007	Rescue Methods for Well Blowout Ignition
24	SY/T 5289—2008	Evaluation Method for Fracturing Design, Operation and Effect of Oil, Gas and Water Wells
25	SY/T 6376—2008	General Specifications for Fracture Fluid
26	SY/T 6690—2008	Technical Specification for Well Control in Downhole Operations

No.	Standard No.	Standard name
27	Q/SY 32—2002	Technical Supervision and Acceptance Code for Acidification Engineering Quality
28	Q/SY 91—2004	Fracturing Design Specification and Operation Quality Evaluation Method
29	Q/SY 31—2007	Technical Supervision and Acceptance Code for Fracturing Engineering Quality
30	Q/SY 1145—2008	Specification for Preparing the Summary of Fracturing Operations of Oil, Gas and Water Wells

4 technical standards have been newly formulated for the study and application of the staged fracturing technologies of open hole horizontal wells:

(1) Q/67579579-6·417-2011 Self-sealing setting ball seats for staged fracturing and acidification of open hole horizontal wells;

(2) Q/67579579-6·418-2011 Differential pressure sliding sleeves for staged fracturing and acidification of open hole horizontal wells;

(3) Q/67579579-6·419-2011 Packers for staged fracturing and acidification of open hole horizontal wells;

(4) Q/67579579-6·420-2011 Ball injection sliding sleeves for staged fracturing and acidification of open hole horizontal wells.

6 EXPERT TEAM

CNPC has a skilled and experienced completion and downhole service expert team and can provide various customers with high quality matching completion solutions and reservoir stimulation series technology solutions.

Shi Lin He has long been engaging in technical management of the study of oil and gas well drilling and completion technologies and equipment. He has taken charge of the research work for national 863 projects, national major special science and technology projects, major scientific research projects of CNPC, etc. He has obtained remarkable achievements in deep well and complex well drilling technologies, homemade deep well electric drilling rig development, shallow water drilling technology and offshore drilling technology and equipment research, etc. He was awarded with science and technology prizes of provincial and ministerial levels or higher. 10 research papers published.

Wu Xianzhu Technical expert. He has long been engaging in drilling engineering and technology management work and has solid professional theory foundation and plenty of field practice experience. He has organized and participated in a large number of scientific research projects and obtained grade II national science and technology advance prizes, grade I national energy science and technology prizes, 7 provincial and ministerial prizes, 10 bureau level prizes and 3 patents. Over 10 papers published.

Xu Chunchun He has long been engaging in exploration, engineering and supervision work. He was awarded 2 grade I science and technology advance prizes of Sichuan and CNPC, 1 grade I excellent exploration project prize of PetroChina, 5 grade I science and technology achievement project prizes of Southwest Oil and Gas Field Company and Sichuan Petroleum Administration and nearly 20 other scientific research achievement prizes. Over 20 research papers published.

Zhao Jinzhou He has long been engaging in the study and development of fracturing and acidification theory and technology and enjoys the government special allowance from the State Council. He has taken charge of over 50 scientific research projects and their achievements have been awarded 1 special grade national science and technology advance prize, 1 grade I national energy science and technology advance prize and 14 provincial and ministerial science and technology achievement prizes. 9 authorized patents of invention and 7 authorized software copyrights. Over 200 papers and 7 works published.

Ye Dengsheng Technical expert. He has long been engaging in reservoir stimulation technology research and technical management work. He has taken charge of and participated in over 40 scientific research projects and has obtained 4 provincial and ministerial achievement prizes, 8 bureau level achievement prizes and 5 patents. 12 papers published.

Qian Bin Technical expert, He has long been engaging in reservoir stimulation technology research and technical management work. He has organized and completed the study of over 20 scientific research projects and has obtained 1 provincial and ministerial prize, 4 bureau level prizes and 6 national patents. 5 papers published.

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