Economic and Efficient Development Technologies of Super-Heavy Oil

Science & Technology Management Department

2013

CHINA NATIONAL PETROLEUM CORPORATION

CNPC-The Technical Expert in Super-Heavy Oil Development Field !

Contents

1 Introduction	3
2 Unique Technologies	4
3 Typical Cases	13
4 R&D Equipment	14
5 Qualifications & Standards	15
6 Expert Team	17

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 2012 CNPC produced 110 million tons of crude oil and 79.82 billion cubic meters of natural gas, while crude processing volume reached 191 million tons. The total revenue of RMB 2,690 billion with a profit of RMB139.1 billion had been achieved the same year.

CNPC was ranked 4th among the world's largest 50 oil companies and 6th in Fortune Global 500 in 2012.

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.

Economic and Efficient Development Technologies of Super-Heavy Oil is one of representatives for major innovations of CNPC.

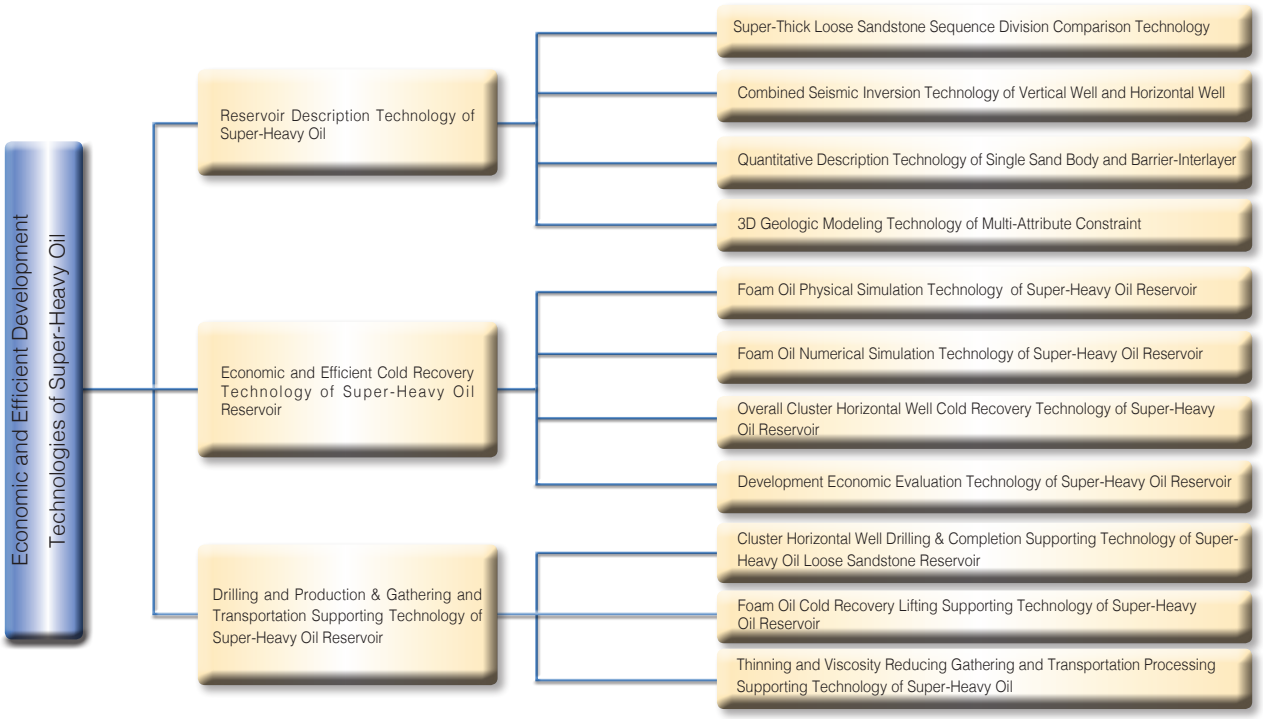
CLEAN ENERGY SUPPLY FOR BETTER ENVIRONMENT

1 INTRODUCTION

Along with the increasing depletion of conventional oil and gas resources, the development of unconventional oil resources has been getting more attention. The heavy oil belt of Venezuela with abundant super-heavy oil resources and tremendous development potential is a hot spot for various international major petroleum companies to chase at present. The super-heavy oil has such features as high density, high viscosity, high asphaltene content, high sulfur content and high heavy metal contents of V and Ni, etc.

Conventional thermal recovery and development bears a very high economic risks. By aiming at implementing the economic and efficient development of super-heavy oil, and being based on key technique researches and innovation, CNPC has formed cold recovery and development supporting technologies that are suitable for the features of such reservoir, including three technology series of super-heavy oil reservoir description technology, super-heavy oil reservoir economic and efficient cold recovery and development technology, and super-heavy oil reservoir drilling and production & gathering and transportation supporting technology that cover 10 single technologies.

The super-heavy oil development technology of CPNC has successfully applied to the production practice in the cooperative development block of the heavy oil belt, obtained remarkable economic and social benefits, sufficiently reflected the engineering level and service capacity, and won good reputation.



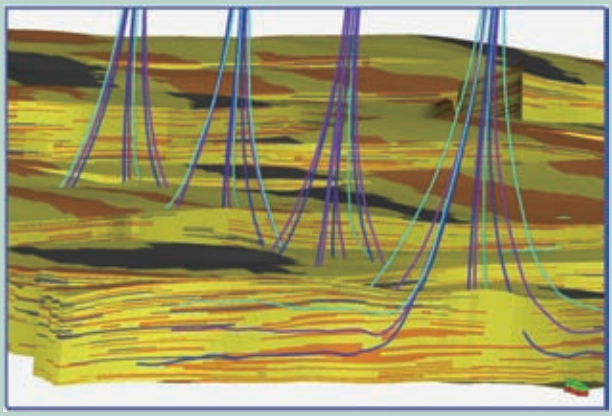
2 UNIQUE TECHNOLOGIES

2.1 Reservoir Description Technologies of Super-Heavy Oil

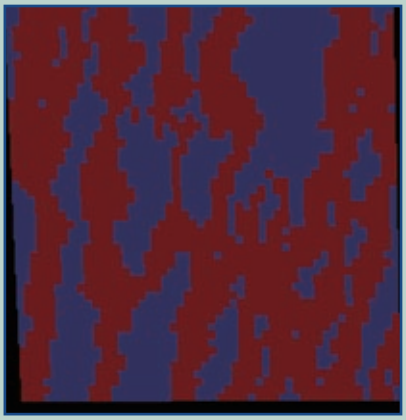
The super-heavy oil reservoir description technologies aim at the super-thick and loose features of the reservoir and integrate a long horizontal section horizontal well development mode, make quantitative recognition and characterization on such development geology characteristics as reservoir structure, reservoir, fluid etc., and builds a fine 3D geological model.

The technologies include super-thick loose sandstone sequence division comparison technology, vertical well and horizontal well combined seismic inversion technology, single sand body and barrier-interlayer quantitative description technology, and multi-attribute constraint 3D geologic modeling technology.

The super-heavy oil reservoir description technology of CNPC can implement to sufficiently integrate plenty of horizontal well information and dense well data with the seismic information to build a reservoir quantitative geological knowledge base, depict the spatial distribution of sand bodies & barriers-interlayers due to different genesis, and provide the user with an combined super-heavy oil reservoir description technology solution.



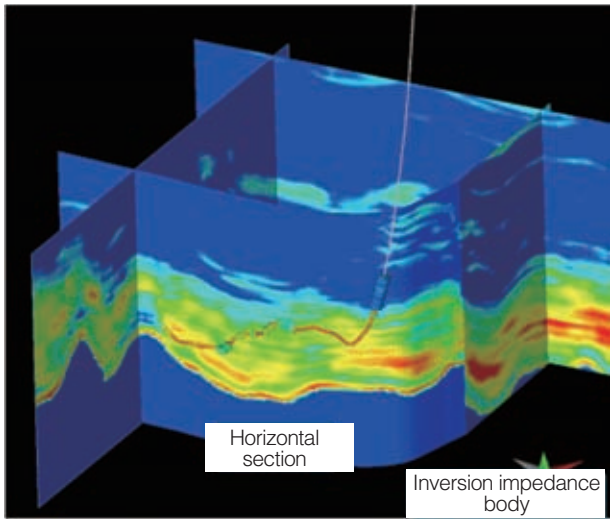
Horizontal Well Sand Body Quantitative Characterization



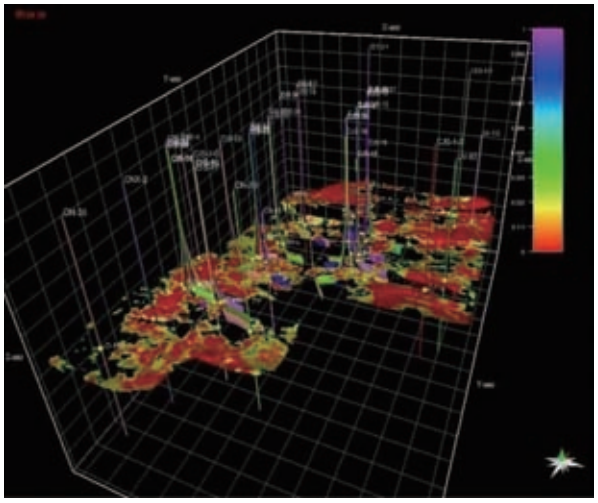
Multi-Shot Geologic Statistics Image Training

2.1.1 Combined Seismic Inversion Technology of Vertical Well and Horizontal Well

Taking porosity as a bridge and using GR and RT data the acoustic waves were restructured based on petrophysical study, which the restructured acoustic wave synthetic seismogram tallies with the well side trace, providing reliable speed information for the inversion. The well trajectory is projected on the cross-well seismic line and the seismic traces beside the well of the well trajectory is ertracted by sections according to the dip angles. The well side traces are stacked to synthesize a new seismic trace. The horizontal well synthetic seismogram with the dip angle is stacked with seismic trace to demarcate horizontal well seism.



Combined Inversion



Barriers-Interlayer Spatial Distribution Inversion Result

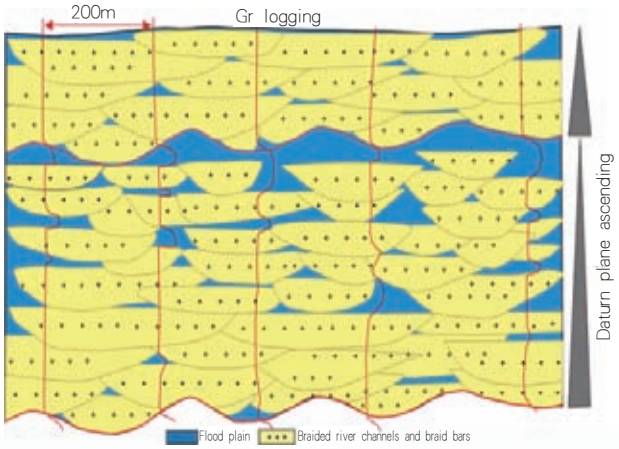
Participation of the horizontal section in the seismic inversion has greatly increased the reservoir sampling quantity participated in the inversion, obviously improved the seismic inversion precision and reliability, which effectively solves the uncertainty of reservoir prediction among the wells, outside the wells and inside the reservoir.

Applicable to horizontal well developed sandstone reservoir.

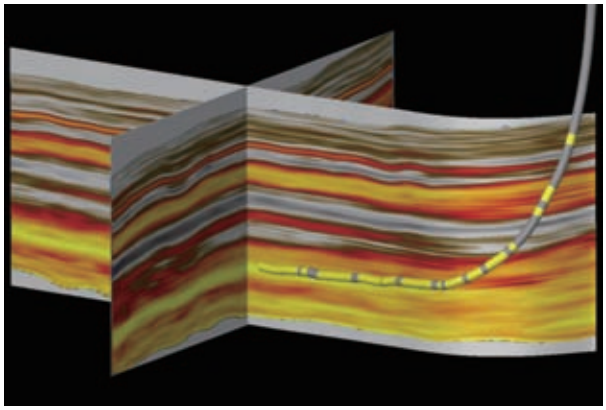
2.1.2 Quantitative Description Technology of Single Sand Body and Barrier-Interlayer

The quantitive reservoir knowledge database is built, utilizing the horizontal section information of the horizontal well and adopting the method of combining well logging with seism to quantitatively describe the geometrical characteristics of the single sand body and barrier-interlayer. By dividing barriers and the interlayers in the river facies sand body according to core analysis and geophysical response characteristics, the relation of the barriers-interlayers and bounding interfaces at different levels is obtained. Finally, the spatial distribution of the barriers-interlayers and the sedimentary units is determined, according to the barriers-interlayers recognized on the well points as well as the corresponding spatial distribution of the bounding interfaces and the quantity of the sedimentary units.

Applicable to horizontal well developed sandstone reservoir.



Sand Body Distribution Mode

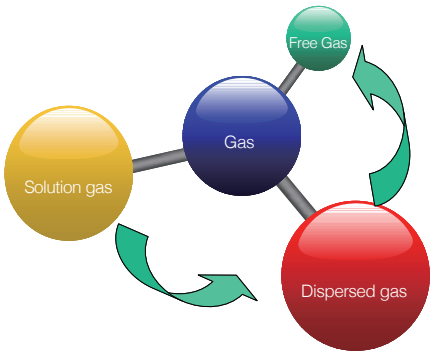


Horizontal Well Barrier-Interlayer Characterization

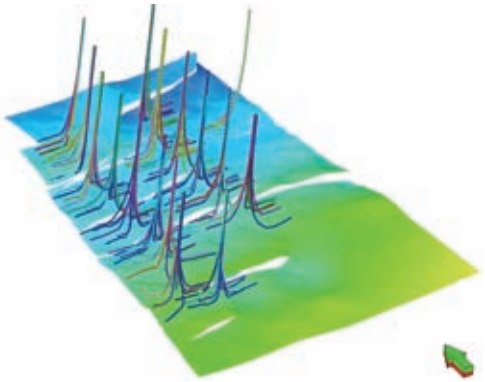
2.2 Economic and Efficient Cold Recovery Technology of Super-Heavy Oil Reservoir

The targeted and unique economic and efficient cold recovery and development technology of super-heavy oil reservoir, including foam oil physical simulation technology of super-heavy oil reservoir, foam oil numerical simulation technology of super-heavy oil reservoir and overall cluster horizontal well cold recovery technology of super-heavy oil reservoir, has been formed by aim at the unique super-heavy oil reservoir fluid features and focusing on studying the cold recovery mechanism and numerical simulation technology.

CNPC has the capacity of providing design optimization for large-scale super-heavy oil reservoir cold recovery project.

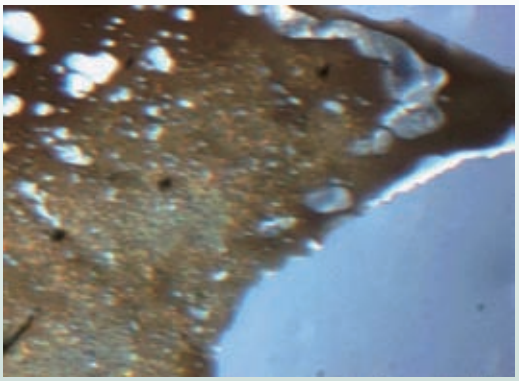


Foam oil Multi-Component Simulation Method



Overall Cluster Horizontal Well Development Well Pattern

2.2.1 Foam Oil Physical Simulation Technology of Super-Heavy Oil Reservoir



Foam Oil Microscopical Seepage Mechanism

CNPC has a set of systematic foam oil displacement physical simulation experiment method and experiment units, which are capable of disclosing the forming, coalescence and breaking micromechanism of the foam oil, unconventional PVT characteristics, displacement characteristics, rheological characteristics, percolation characteristic, etc., and capable of symmetrically analyzing various factors that affect the foam oil forming and displacing effects, and determining important parameters such as the pseudo-bubble point pressure and critical gas

saturation, etc.

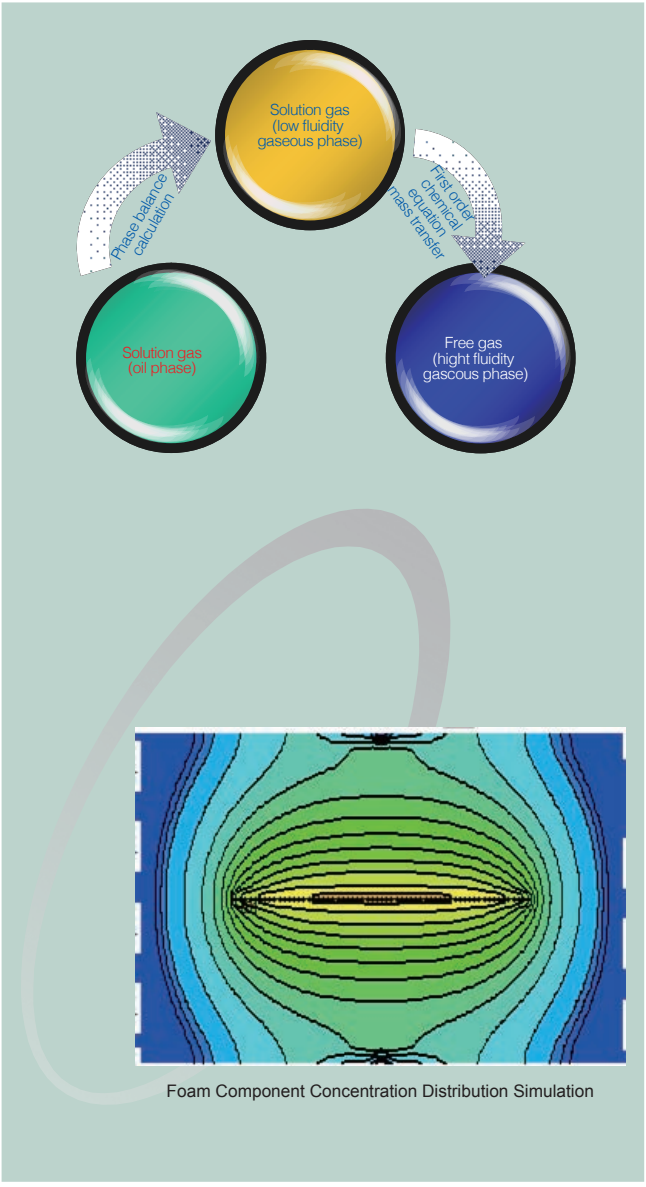
- Foam oil one-dimensional displacement physical simulation system;
- Foam oil two-dimensional microscopic physical simulation system;
- Foam oil rheological property determinator;
- Foam oil strength and stability determinator;
- Foam oil unconventional PVT determinator;

2.2.2 Foam Oil Numerical Simulation Technology of Super-Heavy Oil Reservoir

Multi-component dynamics simulation method digitally reappears the displacement process of the foam oil in porous media, which can truly disclose the process of dynamic generation, coalescence and inter-phase mass transfer of gas bubbles in underground porous media percolation condition as well as multi-phase fluid percolation characteristics during the process.

It is capable of providing effective approaches for studying foam oil depletion milling characteristics and development strategy optimization.

Applicable to foam oil cold recovery and development design optimization super-heavy oil reservoir as well as numerical simulation of cold recovery replacement development mode (gas and heat medium injection, etc).



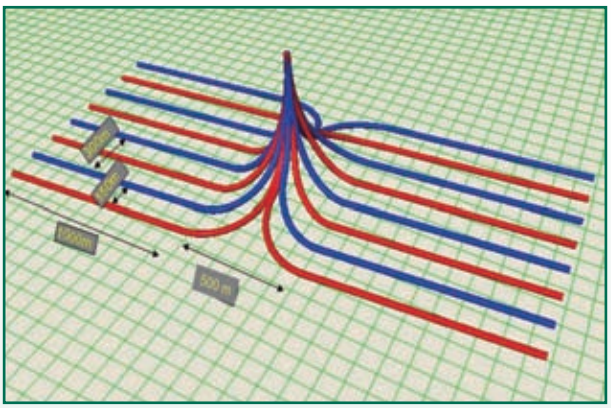
Foam Component Concentration Distribution Simulation

2.2.3 Overall Cluster Horizontal Well Cold Recovery Technology of Super-Heavy Oil Reservoir

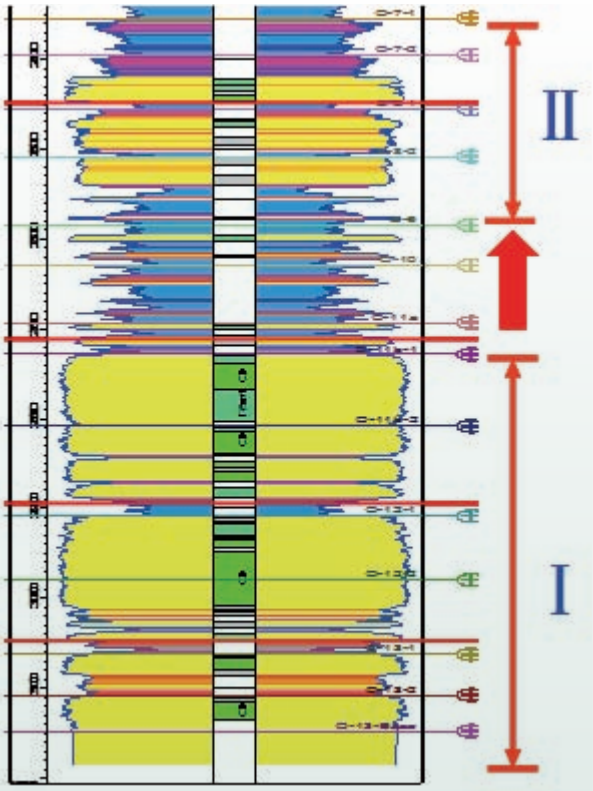
Higher oil production rate and primary recovery ratio can be obtained by optimizing horizontal well and multilateral well development design and deployment according to the recovery characteristic of the foam oil flow possessed by the super-heavy oil.

The horizontal well has large reservoir contact area, high cumulative production of single well, low milling cost and good economic benefit. Meanwhile, adopting cluster horizontal well deployment on the surface is beneficial for surface construction, oil and gas gathering and transportation management as well as environmental protection.

CNPC has the technical strategy research capacities of systematically studying and optimizing the reservoir development series of strata in middle, deep and shallow strata, well distance, well type and hole pattern and improving the cold recovery and development effects as well as the capacities of compiling large-scale super-heavy oil reservoir overall cluster horizontal well development program and development evaluation program.



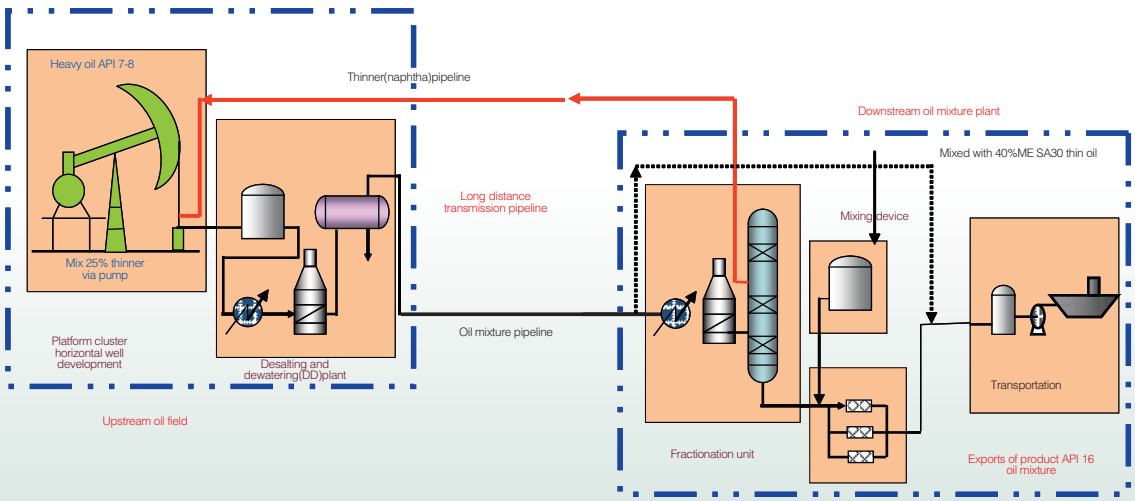
Platform Cluster Horizontal Well Hole Pattern



Division of Development Series of Strata and Inter-Strata Replacement

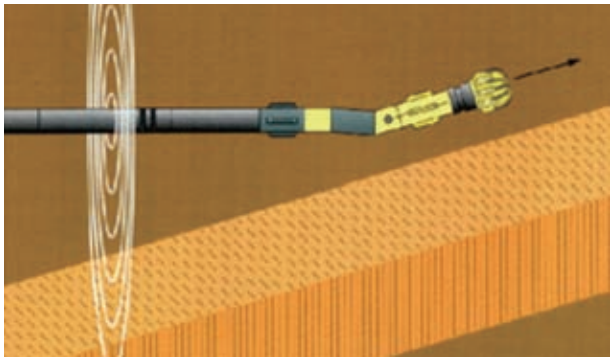
2.3 Drilling and Production & Gathering and Transportation Supporting Technology of Super-Heavy Oil Reservoir

In order to adapt to the requirements of the fluid characteristic and horizontal well cold recovery mode of super-heavy oil reservoir, and takeing the requirements of overseas operating background on economic and effective development into consideration, a series of drilling and production & gathering and transportation technology of unique super-heavy oil reservoir has been integrated, including cluster horizontal well drilling & completion supporting technology of super-heavy oil loose sandstone reservoir, foam oil cold recovery lifting supporting technology of super-heavy oil reservoir and thinning and viscosity reducing gathering and transportation processing supporting technology of super-heavy oil.



Thinning and Viscosity Reducing Non-heating Closed Reducing Gathering Process Flow

2.3.1 Cluster 3D Horizontal Well Drilling and Completion Technology of Super-Heavy Oil Loosen Sandstone Reservoir



Technologiey of Well Logging during Drilling and Measuring during Drilling

It meets the requirements of super-heavy oil loose sandstone reservoir cluster horizontal well cold recovery and development and solves the problems of design optimization and geologic steering problems of the well trajectory during the horizontal section drilling process of the horizontal well as well as sand production and control problems during the production.

- Cluster well development drilling platform plan and implementation;
- 3D horizontal well drilling of medium curvature radius;
- Welling logging during drilling and measuring the loose sandstones during drilling;
- Horizontal section near-balanced drilling;
- Slotted screen sand control completion process.

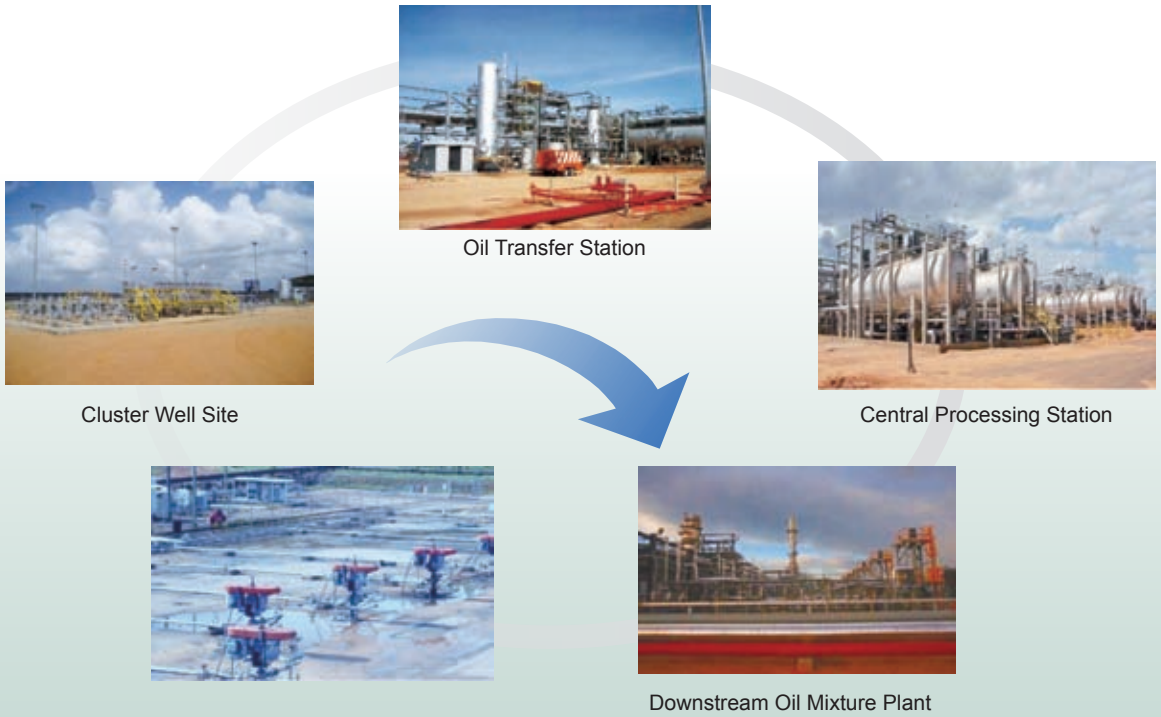
2.3.2 Foam Oil Cold Recovery Lifting Supporting Technology of Super-Heavy Oil Reservoir

Electric submersible pumps and screw pumps are choosed as super-heavy oil cold recovery lifting ways and the supporting technologies such as sand control, sand washing, gas control, thinning and viscosity reducing are adopted to solve the coexistence problem of three difficulties including dense oil, high GOR and sand production.

Bottom hole thinning and lifting of the electrical submersible pump wells is suitable for a lifting height within 2500m, a theoretical displacement of 80~900m^3/d and a reservoir crude oil viscosity range of 60~5500mPa·s, which is suitable for low sand production well lifting. The wellhead thinner mixing and lifting of the screw pump wells is suitable for a lifting height within 1700m, a theoretical displacement of 16~250m^3/d and a reservoir crude oil viscosity range of 2000~5500mPa·s, which is suitable for higher sand production well lifting.

2.3.3 Thinning and Viscosity Reducing Gathering and Transportation Processing Supporting Technology of Super-Heavy Oil

- Oil gas gathering and transportation techniques such as well site centralized construction, gas oil closed gathering and transportation, crude oil centralized treatment, produced water reinjection, comprehensive utilization of gas, etc;
- Thinning and viscosity reducing non-heating closed reducing gathering process flow;
- Oil production well site-oil transfer station-desalting and dewatering plant three-level station distribution mode;
- Intensive, efficient, environmental protection and safe.



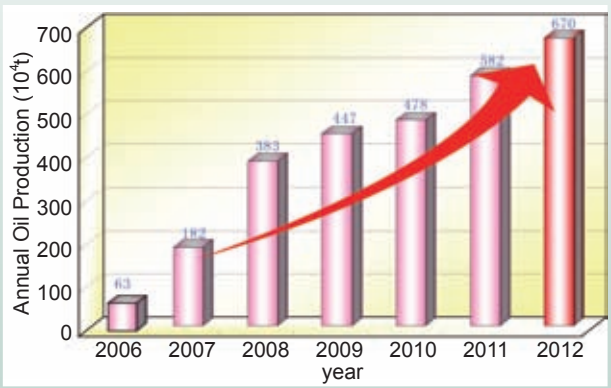
3 TYPICAL CASES

3.1 Overall Cluster Horizontal Well Cold Recovery and Development of Super-Heavy Oil Reservoir MPE3

The reservoir middle depth of MPE3 block of Orinoco heavy-oil belt in Venezuela is 2910ft, a porosity of 30%~36%, a permeability of 5~12D and an in-place crude oil viscosity of 5516mPa·s. The horizontal well foam oil cold recovery and development supporting technologies are adopted. The length of the horizontal well section is 800~1000m, the well distance is 500~600m, the average initial oil production of single well is 1200bbl/d, and the operation cost for single barrel is lower than $5USD. At present, the biggest heavy oil production base of CNPC with an annual production of 700×10^4 t has been built.

3.2 Overall Cluster Horizontal Well Development of Huning 4 Super-Heavy Oil Reservoir

Block 4 of Orinoco heavy-oil belt in Venezuela is an ultra-shallow heavy oil reservoir with a crude oil gravity of 8.5API. Overall cluster horizontal well development is adopted. The length of the horizontal well selection is 500~1000m. The well distance during the cold recovery stage is 300m. 7 ″ slotted sand control liner is hung on the horizontal section of the horizontal well for open hole completion. During the cold recovery stage, the screw pump wellhead thinning and lifting technology as well as thinning and closed gathering and transportation flows are adopted. At present, a development implementation stage has been entered and an annual super-heavy oil production capacity of 2300×10^4t will be built.



Heavy-Oil Production of MPE3 Project Over the Years

Location Map

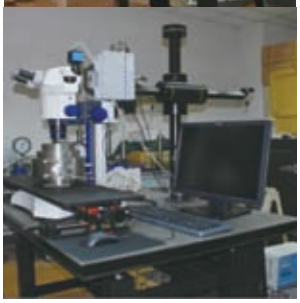
4 R&D EQUIPMENT

Depending upon State Key Laboratory of Enhancing Oil Recovery (690 sets of instruments and equipment), CNPC has experiment equipment with high quality equipments and advanced technologies on foam oil physical simulation, including foam oil one-dimensional/two-dimensional physical simulation experiments, unconventional PVT testing devices, rheological property determinators, etc. Means and methods on super-heavy oil fluid physical property analysis etc. is equivalent to the worldwide level, and the percolation physical simulation method in macro, medium and micro angles is synchronous with the world.

CT scanning system

Long core displacement system

Ultrahigh pressure PVT equipment



One-dimension Percolation Model Experiment Device

One-dimension Percolation Model Experiment Device

5 QUALIFICATION &STANDARDS

5.1 Qualifications

CNPC has 14 national qualifications of class A in EPC and engineering investigation design as well as grade I construction qualifications of the Ministry of Construction and the Ministry of Communications, obtained a national grade AAA credit certificate and passed GB/T19001 quality management system authentication.

The economic and efficient development technology of super-heavy oil has many prizes such as grade II National Science and Technology Advance Prize, etc.

5.2 Standards

CNPC strictly carries out relevant national or industry standards.

composing:

Requirements on Heavy Oil Reservoir Description Technology SY/T 6191—1996;

Analytical Method of Formation Crude Oil Physical Properties SY/T 5542-2000;

Test Method for Two-Phase Relative Permeability in Rock SY/T 5345—2007;

Sampling Procedures for Reservoir Fluids SY/T 5154—1999;

Analytical Method of Fluid Physical Property of Heavy Oil Reservoir: Crude Oil Viscosity Measurement SY/T 6316—1997;

Analytical Methad of Fluid Physical Property for Heavy oil Reservoir: Measurement of Percolation Rheological Properties of Crude Oil SY/T 6282—1997;

Platform Arrangement of the Cluster Well SY/T 5505—2006;

Well selection Rules of Electric Sabmersible Pump and Pump Selection Design Method SY/T 5904—2004;

Upper cementing and Lower sieve Tube completion Method of Horizontal well SY/T 6846—2012;

The Operation Regulation of Crude Oil Pipeline SY/T 5536—2004.

5.3 Patents

A method and device of measuring intensity and stability of foam oil;

A surfactant and preparation and application;

A process method of modifying and processing super-heavy crude oil.

6 EXPERT TEAM

Mu Longxin Field development engineering expert. He is dedicated in various types of oilfield development theories, development method study and technical innovation, has taken in charge of many scientific research projects of the state or the company about heavy-oil development, and has been awarded with more than 10 national as well as provincial and ministerial science prizes. Over 30 papers and 7 works published.

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Bian Dezhi Field development engineering expert. He has over 30 years of experiences in field development technology study and management at home and abroad. He has reached domestic and foreign advanced level on super-high pressure ultra-low permeability and carbonate rock oil gas field development technology, and taken in charge of national major customized reaches relevant to heavy oil. He awarded with 2 grade I and grade II National Science and Technology Advance Prize and provincial and ministerial prizes. 16 papers and 3 works published.

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Li Fangming Field development engineering expert. He has engaged in field development scientific research and management work for 25 years, and devoted himself to development technology breakthrough and production management on reservoir such as heavy oil in recent years, taken in charge of many scientific research breakthrough subjects of the Company, and obtained outstanding achievements on horizontal well development technology.

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Chen Heping Field development engineering expert. He has engaged in field development scientific research and management work for about 30 years and awarded with 6 provincial/ ministerial science and technology advance prizes and above. He has undertaken many national major special subjects and national major special subjects of the company. 4 works and more than 10 papers published.

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Lü Binchang Oilfield development geologist. He has more than 25 years of working experiences on field development geological research and comprehensive development management; and particularly, on operating management of overseas heavy oil development project. more than 10 papers published.

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Liu Shangqi Heavy-oil development technical expert. He has engaged in researching basic theory and application of heavy-oil development technology, and obtained outstanding achievements in heavy-oil and super-heavy oil thermal recovery by steam injection, super-heavy oil foam oil cold recovery mechanism and application research.

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Li Xingmin Field development engineering expert. He has many years' working experiences in heavy-oil development technology, and rich experiences in foam oil numerical simulation and development design optimization. moreover, more than 10 papers published.
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Huang Wensong Field development geologist. He has more than 10 years' working experiences in development geology and reservoir description and has researched depply on braided river deposit reservoir geology modeling. More than 10 papers published.
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Li Zhenjun Field development engineering expert. He has many years' working experiences in oil field development and drilling engineering and particularly in shallow strata loose sandstone 3D horizontal well technology. He has been awarded with 2 bureau level grade I and grade II science and technology advance prizes.
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