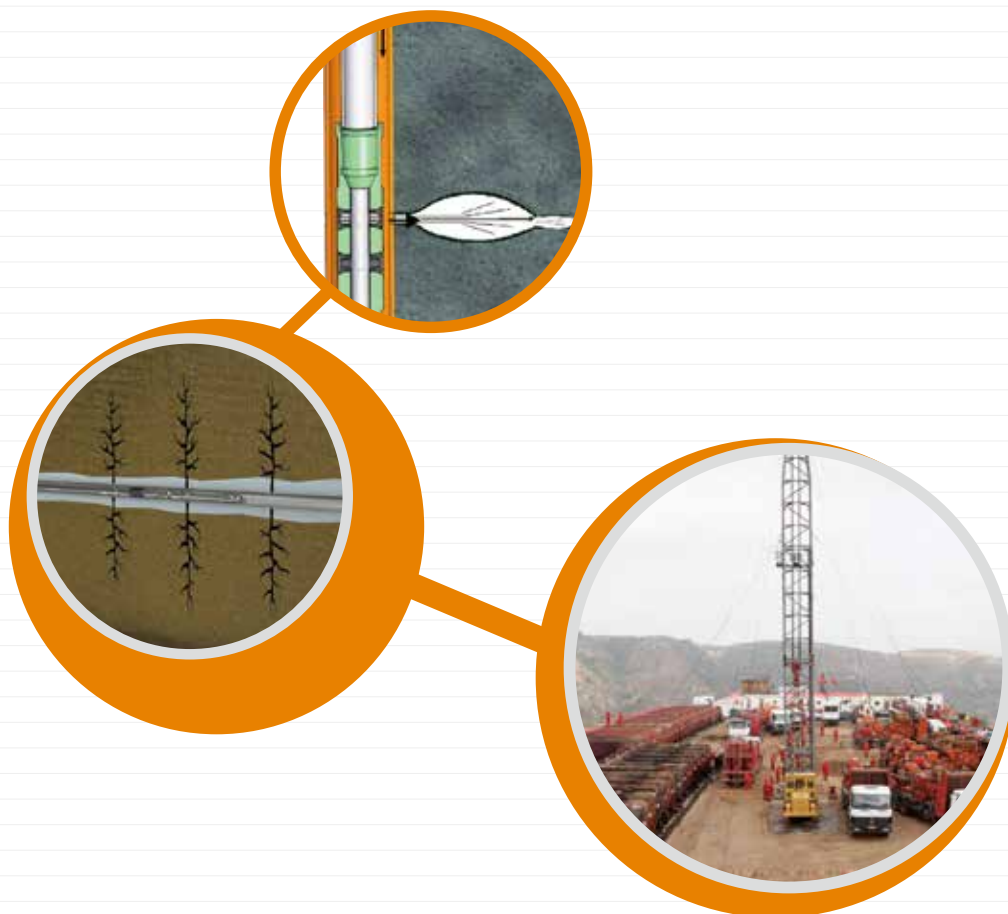




Hydrojet Fracturing Technology

Science & Technology Management Department, CNPC

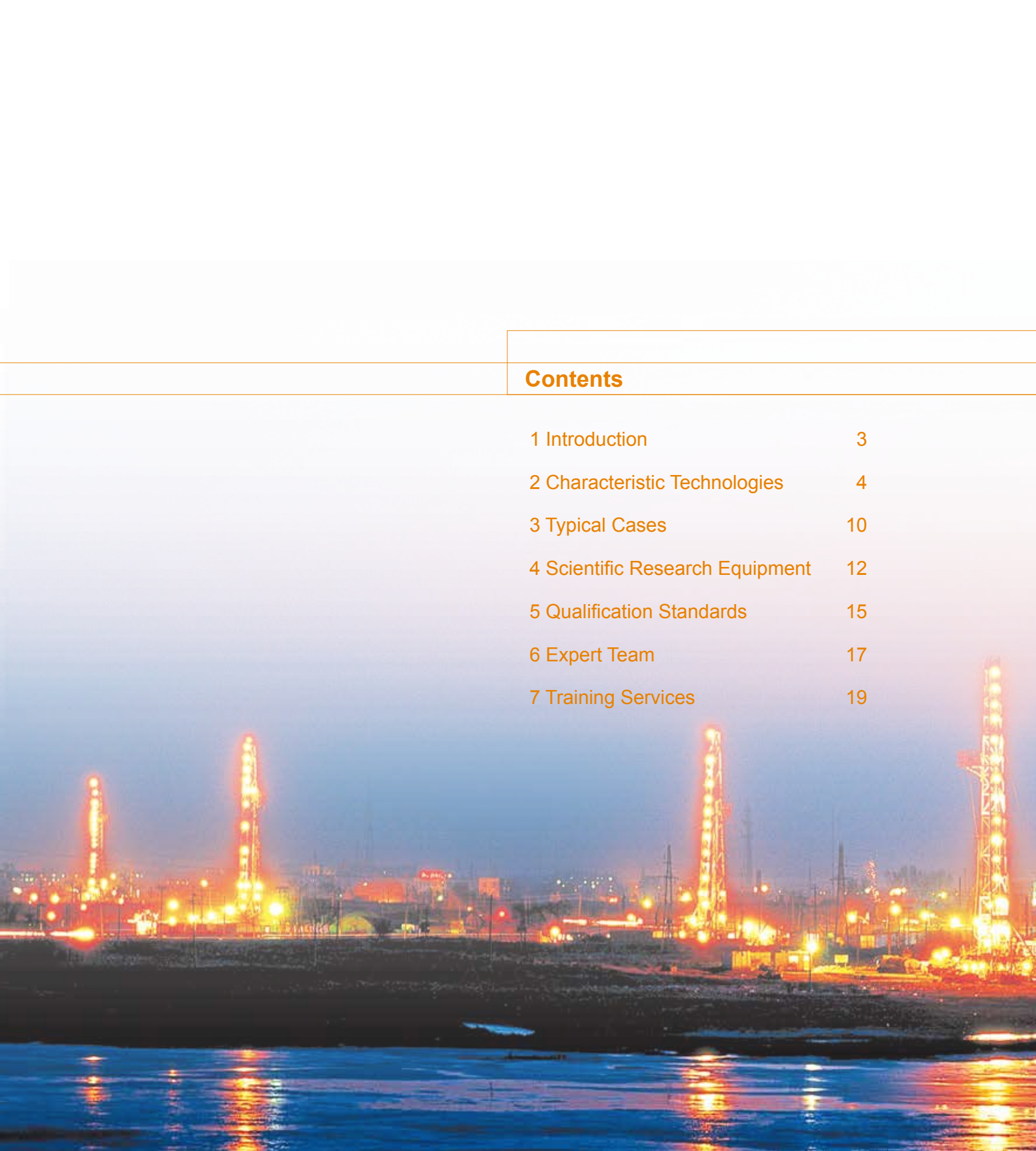
2015



CHINA NATIONAL PETROLEUM CORPORATION

*Hydrojet Fracturing Technology:
“Golden Key” to Opening up Low
Permeability Oil and Gas Fields!*





Contents

1 Introduction	3
2 Characteristic Technologies	4
3 Typical Cases	10
4 Scientific Research Equipment	12
5 Qualification Standards	15
6 Expert Team	17
7 Training Services	19



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 reorganized 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 2014 CNPC produced 113.67 million tons of crude oil and 95.46 billion cubic meters of natural gas, while crude processing volume reached 150.2 million tons. The total revenue of RMB 2,730 billion with a profit of RMB173.4 billion had been achieved the same year.

CNPC was ranked 3th among the world's largest 50 oil companies and 4th in Fortune Global 500 in 2014.

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 hydrojet fracturing technology is one of representatives for major innovations of CNPC.

OFFERING ENERGY SOURCES, CREATING HARMONY

1

INTRODUCTION

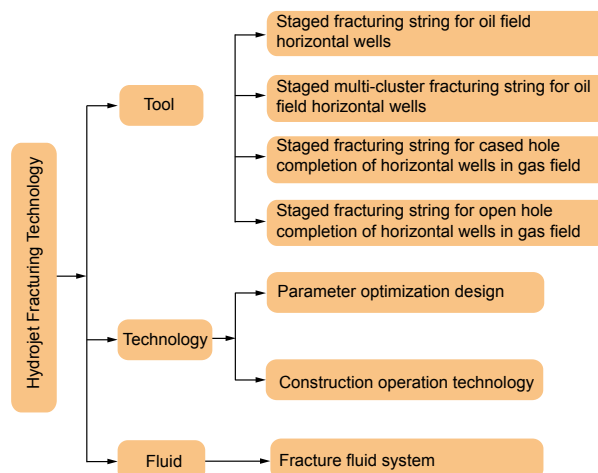
The hydrojet fracturing technology is a horizontal well staged fracturing technology integrating perforation, isolation and fracturing. The basic principle of the hydrojet fracturing technology is formations are fractured to form fractures depending upon the boosting effect generated by hydrojet; carrying in oil tube fluid is pumped and jetted via nozzles into fractures, and fluid is pumped into annulus for pressure compensation, thus completing reservoir stimulation.

Compared with the traditional fracturing technologies such as limited entry fracturing, sand filling rubber plug staged fracturing, etc. The hydrojet fracturing technology can be used in multiple completion modes such as open hole completion, cased hole completion, etc., and is characterized by low operation risk, high efficiency, low cost, etc. With the help of hydrojet fracturing technology, multi-stage fracturing can be completed within one round trip, thus shortening

operation period and reducing reservoir damage. The technology was awarded with 10 national authorization patents and the technological string was awarded with the 19th session of the national invention exhibition bronze prize. The technology is also the significant self-innovative product of CNPC. The technology has been applied in totally 1172 wells and 9032 sections in Changqing oil field. With the help of Technology, 8 sections of a horizontal well can be constructed within one round trip, and the increased production of a single horizontal well is over 3 times that of a single vertical well. 10 sections are fractured at a time in $4\frac{1}{2}$ " casing of a horizontal well, 23 sections are fractured at a time in open hole in the gas field, the cost of the tool is 1/5 that of the gas field tool, and the increased production of a single horizontal well is 5 ~ 8 times that of a single vertical well. The technology reaches to international leading level on the whole.



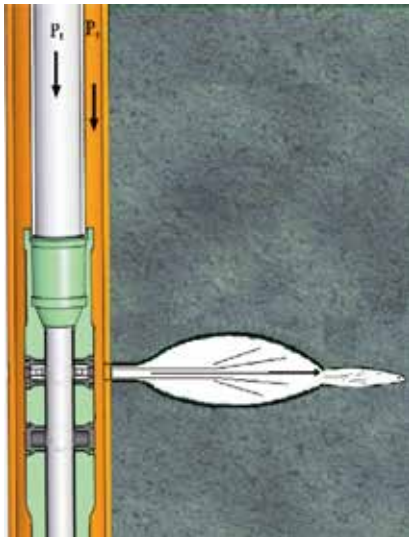
The hydrojet fracturing technology of CNPC is widely used in China



The hydrojet fracturing technology frame diagram

2

CHARACTERISTIC TECHNOLOGIES



The hydrojet fracturing technology schematic



hydrojet fracturing site operation

2.1 Fracturing string for horizontal well in oil field

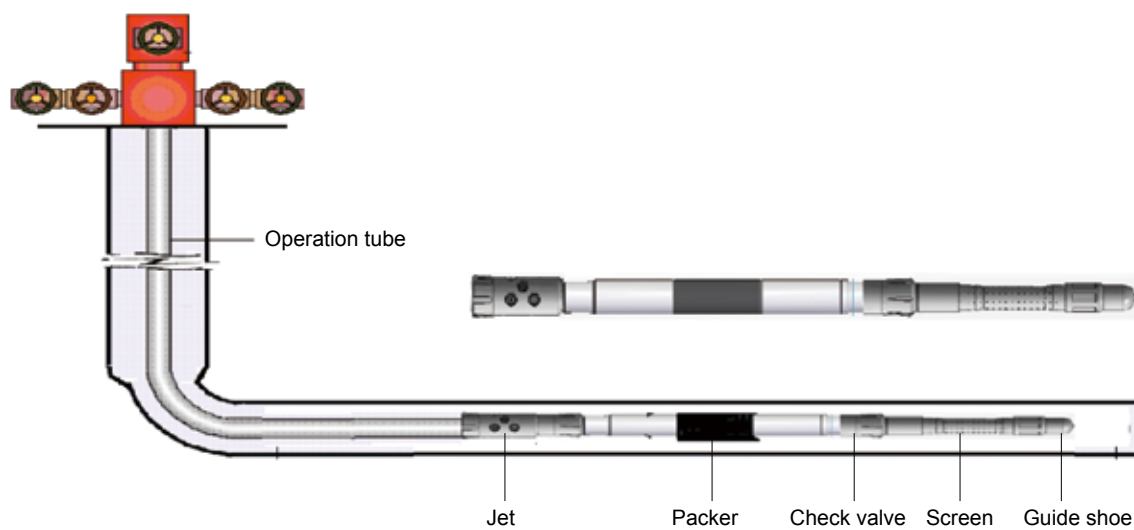
Hydrojet staged fracturing and staged multi-cluster fracturing string series for horizontal well in oil field mainly consist of jet, packer, check valve, screen, etc.

Characteristics and advantages of the technology

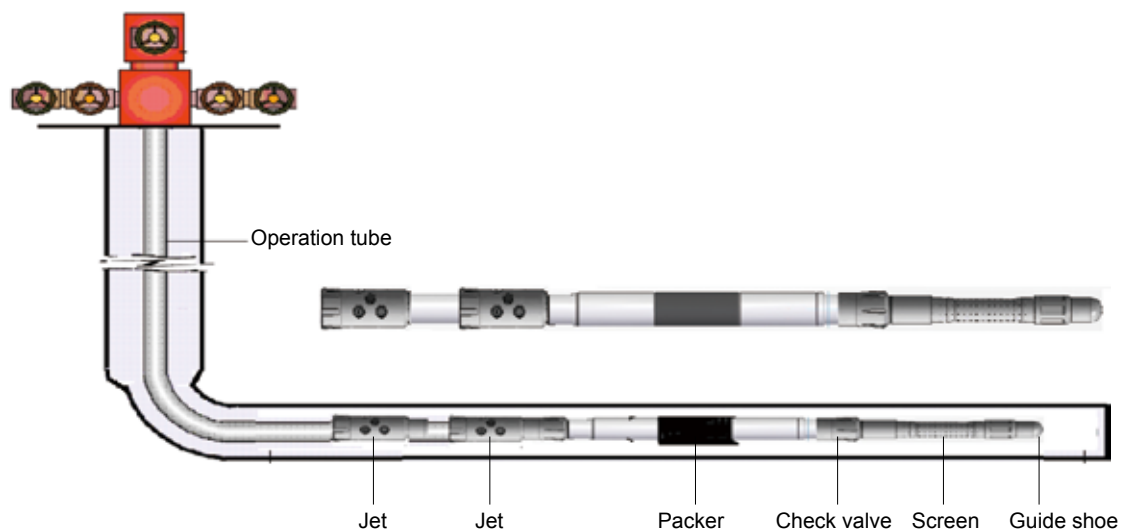
(1)The staged hydrojet fracturing string for horizontal well in oil field is applicable to 5.5in casing cementing completion and resistant to 70MPa pressure

and 120°C temperature. At most 8 sections can be constructed within one round trip. Using the dragging method, unlimited stage fracturing can be realized;

(2)The staged multi-cluster hydrojet fracturing string for horizontal well in oil field is applicable to 5.5in casing cementing completion and resistant to 70MPa pressure and 120°C temperature. 2 sections and 4 clusters of fracturing stimulation can be completed within one round trip. With the string, three-dimensional fracturing stimulation of reservoirs can be realized.



Schematic of the staged hydrojet fracturing string for horizontal well in oil field

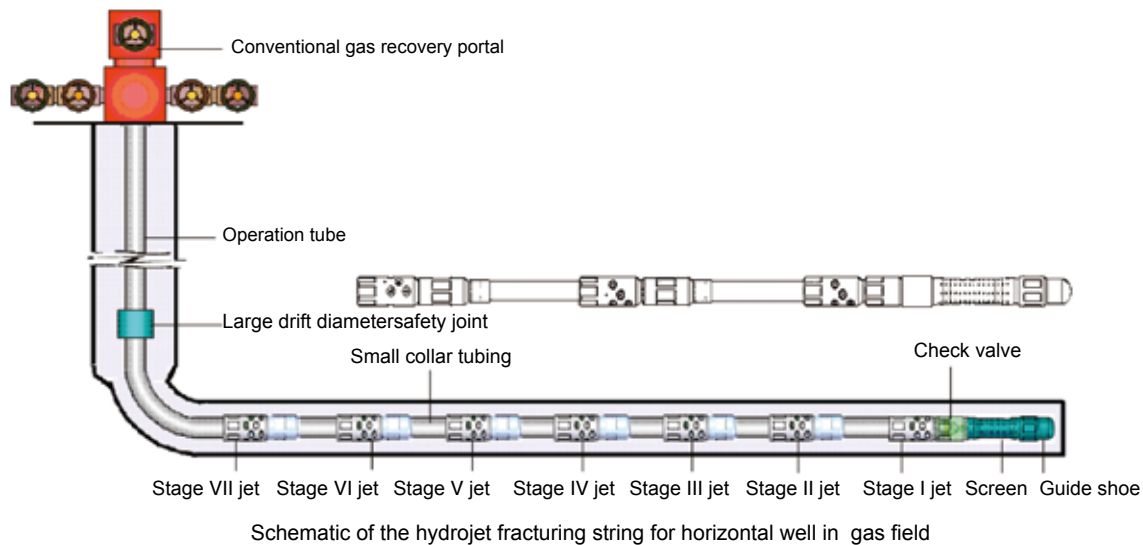


Schematic of the staged multi-cluster hydrojet fracturing string for horizontal well in oil field

2.2 Fracturing string for horizontal well in gas field

The hydrojet fracturing string without pulling string for horizontal well in gas field consists of mainly sliding sleeve jet, sliding sleeve working barrel, etc. Multi-stage fracturing stimulation can be completed successively by throwing balls without pulling string.

The hydrojet fracturing string without pulling string for horizontal well in gas field is applicable to two completion modes such as 4.5in casing completion and 6in open hole completion and resistant to 70MPa and 120°C temperature. 10 sections can be fractured at a time in 4.5min casing, and 23 sections can be fractured at a time in 6in open hole.



2.3 Core tools and their performance

1) Jet



Working temperature: 150°C;
Working pressure: 70MPa;
Body and nozzle lock nut material: 42CrMo;
Nozzle material: Carbide alloy YJF03X or ROCTEC500;
Nozzle hardness: HRA93.

2) Small diameter packer



Max diameter: 108mm;

Pressure resistance: $\leq 70\text{MPa}$;
Temperature resistance: $\leq 120^\circ\text{C}$;
Tensile strength: no less than 65t;
Repeated setting capacity: Over 10 times

3) Safe release device



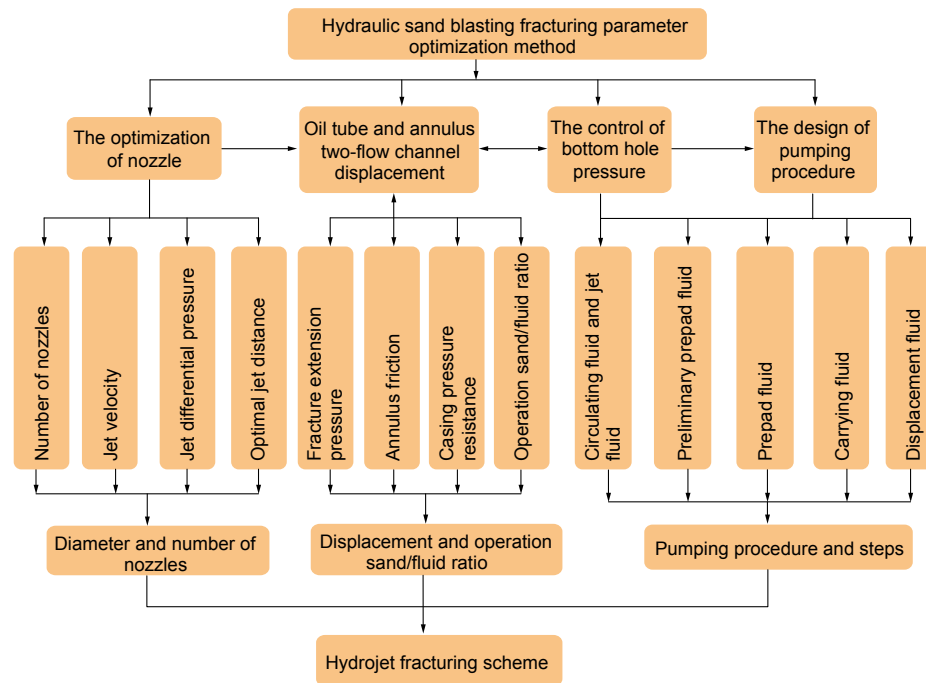
Material: 35CrMo;
Pressure resistance: $\leq 70\text{MPa}$;
Tensile strength: no less than 65t;
Ball throwing starting pressure: 15~20 MPa;
Releasing tensile force: 4~8t

2.4 Parameter optimization design

1) Design process optimization

Design process optimization mainly includes: the optimization of nozzle number, the optimization of

tubing and annulus two-flow channel displacement, the control of fracture extension pressure, the design of pumping procedure, etc.



2) Jet parameter optimization

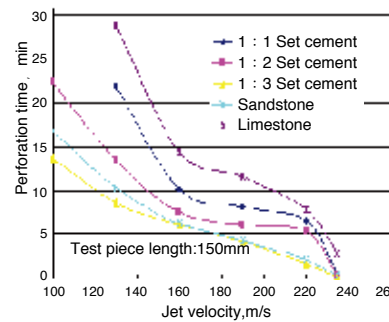
The jet parameters such as critical jet velocity, jet boosting, jet medium, etc. are optimized, thus providing theoretical bases for initiation, extension and automatic isolation of hydrojet fractures.

Critical jet velocity: at the jet velocity of 130~200m/s can achieve the purpose of perforation and rock

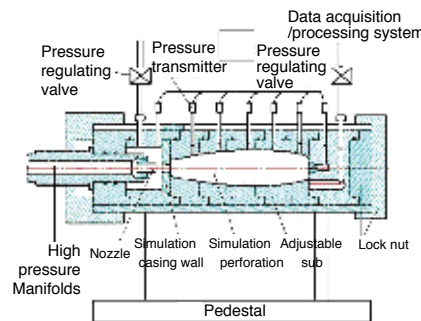
breaking via hydrojet. As displacement increases, perforation depth is increased obviously.

Jet boosting: pressure can be increased by 6~10MPa through jet at the jet velocity of 160~220m/s.

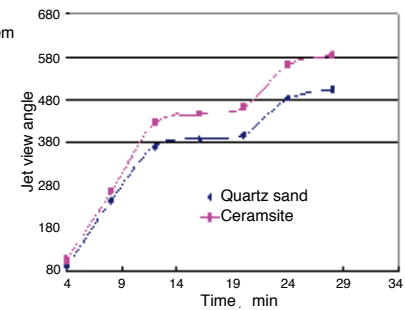
Jet medium: quartz sand is used in oilfield jet operation, and ceramicsite in gas field jet operation.



Result of experiment on perforating a constant length test piece at different flow velocities



Test bench for hydrojet perforation and pressure distribution in perforations



Impact of hydrojet abrasive type on jet depth

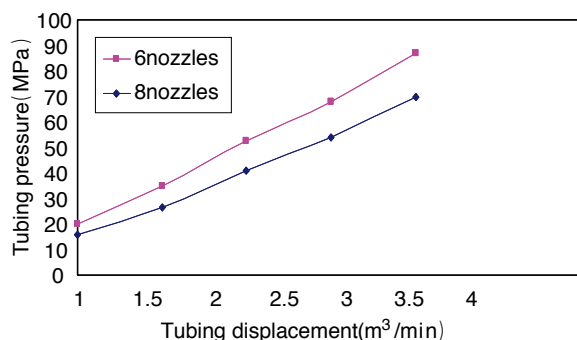
3) Operation parameter optimization

Ensure safe and reliable hydrojet fracturing string operation by optimizing tubing displacement, fracture extension pressure control and annulus displacement.

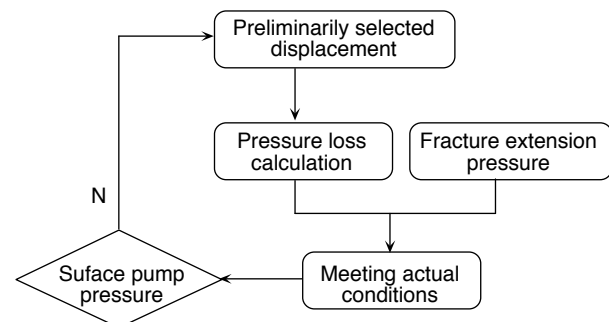
Tubing displacement: with the wellhead pressure limited to be 60MPa, using 6 nozzles then the tubing displacement is 2.2m³/min; Using 8 nozzles then the

tubing displacement is 2.7m³/min.

Fracture extension pressure control and annulus displacement: determine the needed bottom hole pressure and calculate the pumped annulus displacement according to formation fracture extension pressure.



Relation curve of tubing pressure vs. operation displacement



Annular parameter optimization process

2.5 Construction operation technology

Hydrojet fracturing operation technology series have been formed based on oil and gas field reservoir features and the difference in completion mode and technological string and in comprehensive consideration of the special needs and risks of well control and operation technology.

1) Hydrojet fracturing technology in oil field

Run the hydrojet fracturing tool string through tubing; align the jet with the first stimulation section and complete hydraulic sand blasting perforation and fracturing of the first section; then drag the string to the second stimulation section and carry out hydraulic sand blasting perforation and fracturing of the first section. In a similar fashion, complete the stimulation of the residual sections by dragging the string; finally carry out suction and production calculation.

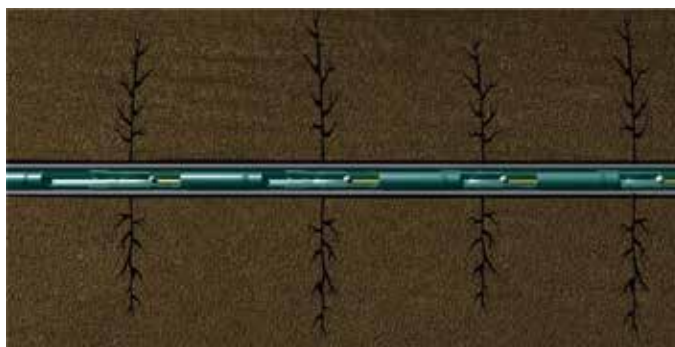


Schematic of hydrojet fracturing technology process in oil field

2) Hydrojet fracturing technology in gas field

Run the hydrojet fracturing tool string at a time through tubing; align each jet with the corresponding stimulation section. Firstly complete hydraulic sand blasting perforation and fracturing of the first section. Open the sliding sleeve of stage II jet by throwing a

ball while blocking the lower channel and carry out hydraulic sand blasting perforation and fracturing of the second section. In a similar fashion, complete the stimulation of the residual sections without pulling string. Finally carry out combined layer drainage and production calculation.



Schematic of hydrojet fracturing technology process in gas field

3

TYPICAL CASES

3.1 Industrial scale application of the hydrojet fracturing technology in Changqing oil field

The hydrojet fracturing technology has been applied in totally 1172 wells and 9032 sections in Changqing oil field. 8 sections of a horizontal well can be constructed within a round trip, and the increased production of a single horizontal well is 5~8 times that of a single vertical well in the oil field. The technology promotes significant transformation of Changqing low permeability reservoir development mode and became the main technological means for horizontal well stimulation in oil and gas field.

Well A is a tight reservoir horizontal well in Changqing oil field, with the horizontal section length of 1535.13m, the TD of 3725m and the TD horizon of ##. 20 sections and 40 clusters of fracturing operations in the well were completed by using the multi-stage multi-cluster hydrojet fracturing string in the oil field. The cumulative sand addition quantity was 1058m^3 , the cumulative fluid quantity into formation 16046.7m^3 and the daily pure oil production during production test 184.05m^3 , thereby creating 3 new records including the number of fracturing sections in a tight reservoir horizontal well, single-well sand addition quantity and fluid quantity into formation in China.



Hydrojet fracturing operation site of well A (oil field)

Well B is a horizontal well in Sulige gas field, with the horizontal section length of 1500m and the TD of 5032m. The hydrojet fracturing string without pulling string for gas field horizontal well was used in the well. 15 sections were continuously fractured separately in

6in open hole within one round trip for the first time. A new record of the technology has been created. The tested AOF reached $128 \times 10^4 \text{m}^3/\text{d}$, which is 7.8 times that of a vertical well in the same block.



Hydrojet fracturing operation site of well B (gas field)

3.2 Successful pilot test with the hydrojet fracturing technology in Jilin oil field

Pilot test of 2 wells was conducted in Jilin oil field in order to evaluate the adaptability of the hydrojet fracturing technology. At most 9 sections were designed in a single well; the annular sand addition fracturing mode was used; fracturing of each section was completed within one round trip; the maximum dragging times within one round trip were 8 times,

and the working time reached 900min. Successful application of the technology has provided new means for staged fracturing technology for horizontal wells in Jilin oil field. Compared with open hole packer staged fracturing technology and in-casing packer staged fracturing technology used previously in the oil field, the hydrojet fracturing technology is characterized by operation reliability, fracturing without throwing a ball, low cost, maintaining full drift diameter of well bore after fracturing without fishing or drilling and milling, etc., and it has a very good application prospect.



Hydrojet fracturing operation site of well XX (Jilin oil field)

4

SCIENTIFIC RESEARCH EQUIPMENT

4.1 National engineering laboratory for low permeability oil and gas field exploration and development

The national engineering laboratory for low permeability oil and gas field exploration and development is the only international level laboratory for low permeability oil and gas fields in China. At present, the laboratory has 187 fixed personnel, including 8 experts of CNPC, 29 doctors and 22 professor level senior engineers. The building area of the laboratory is 15000m². The laboratory is fitted with over 120 pieces (sets) of various major instruments and equipment which take lead at home and abroad. The total investment in the laboratory is 46.5463 million yuan. The experiment equipment capacity of the laboratory reaches to the domestic leading level.



Main building of the national engineering laboratory for low permeability oil and gas field exploration and development

4.2 Symbolic experiment equipment

1) MTS-815 three-axis rock mechanics testing system



Physicals picture of MTS-815 three-axis rock mechanics testing system

MTS-815 three-axis rock mechanics testing system can test the rock mechanics parameters such as Young's modulus, Poisson's ratio, tensile strength, coefficient of compressibility, fracture toughness, etc. as well as earth stress by simulating formation temperature conditions, thus providing accurate input parameters for recognizing the fracture characteristics of formation rocks and designing hydrojet sand blasting fracturing.

2) Downhole tool experiment and testing system



Layout of downhole tool experiment and testing system



Remote control terminal of the system

The downhole tool experiment and testing system is used mainly in performance detection and testing of packers and other downhole matching tools for oil wells and injection wells (involving setting and

unsetting load, pressure resistance and temperature resistance, shear pressure, sealing property, backwashing channel opening property, throwing and fishing property, etc.) and provides an experiment platform for R&D and evaluation of downhole matching tools for multi-layer fracturing in vertical wells and multi-section fracturing in horizontal wells.

3) Downhole tool experiment equipment for horizontal wells



Physical picture of downhole tool experiment equipment for horizontal wells

The downhole tool experiment equipment for horizontal wells can test the mechanical property and sealing property of matching tools for the hydrojet fracturing string, perform a high pressure and large displacement fluid circulation test of them, and provide a high pressure horizontal section simulation test well bore with multiple flow channels. The downhole tool experiment equipment has visual well bore function and can observe tool action visually.

4) Hydrojet fracture starting simulation experiment equipment



Hydrojet fracture starting simulation experiment site picture

The hydrojet fracture starting simulation experiment equipment can evaluate the performance of the hydrojet fracturing string, investigate the impact of the factors such as displacement, jet time, etc. On key tools, detect hole shape, hole depth and fracture

shape after fracture starting, deepen fracture shape recognition, and improve the pertinence of hydrojet fracturing string optimization design, thus providing bases for hydrojet fracturing mechanism research and field operation.

5 QUALIFICATION STANDARDS



The hydrojet fracturing technology is provided with 1 enterprise standard of CNPC and 2 enterprise standards of oil field companies and was awarded with 10 authorized national patents. The technology was awarded with the 19th session of the national invention exhibition bronze prize and is the significant self-innovative product of CNPC.

Standards:

- Q/SY 1460-2012 Specification for staged fracturing technology for horizontal wells
- Q/SY CQ3449-2012 Operating specification for hydrojet fracturing technology in oil field
- Q/SY CQ3447-2012 Operating specification for staged hydraulic sand blasting fracturing technology without pulling string for horizontal wells in gas field

Patents:

- 200810105642.2 Staged perforation and fracturing technology and self-gel breaking liquid rubber plug for horizontal well
- ZL200620113021.5 A new hydraulic jet
- ZL200720173194.0 An integrated string for separate layer hydrojet perforation and fracturing without pulling string
- ZL200920108820.7 Multi-stage dragging fracturing string for horizontal well
- ZL201020275485.2 An integrated string for separate layer hydrojet and separate layer fracturing without pulling string
- ZL201020520348.0 Staged hydraulic sand blasting fracturing string without pulling string in open hole completion

ZL201020569352.6 An integrated string for hydrojet perforation, fracturing, gas lifting and drainage
ZL201220605206.4 Staged fracturing stimulation string for open hole horizontal well

ZL201120169285.3 Staged multi-cluster hydrojet fracturing string for horizontal well
ZL201120264146.9 Staged fracturing downhole string with unlimited stage number for open hole horizontal well



6

EXPERT TEAM



**Shen
Zhonghou**

Academician of Division of Energy and Mining, Chinese Engineering Academy, member of the Advisory Committee of American journal High Water Jet, Vice-chairman of Water Jet Professional Committee of Chinese Society of Labor Protection, Editorial Board Member of the journals such as Journal of Hydrodynamics and Oil Drilling & Production Technology. He is mainly engaged in the study of high pressure water jet theory and technology. He has successively obtained 1 grade II national science and technology advance prize, 1 grade III national invention prize, 2 grade I provincial and ministerial science and technology advance prizes and 3 grade II provincial and ministerial science and technology advance prizes. He has obtained 13 domestic and foreign patents. Over 70 papers, 1 English monograph and 2 Chinese monographs written by him have been published in Chinese and foreign journals.

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**Li
Gensheng**

Professor, Ph.D. candidate supervisor, chief scientist of “973” project, winner of the “National Science Foundation for Distinguished Young Scholars of China”, candidate of layers I and II talents of “National Millions of Talent Project”, expert enjoying the “government special allowance from the State Council”, winner of “Sun Yueqi Energy Grand Prix”. He is engaged mainly in the study of high pressure water jet theory and application in petroleum engineering. He has obtained over 20 national invention patents. Over 200 papers written by him have been published.

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Mu Lijun

Liu Shoujun: senior engineer, senior technical expert. He is mainly engaged in the study of stimulation technologies such as low permeability gas reservoir fracturing and acidification, etc., research on major technologies for ultra-low permeability reservoirs, etc. He has successively organized and participated in 6 national and CNPC's (PetroChina's) major projects and over 20 projects of oilfield companies. He has obtained 32 national patents. Over 30 papers written by him have been published in core journals.

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**Zhao
Zhenfeng**

Professor level senior engineer, senior technical expert. He is mainly engaged in the study of reservoir stimulation, stimulation technology, etc. for oil and gas fields. He has studied and formed the ultra-low permeability fracturing technology mode including the main contents “pre-fracturing diagnosis, optimization design, medium-conductivity long fractures, low damage frac fluid, control of open flowing and forced fracture closure after fracturing, etc.”. He has obtained 32 patents. 1 monograph and over 20 papers written by him have been published.

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**Li
Xianwen**

Professor level senior engineer, technical expert. He is mainly engaged in the study and test of stimulation technologies mainly involving fracturing and acidification. He has firstly carried out a study and scale application of new technologies involving hydrojet fracturing, multi-stage injection acid fracturing, CO₂ fracturing, carbonate rock hydraulic sand fracturing, multi-stage sand fracturing, multi-fracture fracturing, etc. He has obtained 34 patents. 1 monograph co-authored by him and other persons and over 30 papers written by him have been published.

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**Fu
Gangdan**

Senior engineer, technical expert. He is mainly engaged in the study of fracturing technology, oil production technology, gas production technology and matching tools and technologies. He has organized the R&D of multiple oil and gas well stimulation series technologies and tools such as separate fracturing and combined production technology and string for gas well, hydraulic sand blasting fracturing technology and string, staged fracturing technology and string with open hole packer, etc. He has obtained 43 national patents. Over 20 papers written by him have been published.

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Gui Jie

Senior engineer, technical expert. He is mainly engaged in the study of reservoir stimulation tools and oil (gas) production downhole operation technologies and tools for oil and gas field. He has taken charge of organizing and completing the R&D of multi-layer and multi-stage stimulation tools involving separate fracturing and combined production of gas wells, hydraulic sand blasting fracturing, staged fracturing with open hole packer, etc. He has obtained 37 national patents. 18 papers written by him have been published.

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**Zhang
Kuangsheng**

Technical expert. He is mainly engaged in the study of reservoir stimulation, stimulation technology and production technology for oil and gas fields. He has obtained multiple achievements in separate layer fracturing of tight oil and gas vertical wells, staged fracturing of horizontal wells and low cost and low damage frac fluid. He has obtained 3 grade provincial and ministerial science and technology advance prizes and 5 science and technology advance prizes of oilfield companies. 8 papers written by him have been published.

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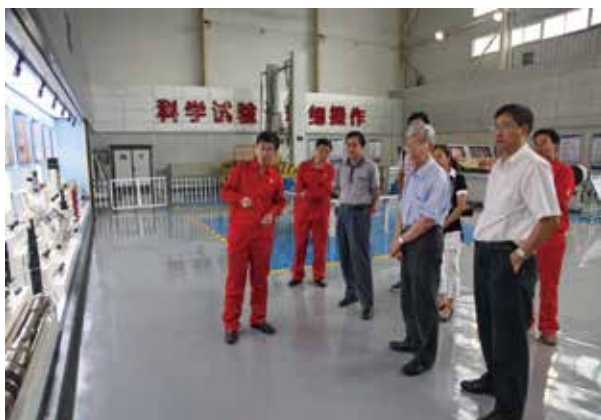
Email: zks_cq@petrochina.com.cn

7

TRAINING SERVICES

CNPC has professional training service teams and works out relevant training plans according to different demands of users. There are multiple service means. CNPC can provide all-in-one services involving indoor tool assembling and explanation, field operation training, simulation equipment demonstration, etc. CNPC has detailed training courseware and manuals.

Combining software with hardware, to train actual operating personnel visually. A perfect after-sales service system has been established. CNPC has professional technical personnel “on-call” round the clock and can provide remote technical support and diagnosis and solve product problems effectively in time.



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