CO_2-flooding Recovery Technology

Science & Technology Management Department

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CHINA NATIONAL PETROLEUM CORPORATION

CNPC boasts the advanced CO_2-flooding Recovery Technology, helping you to enhance the efficiency of oilfield development!

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 one of the largest refined oil products 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 10th 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 CO_2-flooding Recovery Technology is one of representatives for major innovations of CNPC.

CLEAN ENERGY SUPPLY FOR BETTER ENVIRONMENT

1 INTRODUCTION

Equipped with a group of excellent professional and technical talents, the first-class laboratories and field pilot test bases, CNPC has dedicated itself to tackling key problems and practising in low-permeability oilfield EOR and producing-rate technologies, and developed many unique technologies, being able to provide various technical services.

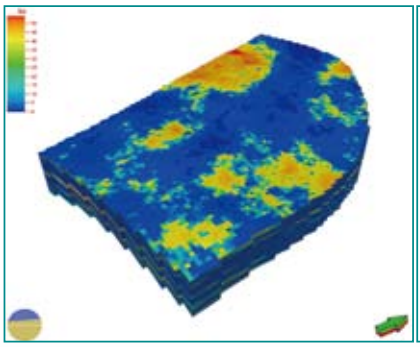
CNPC has developed 3 series of CO_2-flooding recovery technologies (i.e. Reservoir Engineering, Injection-production Engineering and Surface Engineering) and 10 unique techniques, and owns 24 patents and technical secrets.

The CO_2-flooding Recovery Technology is successfully applied to the oilfields such as Jilin Oilfield and Daqing Oilfield, provides great technical support for the development of low-permeability oilfields with impressive reserves and will be extensively applied as an effective EOR technology.

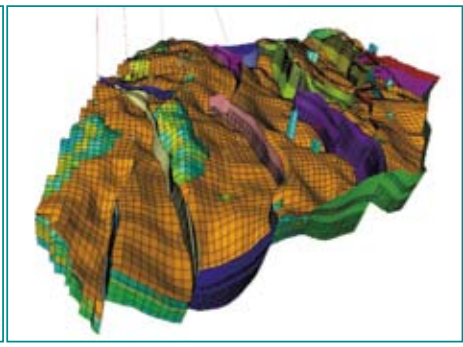
2 UNIQUE TECHNOLOGIES

2.1 CO_2-flooding Reservoir Engineering Technologies

Based on the laboratory mechanism experiments, the comprehensive CO_2-flooding Reservoir Engineering Technologies take the finely geological modeling as the means of recognizing strata, predict the development indexes through numerical simulation, and then conduct the optimization design of development plan.



Reservoir Geological model



Oil Saturation Field

2.1.1 Experimental Technology for CO_2-flooding Mechanism

The Experimental Technology for CO_2-flooding Mechanism includes: Experimental Technology for Miscible CO_2-flooding Conditions, Experimental Technology for CO_2-flooding Characteristics and Displacement Efficiency.

Through the research and experiment of miscible conditions, the minimum miscible pressure (MMP) of CO_2-flooding can be determined.

Gas Chromatograph

Slim Tube Experiment Device

Through the experiments for displacement characteristics and efficiency, the displacement characteristics during CO_2-flooding can be described, the oil-displacement efficiency can be evaluated and the oil-displacement manner can be optimized.

2.1.2 Establishment of Fine Geological Model for CO_2-flooding Reservoir

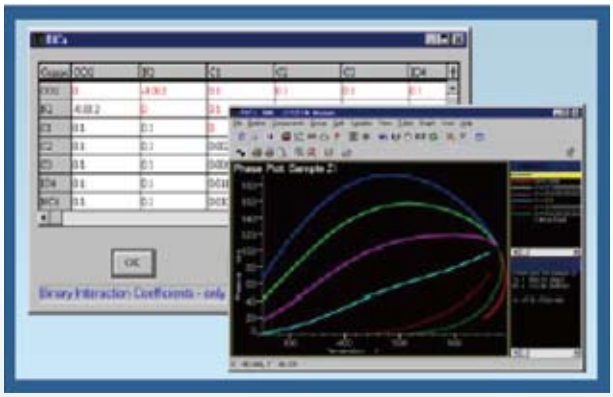
The Fine Geological Model for CO_2-flooding Reservoir is the characterization of 3D spatial variation and distribution of reservoir characteristics and heterogeneity. The establishment of the fine 3D reservoir geological model is the core of the CO_2-flooding reservoir description and the basis of numerical reservoir simulation.

2.1.3 Optimal Design of Numerical Simulation for CO_2-flooding

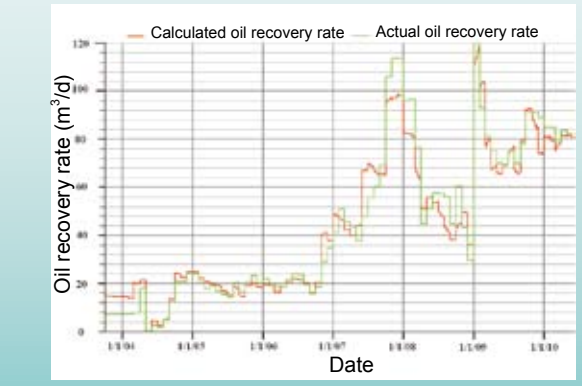
The Numerical Simulation for CO_2-flooding is a kind of technology that grows with the emergence and development of computers, which is developed

quickly and applied extensively at home and abroad.

The technology refers to the comprehensive application of seepage mechanics and physical & chemical theories. In consideration of the effect of the complicated facies change and mass transfer on the wellbores of injection-production wells and reservoirs, the development indexes of CO_2-flooding can be predicted accurately, the miscible oil-displacement can be identified, and the gas-flooding front can be analyzed.



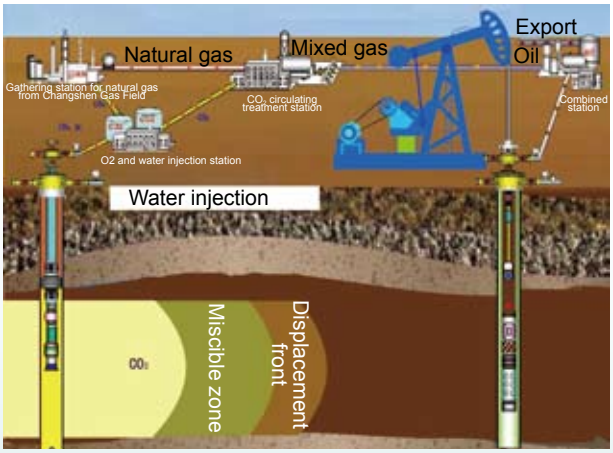
Phase State Experiment Fitting



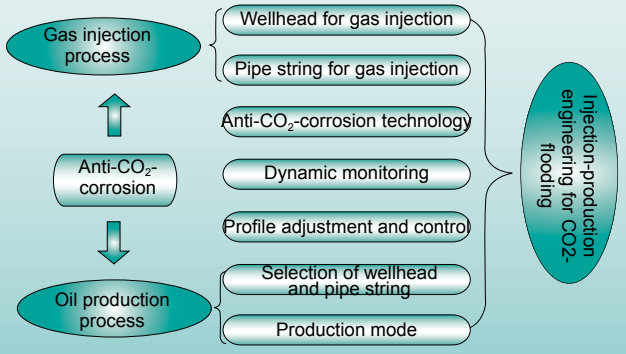
Oil-recovery Rate Fitting

2.2 Injection-production Engineering Technologies for CO_2-flooding

According to the behavior difference of gas injection and oil production wells, the combined method of the corrosion-resistant material and corrosion inhibitor injection is selected to prevent the corrosion to wellbores and downhole tools. The monitoring of CO_2-flooding performance is strengthened and the measures of profile adjustment and control are adopted,



Sketch Map of CO_2-EOR Process



Framework of Injection-production Engineering Technology for CO_2-flooding

thus improving the swept volume and enhancing the producing rate and recovery factor of low-permeability oilfields.

2.2.1 Anti-CO_2-Corrosion Technology

The Anti-CO_2-Corrosion Technology is one of the key technologies of injection-production engineering for CO_2-flooding. CNPC has developed Anti-corrosion and Cementing Technology, Chemical Anti-corrosion Technology, Anti-CO_2-Corrosion Technology, etc. Better results have been obtained in the field application, and the corrosion rate can be controlled within the industrial standard.

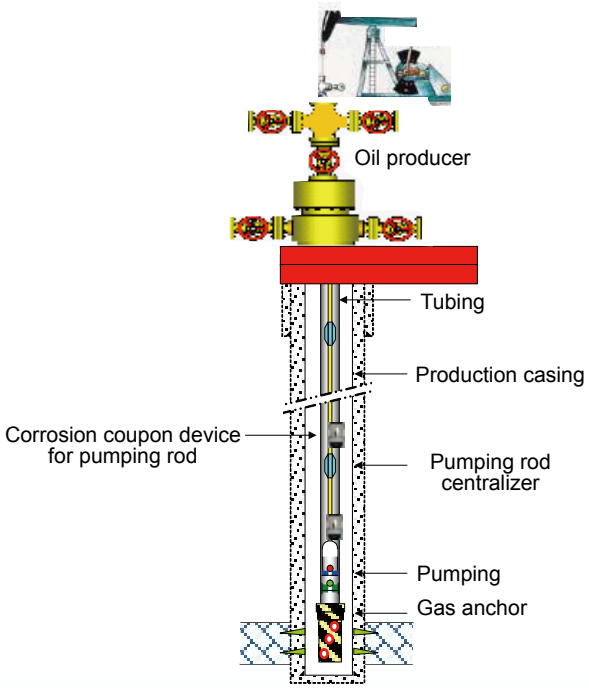
Based on the corrosion mechanism of CO_2 to cement, the CO_2-resistant cement slurry system of additive-type has been developed. This helps to resolve the problem that leaching, dissolution and carbonization shrinking of the conventional cement slurry are easy to take place, and makes the cement-rock porosity and permeability increase and the compressive strength decrease.

In view of the different water qualities and working conditions of injection and production wells with CO_2-flooding as well as the corrosion elements of formation water, the compound CO_2-corrosion inhibitor system has been developed. The combined chemical-addition technologies, which cover balance tank, metering pump and vehicle-mounted shock-type filling, have been developed to guarantee the timely and efficient filling of the corrosion inhibitor.

2.2.2 Gas Injection Technology for CO_2-flooding

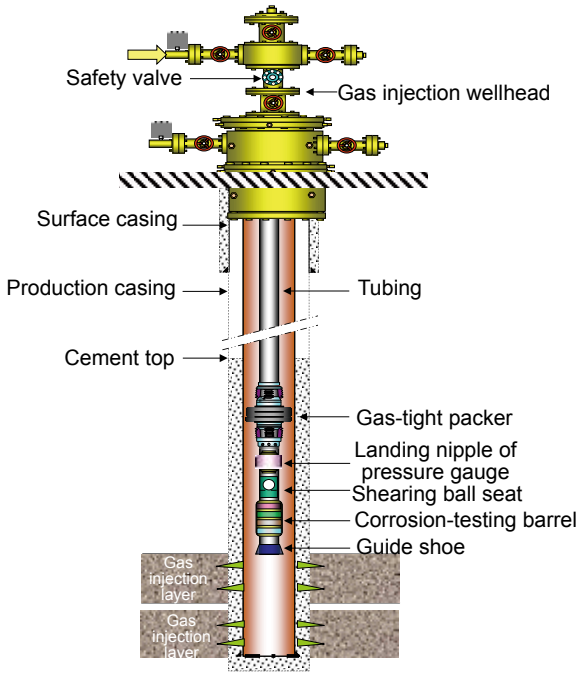
The Gas Injection for CO_2-flooding is the technology that gas is injected into the formation with special wellheads, tubing string and a series of downhole tools, including commingled gas injection, separate layer gas injection, and so on.

In the commingled gas injection process, the tubing with gas-tight thread and the gas-tight packer are adopted while the pressure tester (patent number: ZL 2009 2 0107814.X) and the corrosion tester (patent number: ZL 2009 2 0105975.5) are installed. In the gas injection well, intervals are not separated, and gas is injected into the formation under the same pressure system.



Anti-CO_2-Corrosion Technology for Production Well production Engineering Technology for CO_2-flooding

In the gas injection technology of concentric, dual-string and separate layers for CO_2-flooding, 2 concentric strings are adopted, packers are used to separate two formations, and gas is injected into the lower oil-layer with central pipe and into the upper oil-layer through the annulus between the central pipe and the tubing. The process is suitable for the separate layer gas injection for the wells that have dual oil-layers and interlayer contradictions.



Commingled Gas Injection String for CO_2-flooding

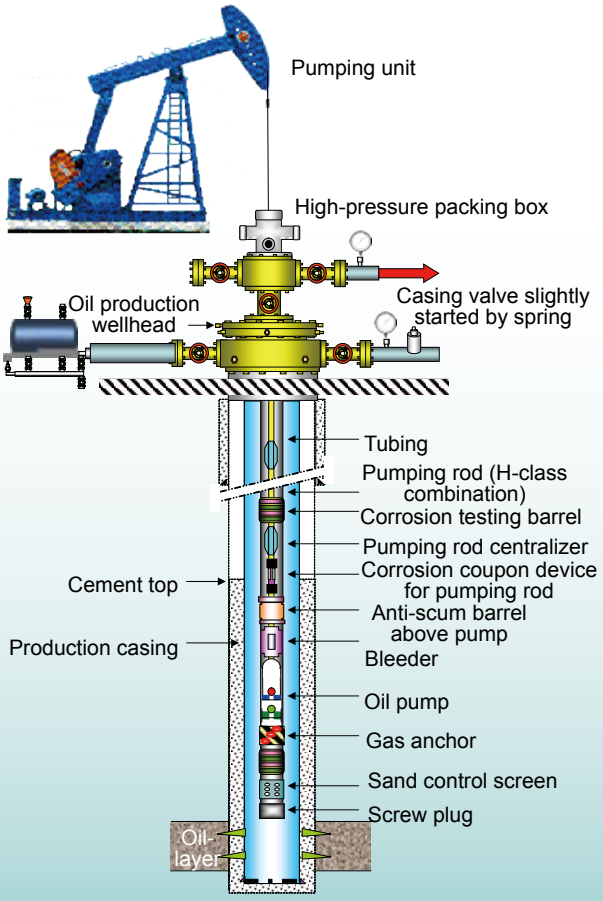
2.2.3 Oil Production Technology for CO_2-flooding

For CO_2-flooding, there are 3 main modes of oil production, e.g. tubing pump, flowing production and production with the integration of flowing and rod pumping.

The oil production process of mechanically pumping with tubing pump, means to extract oil with a complete system of casing controller and monitoring tools for the downhole corrosion and pressure on the basis of the conventional oil production technology by mechanical pumping. The corrosion-resistant stainless steel is used for the key parts, and filling corrosion inhibitor through the annulus is adopted for anti-corrosion. The technology realizes the normal oil production and data acquisition in the CO_2 corrosion environment, and guarantees long-term safe production.

The oil production technology with the integration of flowing and rod pumping considers the requirements for flowing production and anti-corrosion after the response to CO_2-flooding. The anti-corrosion is conducted by installing a packer below the pump, adding the protective liquid above the packer or injecting the solid corrosion inhibitor in the tubing. The pipe string not only realizes the flowing production, but also pumps oil through the rod pump when the flowing energy is insufficient.

The process is suitable for the condition of high gas-oil ratio and high pressure after the response to



Pipe String for Oil Production Process of Mechanically Pumping with Tubing Pump

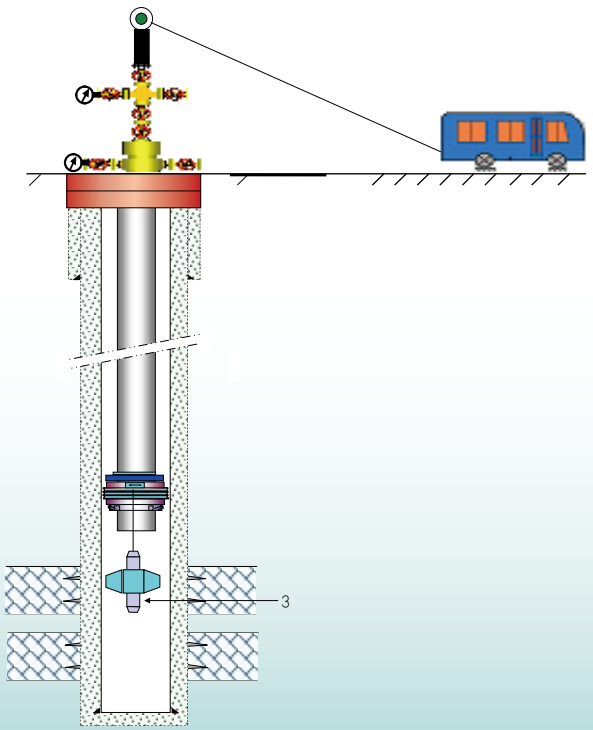
CO_2-flooding, and realizes the flowing in the production well with poor continuity.

2.2.4 Monitoring Technology for CO_2-floodig

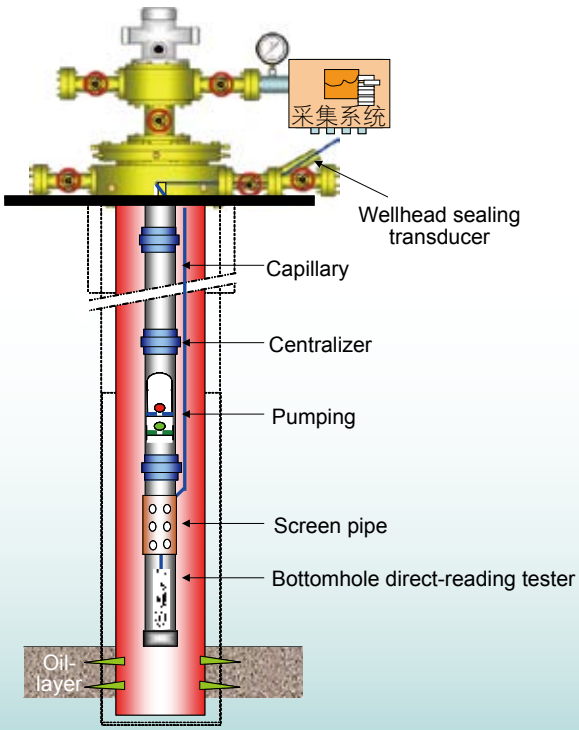
The technology is used for monitoring the pressure, temperature, flow rate, gas injection situation and CO_2-floodig front of injection and production wells with CO_2-floodig and the important means for understanding the CO_2-flooding effects.

The Gas Injection Profile Testing Technology is developed to test the gas injection situations of different intervals during CO_2-floodig. The technology trips memory-type gas-injection profile tester by using the testing steel wire or electric cable, and calibrates the depth with the magnetic positioning technology. The tester can measure parameters (e.g. CO_2 flow rate, temperature and pressure) accurately. The data, such as the gas injection rate from each sublayer and the gas injection profile of oil-layers, are obtained through the testing data explanation.

In view of the requirements for long-term and real-time monitoring of the wellbore pressure from gas injection well and the bottomhole flowing pressure from oil production well, The monitoring technology of bottomhole direct-reading pressure trips the pressure testing tool into the wellbore with the electrical cable, and transmits the pressure signal to the surface receiver through the electrical cable, thereby the real-time bottomhole pressure situation is mastered. The testing process considers the requirement of anti-CO_2-corrosion sufficiently, the anti-corrosion material is adopted for the bottomhole tools, and the electrical cable is tripped through the stainless-steel capillary.



Testing Process of Gas Injection Profile



Monitoring Process of Actual Bottomhole Pressure

2.2.5 Profile Adjustment and Control Technology for CO_2-flooding

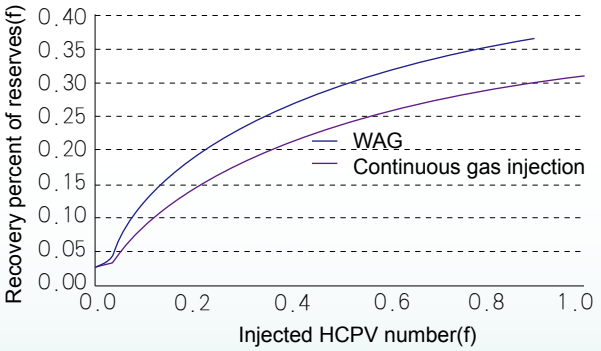
During the oil displacement by CO_2-flooding, gas is broken through untimely because of poor physical properties and strong heterogeneity of reservoir. For this reason, a series of profile adjustment and control technologies have been developed to delay the gas breakthrough time of oil production wells, in order to control the flowing pressure, to guarantee the miscible displacement and to enhance the CO_2 displacement effectiveness.

① The WAG Technology is mainly for the water and gas to be injected alternately in order to decline water permeability, thereby declining water mobility, improving the oil-water mobility ratio and swept volume and enhancing the recovery factor.

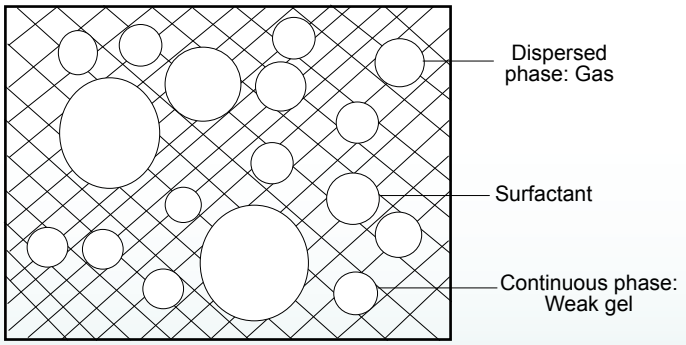
② The Foam-enlarging Swept Volume Technology is mainly for the foaming agent and gas to be injected alternately—sufficiently foaming underground. By using the foam system's feature of plugging high location and not plugging low location, the adjusting and plugging are conducted for the heterogeneous reservoirs within the layer, and the remaining oil in low-permeability location is generated.

③ The Acidic Polymer Gel System is mainly to compound by using the heat-resistant polymer and the cross-linking system, and to gel under the reservoir conditions with high gelling intensity, good heat-resistance and acid-resistance as well as good stability.

④ The foam gel is the uniform foam formed by gas and liquid phases, with very good stability. The gelatinization of fluid film on the foam's outside wall improves the ductility of foam wall and facilitates to form the foam-shaped gel system. Meanwhile, the plugging is conducted by use of the double plugging mechanism of foam and gel.



Relation Between Recovery Percent of Reserves and HCPV Number



Foam Gel System

2.3 Surface Engineering Technologies for CO_2-flooding

To meet the needs of the development and test of the CO_2 oil-displacement scale, the Surface Engineering Technologies were developed, focusing on the pipeline transportation of gas-phase CO_2 and the liquid-phase CO_2 injection.

Through the field test and plan optimization, many technologies have been developed, involving gas gathering of CO_2 gas-field, dehydration, pipeline transportation of gas-phase CO_2, liquefaction, storage, liquid-phase CO_2 injection and corrosion prevention of surface system. These technologies are able to meet the need of surface engineering design for the large-scale CO_2-flooding development.

2.3.1 Pipeline Transportation Technology for Gas-phase CO_2

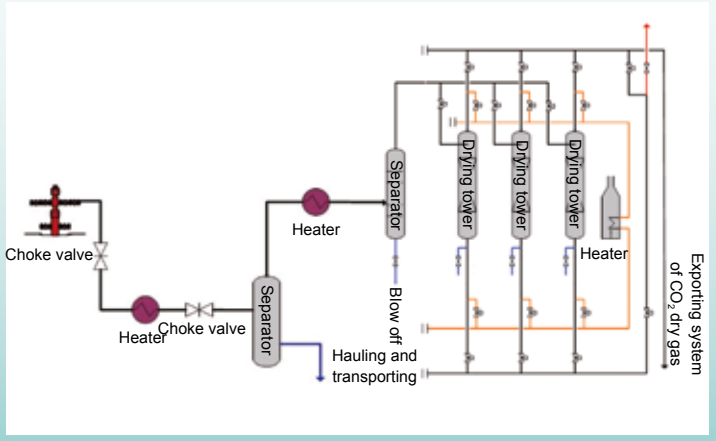
By controlling gas process parameters at the pipeline's head and end, all CO_2 during the transportation is kept in gas state. This is used to handle and transport the gas from CO_2 gas-fields.

During the plan design, the software is used to simulate and calculate CO_2 flow regime at different flow rates, temperatures and pressures, to select the gas-gathering transportation and the economically and technically optimal dehydration plans and to guarantee the continuous gas-phase CO_2 transportation and take the anti-corrosion and monitoring measures, thus ensuring the safe transportation.

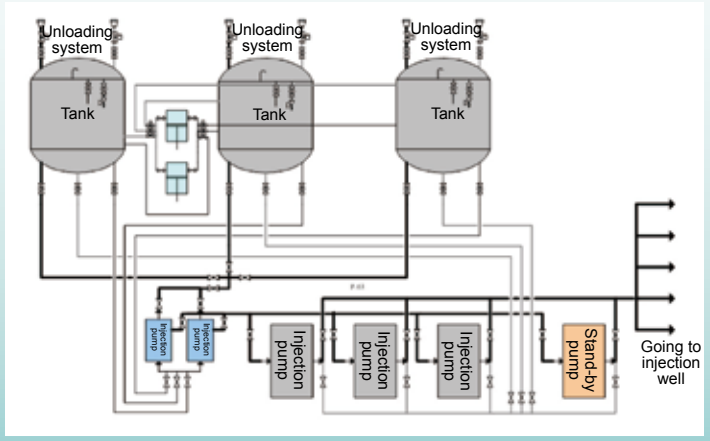
2.3.2 Liquid-phase CO_2 Injection Technology

This is a kind of pumping and injecting technology specially developed for the ultrahigh pressure demand in reservoir engineering and has the following advantages: high injection pressure, suitability to different reservoir scales, mature process equipment and technology, reliable safety performance, and so on.

The Liquid-phase CO_2 Injection Technology developed by CNPC includes CO_2 liquefaction, liquid-phase CO_2 storage, high-pressure injection and relevant processes, which meets the requirement of WAG injection. The research in low-temperature, heat-proof and field operation technology is mature. Two CO_2 liquefaction stations and two CO_2 liquid-phase injection stations have been built. Besides, the injection test has been conducted smoothly in 24 well groups.



Flow Scheme of CO_2 Gathering and Dehydration for Individual Well



Technical Flow Scheme of Liquid-phase CO_2 Injection

3 TYPICAL CASES

The important development test has been performed successfully in Block Hei-59 in Jilin Oilfield.

In Hei-59 Test Area, there are totally 31 oil-gas wells—6 gas injection wells and 25 oil production wells. Before gas injection was conducted in the test area, the researches (i.e. of laboratory mechanism, geology, reservoir and injection-production) had been done, and the optimized plans for reservoir engineering and implementation were determined.

In CO_2 gathering, the Gas Transportation Technology and Liquid Gas Injection Technology are applied, and one liquid gas injection station has been built. In the Injection-production Technologies, the anti-corrosion string and anti-corrosion process of annular corrosion-inhibitor addition for 31 injection and production wells are designed, and the ideal low-corrosion rate of 0.076mm/a is obtained through the monitoring of the injection and production wells.

Gas was injected in the block in 2008, with the obvious dynamic characteristics of miscible displacement occurring in the block one year later, the average daily oil production rate per well increasing by more than 30% as compared with that generated by the water-flooding prediction, and the predicted recovery factor standing at about 10%.

Hei-59 Liquid Gas Injection Station

Interior of Injection Station

4 R&D EQUIPMENT

4.1 Reservoir Engineering Laboratory

Relying on the technical force from the State Key Laboratory of EOR of Research Institute of Petroleum Exploration & Development, CNPC, the perfect Technological System for CO_2-flooding Reservoir Engineering has been established, encompassing:

Experimental equipment: Displacement system for long cores, high-pressure phase-state device, high-pressure interfacial tension device, high-pressure testing system for solid deposition.

Hardware equipment: More than 10 suits of ThinkStation S20 workstations and other high-performance computers, mainly being used for CO_2-flooding reservoir geological modeling and numerical simulation research.

Application software: the reservoir geological modeling software Petrel Workflow Tools, and the integrated software package of compositional model & numerical simulation ECLIPSE.

Anti-CO_2-Corrosion Laboratory

HTHP Reactor

High-pressure Phase-state Device

Displacement Apparatus for Long Cores

4.2 Anti-CO_2-Corrosion Laboratory

There are 4 laboratories, including High Temperature & High Pressure (HTHP) Laboratory, Physical and Chemical Laboratory, Electrochemical Laboratory, and CO_2 Corrosion Monitoring Laboratory.

The laboratories possess the following experimental and analytical abilities: simulation of HTHP corrosion, evaluation of corrosion inhibitor screening, evaluation of electrochemical corrosion, evaluation of electromagnetic coupling corrosion rate, ultrasonic thickness testing, analysis of metal composition in the corrosion products, analysis and evaluation of corrosion appearance, and detection of the residual concentration of corrosion inhibitor.

5 QUALIFICATION AND STANDARD

5.1 Safety rules for CO_2 injection in oil-gas fields, SY 6565

5.2 Contents and requirements for CO_2-flooding dynamic monitoring data acquisition for low-permeability reservoirs

5.3 Specification for drafting CO_2-flooding development plan for sandstone oilfields

5.4 Technical requirements for HSE in CO_2-flooding

5.5 Technical requirements for injection and production well completion during CO_2-flooding

5.6 Technical criteria for downhole operation during CO_2-flooding

5.7 Technical requirements for anti-corrosion of injection and production wells during CO_2-flooding

5.8 Design specification for injection engineering for CO_2-flooding

5.9 Design specification for pipeline transportation of gas-phase CO_2

5.10 Design specification for oil-gas gathering during CO_2 -flooding

5.11 Design specification for selecting automatic instrument type for CO_2 -flooding

5.12 Design specification for selecting materials for CO_2 -flooding

5.13 Technical specification for inner polythene powder anti-corrosion coating for CO_2 -flooding

5.14 Technical requirements for production maintenance during CO_2 -flooding

5. 15 Technical specification for injection-production drilling during CO_2 -flooding

6 EXPERT TEAM

Shen Pingping: (Professor-level senior engineer, Ph.D. supervisor, expert who enjoys the governmental special allowance)

He has been engaged in the basic research on CO_2-EOR for a long time, and is the chief scientist of "Resource Utilization of Greenhouse Gas for EOR and CO_2 Underground Storage in China".

Email: spp@petrochina. com. cn

Phone: 010-83598035

Song Xinmin: (Professor-level senior engineer, Ph.D. supervisor, senior technical expert)

He is the project group leader of "CO_2-bearing Natural Gas Development & CO_2 Underground Storage and Comprehensive Resource Utilization in Jilin Oilfield".

Email: sxm@petrochina. com. cn

Phone: 010-83598035

Wang Feng: (Professor-level senior engineer, Ph.D. supervisor, senior technical expert)

He has obtained the special allowance of the State Council and Sun Yueqi Youth Science and Technology Award, and is the deputy project group leader of "CO_2-bearing Natural Gas Development & CO_2 Underground Storage and Comprehensive Resource Utilization in Jilin Oilfield".

Email: w-feng@petrochina. com. cn

Phone: 0438-6258012

Liu Yuncheng: (Senior technical expert in oil and gas field development)

He has taken charge of many CO_2-bearing natural gas development and CO_2-flooding projects.

Email: liuyc-jl@petrochina. com. cn

Phone: 0438-6224666

Liu Changyu: (Senior engineer, technical expert in CO_2-flooding injection-production engineering)

He has been engaged in the research and field application of CO_2-flooding injection-production process and anti-CO_2-corrosion technology for a long time. Moreover, he has undertaken and finished the study of many important national research subjects.

Email: liucyu@petrochina. com. cn

Phone: 0438-6336590

Sun Ruiyan: (Professor-level senior engineer, senior technical expert)

She has been engaged in the research and field application of CO_2-flooding injection-production process and anti-CO_2-corrosion technology for a long time. Furthermore, she has undertaken and finished the study of many important national research subjects.

Email: sjyyldsry@petrochina. com. cn

Phone: 0438-6259705

Qin Jishun: (Professor, Ph.D. supervisor, senior technical expert)

He has been engaged in the CO_2-flooding application base research for a long time, and has undertaken and finished the study of many important national research subjects.

Email: qinjs@petrochina. com. cn

Phone: 010-83593019

Li Yazhou: (Senior engineer, technical expert in CO_2-flooding injection-production engineering)

He has presided over and finished many researches on fracturing, water flooding and petroleum engineering. He has presided over the field experiments for the key developmental test project of CO_2-flooding.

Email: liyz@petrochina. com. cn

Phone: 0438-6223900

CNPC
中国石油

联系人：刁顺 先生
电　话：59986059
Email: sdiao@cnpc.com.cn

Contact: Mr. Diao Shun
Tel: 59986059
Email: sdiao@cnpc.com.cn