GW-LWD (BWR)

Science & Technology Management Department, CNPC

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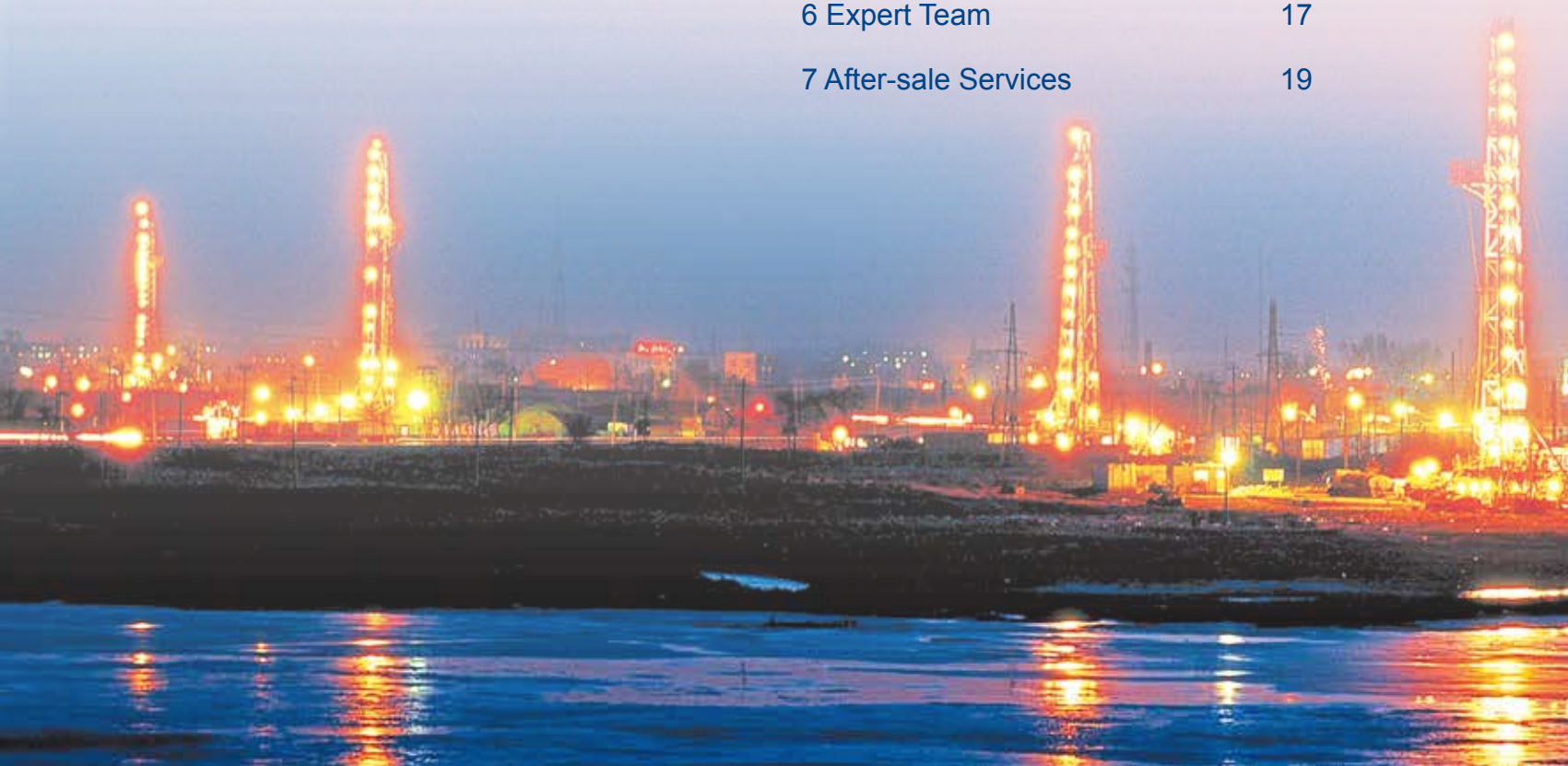
CHINA NATIONAL PETROLEUM CORPORATION

GW-LWD (BWR): A Steering Wheel to Accurate Tracking of Reservoirs!

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.

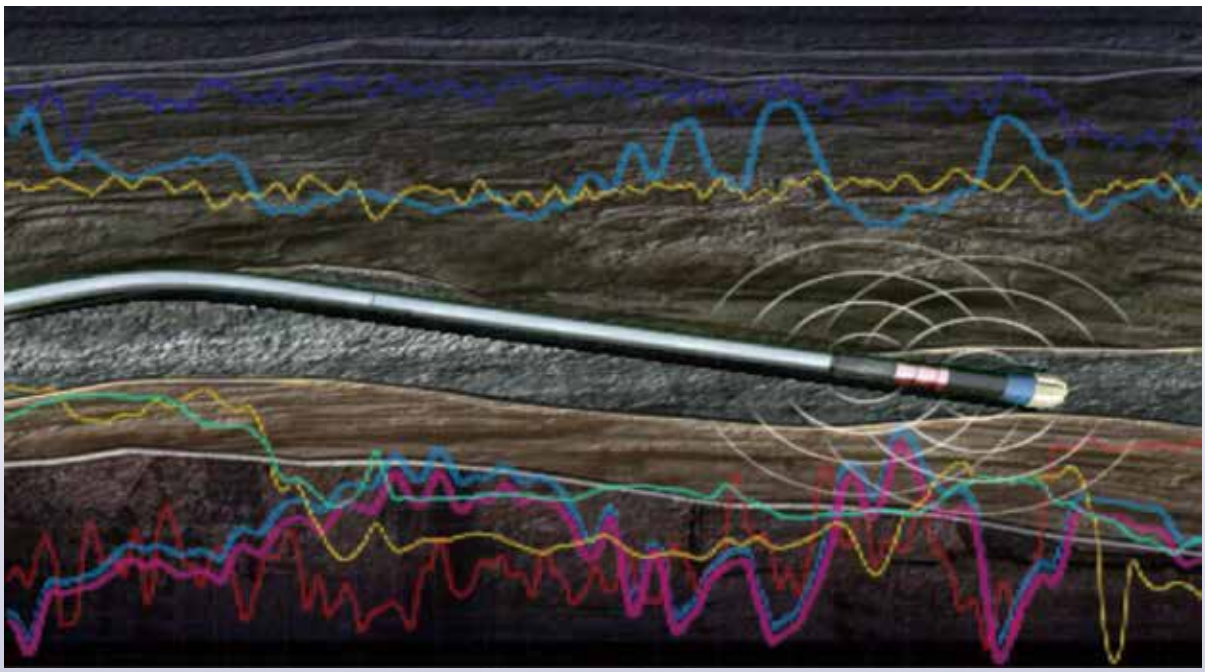
CNPC strictly follows by the combined strategies of increasing resource capacity, expanding market shares and consolidating the international role, and persists in regarding technical innovation as a key framework to advance technological progress. To develop its core businesses, focuses will be placed 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 GW-LWD (BWR) is one of representatives for major innovations of CNPC.

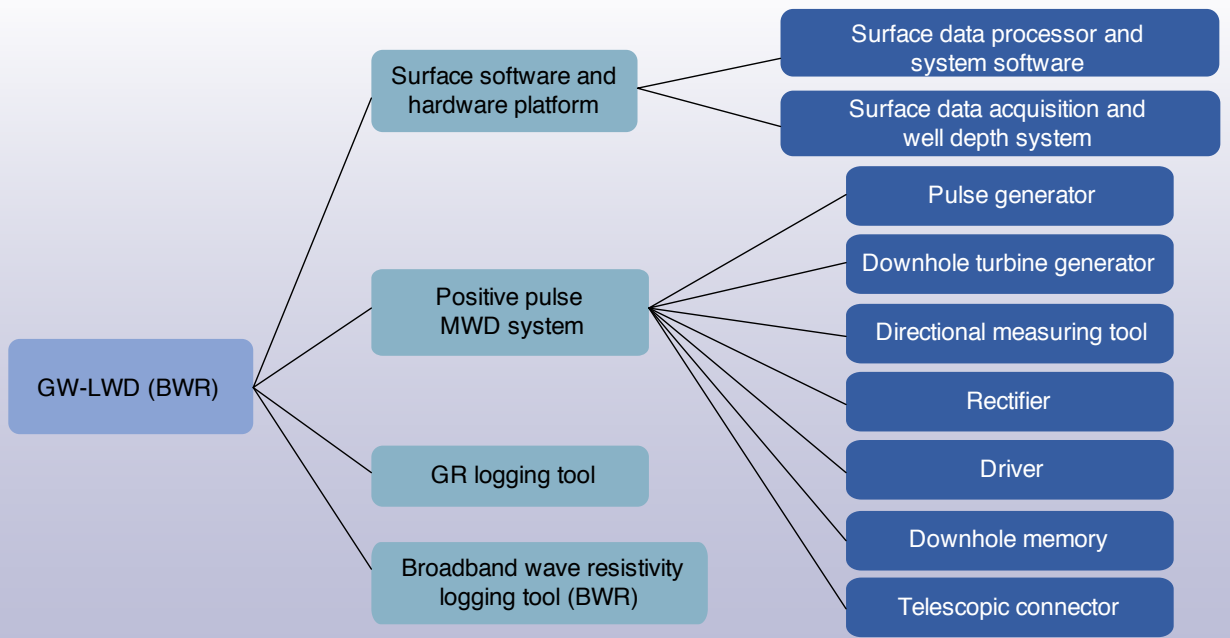
OFFERING ENERGY SOURCES, CREATING HARMONY

1 INTRODUCTION

GW-LWD(BWR) system integrates measurement and transmission of information while drilling and provides bases for adjusting drilling direction and maintaining high drilled ratio of reservoirs at any time through real-time monitoring of downhole geologic parameters and engineering parameters in the drilling process. The system is widely applied in geosteering and formation evaluation of complex structure wells such as horizontal wells, extended reach wells, etc., and can greatly increase drilling success ratio, single-well production and recovery ratio, reduce oilfield development and production cost and realize high efficiency development of oilfields.



GW-LWD(BWR)—Great Wall-Logging While Drilling (Broadband Wave Resistivity) system has three sizes including ϕ120, ϕ172 and ϕ203. The system can work in HTHP environment of 150 ℃ and 140Mpa and measures 3 engineering parameters (inclination, azimuth and tool face) and 3 geologic parameters (formation depth, shallow resistivity and formation GR value) in real time. CNPC has proprietary intellectual property rights of the system, 7 national utility model patents and 1 invention patent. The system is the first set of broadband wave resistivity logging tool while drilling designed and manufactured independently by China and reaches the advanced level of international like tools.



◆ 6 key technologies

- ➢ Accurate BWR calculation chart modeling

  ——realization of wider BWR measuring range;

- ➢ Perfect BWR logging tool calibration system

  ——ensurance of the trueness and reliability of resistivity measurement data;

- ➢ Originally created high-speed stable FS33 network communication protocol

  ——realizing tool expandability;

- ➢ Advanced mud pulse encoding and decoding technology

  ——realizing signal transmission in severe environment;

- ➢ Complete data processing algorithm

  ——performing accurate measurement of directional parameters in pumping state;

- ➢ High power generator and high performance positive pulse system

  ——meeting the requirements of connection and power supply to subsequent tools and upload large quantity of data.

◆ 3 innovative technologies

- ➢ Self-adaptive transmitting power adjustment technology

  ——increasing the dynamic range of receiving signals and measurement SNR;

- ➢ Pulse signal decoding time perturbation technology

  ——increasing decoding ratio in high noise environment;

- ➢ Man-machine interactive intelligent decoding technology

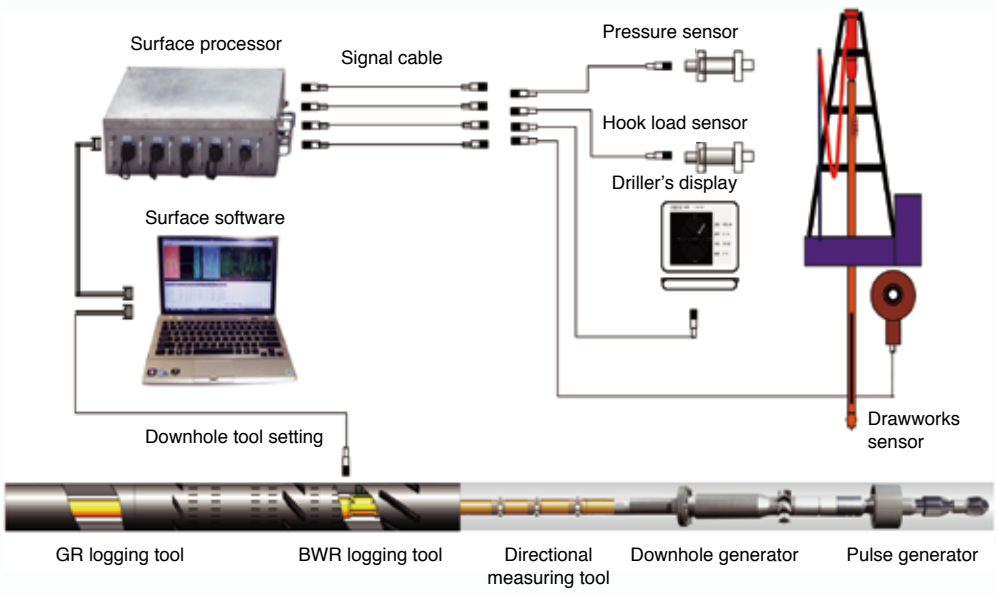
  ——avoiding secondary pumping and saving operation time.

◆ Better than international like tools in 3 technical indexes

- ➢ Resistivity logging tool detection depth;
- ➢ System data transmission rate and storage capacity
- ➢ Mud pulse signal decoding capacity

2 CHARACTERISTIC TECHNOLOGIES

GW-LWD(BWR) system mainly consists of four parts including surface software and hardware platform, positive pulse MWD system, BWR logging tool and GR logging tool.



2.1 Surface Software and Hardware Platform

The surface software and hardware platform includes surface data processor, sensor, signal transmission cable, surface software system, etc. The surface system acquires downhole mud pulse signals and well depth signals via the senor, transmits them to the PC via the CAN bus for decoding and processing by the surface software, and displays and records downhole information in real time.

The surface hardware is characterized by high reliability, water proofing, explosion proofing, etc., and the data processor has independent system software and can realize remote high speed communication with the driller's display.

2.2 Positive Pulse MWD System

The positive pulse MWD system mainly consists of pulse generator, downhole turbine generator and directional measuring tool (downhole central processor) and has relevant matching subs such as drive controller, rectifier, downhole memory, etc. The system can provide directional measurement and auxiliary parameters such as inclination, azimuth, tool face, etc., communicate with other measuring modules, receive and store other measuring data, realize pulse signal encoding (pulse width adjustable) and control pulser to generate signals.

GW-LWD(BWR) is designed with a large power downhole turbine generator and the control signal downloading technology based on displacement adjustment has been developed, so that the positive pulse system is characterized by strong anti-interference capacity and stable and reliable working and accurate measuring of directional parameters can be realized in pumping state.

2.3 BWR Logging Tool

The BWR Logging Tool of GW-LWD(BWR) uses the four-transmitter two-receiver six-antenna mode, measures the amplitude ratio and phase difference of two receiving coils by alternately transmitting 2MHz and 500kHz sine electromagnetic waves depending upon the difference of different formations in absorbing electromagnetic waves during electromagnetic wave propagation in formations, and obtains formation resistivity information through further conversion. The logging tool can realize electromagnetic signal detection in complex drilling environments involving high temperature, high pressure, vibration, impaction, etc. and eliminate various possible interferences through acquisition and processing of multi-frequency and multi-coil signals.

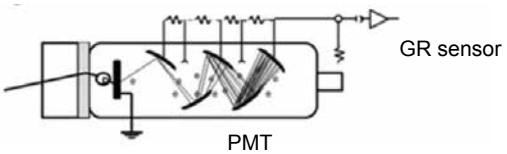
The system is designed with a downhole dual-64M memory system, stores 32 measurement parameters downhole, provides 8 BWR logging curves at different detection depths and deep and shallow resistivity logging curves in real time, and can perform measurement for continuous 300hr, with the maximum effective detection depth up to 2.2m.

Tool antenna structure

2.4 GR Logging Tool

The GR Logging Tool can connect MWD and other measuring modules, communicate with them and provide GR measurement data of formations.

GW-LWD(BWR) integrates a high precision GR detection sensor and is designed with the matching GR interface circuit, independent high voltage power supply and self-adaptive filter, thus realizing accurate GR measurement.



2.5 Specifications of GW-LWD (BWR)

General specifications	
Sand content	No higher than 1%
Drilling fluid type	Non-limited
Drilling pump	Duplex or triplex pump
Vibration	Acceleration 196m/s^2 (frequency sweep range 20~200)Hz
Impaction	Acceleration 455m/s^2 (half-sine waveform)
Tool face update time	11, 24 or 35s
Full measurement time	55s

General specifications			
Tool OD	203 mm	172 mm	120 mm
Total length of the tool	13.40 m	13.48 m	12.33 m
Hole size	311 mm	215.9 mm/241.3 mm	149 mm/172 mm
Connecting thread type	630 × 630	410 × 411	311 × 310
Rate of over-all angle change	Directional : 8.2° /30m Rotate : 8.2° /30m	Directional : 16° /30m Rotate : 9° /30m	Directional : 30° /30m Rotate : 12° /30m
Max temperature	150℃	150℃	150℃
Maximum pressure	140 MPa	140 MPa	140 MPa
Displacement	32 ~ 72 L/s	28 ~ 46 L/s	11 ~ 22 L/s
Pulser type	Positive	pulse	Positive

Directional measuring tool specifications		
	Measurement accuracy	Measurement range
Inclination	± 0.1°	0 ~ 180°
Azimuth	± 0.25°	0 ~ 360°
Tool face	± 0.5°	0 ~ 360°

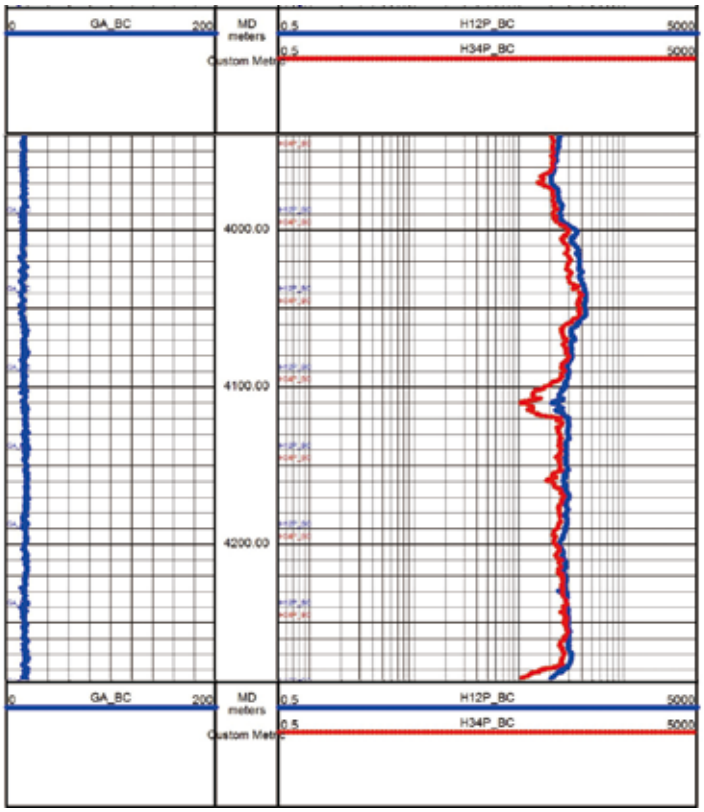
GR logging tool specifications	
Measurement range	
Real time transmission	Yes
Downhole storage	
Accuracy	±3% full range
Vertical resolution	6” (153mm)

BWR logging tool specifications				
Frequency	Measurement method	Source distance	Measurement range	Accuracy
2MHz	Phase	Long	0.1 ~ 2.000 Ω·m	± 1% [0.1 ~ 50Ω·m] ± 0.1mmho/m [above 50Ω·m]
		Short	0.1 ~ 2.000 Ω·m	± 1% [0.1 ~ 50Ω·m] ± 0.1mmho/m [above 50Ω·m]
	amplitude	Long	0.1 ~ 500 Ω·m	± 2% [0.1 ~ 25Ω·m] ± 0.8mmho/m [above 25Ω·m]
		Short	0.1 ~ 300 Ω·m	± 2% [0.1 ~ 25Ω·m] ± 1mmho/m [above 25Ω·m]
500kHz	Phase	Long	0.1 ~ 1.000 Ω·m	± 1% [0.1 ~ 25Ω·m] ± 0.8mmho/m [above 25Ω·m]
		Short	0.1 ~ 1.000 Ω·m	± 1% [0.1 ~ 25Ω·m] ± 0.8mmho/m [above 25Ω·m]
	amplitude	Long	0.1 ~ 300 Ω·m	± 2% [0.1 ~ 25Ω·m] ± 2mmho/m [above 25Ω·m]
		Short	0.1 ~ 200 Ω·m	± 2% [0.1 ~ 25Ω·m] ± 2mmho/m [above 25Ω·m]

3 TYPICAL CASES

(1) Successful application in overseas high resistivity formations

GW-LWD(BWR-120) has been applied in Rangnaruoer Region, Kazakhstan in 2014. The block is marine carbonate rock oilfield with high formation resistivity; as generally accepted in the industry, operation is difficult in the horizons in the block. With GW-LWD, the single-well footage is 400m, the highest measured formation resistivity is up to 433Ω; waveform is stable; data are accurate. After 230h continuous working, the system has zero failure. The drilled ratio with the reservoir thickness less than 1m is up to over 90%. A good effect has been obtained and the system has been highly recognized by Party A.



(2) Keeping high drilled ratio in marginal thin reservoirs

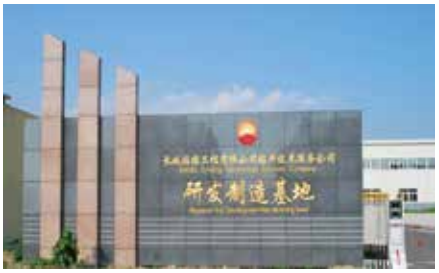
GW-LWD (BWR) system was successfully applied in a block in Hailar, Inner Mongolia in May, 2014. The reservoirs in the block of the well are marginal thin reservoirs with the thickness less than 2m, and the average drilled ratio of reservoirs in ambient wells is less than 60%. After 250h of downhole working, GW-LWD(BWR) had no failure. The data acquisition accuracy ratio is 100%, reservoir conditions are reflected accurately in time, and the drilled ratio of reservoirs is up to over 93%.

(3) Adapting to oil base drilling fluid and successful application in shale gas wells

GW-LWD (BWR) system was successfully applied in Pengshui block in Chongqing at the end of 2012. Pengshui block is a newly registered region with low exploration degree. The operation well is a sidetracked horizontal shale gas well and belongs to a very important appraisal well. Oil base mud was used during operations. The tool worked stably and had no failure after 436h continuous testing. Curves have obvious and clear reflection and the drilled ratio is up to 100%.

4 SCIENTIFIC RESEARCH EQUIPMENT

The internationalized joint R&D mode is used for GW-LWD(BWR). CNPC has a specialized LWD industrialized base integrating R&D, manufacturing, detection and calibration, high-end R&D environment and advanced equipment conditions.



Instrument R&D and manufacturing base

Key laboratory of CNPC

High and low temperature & vibration three-comprehensive tester LT0606

LWD cyclic simulation test bench

Probe heating test furnace R72-45-10

Hydraulic spinner assembly
THJY-CZJ356ZJ

The first BWR verification pool in China

5 QUALIFICATION STANDARDS

5.1 Qualification

CNPC has passed ISO9000 quality system certification and is qualified in oil and natural gas drilling engineering research, product provision and technical services.

5.2 Standards

GW-LWD (BWR) system strictly conforms to relevant national and industrial standards, and three sets of enterprise standards have been self-formulated.

Executed relevant standards (part)

General specifications for MWD SY/T 6702
Measurement and inspection regulation of directional surveying instruments SY/T 5416
Method for basic environmental testing of petroleum exploration and development instruments SY/T 5102
The calibration for petroleum nuclear logging tool SY/T 6582.2-2003
Calibration method for electronic inclinometers SY/T 6587

Self-formulated standards

GW-LWD logging while system Q/SY-GWDC 0033-2011
GW-LWD(BWR-172) logging while drilling system configuration standards Q/SY-GWDC 0038-2011
Logging while drilling resistivity tool calibration Q/SY-GWDC 0077-2013


Q/SY-GWDC
中国石油集团长城钻探工程公司企业标准
Q/SY-GWDC 0033-2011
GWLWD随钻测井系统
GW-LWD Logging While Drilling System
2011-10-20 发布 2011-10-20 实施
中国石油集团长城钻探工程公司 发布


Q/SY-GWDC
中国石油集团长城钻探工程公司企业标准
Q/SY-GWDC 0038-2011
GWLWD（BWR-172型）
随钻测井系统配置标准
GW-LWD (BWR-172) Logging While Drilling System
Configuration standards
2012-07-25 发布 2012-08-01 实施
中国石油集团长城钻探工程公司 发布


Q/SY-GWDC
中国石油集团长城钻探工程有限公司企业标准
Q/SY-GWDC 0077-2013
随钻电磁波电阻率测井仪刻度校验规范
Logging While Drilling Resistivity Tool Calibration
2013-04-22 发布 2013-04-25 实施
中国石油集团长城钻探工程有限公司 发布

5.3 Patents

1 invention patent
A nonmagnetic wear-proof sleeve for logging and drilling tool ZL 2008 1 0228215.3.
7 utility model patents
Slotted hexagon screw nailhead and bolt ZL 2008 2 0218307.7;
A soft docking cable conveyer in horizontal well hydraulic pumping ZL 2004 2 0113588.3;
An inner and outer hexagon bolt for MWD ZL 2008 2 0218606.2;
A self-locking bolt for MWD ZL 2008 2 0218605.8;
A matching tool for slim hole MWD ZL 2011 2 0495387.4;
A pulse generator oil filling machine ZL 2013 2 0266670.9;
A radar RF connection maintenance tool ZL 2013 2 0263119.9

6 EXPERT TEAM

Li Yonghe

Senior technical expert, professional level senior engineer. He has been long engaged in drilling engineering research and application. He has obtained 5 CNPC science and technology advance & technology innovation prizes and 32 national patents, and 15 papers written by him have been published.

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Wang Xuejian

Senior technical expert, senior engineer. He has been long engaged in drilling engineering research and application. He has obtained 1 grade I CNPC science and technology advance prize and 2 grade II CNPC science and technology advance prizes, and 8 papers written by him have been published.

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Bai Rui

Senior technical expert, senior engineer. He has been long engaged in drilling and logging technology research and field application. He has obtained 28 national patents and 1 grade I CNPC science and technology advance prize, and 6 papers written by him have been published.

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Wang Haimin Senior engineer. He has been long engaged in LWD technology field application and is experienced in tool design and improvement. He has obtained 1 grade I CNPC science and technology advance prize and 2 national patents.
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Zhang Lei Engineer. He has been engaged in study and application of downhole drilling tool electronics for many years. He has obtained 1 grade I CNPC science and technology advance prize and 7 national patents, and 3 papers written by him have been published.
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Email: leiz.gwdc@cnpc.com.cn

Zhang Meijun Engineer. He has been engaged in LWD technology field application and improvement of LWD related software for many years. He has obtained 1 grade I CNPC science and technology advance prize and 5 national patents.
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Email: zhgmj.gwdc@cnpc.com.cn

7 AFTER-SALE SERVICES

GW-LWD (BWR) system provides customers with comprehensive quality guarantee services.

- Free tool maintenance within one year after sale;
- Free software upgrading and maintenance within one year after sale;
- Provide comprehensive technical training and actual production logging operation guidance to customers;
- Provide customers with the needed technical support and fittings.

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