Reservoir Reconstruction Technology

Science & Technology Management Department

2011

CHINA NATIONAL PETROLEUM CORPORATION

CNPC possesses advanced Reservoir Reconstruction Technologies with independent intellectual property rights, making oilfield development more economic and efficient!

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China National Petroleum Corporation (CNPC) is a state-authorized investment agency and a state holding company. As an integrated oil company of cross-regions, cross-industries and cross-countries, it adopts modern enterprise system to realize the integration of upstream and downstream operations, internal and external trade and production and marketing. CNPC has 17 upstream companies, 33 downstream companies and 36 large-scale marketing companies. It is China's largest producer and supplier of oil and gas, and also one of the largest refined oil products and petrochemicals. In 2010 CNPC produced 105 million tons of crude oil and 72.5 billion cubic meters of natural gas, while crude processing volume reached 135 million tons. The total revenue of RMB1, 720 billion with a profit of RMB172.7 billion had been achieved the same year. Its profit is among the highest of the domestic enterprises in China.

CNPC was ranked 10rd in Fortune Global 500 in 2010 and 5th among global top 50 oil companies.

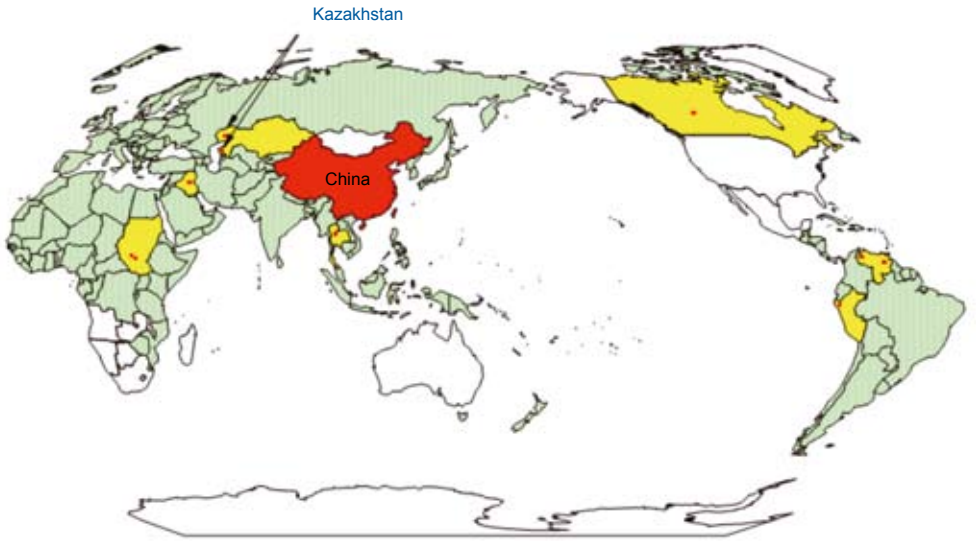
CNPC strictly follows by the combined strategies of increasing resource capacity, expanding market shares and consolidating the international role, and persists in regarding technical innovation as a key framework to advance technological progress. To develop its core businesses, focuses will be placed 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.

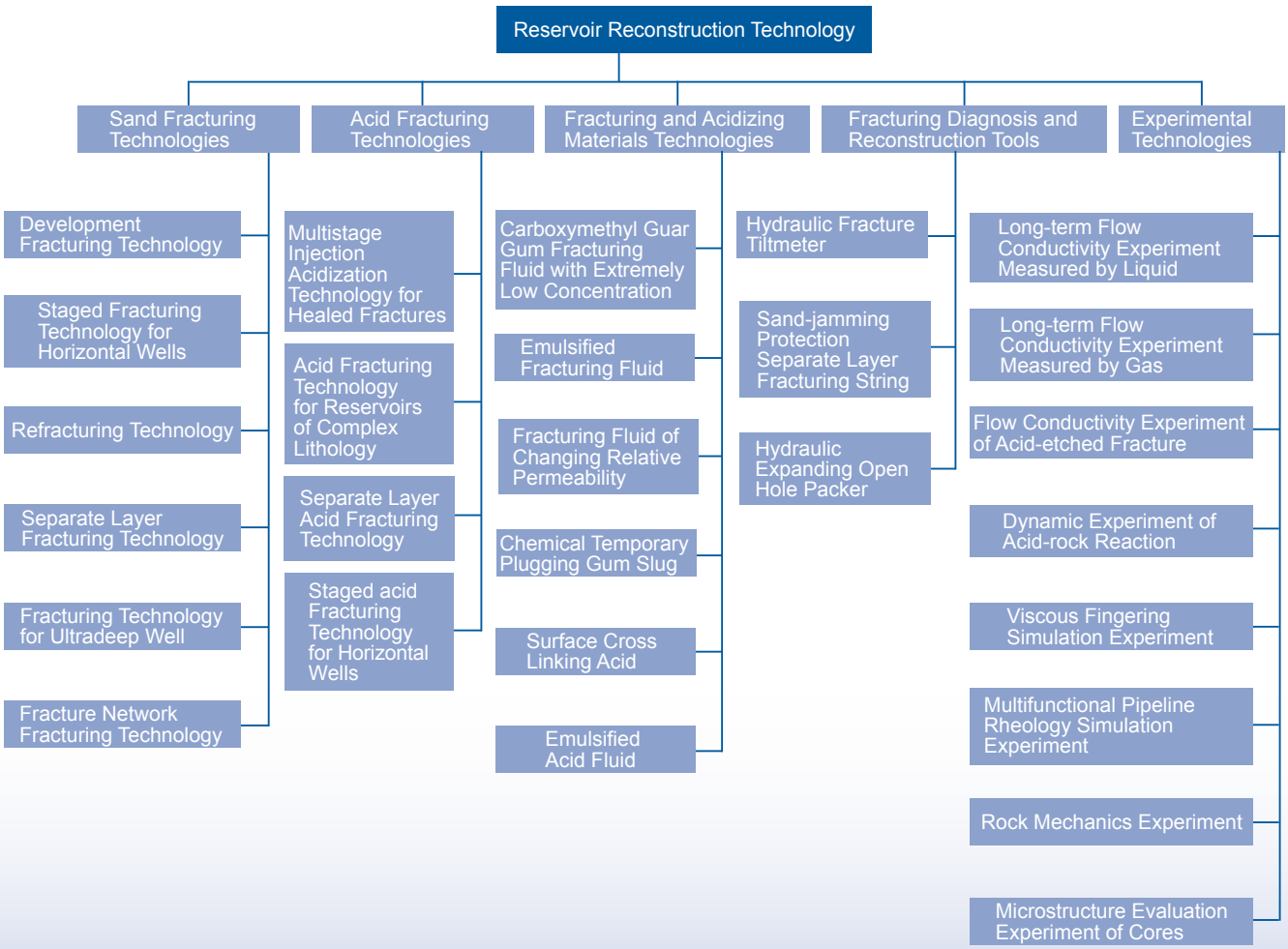
The Reservoir Reconstruction Technology is one of representatives for major innovations of CNPC.

1 INTRODUCTION

CNPC has been hammering at the study and practice on Reservoir Reconstruction Technologies and has independently developed 27 unique practicable technologies of 5 series. It has significant technical advantages and broad service fields and its overall technical level is on a par with the advanced international one. CNPC can provide technical services including sand fracturing, acid fracturing, fracturing and acidizing materials, fracture diagnose and reconstruction tools and reservoir reconstruction experiments, etc.

The Reservoir Reconstruction Technology has been successfully applied to low permeability oil and gas fields in Changqing, Daqing, Tarim, Sichuan, Jilin, Qinghai, Jidong and Sinkiang, etc. in China and those in several countries such as Kazakhstan, Azerbaijan and Venezuela, etc.

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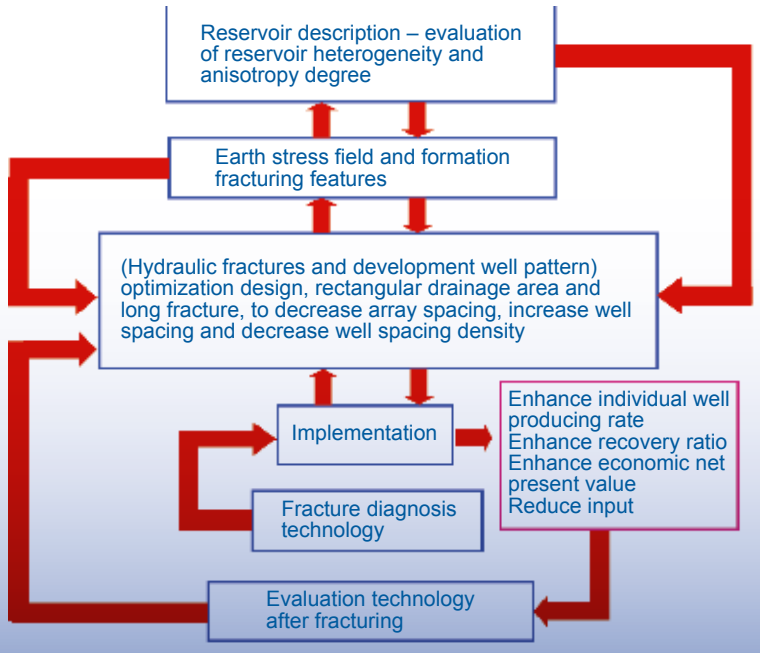
2 UNIQUE TECHNOLOGIES

2.1 Sand Fracturing Technologies

Sand fracturing is a technical measure to stimulate oil and gas wells through sand packed fractures with certain physical dimension and flow conductivity, which are formed in vicinity of bottom holes by the method of injecting fracturing fluid into target strata at high pressure through fracturing equipment and then adding proppants into the generated fractures. It mainly includes Development Fracturing Technology, Staged Fracturing Technology for Horizontal Wells, Refracturing Technology, Fracturing Technology for Ultradeep Wells and Fracture Network Fracturing Technology.

2.1.1 Development Fracturing Technology

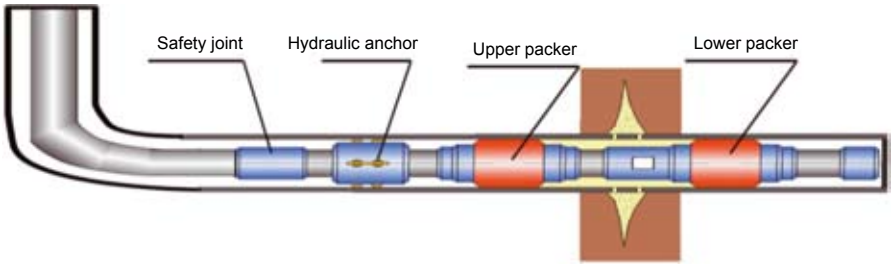
Development Fracturing Technology is the further combination of fracturing technique and reservoir engineering, in which the development well pattern and artificial fractures are matched and optimized with consideration of earth stress azimuth. Compared with the overall fracturing, it can play the maximum role of hydraulic fractures to enhance the output and degree of reserve recovery of low permeability reservoirs.



Schematic Diagram of Development Fracturing of Low Permeability Reservoirs

2.1.2 Staged Fracturing Technology for Horizontal Wells

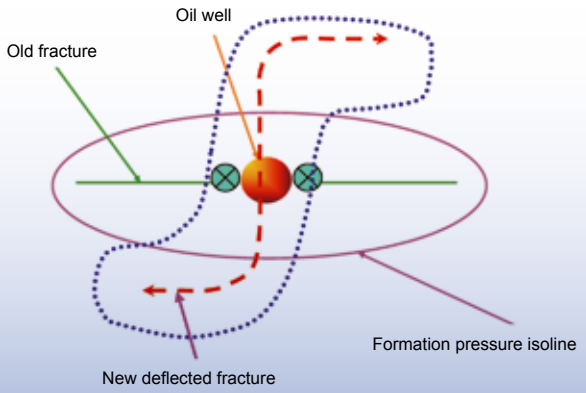
It is a technical measure to conduct staged fracturing reconstruction for horizontal interval of horizontal well by combining downhole reconstruction tools with fracturing technique. It mainly includes sand jet staged fracturing, sliding sleeve packer staged fracturing, twin packer single-grip staged fracturing, sliding sleeve + bridge plug staged fracturing, chemical temporary plugging gum slug staged fracturing, etc. and is applicable to staged fracturing reconstruction of horizontal wells with various well completion systems including casing completion, open hole completion and screen completion, etc.



Schematic Diagram of Twin Packer Single-grip Staged Fracturing Tool

2.1.3 Refracturing Technology

The purpose of refracturing fractured reservoirs is to recover the flow conductivity of the original fractures or to create new fractures through fracture deflection, thus realizing production enhancement and stabilization of stimulated wells. The key technologies include well and layer selection technology before refracturing, prediction technology of earth stress field and fracture deflection, design and implementation of refracturing deflection technique and evaluation technology after fracturing. It is applicable to the wells with unsuccessful or ineffective fracturing and the fractured wells with productions under the economic production line.



Schematic Diagram of Refracturing

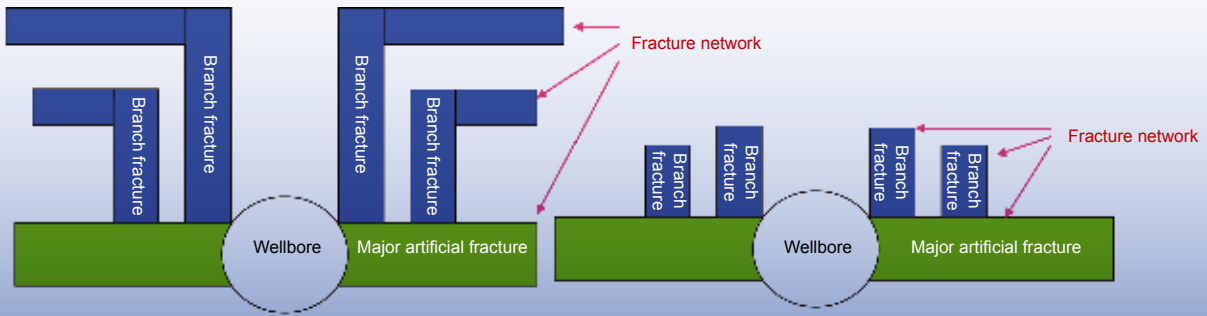
2.1.4 Fracturing Technology for Ultradeep Wells

It is mainly used to solve the problems such as high operation pressure and high operation friction, etc. existing in ultradeep wells (e.g. wells with depth greater than 4,500m) and reservoirs with abnormal high stress during fracturing and acidizing operations. Fracturing of ultradeep well is generally realized by using the delayed cross linking fracturing fluid with low friction and the weighted fracturing fluid with high density to decrease on-way friction of fracturing fluid and increase pressure of liquid column.

Fracturing Operation Site of Well Ake1 in Tarim

2.1.5 Fracture Network Fracturing Technology

Its purpose is to enhance the swept volume of hydraulic fractures as far as possible. After the major fractures meet the expected fracture length requirement, a reasonable method is used to realize the rapid increase of net fracture pressure, so as to create branch fractures at different fracture positions, thus forming an interlaced “fracture network” system with the major fractures as the trunks. The key technology is the realization method of “fracture network”. By realizing the “fracture network” effect both in vicinity of the wellbore and in zones far from the well, the capacity of reservoir matrix supplying oil and gas to artificial fractures can be increased and thereby the fracturing reconstruction effect can be greatly enhanced.



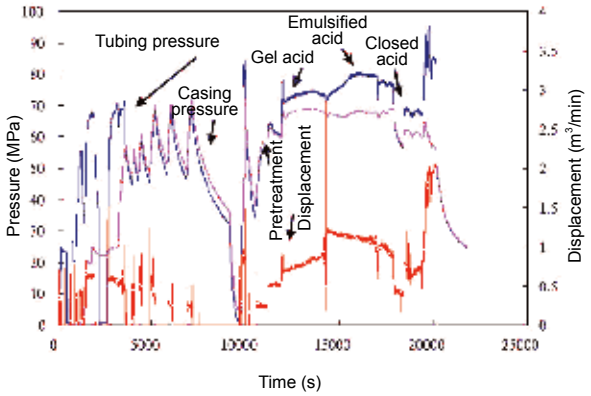
Schematic Diagram of Formation of “Fracture Network” System

2.2 Acid Fracturing Technologies

The acid fracturing operation of a reservoir can be conducted by employing liquid which can react with reservoir rocks chemically or by combining non-reactive fluid and reactive fluid; the acid is injected into formations at a pressure higher than the rock fracturing pressure to form fractures with high flow conductivity through non-uniform etching of substances on fracture wall surfaces by the acid. The main unique technologies include Acid Fracturing Technology for Reservoirs of Complex Lithology and Separate Layer Acid Fracturing Technology.

2.2.1 Acid Fracturing Technology for Reservoirs of Complex Lithology

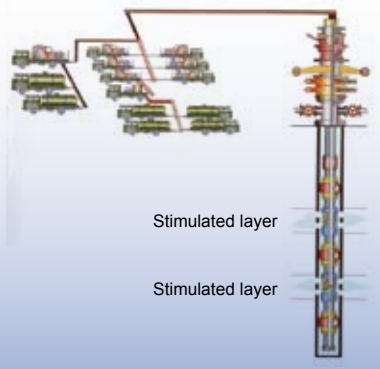
The technology is mainly used for reservoirs of complex lithology whose characteristics are that the proportions of clastic rock, carbonate rock and clay minerals are respectively one-third. In this technology, the prepad acid system is used to fracture the reservoir and form effective acid-etched fractures, and then the closed acidizing fluid system is used to etch the clastic rocks and clay minerals in the reservoir in vicinity of the well to enhance the flow conductivity in the region. It is applicable to acid fracturing reconstruction of reservoirs of complex lithology.



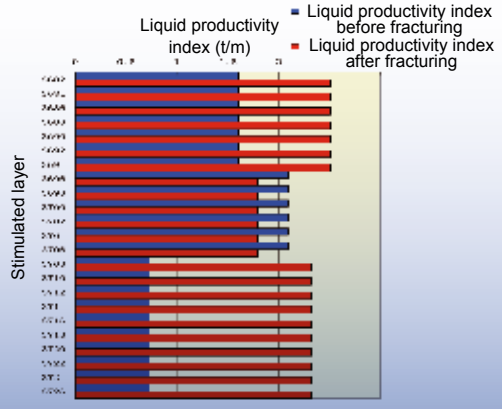
Acid Fracturing Operation Curve of Well Long 8

2.2.2 Separate Layer Acid Fracturing Technology

Separate Layer Acid Fracturing Technology can maximally enhance the tapping degree of reservoirs by employing the separate layer technologies by means of mechanical packer, ball off, tool + ball off and viscous deflected acidizing fluid, etc., thus realizing balanced stimulation of all reservoirs vertically and enhancing production of individual well. It is applicable to the reconstruction of carbonate rock reservoirs in which many small members distribute vertically.



Schematic Diagram of Separate Layer Acid Fracturing String with Packers



Comparison of the Produced Liquid Profiles Before and After Separate Layer Acid Fracturing of Well 2015

2.3 Fracturing and Acidizing Materials Technologies

The fracturing and acidizing materials refer to various fracturing fluids and acidizing fluid systems applied in fracturing and acidizing reconstruction, and mainly include carboxymethyl guar gum fracturing fluid system with extremely low concentration, emulsified fracturing fluid system, fracturing fluid system changing relative permeability, chemical temporary plugging gum slug system and surface cross linking acid system.

2.3.1 Carboxymethyl Guar Gum Fracturing Fluid with Extremely Low Concentration

The Carboxymethyl Guar Gum Fracturing Fluid with Low Concentration is a technical renovation to existing guar gum fracturing fluid. It breaks through the bottleneck of "cross linking technology at super low concentration" of carboxymethyl guar gum and solves the problems that conventional fracturing fluid leaves residual gum greatly damaging formations and is difficult to be used in deep wells with ultrahigh temperature. The carboxymethyl guar gum fracturing fluid systems resistant to 50~190℃ have been developed. Compared with conventional hydroxypropyl guar gum fracturing fluid, the utilization concentration of thickener is reduced by 20%~50%, the liquid friction is decreased by 30%~40% and the damage caused by remaining slag and residual gum is decreased by 25%~55%.

Hanging Performance of Carboxymethyl Guar Gum Fracturing Fluid

Sand Suspension Performance of Carboxymethyl Guar Gum Fracturing Fluid

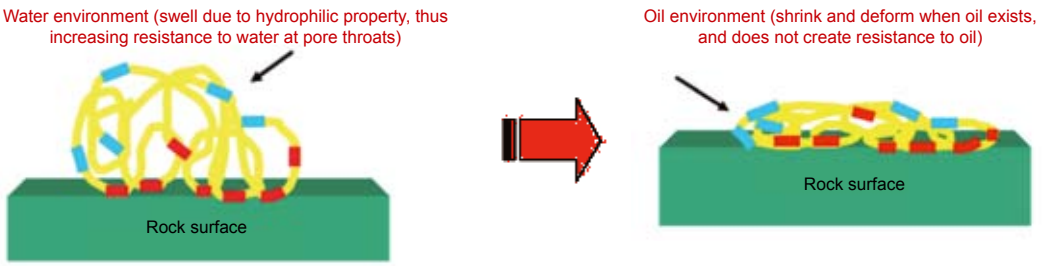
2.3.2 Emulsified Fracturing Fluid

The Emulsified Fracturing Fluid is stable emulsion formed by oil phase, water phase and surfactants absorbed or accumulating on the two-phase interface, and can be divided into oil-in-water emulsified fracturing fluid and water-in-oil emulsified fracturing fluid. Through the surfactants adhering to the oil-water interface, water and oil are closely combined in emulsified fracturing fluid to form stable emulsion, which is characterized by low filter loss, high liquid effect and small damage to formations.

Emulsified Fracturing Fluid

2.3.3 Fracturing Fluid of Changing Relative Permeability

The Fracturing Fluid of Changing Relative Permeability features cross links and polymerizes underground to from water soluble brush type polymer, in which the hydrophilic groups such as -CONH2 and -COO-, etc. are absorbed on pore structure surfaces of rocks through the actions of hydrogen bond, static electricity, van der Waals force and so on. Part of groups not being absorbed can extend in the water, thus increasing the flowing resistance of water and reducing the permeability of formation water. However, when oil or gas goes through the pore channels with water film, the polymer molecules are not oleophylic and cannot extend in oil, so this has little impact on the flow of oil. The fracturing fluid of changing relative permeability features has the property of changing the permeability of water phase selectively. It is injected into formations before fracturing, and after cross linking and polymerization are finished, normal fracturing can be conducted.



Action Mechanism of Fracturing Fluid of Changing Relative Permeability

2.3.4 Chemical Temporary Plugging Gum Slug

It refers to a chemical liquid system which can form gel with high strength through chemical cross linking and polymerization actions to plug oil wells temporarily. It can accurately plug and separate operation well intervals during fracturing reconstruction and substitute mechanical packers to complete separate layer fracturing operation, and is characterized by high compressing strength, controllable gel forming and gelout time, no remaining slag and low damage to formations after gelout, etc.

Chemical Temporary Plugging Gum Slug

2.3.5 Surface Cross Linking Acid

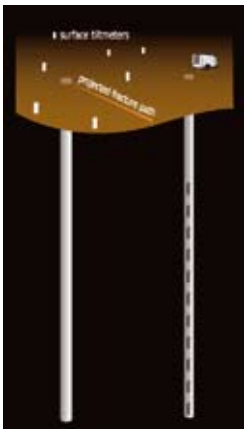
The Surface Cross Linking Acid, by cross linking with high molecular polymers, can form gel to enhance the viscosity of acidizing fluid, slow down the acid-rock reaction speed and reduce the filter loss of acidizing fluid, thus realizing the deep reconstruction of carbonate rock reservoirs. Combined application of Surface Cross Linking Acid Fracturing Technology and Sand Carrying Acid Fracturing Technology has become the most effective technology in the deep reconstruction of carbonate rock reservoirs.

Sand Carrying Performance of Surface Cross Linking Acid

2.4 Fracturing Diagnosis and Reconstruction Tools

2.4.1 Hydraulic Fracture Tiltmeter

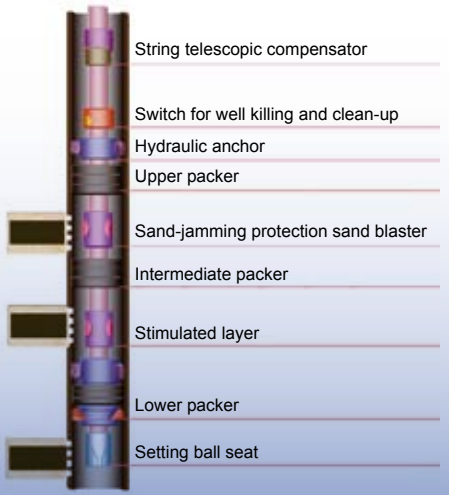
It is an effective fracture diagnosis tool to identify the azimuth, form and physical dimension of hydraulic fractures by measuring the deformation of rocks during fracturing. It is applicable to wells shallower than 4,000m.



Schematic Diagram of Downhole Tiltmeter

2.4.2 Sand-jamming Protection Separate Layer Fracturing String

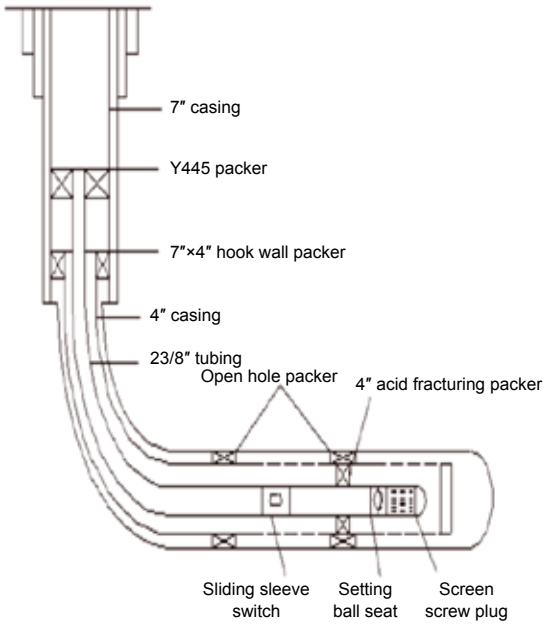
The fracturing string mainly comprises pipe string telescopic compensator, hydraulic anchor, switch for well killing and clean-up, sand-jamming protection sand blaster, sand-jamming protection tool, fracturing packer and setting ball seat, etc. It is applicable to vertical wells shallower than 5000m and inclined wells with borehole deviation less than 45 degree.



Schematic Diagram of Pipe String

2.4.3 Hydraulic Expanding Open Hole Packer

It includes two series with expanding rubber barrel as sealing element: K344 type without valve assemblage controlling setting and K341 type with valve assemblage controlling setting. They can be used for separate layer reconstruction operations of open holes and cased holes and completion operations of complex oil, gas and water wells to realize downhole isolation and bridge plugging for various purposes.



Pipe String Diagram of Segregated Completion and Segregated Reconstruction with Open Hole Packer

2.5 Experimental Technologies

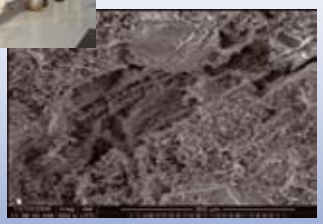
The Experimental Technology of Reservoir Reconstruction refers to the analyses and tests providing specific basic data for reservoir evaluation of fractured and acidized reservoirs, rock mechanics and fracture diagnosis, flow conductivity of proppant, evaluation of fracturing and acidizing fluid and evaluation of microscopic pore structure, etc.

The experiments include long-term flow conductivity experiment measured by liquid, long-term flow conductivity experiment measured by gas, flow conductivity experiment of acid-etched fracture, dynamic experiment of acid-rock reaction, viscous fingering simulation experiment, multifunctional pipeline rheology simulation experiment, rock mechanics experiment and microstructure evaluation experiment of cores.

Etching Form of Core Surface After Reaction of Gel Acid and Grainstone

Etching Form of Core Surface After Reaction of Cross Linking Acid and Grainstone

Multifunctional Pipeline Rheology Simulation Experiment Device



Scanning Electron Microscope Diagram of Rock Environment

3 TYPICAL CASES

3.1 Sand Fracturing

34 production wells were fractured in ZJ60 development test area in Jing'an Oilfield of Changqing, in which the operation success ratio was 97% and the effective success ratio was 100%; the production and injection effect was obviously improved after fracturing: the individual well production was averagely increased by 1.7 times and the degree of reserve recovery was increased by 7%.

The Staged Fracturing Technology for Horizontal Wells was conducted on nearly 400 wells in low permeability oil and gas reservoirs, in which the average stabilized production after fracturing is more than 3.3 times of that of vertical wells after fracturing.

The Refracturing Technology was applied on 133 wells in oilfields such as Jilin, Shengli, Erlian and Tuha, etc., in which the water cuts were stabilized and the stimulation ratios were generally above 2 after fracturing. Among them, the refracturing operations were conducted on 32 wells in Xinmin and Fuyu oilfields in Jilin Oilfield, in which the average individual well production increment, compared with pervious fracturing operations, increased by 24% and the average effective stimulation period increased from 142 days to 300 days, obtaining good stimulation effect.

The Fracturing Technology for Ultradeep Wells has been extensively applied in oilfields such as Tarim, Sichuan and Yumen, etc. At present, the maximum well depth by sand fracturing has broken through 6,740m.

Fracturing Operation Site of Changqing Oilfield Development

Fracturing Operation Site of Ultradeep Well in Tarim

Operation Site of Carboxymethyl Guar Gum Fracturing Fluid with Extremely Low Concentration

The Fracture Network Fracturing Technology was applied on 26 wells in oilfields such as Changqing, Daqing and Jilin, etc. and all of them succeeded with the average individual well production increased by 28%. It has become a new method to enhance overall stimulation volume in low permeability tight oil and gas reservoirs and has extensive application prospect.

3.2 Cases of Acid Fracturing

In field practice of Yumen Qingxi Oilfield during 2001~2004, the Acid Fracturing Technology for Reservoirs of Complex Lithology was conducted for 48 well times; the operation success ratio reached 100%, the effectiveness ratio was 75% with the effective operations of 36 wells, and the accumulated oil production increment was 25.49×10^4t. The operation of Well Long 8, a typical well, came into operation on May 18, 2002. Its production before fracturing was 60t/d, that after fracturing reached 154t/d, and the present production is 35t/d; the effective period was over 7 years, cumulatively 2,815 days.

The Separate Layer Acid Fracturing Technology was applied on 285 wells in Zanarol Oilfield and Kenneyak Oilfield in Kazakhstan. The average daily oil production increment of individual well was 22.6t/d, the average effective period was 629 days and the accumulative crude oil increment reached 202×10^4t; the maximum accumulative oil production increment of individual well was 4.07×10^4t and the longest effective period of increment reached 1,671 days.

Operation Site of Separate Layer Acid Fracturing in Kazakhstan

3.3 Fracturing Fluid

The carboxymethyl guar gum fracturing fluid with extremely low concentration has been successfully applied for 39 well times in several oilfields such as Changqing, Jilin, Jidong, Haita, Huabei, Qinghai and Tarim, among which the Well Changshen 5 in Jilin Oilfield, with temperature of 183 ℃ , well depth of 5224m, the operation pressure up to 83~88MPa and the quantity of added proppants of $55m^3$, generated a daily gas production

of 30,000 m^3 after fracturing. In the large-scale fracturing of high temperature deep volcanic reservoir in Well Chang 37 in Jilin Oilfield, 154m^3 of proppants were added successively. In the large scale fracturing of high temperature deep volcanic reservoir in Well Nanpu 5-98 in Jidong Oilfield, the maximum continuous operation time was 4 hours and the maximum liquid volume was 1,200m^3.

The Emulsified Fracturing Fluid System has been successfully applied on 152 wells in strong water sensitive reservoirs in Qinghai Oilfield, Jilin Oilfield and Tuha Oilfield, etc. and obtained good effect. By employing the emulsified fracturing fluid, the fracturing operation success ratio in Wunan-lvcaotan, Qigequan and Hongliuquan oilfields in Qinghai Oilfield was increased from previously below 50% to over 87% and the 5,500×10^4t grade reserves in Wunan slope area was ascertained; for Exploratory Well Yi 59 in Jilin Oilfield, the daily oil production after fracturing was 182.1m^3 and the predicted oil reserves of 1.2631×10^8t was ascertained; in Santanghu Oilfield in Tuha Oilfield, the final flowback ratio of emulsified fracturing fluid was above 70%, increased by 40% compared with that of water base fracturing fluid.

In 2007, the cross linking acid sand fracturing was applied in the interval of 5,529~5,550m of Well Tazhong 724, in which 36.2m^3 of proppants were added. It was the first successful cross linking acid proppant adding operation applied in a well deeper than 5,000m and a formation with temperature higher than 143℃ . At present, the combined application of surface cross linking acid fracturing and sand carrying acid fracturing has been completed for nearly 100 well times in the oilfields, and has become the most effective technology for the deep reconstruction of carbonate rock reservoirs.

Operation Site of Staged Acid Fracturing Technology for Horizontal Wells (Surface Cross Linking Acid)

4 R&D EQUIPMENT

CNPC has a key reservoir reconstruction laboratory authorized by the national laboratory and having obtained metering certification according to ISO/IEC17025:2005 “General Requirements for the Competence of Testing and Calibration Laboratories”. The laboratory, with a building area of 6,000m^2, has 200 pieces (sets) of experimental equipment and 50 pieces (sets) of large-scale experimental equipment software. It can carry out evaluation and detection of 15 items and 102 parameters authorized by national laboratory in three major categories including fluid, proppant and rock. Focusing on low permeability reservoirs both at home and abroad, the key reservoir reconstruction laboratory mainly carries out original experimental studies on technical innovation in fracturing and acidizing field and develops new processes, materials and technologies of fracturing and acidization to provide powerful technical supporting for economic and effective development of low permeability reservoirs from the viewpoint of enhancing reserves grade and productivity level based on extremely low permeability sandstone reservoirs, low permeability carbonate rock reservoirs and the reservoirs with special lithology such as volcanic rock and glutenite, etc.

Three-axis Rock Mechanics Experiment Device

Flow Conductivity Experiment Device of Proppant

Large-scale Multifunctional Loop Experiment Device

Rotating Disc Acid-rock Reaction Experiment Device

Large-scale Physical Model of Transparent Pipeline for Flow Regime Simulation Study for Horizontal Well

Large-scale Physical Model of Transparent Parallel Plates for Viscous Fingering Study

5 QUALIFICATION AND STANDARD

Enterprise Qualification

After passing the ISO Quality System Certification in 1997, the laboratory improves continuously and obtained ISO9001:2000 Quality Management System Certification. In addition, it possesses Grade A national qualifications in fracturing fluid grade evaluation and technical service of fracturing reconstruction project, etc., and obtained National AAA Credit Certificate. In 2000, the laboratory passed the national laboratory authorization and metering certification according to ISO/IEC17025:2005 “General Requirements for the Competence of Testing and Calibration Laboratories”.

Technical Standard

The lab personnel presided over the formulation of 35 national and industrial standards relating to reservoir reconstruction field and are constantly perfecting their services according to the API international industrial standards. The laboratory’s technologies and product units are completely in line with those in the industry.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6 EXPERT TEAM

Lei Qun Professor-level senior engineer and senior technical expert. He has won one national achievement prize, 16 provincial/ ministerial achievement prizes and 26 departmental prizes. 7 monographs co-authored by him and 60 papers have been published.

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Ding Yunhong Professor-level senior engineer and senior technical expert. He has won one national achievement prize, 6 provincial/ ministerial-level achievement prizes and 25 departmental prizes. 3 monographs co-authored by him and 35 papers have been published.

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Xu Yun Senior engineer. He has long been occupied in application basis theory, technology, software model, acid-rock reaction mechanism, field application and management work mainly in fracturing and acidizing technologies. He has taken charge of and participated in 79 scientific research projects and won one national achievement prize, 17 provincial/ ministerial-level achievement prizes and 28 departmental prizes. 4 monographs co-authored by him and 50 papers have been published.

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Wang Zhenduo Senior engineer. He has long been occupied in technical research works of fracturing and acidizing technologies for reservoir reconstruction. He has taken charge of and participated in more than 30 key subjects such as fracturing and acidizing reconstruction of deep and ultradeep wells, overall oilfield fracturing reconstruction, deep acid fracturing reconstruction of carbonate rock reservoirs and fracturing reconstruction of horizontal wells, etc. He has won 10 provincial/ ministerial-level achievement prizes and 10 departmental prizes. 14 of his papers have been published.

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Cui Mingyue Senior engineer. He has long been occupied in study works such as research and development, experimental evaluation and standardization of fracturing and acidizing materials, research of fracturing and acidizing technologies and relevant application technologies, etc. He has won 3 provincial/ ministerial-level achievement prizes and 14 departmental prizes, applied for 3 patents and drafted 6 industrial standards. 1 monograph co-authored by him and 35 papers have been published.

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Wang Yonghui Senior engineer. He has long been occupied in study works of application basis and technologies such as fracturing and acidizing techniques, simulation of hydraulic fracture and reservoir simulation, etc. He has taken charge of and participated in 45 research subjects and won 3 provincial/ ministerial-level achievement prizes and 19 departmental prizes. 3 monographs co-authored by him and 39 papers have been published. Phone: 010-69213019

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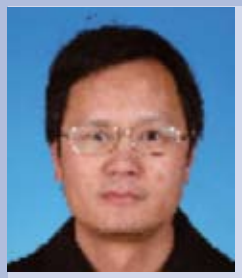

Guan Baoshan Senior engineer. He has long been occupied in works such as application basis theory study mainly in fracturing and acidizing technologies, development and field application of novel fracturing fluid system and relevant additives, etc. He has taken charge of and participated in more than 30 research subjects, won one provincial/ ministerial-level achievement prize and 32 departmental prizes, and been granted with 2 patents. Over 40 of his papers have been published.

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