# Thermal Recovery Technology For Heavy Oil

Science & Technology Management Department

2011

CHINA NATIONAL PETROLEUM CORPORATION

*We are willing to cooperate with colleagues in petroleum industry to promote heavy oil development around the world.*

## Contents



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 of refined oil produts 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.

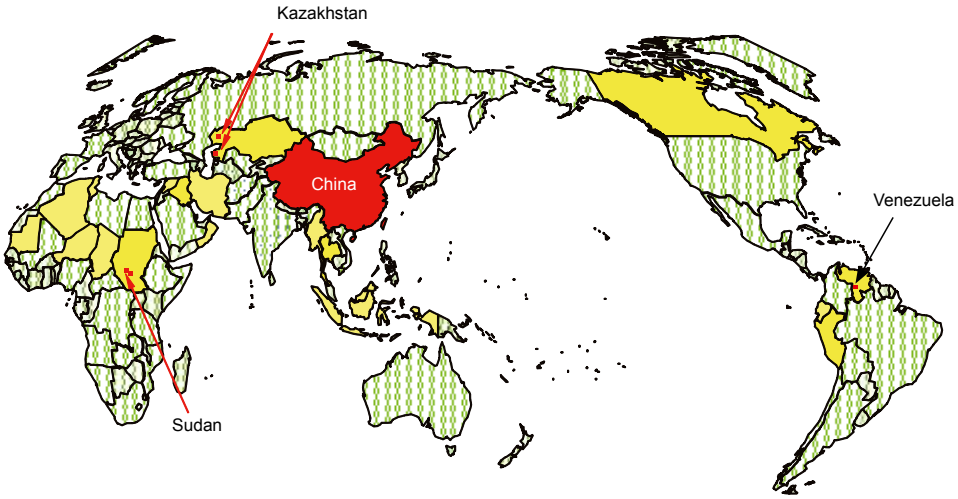
The Thermal Recovery Technology of Heavy Oil (HOTHER) is just one of the representatives for major innovations of CNPC.

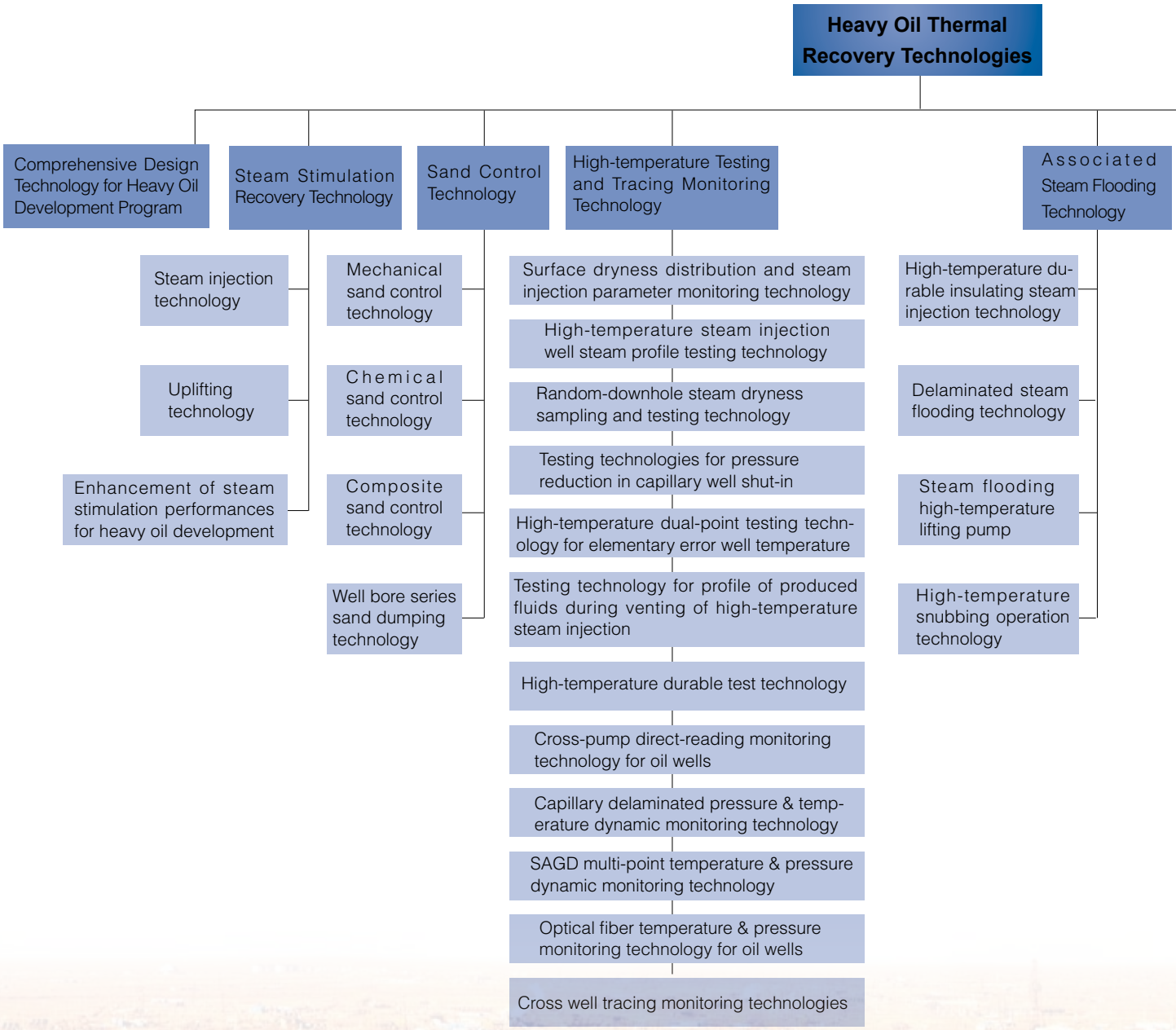
# 1 INTRODUCTION

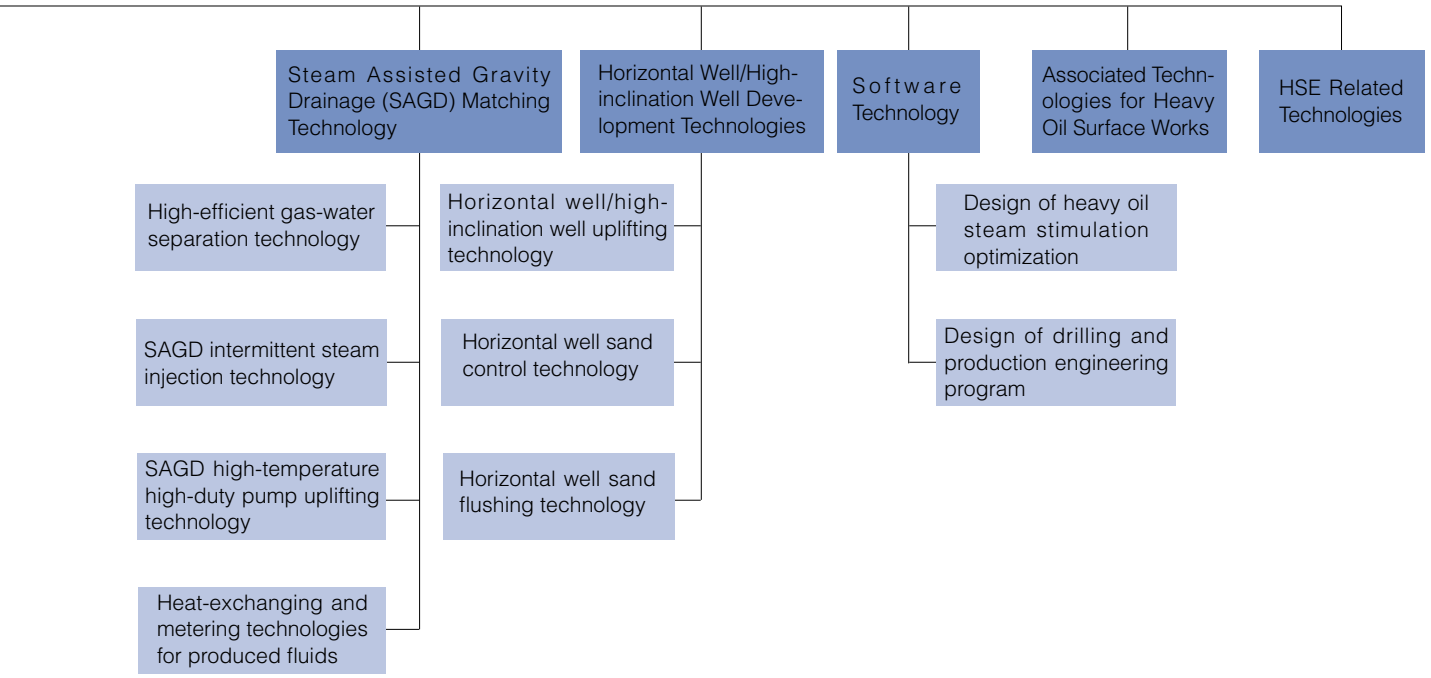
Since 1970, CNPC has devoted to the research and practice of recovery technologies for heavy oil and super heavy oil. CNPC has successfully recovered the world-class heavy oil with viscosity of up to hundreds of thousands centipoise. A group of professionals in the thermal recovery of heavy oil, combined with efficient associated tools and equipment which support, CNPC to provide various technolongical services related to thermal recovery of heavy oil.

CNPC independently developed 45 practical technologies in 10 major series for thermal recovery of heavy oil. These technologies include Comprehensive Design Technology for Development Plan of Heavy Oil, Steam Stimulation Recovery Technology, Sand Control Technology, High-temperature Testing and Tracing Monitoring Technology, Associated Steam Flooding Technology, Steam Assisted Gravity Drainage (SAGD) Technology, Horizontal Well/high-angle Well Recovery Technology, Software Technology, Heavy Oil Surface Works Technology and HSE Related Technologies.

Thermal Recovery Technology for Heavy Oil has been also successfully applied in Liaohe, Shengli, Henan, Xinjiang Uygur Autonomous Region, Dagang and Jilin and other heavy oil producing areas of China, and also in heavy oil producing countries of Sudan, Kazakhstan and Venezuela.

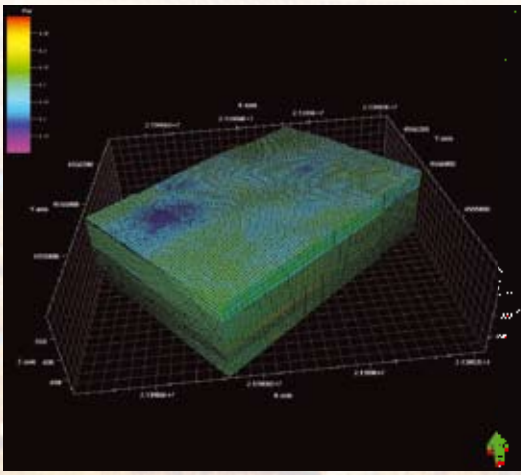




Heavy Oil Thermal Recovery Technologies
Comprehensive Design Technology for Heavy Oil Development Program
Steam Stimulation Recovery Technology
Steam injection technology
Uplifting technology
Enhancement of steam stimulation performances for heavy oil development
Sand Control Technology
Mechanical sand control technology
Chemical sand control technology
Composite sand control technology
Well bore series sand dumping technology
High-temperature Testing and Tracing Monitoring Technology
Surface dryness distribution and steam injection parameter monitoring technology
High-temperature steam injection well steam profile testing technology
Random-downhole steam dryness sampling and testing technology
Testing technologies for pressure reduction in capillary well shut-in
High-temperature dual-point testing technology for elementary error well temperature
Testing technology for profile of produced fluids during venting of high-temperature steam injection
High-temperature durable test technology
Cross-pump direct-reading monitoring technology for oil wells
Capillary delaminated pressure & temperature dynamic monitoring technology
SAGD multi-point temperature & pressure dynamic monitoring technology
Optical fiber temperature & pressure monitoring technology for oil wells
Cross well tracing monitoring technologies
Associated Steam Flooding Technology
High-temperature durable insulating steam injection technology
Delaminated steam flooding technology
Steam flooding high-temperature lifting pump
High-temperature snubbing operation technology


Steam Assisted Gravity Drainage (SAGD) Matching Technology
Horizontal Well/High-inclination Well Development Technologies
Software Technology
Associated Technologies for Heavy Oil Surface Works
HSE Related Technologies
High-efficient gas-water separation technology
SAGD intermittent steam injection technology
SAGD high-temperature high-duty pump uplifting technology
Heat-exchanging and metering technologies for produced fluids
Horizontal well/high-inclination well uplifting technology
Horizontal well sand control technology
Horizontal well sand flushing technology
Design of heavy oil steam stimulation optimization
Design of drilling and production engineering program

# 2 UNIQUE TECHNOLOGIES

## 1. Comprehensive Design Technology for Development Program of Heavy Oil



During the thermal recovery of heavy oil, researches should be conducted to cope with different types of oil reservoirs and specific features of different development stages. Accordingly, physical simulation, numerical simulation, economic assessment and other technologies should be applied on the basis of the reservoir description and in-house experiment. In this way, multiple development programs involving different recovery methods, development sequences, well patterns, well intervals, injection & production parameter optimizations and various other policy-making technologies can be assessed not only to identify the best development programs butalso to ensure high-efficient recovery and sufficient space for future adjustments. Development methods for the heavy oil reservoirs should be based on the latest technologies with economic efficiency and recovery factor as main objectives to cope with the specific reservoir conditions and properties of the contained oil.

CNPC has prepared and implemented the development programs for 15 blocks with reserve of over 25 million tons in each block. Conformity between implementation outcomes and designed indexes is over 95%. It can be seen that the prepared programs are highly scientific with favorable predictive and operability characters. In other words, these programs can provide favorable guide for the development.

At the same time, CNPC's thermal recovery technologies for heavy oil also updated the screening criteria of development modes for heavy oil both at home and overseas.

**Screening criteria of development mode for heavy oil in CNPC**

| Development mode | Steam stimulation | Steam flooding | SAGD |
|---|---|---|---|
| Buried depth of reservoir (m) | <1,800 | <1,400 | <1,000 |
| Thickness of oil zone (m) | ⩾ 10 | 7~60 | ⩾ 10 |
| Net-total thickness ratio | ⩾ 0.35 | ⩾ 0.4 | ⩾ 0.5 |
| Effective porosity (%) | ⩾ 20 | ⩾ 20 | ⩾ 20 |
| Permeability ($10^{-3}\mu m^2$) | ⩾ 200 | ⩾ 200 | $K_v/K_h$ ⩾ 0.35 |
| Crude oil viscosity (mPa·s) | ⩽ 400,000 | ⩽ 10,000 | ⩽ 400,000 |
| Original oil saturation (%) | ⩾ 55 | ⩾ 45 | ⩾ 50 |
| Permeability variation coefficient (decimal fraction) | | ⩽ 0.65 | ⩽ 0.65 |

## 2. Steam Stimulation Recovery Technology

Steam stimulation is also known as periodic steam injection or cyclic steam injection method. With simple application, quick production enhancement and high economic efficiency, steam stimulation is the most popular method for heavy oil development. CNPC is an outstanding representative for the development of heavy oil reservoirs by the use of steam stimulation in China. Through years'researches and development, CNPC has established an entire package of proprietary practical technologies for the reservoir development by the use of steam stimulation. These technologies can be divided in three series, Steam Injection Matching Technology, Uplifting Associated Technology, Enhanced Heavy Oil Steam Stimulation Recovery Technology, Which are ten major thermal injection and production technologies. These technologies can provide powerful supports and guarantee to production incremental and enhancement of recovery factors in oilfields.

### Steam injection technology

Core of the steam injection technology is the borehole steam injection thermal insulated tubing. Thermal insulated tubing may minimize heat losses during steam injection. CNPC independently developed steam-injection thermal insulated tubing composed by vacuum insulation pipe, extension pipe and heat-sensitive packer. Apparent conducting factor of the vacuum insulation pipe may be up to 0.007W/(m · ˚C) and efficiency of heat-sensitive packer may reach 98.4%. Successful rate of blockage removal is 100%. Borehole steam injection thermal insulated tubing developed by CNPC is one of the most efficient thermal insulated tubing around the world.

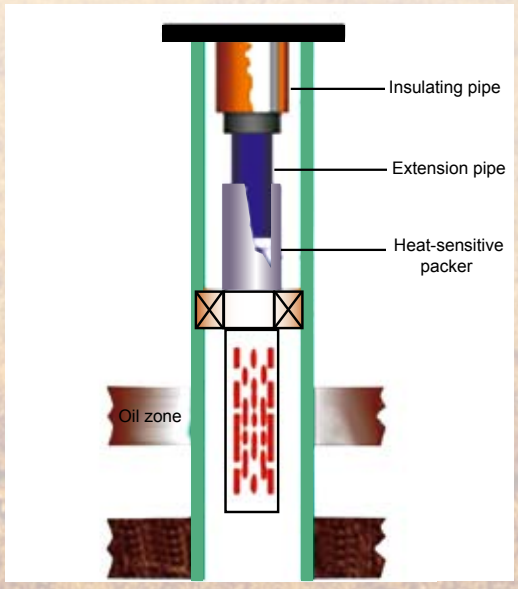
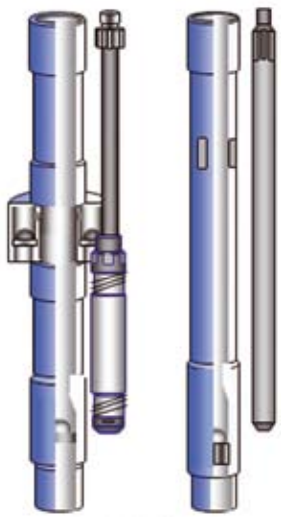



Diagram for K331 heat-sensitive packer and steam injection thermal insulated tubing

## Uplifting technology

Uplifting technology is composed by heavy oil uplifting, extra heavy, super heavy oil uplifting assemblies. At present, there are heavy oil pumps of 16 models in 3 series; 14, 16, 20, 22t loading capacity 5~8m stroke sucking pump series; application of Grade H sucker rod; application of anti-sand pump; moderate-frequency skin effect empty pipe cross-pump electric heating technologies and new formulate active water technologies.



Dual-stage heavy-oil pump (left)
Primary pipe column with dynamic sealing (right)

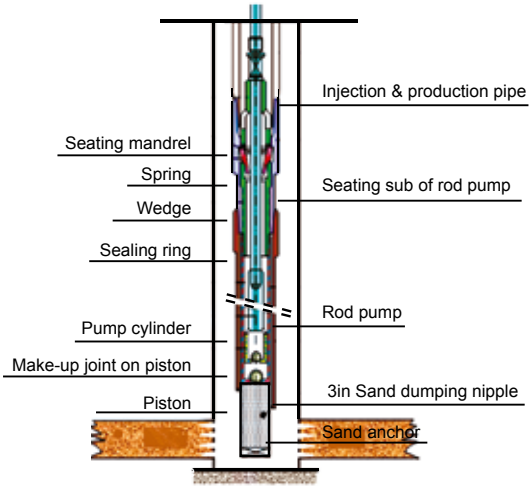



Diagram of injection, production, flushing and prevention string

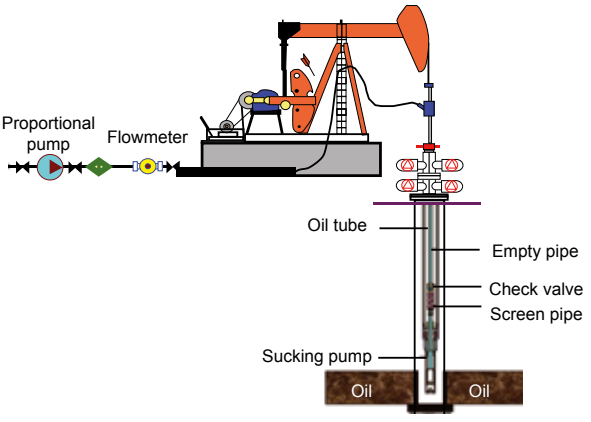
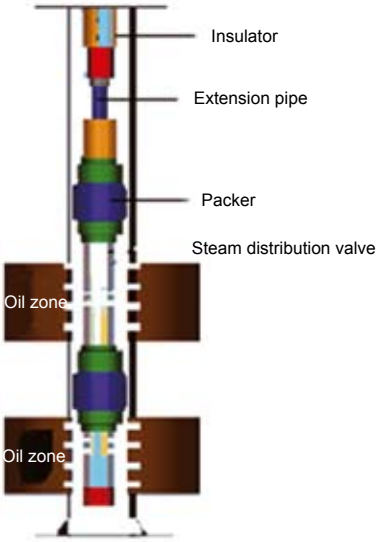
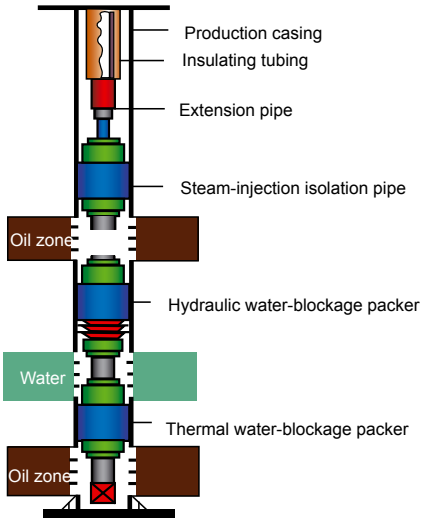


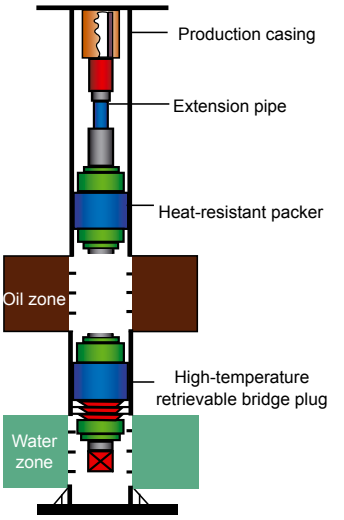

Diagram of cross-pump electric heating technology




Delaminated steam injection pipe string




Primary string for blockage of formation water and for steam injection




Primary string for blockage of bottom water and for steam injection

## Technologies for enhancement of heavy oil steam stimulation recovery performance

Technologies for enhancement of heavy oil steam stimulation recovery performance are the most special steam stimulation recovery technologies developed by CNPC. These technologies include 7 independent stand-alone technologies:

- Delaminated injection & production technologies;
- Heavy oil profile control, channeling-blockage technologies;
- Technologies to enhance steam stimulation performance by use of chemical additives;
- Technologies to enhance thermal efficiency of thermal recovery system;
- Comprehensive utilization techniques of nitrogen;
- $CO_2$ huff and puff recovery technologies;
- Technologies for restoration of casing-damaged well for thermal recovery.

Comprehensive application of above-mentioned 7 technologies can effectively enhance heavy oil steam stimulation recovery performances.

## 3. Sand control technology

Sand control is a key in heavy oil development. Through 20 years' studies and researches, CNPC independently developed mechanical sand control, chemical sand control and composite sand control technologies. CNPC is the pioneer for sand-control technologies in heavy oil development in China. These are nation-leading and world-class technologies.

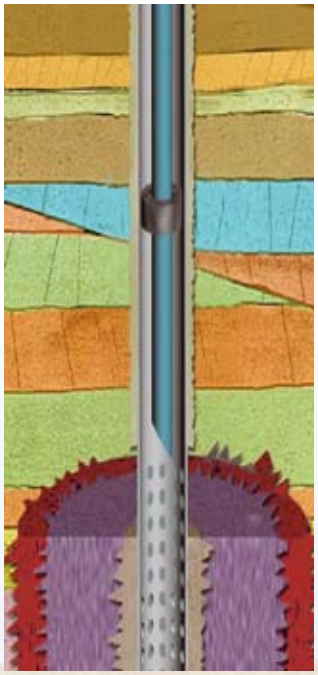
### Series of mechanical sand control technologies

The series are represented by TBS screen pipe and expandable screen pipe. TBS screen pipe has been applied in over one thousand heavy oil wells with sand particle diameter larger than 0.003inches and casing deformation wells; the expandable screen pipes are mainly used for sand control in thin oil.

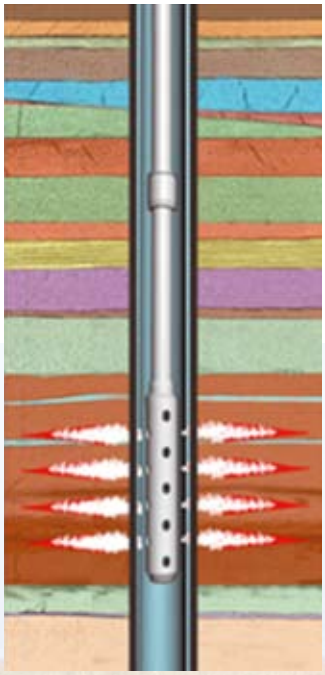
Expandable screen pipe for sand control

TBS screen pipe for sand control

Mechanical fracturing for sand control



Chemical fracturing for sand control



Composite perforation for sand control

## Series of chemical sand control technologies

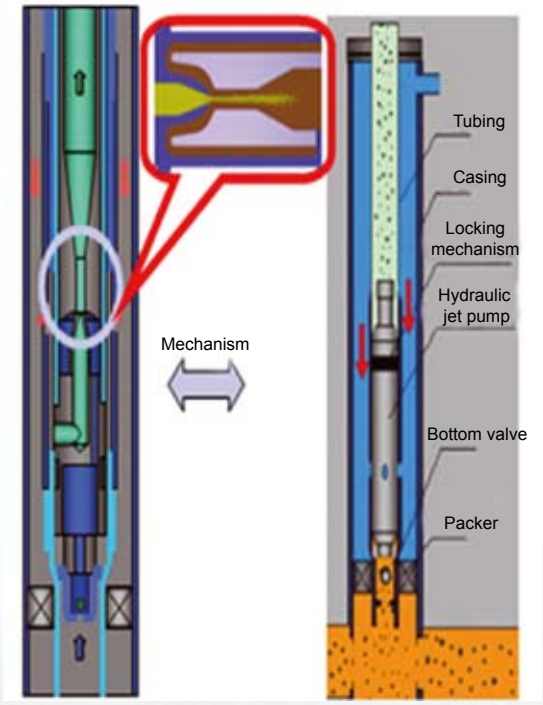
The series are represented by high-temperature sand consolidating technology. The technology can tightly bond formation sands under high-temperature to form a filtering sand formation, which can prevent formation sand from flowing into well bore and consequently achieve sand control objectives. There are more than 10 chemical sand control methods with high temperature sand consolidating as the representative. The high temperature sand consolidating technology has been applied in 316 wells with successful rate of 100% and sand control efficiency of 93%..

## Series of composite sand-control technologies

The series include composite perforation and fracturing technologies. Composite perforation may introduce sand-control materials into formation during perforation. It is a characteristic technology developed by CNPC and has been applied in new wells and/or new formation in more than 300 wells, with controlled sand diameter larger than 0.004in, well depth less than 6562ft and successful rate in heavy oil well is 100%.

Fracturing can be applied to sand control in wells with fine sand particle production, in casing deformation wells and in small hole well for heavy oil development. The technology is especially useful for wells with low productivity and low permeability.

Sand removal by use of sucker rod series pumps




Enforced sand removal by use of reverse circulation hydraulic jet pump

## Well bore series sand control technologies

Well bore series sand dumping technologies include sucker rod pump series sand dumping and reverse circulation hydraulic jet pump forced sand dumping technologies.

Sucker rod pump series sand dumping can apply to following 5 circumstances:

- Inclined wells and horizontal well characterized by large discharging capacity, high sand contents, high-temperature steam flooding with pump depth no larger than.
- Oil wells with moderate to low productivity, poor sand-carrying capacities of fluids and oil wells susceptible to sand stuck and sand-burying of pipe plugs
- Oil wells susceptible to pump stuck during steam flooding under high-temperature.
- Oil producer with low sand contents
- Oil producer with moderate to low sand contents, wells with restored pumping rod and oil wells with pump depth less than.

Reverse circulation hydraulic jet pump forced sand dumping can apply to following 3 circumstances:

- Sand content of producer is less than 3% (volumetric ratio);
- Downhole pumping rate188-629 bbl/d;
- Pump setting depth less than 4921ft.

## 4. High-temperature testing and tracing monitoring technology

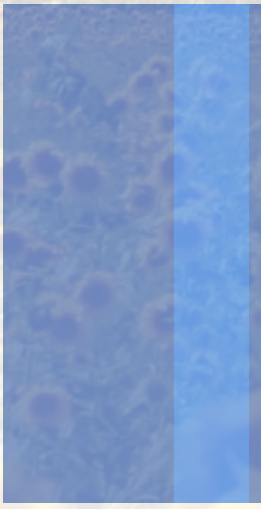
CNPC has matured high-temperature, normal temperature oil well monitoring technology. In addition, it developed a series of high-temperature testing technologies to cope with specific features of steam injection in heavy oil producing wells. The data of whole process from steam injection, well shut-in, venting and production of heavy oil can be monitored to construct high-temperature testing technologies related to steam stimulation, steam flooding and SAGD. Various monitoring technologies can provide oilfield development with abundant first-hand data to actualized effective guides to heavy oil development. In addition, these technologies can plan an important role in deduction of costs, enhancement of recovery factor and increases of reservoir/recovery ratio. Accordingly, favorable economic efficiency can be achieved.

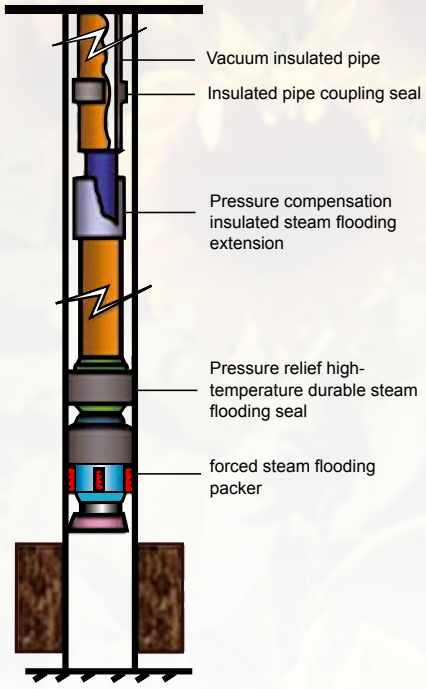
In addition, CNPC developed and imported several advanced well test interpretation software. Accordingly, CNPC has quite high standards for oil well data interpretation.

The high-temperature testing and trace monitoring technologies include following 12 stand-alone technologies:

- Surface dryness distribution and steam injection parameter monitoring technology
- High-temperature steam injection well steam profile testing technology
- Technologies for testing of steam dryness at any given downhole location
- Testing technologies for pressure reduction in capillary well shut-in
- High-temperature dual-point testing technologies for elementary error well temperature
- Testing technologies for profile of produced fluids during venting of high-temperature steam injection
- High-temperature durable test technologies
- Cross-pump direct-reading monitoring technology for oil wells
- Capillary delaminated pressure & temperature dynamic monitoring technology
- SAGD multi-point temperature & pressure dynamic Monitoring Technology
- Optical fiber temperature & pressure monitoring technology for oil wells
- Inter well tracing monitoring technology

## 5. Associated steam flooding technologies




High temperature durable thermal-insulating steam injection technology

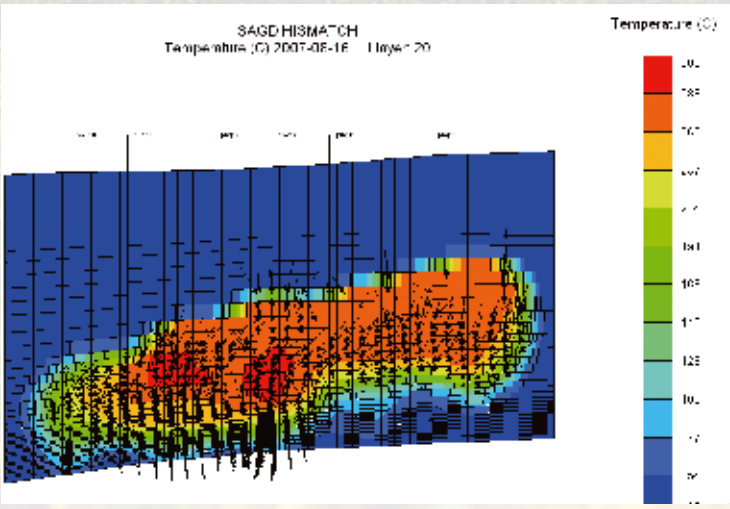
Steam flooding development of heavy oil reservoirs can be implemented after steam stimulation recovery. It is a thermal recovery stage to further enhance crude oil recovery factor. During steam flooding recovery, dry steam will be injected continuously to heat up the oil zone and consequently significantly reduce crude oil viscosity. In addition, the hot fluids injected can drive the crude oil into surrounding producers and eventually enhance crude oil recovery factor 20%~30%. Though steam flooding may consume much more steam than steam stimulation, but it is the major thermal recovery stage. Upon years of researches and studies, break through has been made in steam flooding recovery of heavy oil at all possible depths. Presently, it is possible to develop heavy oil reservoirs in moderate to deep formation by use of steam flooding. High temperature durable insulating steam injection, delaminated steam flooding, high-temperature uplifting, high-temperature snubbing operation and some matching technologies have been developed to ensure large-scale development by use of steam flooding technologies. Favorable economic efficiency and social benefits have been achieved accordingly.

CNPC is the most competitive provider of steam flooding matching technologies in China.

Steam-flooding matching technologies of CNPC include four stand-alone technologies:

- High-temperature durable insulating steam injection technologies
- Delaminated steam flooding technologies
- Steam flooding high-temperature lifting pump
- High-temperature snubbing operation technologies

## 6. Steam Assisted Gravity Drainage (SAGD) technologies




Steam Assisted Gravity Drainage (SAGD) is a technology involving injection of steam into oil reservoir through a vertical or a horizontal producer above horizontal well in vicinity of reservoir bottom. Heated crude oil and condensates of steam can be produced through the horizontal well at the bottom of the reservoir. This technology is characterized by high production capacity, high oil/gas ratio, high final recovery factor, reduced inter-well interference and minimized premature inter-well channeling. In the past years, CNPC continuous developed methods for conversion of development methods for recovery after steam stimulation of super heavy oil. In early 2005, SAGD development involving combination of vertical well and horizontal well was implemented successfully in Guantao Formation (with average depth of 600m). During the process, high efficient gas/oil separation, intermittent steam injection, high-temperature high-duty uplifting, metering of heat in produced fluids and matching technologies were developed successfully. At the same time, favorable SAGD development performances have been obtained through dynamic tracing and optimization. Trend of production reduction has been turned and productivity increased together with enlargement of steam chamber.

Associated Steam Assisted Gravity Drainage (SAGD) technologies are mainly composed by following four stand-alone technologies:

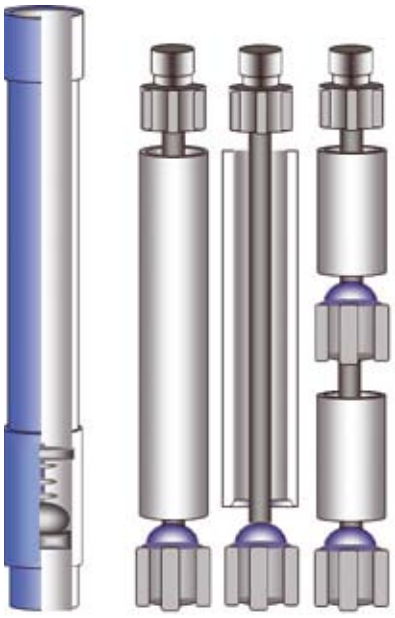
- High-efficient gas-water separation technologies
- SAGD intermittent steam injection technologies
- SAGD high-temperature high-duty pump uplifting technologies
- Heat-exchanging and metering technologies for produced fluids

## 7. Horizontal well/high-inclination well production technology

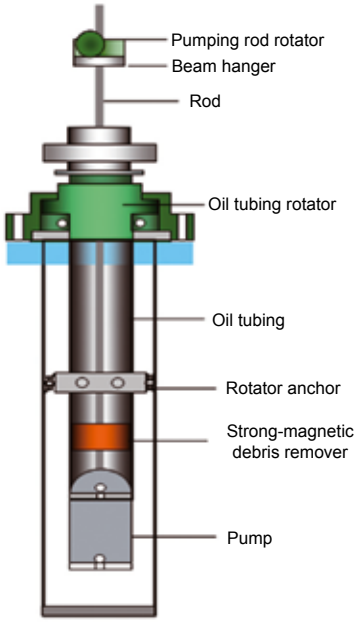
Horizontal well/high-inclination well production technologies are among the most matured technologies of CNPC. Through years of active research, a series of matching technologies including horizontal well uplifting, horizontal well dumping and horizontal well development technologies to cope with difficulties related to horizontal wells. These technologies can provide powerful supports for industrialization of horizontal well. Accordingly, CNPC has become a strong provider for horizontal well / high-inclination well development technologies in China.

Horizontal well/high-inclination well production technologies of LPEA is composed by following three components:

- Horizontal well/high-inclination well uplifting technologies
- Horizontal well sand control technologies
- Horizontal well sand flushing technologies



High-inclination well, horizontal well sucker rod pump




High-inclination well anti-eccentrically worn string

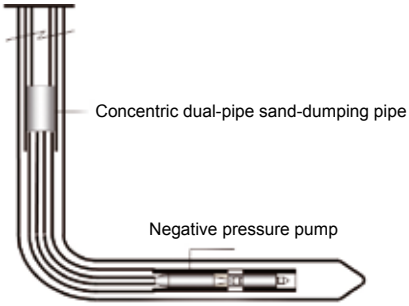



Diagram for negative-pressure sand dumping in horizontal well

## 8. Software technology

Practical development software is one of key element in Liaohe heavy oil development. After researches and studies in the past 20 some years, two series of design software systems have been developed: heavy oil steam stimulation software include parameter optimum design, delaminated selective steam flooding design expert system; steam flooding optimum design software, drilling and completion design software for horizontal well and multi-branch wells, production engineering optimum design software.

## 9. Associated technologies for heavy oil surface works

It is possible to provide gathering & transportation program, gathering & transportation system, injection system, heat utilization system optimum design and equipment selection for heavy oil, extremely heavy oil, super heavy oil development by water injection, steam injection and in situ combustion. Major design works include 48 large-scale heavy oil stations, 28 gathering & transportation system with long-distance pipeline network of $4\times10^3$m.

3 super heavy oil (viscosity>50000mPa·s) transportation pipelines with length over 10km have been constructed.

Leng-1 centralized crude oil processing station

Huansanlian advanced heavy oil sewage treatment station

## Patents

With 174 patents for invention and 887 patents of utility models, CNPC fully deserves the position as the cradle for heavy oil production technologies in China. Achievements in thermal recovery of heavy oil development in Liaohe can be traced back to development of recovery technologies for heavy oil in the world, and in return, we will make our contributions to development of heavy oil in the world by use of state-of-art and most efficient technologies.

| | |
|---|---|
| CN200510046164.9 | Technology for recovery of heavy oil and high pour-point oil |
| CN200610047361.7 | Coal-burning steam injection boiler for heavy oil development |
| CN2005101308190 | Wellhead assemblies for development of heavy oil by use of SAGD technologies in horizontal well |
| CN200510046518x | Technologies and methods for removal of silica from heavy oil-containing sewage |
| CN200610047824.x | Wellhead assemblies for geologic observation wells for steam assisted gravity drainage of heavy oil |
| CN97110664.9 | Low carbon mixing organic acid syntheses |
| CN200410050456.5 | Tri-phase high-temperature foam profile control agent and profile control method |
| CN97115718.9 | Ultrasonic inspection of ring seams on insulating oil tubing |
| CN200610047561.2 | Liquid fuel for industrial boiler with power coal and diesel and its preparation |
| CN200610047783.4 | Utilization of hot coal gas as fuel for steam injection boiler in thermal recovery of heavy oil |
| CN200610047635.2 | Utilization of coal slurry as fuel for steam injection boiler in thermal recovery of heavy oil |
| CN200410050457.x | Technology for integration of profile control and sand control in thermal recovery well |
| CN200510046330.5 | Technology for thermal chemical de-watering of super heavy oil |
| CN03134161.6 | Implementation of integrated water-blockage, profile control and sand control for heavy oil development |
| CN2005100459719 | A method for processing of heavy oil sludge |
| CN99113250.5 | A high-temperature temporary blocking agent and its preparation method |
| CN981137415 | A polymer-based crude oil demulsifier |
| CN2005100465194 | Transportation and matching utilities of de-watered super heavy oil through pipes |
| CN981137407 | Emulsifier and viscosity reducer for emulsification and combustion of super heavy oil |
| CN981137423 | A crude oil demulsifier and its preparation method |
| CN981142729 | A fluorescence-free anti-caving Fluid Loss Additive and its preparation |
| CN97115719.7 | Vacuum insulating oil tubing and fabrication technologies |
| CN200610047636.7 | Retrievable whipstock assembly |
| CN200610045686.1 | Jet welding of valve plate and seating in wellhead of thermal recovery wells for heavy oil by use of nickel-based alloy |
| CN2006100464478 | Technology for water blockage, profile control and channeling-blockage by use of heat-sensitive water-soluble gel |
| CN200610047780.0 | A selective guiding tool for branch well |
| CN200610047915.3 | Selective re-entry method and assemblies for multi-branch wells |
| CN2005100460398 | A dynamic monitoring method for oil reservoirs by use of biological marker compounds |
| CN2005100479676 | Testing technologies for control of delaminated oil production by use of electric cable in oil wells |
| CN021324484 | Vacuum pipe sand removal technology and related borehole assemblies |

# 3 TYPICAL CASES

## I. Development of heavy oil reservoirs in moderate and deep formation

Block Leng-41 is the first super heavy oil reservoir successfully developed by use of steam stimulation in Liaohe Oilfield. Average porosity of the oil reservoir is 17%, average permeability is 1381mD, and de-gas at crude oil viscosity 50˚C is up to 30000~60000mPa·s.

Through steam stimulation test, it was found that the wellbore insulation technologies can be improved significantly with steam dryness injected in oil zone up to over 45%. Total oil production in the first cycle of steam stimulation is 4500t. Development of the reservoir pave new ways for development of super heavy oil in deep formation.

The Block have been developed by steam injection for almost 10 years with maximum oil recovery speed of up to 2.6%, and average oil recovery speed of 1.26%. In the 2005, oil recovery speed was up to 1.46% and recover rate was 15%.

## II. High-temperature snubbing operation technologies

On-site tests for pressurized sand-dumping for the technology were conducted from May 22 to 31, 2006 in Well Magu-5 of Xingcai Plant. All expected goals have been achieved in the test. In addition to open flow capacities, the test also confirmed practicability and reliability of high-temperature snubbing equipment.

## III. Development of one of the heaviest super heavy oil reservoirs in the w orld

Steam stimulation tests for recovery of super heavy oil were conducted in 1996. By optimization of development formation, well pattern, well interval, steam injection parameters and by adoption of well bore steam injection insulation and well bore production by use of uplifting technologies, rational steam injection parameters and drilling pipes integrating injection and production capacities can tackle difficulties in steam injection, low heat-utilization ratio and difficulties in pump installation and uplifting operations for super heavy oil development. Consequently, these technologies can effectively promote development of super heavy oil. In the year 2006, production of super heavy oil was $277\times10^4$t, or 43.1% of heavy oil productions recovered through thermal recovery.

## IV. Successful conversion from steam stimulation to steam flooding for development of average heavy oil reservoirs in moderate and deep formation

Lianhua Formaiton in Block Qi-40 has buried depth of 1050m with average effective thickness of oil zone of 37.7m. According to core analysis, average porosity is 31.5%, average permeability is 2.062D. Specific gravity of crude oil at 20˚C is 0.9686g/cm3, and viscosity of gas-free crude oil at 50˚C is 2639.0mPa·s..

By the end of 2004, Block Qi-40 had been developed by steam injection for 18 years with favorable performances. Total recovery was 29.44%, average annual oil recovery speed was 1.6% and total oil/gas ratio is 0.61. According to changes in dimensionless oil recovery speed and recover rate of recoverable reserves, Block Qi-40 had entered a stage characterized by quick reduction in productivity. With recovery rate of recoverable reserves at 90.96%, it had been necessary to convert to other feasible development methods in timely manner.

Upon converting to steam flooding, significant performances have been observed. Daily fluid production of the wells increased from 325.9 t/d in heat-channel stage to the current 602.0 t/d. Daily oil production increased from 71.2 t/d to the current 95.9 t/d. Till the end of December 2006, over all water content was 69.5%, oil recovery speed was 1.52% and total recovery rate was 31.5%.

## V. Outstanding performance of super heavy oil development by converting steam stimulation to SAGD development

Testing area of Guantao Formation was converted to SAGD development formally in February 2005. It has been two years since the development method was converted to SAGD. According to dynamic tracing, optimization and adjustment, it was determined that outstanding performances have been achieved through SAGD. All production indexes reached expected level. Daily oil production has been increased from 150t/d to the present 330t/d. Average oil recovery speed in the past two years with SAGD was 3.3%. At present, converted oil recovery speed is 4.9% and oil/gas ratio at present phase is 0.22. With enlargement of steam chamber, production may be further promoted. It was predicted that final recovery factor for steam stimulation—SAGD development may be up to 56%.

# 4 SCIENTIFIC RESEARCH EQUIPMENT

## Oilfield development:

### Hardware and equipment

**Servers:** SUN1 0000, SUN2000E are mainly used for researches related to reservoir description and numerical simulation.

**Workstation:** Ultra60, Ultra2, SGI and other 10 more suits of workstations are used mainly for reservoir description and numerical simulation.. They can actualize data sharing through intranet of the enterprise.

**Personal graphic workstation:** There are more than 20 suits of HP personal graphic workstations mainly used for reservoir geological and engineering studies.

### Application software

**Reservoir description software:**

LandMark, GNTJason reservoir parameter inversion software package: Major modules include seismic impedance inversion, logging inversion, random geologic modeling.

**Reservoir engineering software:**

Workbench integrate dark oil numerical simulation software package (may conduct production data analysis, well test analysis, reservoir description and 3D tri-phase light oil numerical simulation researches);

**CMG numerical simulation software package** includes STARS, IMEX module and they can be used for numerical simulation researches related to dark oil, thermal recovery and chemical flooding;

**NUMSIP-5 thermal recovery numerical simulation software package:** Cooperate with Tsinghua University to jointly develop numerical simulation software package capable of parallel calculation and processing capacities for thermal recovery of heavy oil;

**THERM advanced, THERM2.7:** imported numerical simulation software for thermal recovery developed by SSI of United States;

Geologic research and oil reservoir engineering research software and economic assessment; Seismic data interpretation software: LANDMARK, DV, KINGDOM;

Seismic data inversion software: JASON;

Logging data processing and interpretation software: Landmark (PetroWorks), LGI, Forward.net;

Reservoir modeling software: Petrel, GMSS.

## Production engineering:

There are 9 major laboratories: Reservoir Protection Research Laboratory, Recovery Chemical Agent Testing Laboratory, Subsurface Tool Laboratory, Injection Water Quality Analysis and Testing Laboratory, High-temperature Rubber Testing Laboratory, Chemical Sand Control Laboratory, Mechanical Sand Control Laboratory, Microbio Production Laboratory and High-temperature Testing Instrument Calibration Laboratory.

CNPC is capable of conducting in-flow liquid quality monitoring & inspection, oil-recovery chemical agent testing, wet steam safety valve calibration, rubber product inspection, subsurface tool testing and subsurface sucker rod pump testing. In addition, it is going to establish a heavy oil pilot test base-Drilling and Production Technology Testing and Research Center. The Center includes sand-control modeling test assemblies, high-temperature produced fluids on-line test skid, delaminated steam injection testing apparatus, multi-functional sucker rod pump uplifting modeling & testing systems, gate valve inspection and testing assemblies and simulated well for thermal recovery.

Major application software: heavy oil steam stimulation optimum design software and drilling engineering program design software. Major functions include heavy oil steam stimulation parameter optimum design, heavy oil separate & selective injection expert system, heavy oil steam flooding optimum design, horizontal well, branch well drilling & completion optimum design, production engineering optimum design etc.

## Surface works:

It is equipped with state-of-art computer network and scientific information system, advanced publishing, documentation, library and scientific experimental utilities. It has over 10 software packages for oil & gas storage & transportation, gathering & transportation, processing technology design and processing calculation. With 21 Grade A certificates and 12 Grade B certificates, it is one of the leading players in the industry as far as certificates are concerned. In addition, it has design certificates for Class I, II and III pressure vessel s. In addition, it has design certificates for GA, GB and BC pressure pipes.

# 5 QUALIFICATION AND STANDARD

CNPC has 14 national Grade A certificates for overall project contracting, project engineering design and other aspects. In addition, it is Grade I construction certificates issued by Construction Ministry and Transportation Ministry. It has wined National (AAA) Credit Certificates and it has passed GB/ T19001 quality management system certification.. HSE management systems are implemented in 34 branches and 20 of these branches have passed HSE system certification.



# 6 EXPERT TEAM

**Liu Naizhen,** Senior expert of CNPC. He proposed researches related to utilization of drilling technologies for enhancement of oil reservoir development degree and oil recovery. He coordinated horizontal well implementation in over 300 wells and effectively enhanced development of heavy oil. He made outstanding contributions to enhancement of heavy oil recovery.

**Guo Yeyu,** A leading figure majored in surface engineering design and implementation technologies for heavy oil production in Liaohe Oilfield. He coordinated and accomplished surface engineering design for Block Wa-38 Oilfield, Leng-1 Centralized Crude Oil Processing Station, surface construction of Yaha Condensate Gasfield of Tarim, Du-32 Super Heavy Oil Processing Station, surface engineering design for Shuguang First Station with capacity of $2\times10^4m^3$ and other 10 some designs. He won national and provincial awards for several times.

**Liu Junrong,** He coordinated development of super heavy oil in Lengjia Oilfield and Block Shu-1. He organized importation and on-site test of SAGD, steam flooding, mixed phase flooding and other techniques. He contributed to industrialization of horizontal wells in Liahe.

**Jia Qingzhong,** One of major precipitants in first steam stimulation tests for heavy oil development. He coordinated and accomplished several heavy oil development and testing works.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