PCDS™ Precise Managed Pressure Drilling (MPD) system

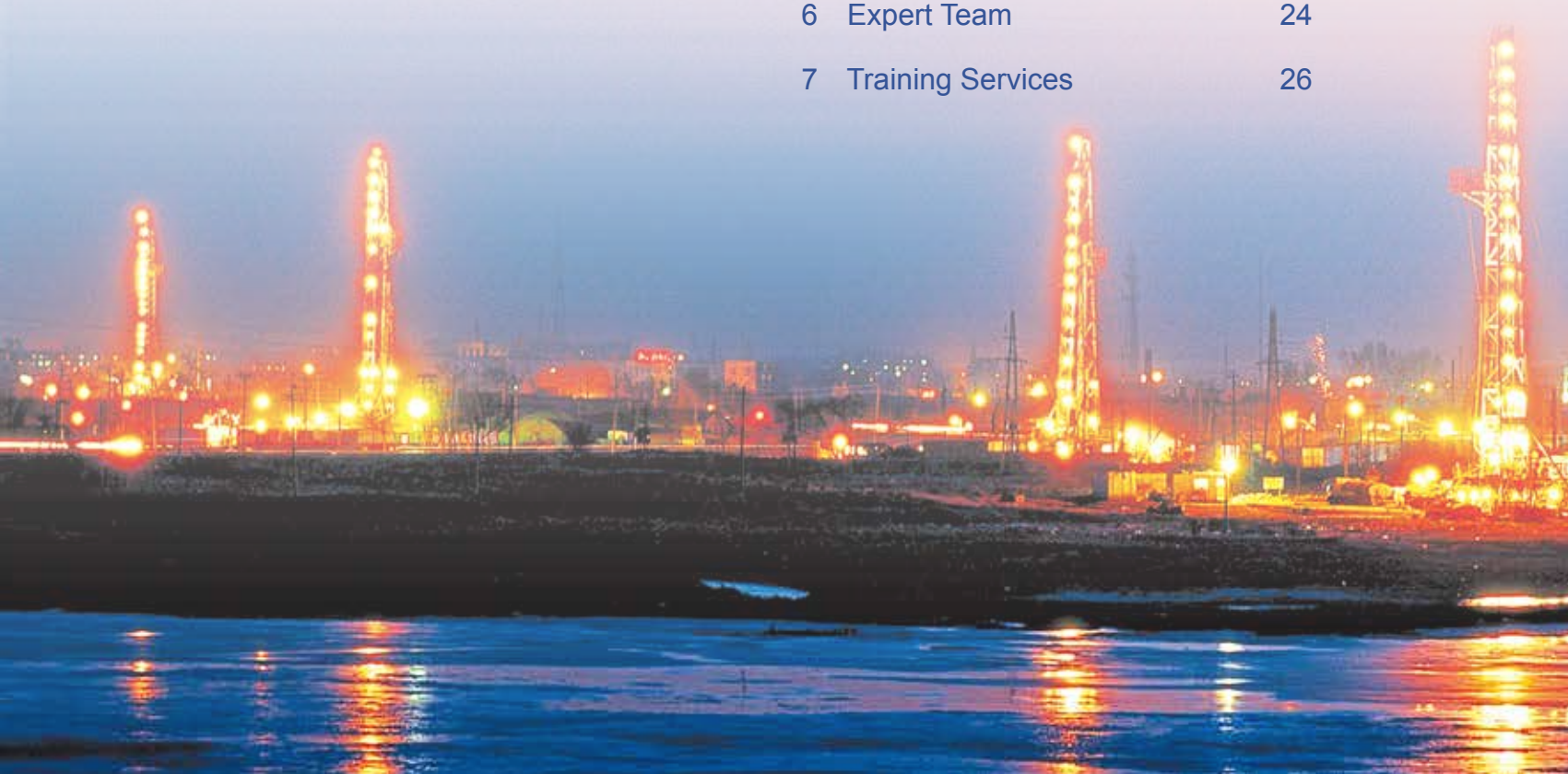
Science & Technology Management Department, CNPC

2015

CHINA NATIONAL PETROLEUM CORPORATION

MPD System: A Powerful Tool for Drilling in Complex Sensitive Formations!

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 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 PCDS™ precise managed pressure drilling (MPD) system is one of representatives for major innovations of CNPC.

OFFERING ENERGY SOURCES, CREATING HARMONY

1 INTRODUCTION

As oil and gas exploration and development are continuously advanced towards deep wells, complex wells and HTHP wells, the narrow density window problem has become increasingly acute. When using conventional drilling technologies, a series of drilling problems including kick, lost circulation, sticking, etc. occur easily and this has become the technical bottleneck which seriously affects and restricts oil and gas exploration and development process.

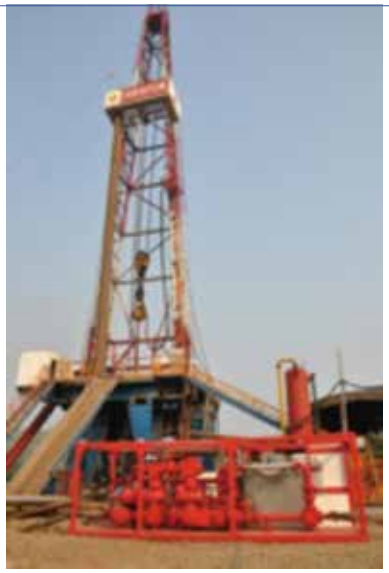
The MPD technology is one of drilling engineering frontier technologies in the present world. The precise MPD system integrates mechanical, electricity, hydraulic and gas systems as well as pressure measurement while drilling, online intelligent equipment monitoring and emergency treatment functions and is characterized by annular pressure closed loop monitoring, multi-strategy and self-adaptation. Through closed loop real-time monitoring and accurate control of well bore annular pressure, overflow and lost circulation can be effectively predicted and controlled, downhole problems can be avoided, and nonproductive time can be reduced greatly. In addition, the system can protect reservoirs and increase horizontal section extension capacity, makes for increasing single-well deliverability, and is the most effective means for solving the drilling problems involving pressure sensitive formations, HTHP formations, narrow density window, etc. in deep wells at present.

PCDS™ precise MPD system is CNPC's drilling equipment with proprietary intellectual property rights and realizes "drilling while knowing bottom hole pressure well". The system integrates constant bottom hole pressure and micro-flow control functions and can be used in near-balanced and under-balanced precise MPD operations. With the system, bottom hole pressure control accuracy can reach ±0.35MPa. The system has become a new powerful tool of safe and highly effective drilling technology and equipment.

PCDS™ precise MPD system has provided high quality MPD technology services in MPD service hotspots and difficult regions including Sichuan and Chongqing, Tarim, Huabei and Jidong as well as overseas ones. With PCDS™ precise MPD system, the drilling problem “coexistence of overflow and leakage” has been solved effectively, the effect of reservoir discovery and protection is remarkable, and safe and highly effective drilling operations have been realized in carbonate formations, narrow density window formations and HTHP complex formations of deep wells.

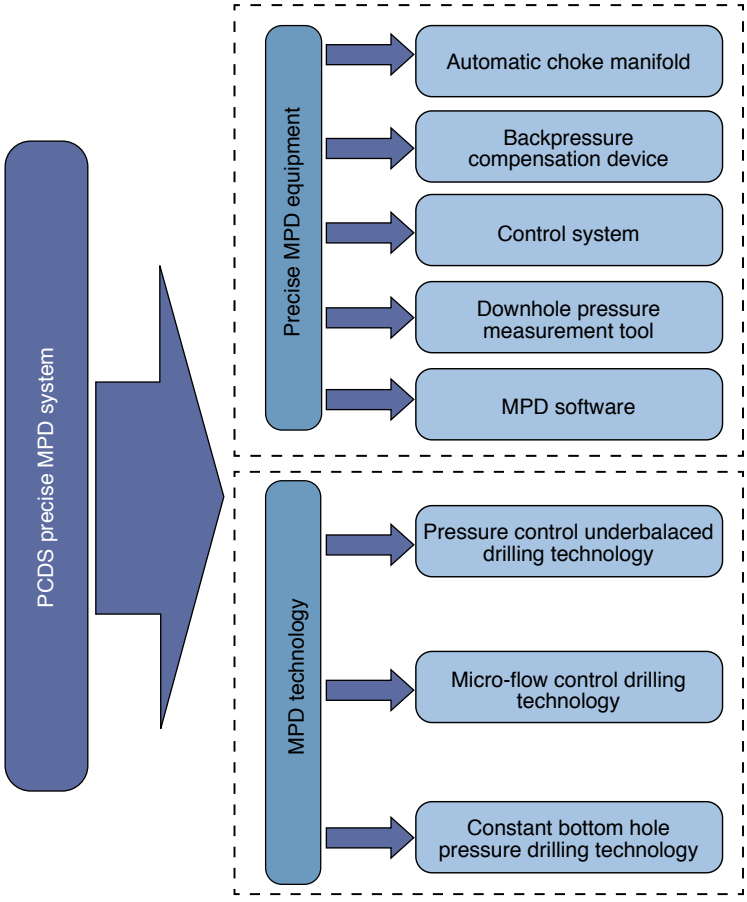
MPD services for well PL9 in Sichuan

MPD services for well ZG5-H2 in Tarim



MPD services for well NP23-P2003

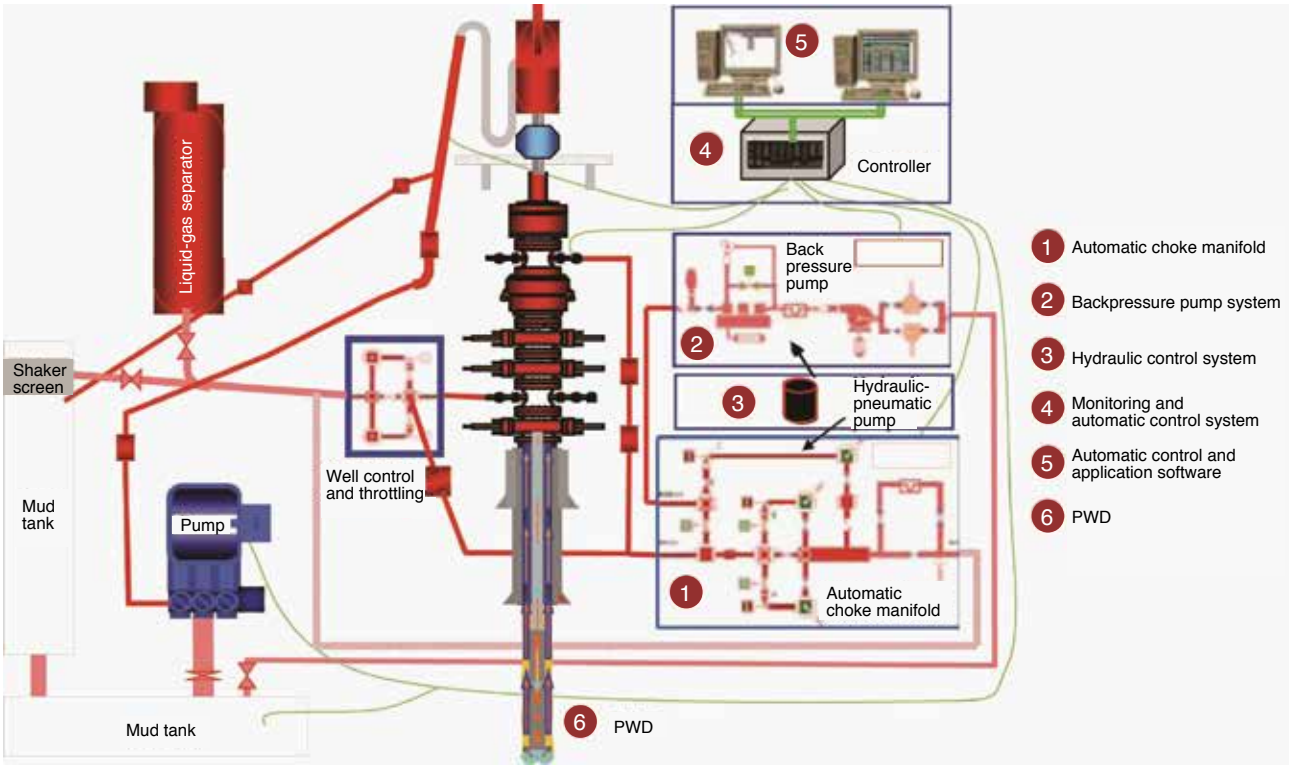
MPD services for well Bssement-l in Indonesia



2 CHARACTERISTIC TECHNOLOGIES

2.1 Precise MPD Equipment

PCDS™ precise MPD system mainly consists of automatic choke manifold, backpressure compensation device, control system, MPD software and downhole pressure measurement tool.



Composition chart of PCDS™ precise MPD system equipment

Main specifications of PCDS™ precise MPD system

Model	Rated pressure ((MPa)	Working pressure (MPa)	Choke accuracy ((MPa)	Applicable hole size (mm)	Drilling fluid density (g/cm^3)
PCDS™	35	7	±0.35	<311	<2.4

Note: the working pressure is decided by the hydrodynamic seal grade of site rotary BOP.

Technical Features and Advantages

PCDS™ precise MPD system integrates constant bottom hole pressure control function and micro-flow control drilling function and can realize MPD operations under various operating conditions.

(1) Four operating modes such as remote/locally manual/automatic etc.; high pressure control accuracy;

(2) Quick choke channel switching under different drilling conditions;

(3) The high strength and erosion resistant throttle valve is applicable to extreme environment and can be maintained on line;

(4) High precision monitoring of outlet flow rate and inlet flow rate;

(5) Closed loop monitoring system, multi-strategy, self-adaptation;

(6) Can realize over-balanced, near-balanced and underbalanced MPD;

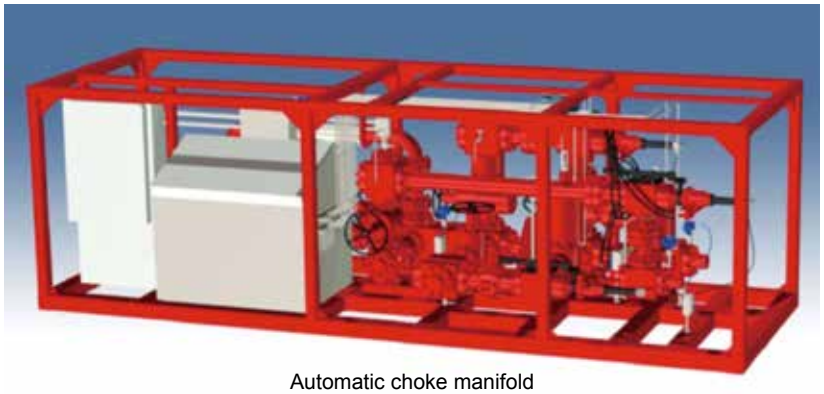
(7) The system uses modular design and can realize flexible and multi-variant combinations;

(8) Precise managed pressure automatic control software integrating hydraulic model, online intelligent equipment monitoring and emergency treatment;

(9) Applicable to various drilling conditions.

2.1.1 Automatic choke manifold

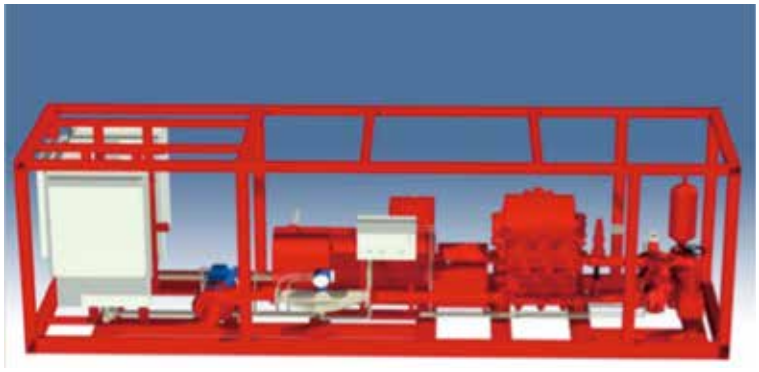
The automatic choke manifold consists of various valves, main choke manifold, auxiliary choke manifold, high precision hydraulic choke console and control box. The automatic choke manifold has three choke channels and functions in automatic throttling, redundant throttling switching, safety alarm and outlet flow monitoring. There are four operating modes such as remote/locally manual/automatic etc. Wellhead pressure is controlled through adjustable throttling, thus keeping bottom hole pressure relatively stable under static and dynamic conditions.



Automatic choke manifold

2.1.2 Backpressure compensation device

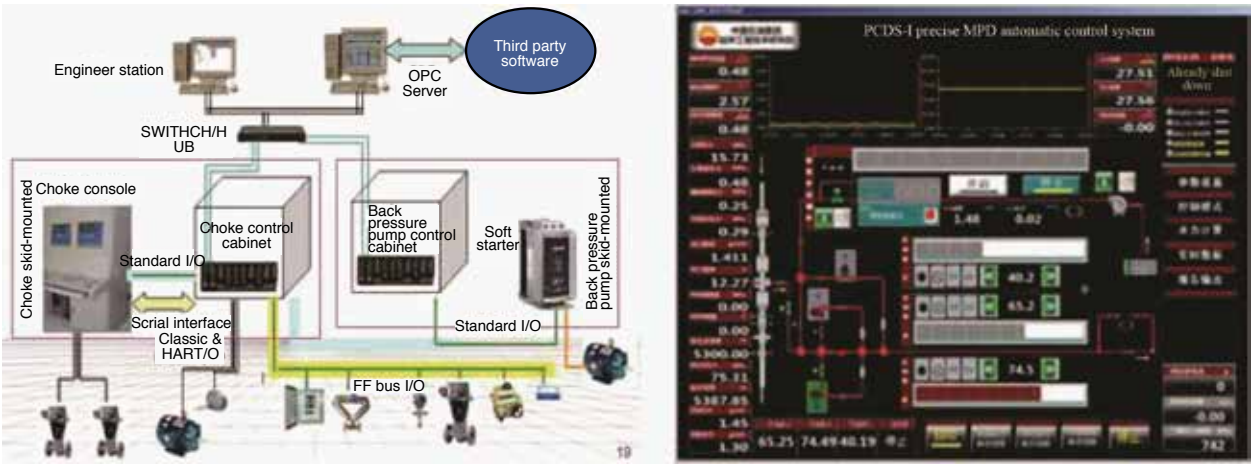
The backpressure compensation device consists of electric triplex plunger pump, AC motor, suction line, discharge line, high density mass flow-meter, etc. The backpressure compensation device can carry out flow compensation during circulation or pump stoppage. The device provides necessary flow rate to throttle valve working. The device can circulate for long and compensate for system flow rate during MPD operations. The device maintains the flow rate needed for wellhead throttling and the best throttling function of the throttle valve.



Backpressure compensation device

2.1.3 Control system

The control system consists of two parts such as remotely automatic control system and hydraulic control system and is the master control center of PCDS™ precise MPD system. The control center can carry out reasonable analysis and logic judgment, complete communication and data exchange with other systems, send down the corresponding adjustment instructions to the hydraulic-pneumatic control system and realize real time decision function according to downhole PWD, drilling parameter acquisition and monitoring system and real time hydraulic calculation information.



Remote control system of PCDS™ precise MPD system

2.1.4 Downhole pressure measurement tool

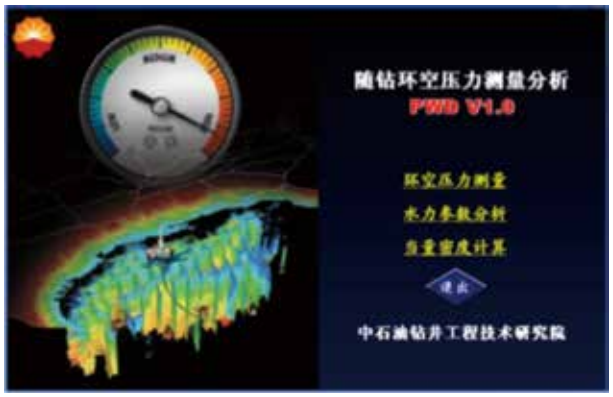
The downhole pressure measurement tool while drilling (PWD) is an important component of the MPD system. The PWD can measure downhole pressure while drilling and transmit it to real time hydraulic calculation software, thus correcting the hydraulic calculation model of the MPD system. CGPWD is the bottom hole annular pressure measurement while drilling system developed independently by CNPC Drilling Research Institute. The tool can be used separately, measure and store data while drilling in real time, and replay the measured data on surface. In addition, the tool can also be used in connection with MWD system, measure data while drilling and upload data.

Performance parameters of the downhole pressure measurement tool

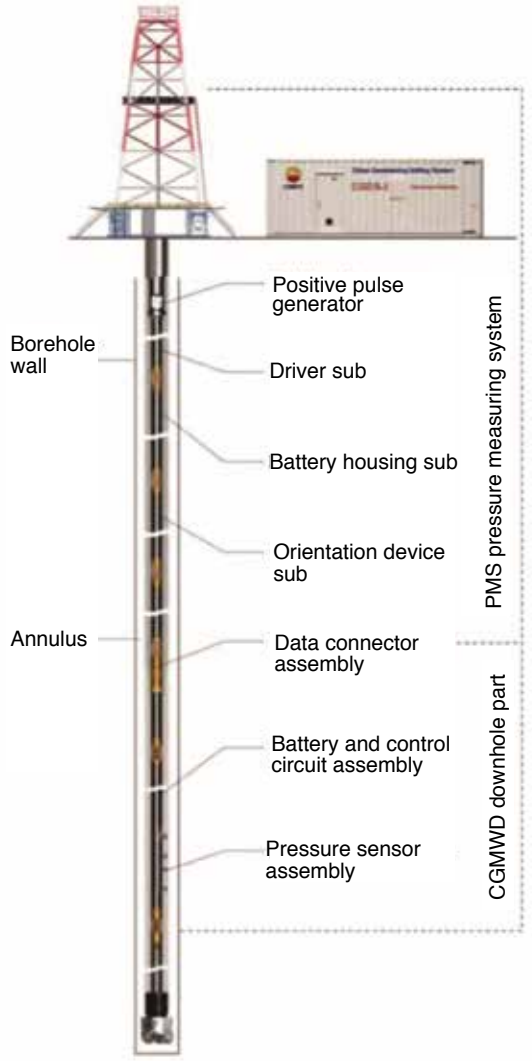
- Applicable hole size: 6in, $8^{1}/_{2}$in~$9^{5}/_{8}$in
- Measurable parameters:

In-string/annual pressure: 0~140MPa±1%FS;
Temperature: -50℃ ~+160℃ ±1%FS;
Inclination, azimuth and tool face angle, the same as CGMWD

- Data transmission rate: 5bits/s
- Maximum working temperature: 150℃
- Continuous working time: 500h
- Sampling interval: 1~6 points/min

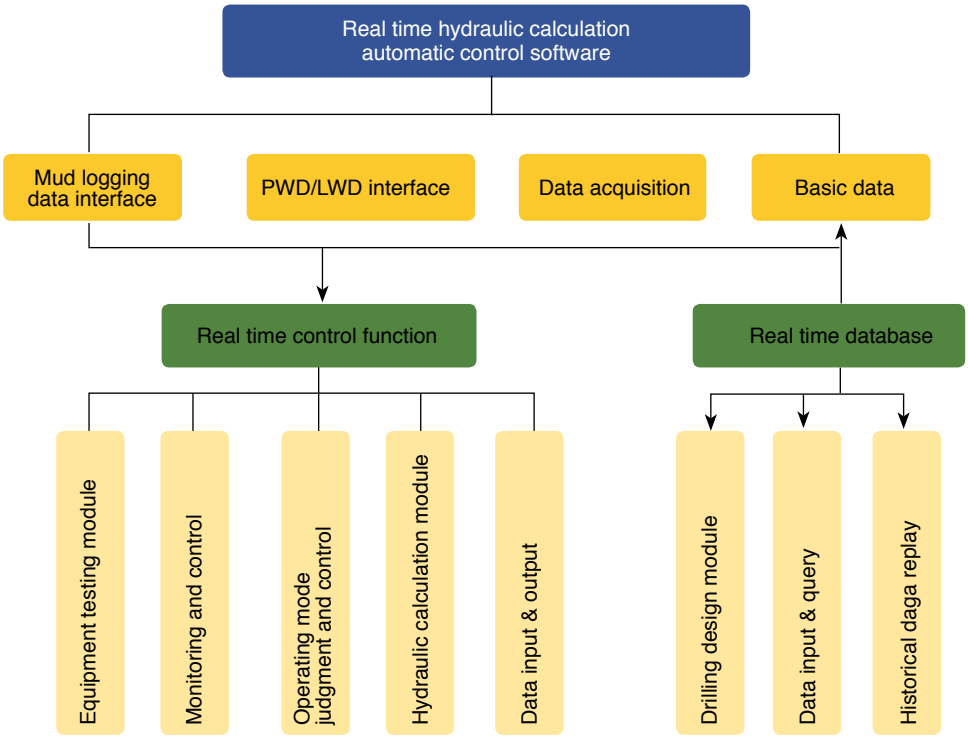


CGPWD downhole pressure measurement tool



2.1.5 MPD software

PCDS™ precise MPD software is the core of the MPD system. According to the bottom hole pressure value acquired in real time, the system calculates the backpressure value needing to be exerted at wellhead using the hydraulic calculation model. With the closed loop pressure automatic control software, the system automatically regulates wellhead compensation pressure in real time, thus controlling bottom hole pressure within the best predetermined range and ensuring downhole safety and reliability.



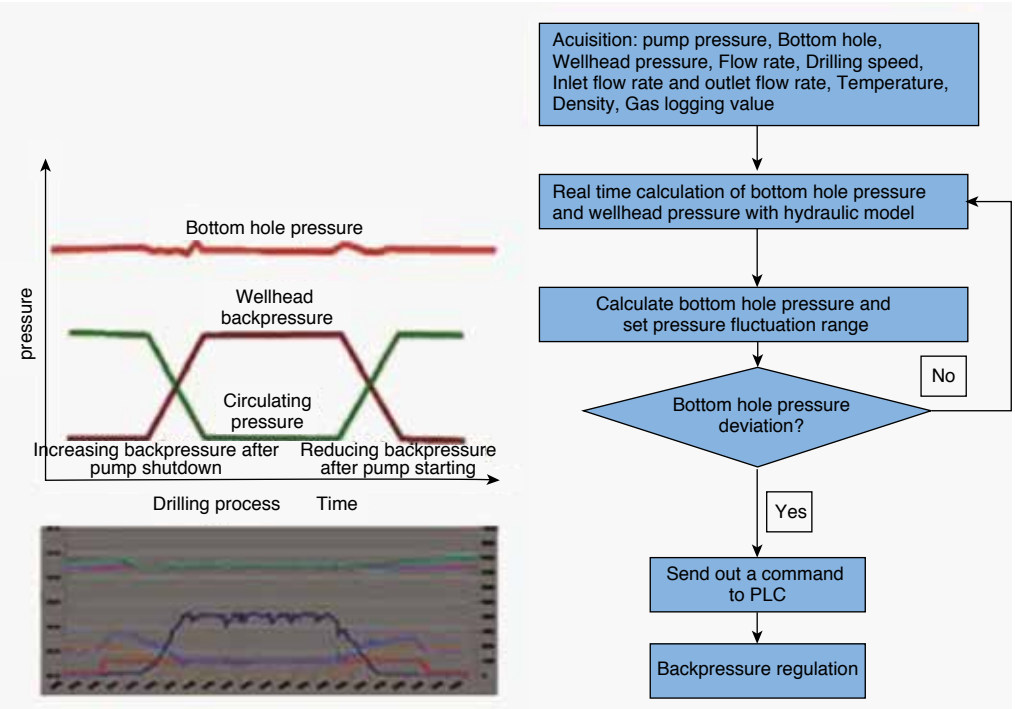
MPD software function architecture

MPD hydraulic calculation software interface

2.2 MPD Technology

2.2.1 Constant bottom hole pressure drilling technology

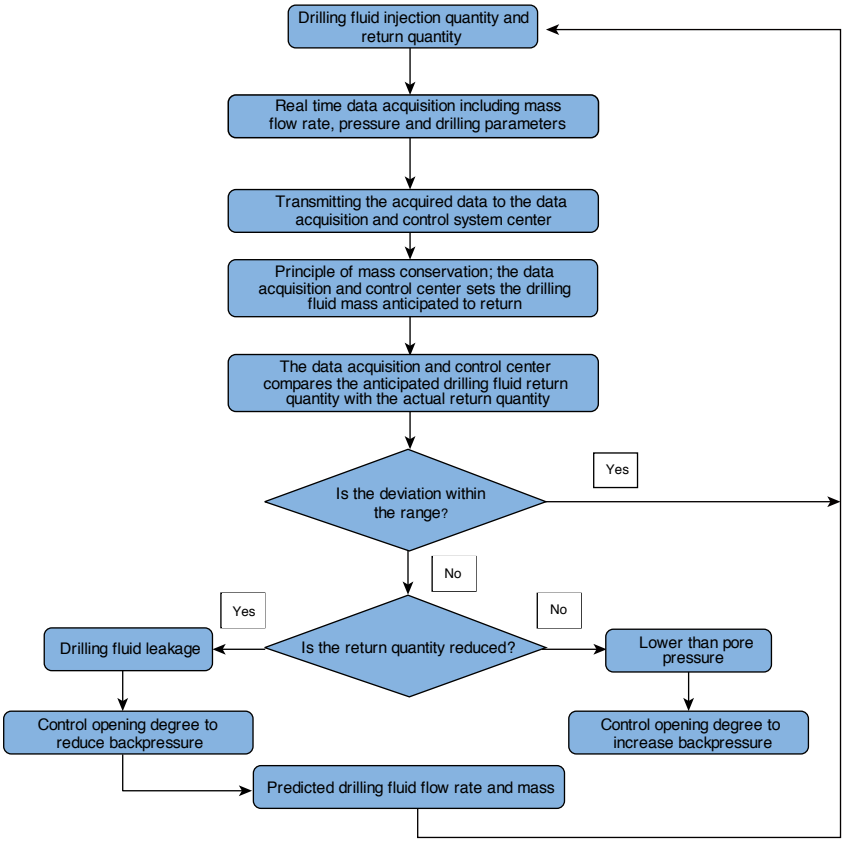
The constant bottom hole pressure drilling technology is a method which accurately controls hole pressure through annular circulation friction, choke pressure and hydrostatic pressure of drilling fluid. The technology regulates wellhead backpressure in real time using the full automatic closed loop pressure control software according to the bottom hole pressure value acquired by PWD in real time, thus realizing accurate control of bottom hole pressure. Bottom hole pressure can be controlled within the predetermined range in MPD operations at constant bottom hole pressure during drilling, making a connection and tripping. The technology provides continuously constant bottom hole pressure control under different operating conditions and ensures safer and more reliable drilling operations in deep wells and narrow density window formations.



Sketch of constant bottom hole pressure drilling control flow

2.2.2 Micro-flow control drilling technology

Micro-flow control drilling technology (Microflux Control) monitors and accurately measures drilling fluid outlet and inlet flow rate in real time and judges well bore overflow and leakage through a high precision mass flow meter depending upon the special function of PCDS™ precise MPD automatic control system and realizes timely discovery and control of overflow and leakage combining MPD real time hydraulic analysis software. The technology is not limited by downhole conditions involving formation pressure, temperature, etc. and can detect early overflow and micro-leakage and accurately measure overflow quantity. The minimum cumulative overflow and leakage monitoring value can reach ±0.1m^3, the occurrence of complex accidents is predicted and controlled, and well control safety is improved in drilling operations.



Control flow chart for micro-flow control drilling technology

2.2.3 Pressure control underbalanced drilling technology

PCDS™ precise MPD system introduces the underbalanced drilling concept into MPD operations, uses precise MPD equipment and well bore closed loop pressure automatic control technology, and realizes precise pressure control underbalanced drilling operations in narrow density window formations of deep wells as well as “drilling while flaring and flowing” on a controlled basis. Provide an integrated solution to “coexistence of overflow and leakage” formations, reservoir discovery and protection demand and cause narrow density window bottom hole pressure control to become safer and highly effective.

3 TYPICAL CASES

(1) ROP increased by 95% with MPD technology in Huabei region

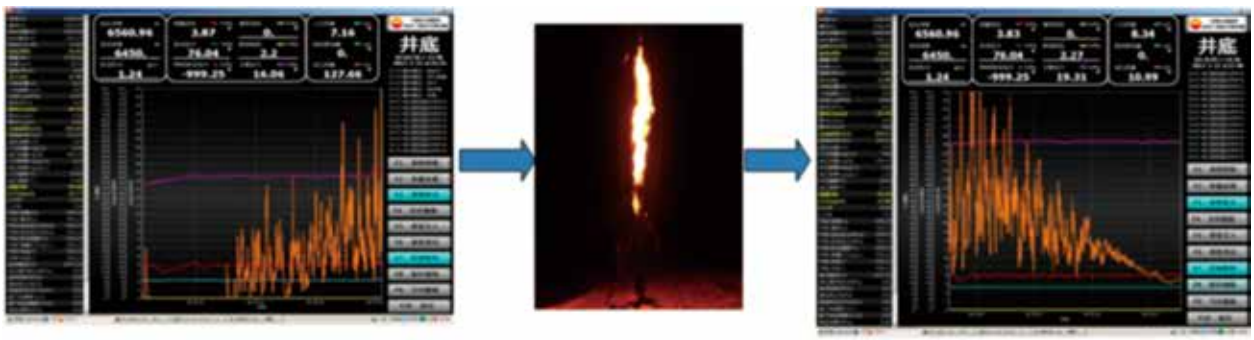
The reservoirs in Niudong buried hill structure, Baxian sag, Bohai Bay basin have developed fractures, narrow density window and high well control risks, thus seriously hindering the exploration and development process. In Feb.~ Mar. 2012, the MPD technology was used in the fourth spudding interval of well ND102 and the ROP was increased by 95%, thus realizing “zero leakage” and “zero problem” in target formations, successfully solving drilling problems involving leakage, borehole wall collapse, etc. in Niudong buried hill structure, effectively reducing drilling fluid density and remarkably improving ROP increase effect.

Drilling site application in well control of well ND102

(2) A new record of 1561m horizontal section footage created in precise MPD application in Tazhong

Well TZ721-8H is a key well on 1# fault slope-break zone in Tarim oilfield. The well has complex formation conditions and active reservoirs, the formations belong to typical narrow pressure window formations, leakage and blowout easily occur, there are multiple sets of pressure series of strata, the formations contain H_2S in general, and operation safety risks are high. With the conventional MPD technology, bottom hole pressure fluctuates greatly and problems occur frequently; in the case of drilling large section leakage zones, it is very difficult to continue drilling. From Jun. 13 to Jul. 11, 2013, PCDS™ precise MPD system (interval 5144~6705m) was used, realizing “zero leakage” and “zero problem” in the whole process.

Multiple records of domestic precise MPD have been created, and a new record of penetrating through multiple sets of fracture and hole development units has been created in Tarim oilfield. The horizontal section footage is 1561m, thus breaking of the oilfield record of 1345m kept by TZ26-H7. The “pressure control underbalanced” concept has been applied revolutionarily, 42 reservoirs have been discovered, and a new record of daily footage 150m in horizontal sections has been created. The ROP in the target formation was increased obviously and the effect of reservoir protection and discovery was remarkable.



Automatic finding and alarm of overflow　　Ignite　　Overflow control and normal drilling recovery

(3) Realization of “drilling while flaring” in the whole process of drilling operations in Indonesia

Well Basement-1 is located in Jiabang block, Sumatra Island, Indonesia and the northeast of Betara oilfield. The well is the first preparatory well in Jiabang block. The lithology of the target formation BASEMENT belongs to granite, the formation drillabillity is bad, the ROP is low, and the formation pressure coefficient is low. The target formation has broken fracture surface features. Sallow gas is developed, gas layers are extremely sensitive to bottom hole pressure, and operation safety risks are high. From Jul. 18 to Sept. 4, 2013, PCDS™ precise MPD system was successfully applied in this well, with the MPD footage of 999m and the average ROP of 3.30m/h. Oil and gas shows were good, and there

was zero leakage and zero problem in the whole interval. “Drilling while flaring” was realized in the whole drilling period. The total flaring time was 79.5% of the total MPD time and reached 240h, and the flame height was 1~5m in general and 15m at most, thus ensuring downhole safety and minimizing drilling fluid pollution to reservoirs.

4 SCIENTIFIC RESEARCH EQUIPMENT

The R&D environment of PCDS™ precise MPD system is a high-end environment and equipment conditions are advanced. The national drilling engineering laboratory was set up in CNPC Drilling Research Institute in 2008. The subordinate MPD laboratory is the only domestic laboratory which can perform full-scale simulation experiments and equipment tests under various MPD conditions. The laboratory can carry out simulation experiments on various site operating conditions and processes, unit testing and whole-machine performance testing and evaluation.

CNPC Drilling Research Institute has multi-function testing machines and triaxial rock testers. CNPC Drilling Research Institute has over 300 pieces (sets) of various large drilling research instruments and equipment including UBDMI underbalanced/gas drilling multi-function evaluation instruments, HTHP thickening instruments, liquid chromatographs, tensile testers, etc. Their newness coefficient is 0.8 and CNPC has strong scientific research and experiment capacity.

MPD full-scale simulation laboratory

MPD laboratory

MPD laboratory

Rock mechanics laboratory

Underbalanced drilling laboratory

TerraTek 4010 triaxial rock tester

5 QUALIFICATION STANDARDS

Qualification

CNPC Drilling Research Institute has passed ISO9001 quality system certification and continuously obtained ISO9001 quality management system certificate. CNPC Drilling Research Institute has obtained grade I market access certificate of Tarim Oilfield Company and is qualified in oil and natural gas drilling engineering research, product provision and technical services.

Standards

API drilling standard are executed for PCDS™ precise MPD system. 3 enterprise standards and 1 industrial standard have been formulated.

Patents

CNPC PCDS™ precise MPD system has 20 national patents including 7 invention patents.

Patent Description

No.	Patent name	Application No. or approval No.	Remarks
1	A combined multi-stage pressure control method and device	ZL201010236362.2	Invention patent
2	Downhole condition simulation method for MPD experiment and test	ZL201010139484.X	Invention patent
3	Method and device for automatic detection and alarming of serious blockage of high pressure closed filter	ZL201110418999.8	Invention patent
4	A whole-interval annular pressure measurement method, device and control method and device	ZL201010570374.9	Invention patent
5	Drilling equipment and method for bottom hole pressure control through flow monitoring	201210226318.2	Invention patent
6	A MPD method and equipment with single choke channel applicable to large flow variation	201310114422.7	Invention patent
7	A method of precise MPD technology to solve borehole wall stability problems	201310114285.7	Invention patent
8	A pressure compensation device for MPD	ZL200920277598.3	Utility model patent
9	A new choke manifold for MPD	ZL200920246846.8	Utility model patent
10	A MPD realization device using FF field bus	ZL201020144452.4	Utility model patent
11	A precise control system for drilling annular pressure	ZL201020108986.1	Utility model patent
12	A downhole condition simulation device for MPD experiment and test	ZL201020149177.5	Utility model patent
13	A combined multi-stage pressure control device	ZL201020269954.X	Utility model patent
14	An integrated manual and automatic choke control device	ZL201020270433.6	Utility model patent
15	A MPD choke device with two-stage choke functions	ZL201020270446.3	Utility model patent
16	A device for automatic detection and alarming of serious blockage of high pressure closed filter	ZL201120523962.7	Utility model patent
17	A backpressure pump system outlet device for MPD	ZL201220226805.4	Utility model patent
18	Drilling equipment for bottom hole pressure control through flow monitoring	ZL201220316400.X	Utility model patent
19	A MPD device with single choke channel applicable to large flow variation	ZL201320163014.6	Utility model patent
20	A borehole wall stabilizing device for precise MPD	ZL201320162860.6	Utility model patent

National key new product certificate

国 家 重 点 新 产 品

证 书

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有 效 期：三年

批准机关：科学技术部

6 EXPERT TEAM

Shi Lin

Senior technical expert, professor level senior engineer. He once took charge of multiple national 863 projects and CNPC's major research projects. He has obtained 1 grade II national science and technology advance prize and 8 provincial and ministerial science and technology advance prizes. He is responsible mainly for the overall design of PCDS™ precise MPD system.

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Zhou Yingcao

Senior technical expert, Ph.D. candidate supervisor, professor level senior engineer. He has been long engaged in drilling scientific research and technology management work. He has taken charge of completing 18 scientific research achievements. He has obtained 1 grade III national invenstion prize, 1 grade II national science and technology advance prizes, 7 provincial and ministerial science and technology advance prizes and 15 patents. He is responsible for the review of the overall plan and overall technology for PCDSTM precise MPD system.

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Fang Shiliang

Drilling technology expert, senior engineer. He has been long engaged in drilling scientific research and technology management work, and his main research direction is new MPD technology. He has obtained 2 CNC science and technology advance prizes and over 10 patents. He is responsible for annular pressure simulation of PCDSTM precise MPD system and the overall plan design of control technology.

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Wang Ying Drilling technology expert, senior engineer. He has been long engaged in drilling scientific research and management work, and his main research direction is new MPD technology. He has obtained over 10 patents. He is responsible mainly for improvement and field popularization and test of PCDSTM precise MPD system.
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Liu Wei Senior engineer. He is engaged in MPD equipment and technology research work. As a technical backbone, he has participated in 2 national projects and 4 ministerial projects and obtained 2 provincial and ministerial science and technology advance prizes. He is responsible mainly for prototype trial-manufacturing and field test of PCDSTM precise MPD system.
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Luo Liangbo Senior engineer. He is engaged drilling scientific research and application work. His research direction is new MPD technology. He has obtained 2 CNC science and technology advance prizes. He is responsible for annular pressure simulation of the precise MPD system and the process scheme and field test of control technology.
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7 TRAINING SERVICES

CNPC Drilling Research Institute has professional training service teams and perfect software and hardware training facilities. The proprietary MPD full-scale simulation experiment system can simulate actual drilling conditions, is used to train MPD engineers and operating personnel, conforms to the actual environment and is intuitive and easy to understand. The system meets the needs of different levels of customers. Work out targeted training plans and provide training services indoors and in operation site environment. The training contents cover MPD machinery, automatic control, hydraulic and hydraulic calculation software, MPD technology, etc.

MPD test simulation and training center

MPD simulation training environment

After training, examine trainees in professional knowledge and comprehensively test them in relevant skills. There are various training contents including field explanation of field, operation site demonstration, simulation system demonstration, etc. for convenience of trainees' understanding.

A perfect drilling site technology service and product after-sales service system has been established. Three precise MPD technology field service teams with plentiful field experience and complete specialties have been organized. CNPC Drilling Research Institute has professional technical personnel integrating mechanical, electrical and hydraulic knowledge and they await orders and provide services round the clock. CNPC Drilling Research Institute can provide site and remote technology support and diagnosis, effectively solve product problems in time, and provide domestic and overseas customers with high quality MPD technology support and services.

CNPC
中国石油

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